EMERGENCE OF DISABILITY IN LATE LIFE

by

Chao-Yi Wu

B.S., National Taiwan University, 2012

M.S., National Taiwan University, 2015

Submitted to the Graduate Faculty of

School of Health and Rehabilitation Sciences in partial fulfillment

of the requirements for the degree of

Doctor of Philosophy

University of Pittsburgh

2019

UNIVERSITY OF PITTSBURGH

SCHOOL OF HEALTH AND REHABILITATION SCIENCES

This dissertation was presented

by

Chao-Yi Wu

It was defended on

February 27, 2019

and approved by

Lauren Terhorst, PhD, Associate Professor, Department of Occupational Therapy

Jordan F. Karp, MD, Associate Professor, Department of Psychiatry

Chair: Juleen Rodakowski, OTD, MS, OTR/L, Assistant Professor, Department of Occupational Therapy

Co-chair: Elizabeth R. Skidmore, PhD, OTR/L, Chair and Professor, Department of Occupational Therapy

EMERGENCE OF DISABILITY IN LATE LIFE

Chao-Yi Wu, PhD

University of Pittsburgh, 2019

In 2050, the life expectancy is anticipated to be 82 years in the United States. This increased in life expectancy has raised questions as to whether a longer period of old age guarantees a longer period of good health. As of now, the potential for a healthy late life is tempered by disability – the loss of independence with activities of daily living (ADL). Disability looms as a personal, family, and public health crisis. Older adults with disability have low autonomy, require assistance from loved ones, and often require costly health care services. Effective interventions to prevent disability are critical to support wellness in late life.

We identified gaps in existing non-pharmacological interventions for the prevention of disability, suggesting that 1) these interventions are associated with modest to moderate effect sizes and 2) the most robust interventions are complex and include multiple "active ingredients." However, the best combination of "active ingredients" remains unclear, and the combinations may vary based on clinical indicators. To better understand these variations, we examined selected indicators of change in brain health (depressive symptoms, cognitive complaints) and their associations with patterns of everyday activities in at-risk older adults (i.e., with a recent diagnosis of a chronic condition). We learned that changes in these indicators of brain health accelerated disablement in older adults with a newly-diagnosed Diabetes Mellitus. We also learned that indicators of brain health influenced patterns of everyday activities in older adults at-risk for disability (i.e., self-reported changes in daily routines); depressive symptoms were associated with engagement in fewer instrumental ADL, and cognitive complaints were associated with

engagement in fewer leisure activities. This information gives insight to the risk architecture contributing to the onset of disability, as well as potential clinical indicators that could be explored in future clinical trials.

Age-related disability is "a situation without precedent." The information gleaned from this dissertation may inform 1) studies to examine the health consequences of everyday activities patterns; 2) the identification of factors that may elucidate the complex disablement; and 3) the structure, timing, and dosage of future interventions that aim to prevent disability in late life.

Table of Contents

List of Tables

List of Figures

Preface

Too much to say and to thank.

1.0 Introduction

1.1 Significance

1.1.1 Disability in late life

The world is facing an unprecedented situation; an estimated 1.5 billion older adults will be 65 years old or older in 2050 (Ortman, Velkoff, & Hogan, 2014). While increased longevity and a growing aging population are great accomplishments in our society, the prevalence of disability accompanies old age. Now, one out of three older adults have a disability (Kraus, 2017), as indicated by the inability to maintain independence in activities of daily living (Kraus, 2017; Ortman et al., 2014). Disability is problematic, because it not only reduces older adults' quality of life but also requires costly health care services (Freedman & Spillman, 2014; S. Hayes et al., 2016; Lubitz, Cai, Kramarow, & Lentzner, 2003). As the aging of the population is inevitable, strategies to prevent disability are critical to support older adults' health and well-being.

1.1.2 Preventing disability in late life

Compared to pharmacological interventions, non-pharmacological interventions that prevent and reduce disability are compelling given low risks and potentially high health benefits. Existing non-pharmacological interventions have demonstrated efficacy for partially reducing disability, once it has occurred. This research is still in the early stages, and the active ingredients of these non-pharmacological interventions are only beginning to be defined and studied (Craig et

al., 2008). Furthermore, intervening after the emergence of disability may be too late to slow down the disablement progression (Capistrant et al., 2014). Therefore, current efforts seek to advance knowledge about potential indications for prevention-oriented interventions, particularly in vulnerable populations who have not yet manifested disability.

1.1.3 Indicators of brain health and disability

The Institute of Medicine (IOM) has proposed a framework for optimizing prevention-oriented programs to address public health issues (Springer & Phillips, 2007). These prevention-oriented programs are characterized by interventions that address the risks factors to prevent the onset of disability in at-risk older adults. The examination of selected indicators of brain health may open a window of opportunity to elucidate the pathway to disability since subtle brain changes are often early signals that give rise to clinical symptomologies, functional decline, and subsequent disability (Cigolle, Langa, Kabeto, Tian, & Blaum, 2007; Mehta, Yaffe, & Covinsky, 2002; Reynolds & Silverstein, 2003).

Indicators of brain health include gait speed, coordination, sensory function, mood symptoms, and cognitive function. Among these, depressive symptoms and cognitive changes have been frequently associated with changes in brain health and changes in everyday life activities in late life (Fritsch, McClendon, Wallendal, Hyde, & Larsen, 2014; Laborde-Lahoz et al., 2014; Westoby, Mallen, & Thomas, 2009), and are relatively understudied relative to sensorimotor function (Robertson, Savva, & Kenny, 2013). Epidemiologic evidence estimates that more than 6.5 million older adults have depression (National Alliance on Mental Illness, 2009). Elevated depressive symptoms are problematic, because they are associated with physiological changes in the brain and dysfunction in the circuits of emotion processing (Alexopoulos et al., 2015; Bruce,

2001). The dysfunction in the circuits of emotion processing may lead to major depressive disorder and if it persists or worsens over time (Gorwood, Corruble, Falissard, & Goodwin, 2008; Karp et al., 2009; Laborde-Lahoz et al., 2014; Leibold, Holm, Raina, Reynolds III, & Rogers, 2014). Cognitive impairments are present in 15% to 20% of older adults (Centers for Disease Control and Prevention, 2011). Furthermore, cognitive abilities decline approximately 10% every 10 years in late life (Singh-Manoux et al., 2012). Even a subtle decline in cognition is associated with pathological changes in the brain, such as grey matter shrinkage or toxic protein accumulation (Morley et al., 2015). These pathological changes may lead to poor memory, slow processing speed, and trouble managing daily activities. Yet, we have little understanding of how these two indicators of brain-health are associated with disablement in late life, especially when disability is just beginning to emerge. This piece of information is critical to identify those who may be predisposed to in late life.

1.1.4 Everyday activity patterns, mood, cognition, and disability

Evidence suggests that involvement in meaningful everyday activities (self-care; exercise; leisure) may be a potent indicator of health in late -life (Agahi, Silverstein, & Parker, 2011; Foley, Hillier, & Barnard, 2011; Iwasa et al., 2012; Villareal et al., 2011). Patterns of everyday activities characterize the variety of activities and the amount of time an individual spends each day for a certain duration (e.g., weekly, monthly) (Carlson et al., 2012). These patterns reflect the complexity and enrichment of everyday lives and may signal health, when sufficiently complex and meaningful (Law, 2002). Changes within patterns may also herald changes in health even before older adults are aware of health declines (Fried, Herdman, Kuhn, Rubin, & Turano, 1991; Hayes et al., 2008). Consequently, a full grasp of everyday activity patterns in late-life may aid

early identification of at-risk populations and inform future intervention strategies to promote healthy patterns of everyday activities for older adults.

Yet, little research has described the real-world lived experience of older adults – their patterns of engagement in everyday activities – partially due to the difficulties in assessing everyday activities in sufficient detail in a given epoch of time (Asch, Muller, & Volpp, 2012). Additionally, the relationships among indicators of brain health (depressive symptoms; cognitive complaints) and patterns of everyday activities are unclear in the early stages of decline – particularly among older adults who are at-risk for disability. To develop strategies that prevent disability, an investigation of the dynamic interactions among indicators of brain health and activity patterns is warranted to in those who are vulnerable to disability.

1.2 Specific Aims

The goal of this dissertation was to generate additional evidence to inform future prevention-oriented interventions that may be used to prevent disability in late life. This dissertation is comprised of three aims designed to summarize the effects of existing non-pharmacological interventions on reducing disability, and examine clinical indicators that may influence the design of future interventions. Specifically, this dissertation examined associations among selected indicators of brain health, everyday activity patterns, and disability in at-risk older adults (i.e., those with new chronic conditions; those with self-reported changes in daily routines).

1.2.1 Aim 1

The first aim summarized the effects of existing non-pharmacological interventions to reduce disability for community-dwelling older adults. We conducted a scoping review of the literature to examine the effects of non-pharmacological interventions on disability and explored the effects of active ingredients embedded in these interventions (**Chapter 2**).

1.2.2 Aim 2

The second aim examined the roles of selected indicators of brain health (depressive symptoms; cognitive decline) in the progression of disablement over time in late life. We focused on one at-risk population, that is older adults with a new chronic condition (in this case, those with a new diagnosis of Diabetes Mellitus, DM). We used secondary data from the Health Retirement Study to examine the longitudinal associations among elevated depressive symptoms, cognitive impairments, and disability over a 10-year period (**Chapter 3**).

1.2.3 Aim 3

The third aim examined patterns of everyday activities and their associations with selected indicators of brain health in a sample of older adults at-risk for disability (in this case, those with self-reported changes in daily routines). We examined the feasibility and usability of mobile devices in measuring the patterns of everyday activities (variety and time) for 14 days (**Chapter 4**). We examined the interactions among depressive symptoms, cognitive complaints, and everyday activities via a measurement burst design approach in at-risk older adults (**Chapter 5**).

1.3 Innovation

The innovation of this dissertation is its focus on elements necessary to inform future prevention-oriented clinical trials. There are several pieces of information needed to advance this goal. First, we must better understand the composition and efficacy of current interventions designed to reduce disability, if we are to consider the design of future interventions designed to prevent disability. Our review of non-pharmacological intervention trials specifically addressed both the composition (i.e., the "active ingredients of interventions) and the aggregation of estimated effects associated with variations in composition. Second, we must better understand clinical indicators that contribute to disability – particularly the associations among these indicators and the onset and progression of disability. We addressed this by focusing on two clinical indicators that have been less well-studied in the disability world, depressive symptoms and cognitive impairments. Furthermore, we conducted longitudinal analyses to estimate the effects of these clinical indicators in a sample of older adults who did not yet have disability, but were vulnerable to the onset of disability with the onset of a new chronic condition. This allowed us to examine the strength of associations over time. Third, we must develop new methods to study patterns of daily activities (an indicator of disability) and their associations with selected clinical indicators. Collectively, these new investigations add to the science addressing the prevention-oriented mandate specified by the Institute of Medicine and others – providing insights that can inform intervention development in future studies.

2.0 A Scoping Review of Interventions in Reducing Disability in Older Adults

In **Chapter 2**, we summarize the effects of existing non-pharmacological interventions for reducing disability in community-dwelling older adults. We only examined non-pharmacological intervention studies that examined disability as an outcome. The Chapter generated a manuscript currently under-review at *The Gerontologist*, titled "A Scoping Review of Non-Pharmacological Interventions to Reduce Disability in Older Adults."

2.1 Introduction

One out of three older adults experience disability. Disability is defined by the inability to sustain independence with basic activities of daily living (ADL) or instrumental activities of daily living (IADL) (Kraus, 2017; Ortman et al., 2014). ADL and IADL disabilities are associated with substantial health care costs; older adults with disability have greater out-of-pocket healthcare expenditures than older adults without disability (Mitra, Palmer, Kim, Mont, & Groce, 2017). Older adults with disability also experience a lower sense of well-being (Groessl et al., 2007). Effective strategies to minimize disability become critical to reduce costly healthcare related to disability and sustain quality of life into old age.

Non-pharmacological interventions are promising to reduce disability in late life. Non-pharmacological interventions adopt behavioral change techniques, devices and technologies to facilitate change in health and quality of life (Boutron, Moher, Altman, Schulz, & Ravaud, 2008). Non-pharmacological interventions may include complementary and integrative medicine (e.g.,

Tai Chi) than the consumption of medication or substances, and thus have fewer risks and side-effects (Krishnan et al., 2018). Typically, non-pharmacological interventions are developed for older adults with a single medical condition, once disability has emerged. For example, moderate-intensity, supervised exercise programs have been developed to improve function after acute myocardial infarction or cardiac arrest (Boyce et al., 2017; Peixoto et al., 2015). Although these non-pharmacological interventions have demonstrated success in reducing disability, intervening after the emergence of medical conditions is often too late to minimize disability because the acute medical condition already results in newly acquired disability (Capistrant et al., 2014). Additionally, after acute medical conditions, these illnesses often have exacerbations or remissions that lead to risks of comorbidity and long-term disability (Brown et al., 2009; Collins et al., 2018).

Instead of focusing on a single medical condition or comorbidity, researchers have adopted various eligibility criteria (e.g., frailty, or at-risk of falling) to examine how to minimize disability through non-pharmacological interventions for broader groups of older adults (Ferrucci et al., 2004). Older adults who fit these criteria may have disability that is not caused by an acute medical condition, but they have a higher risk of acquiring more severe disability, as describe by Ferrucci and colleagues (Ferrucci et al., 2004). Little research has examined how effective these non-pharmacological interventions are at minimizing disability for older adults that fit these eligibility criteria.

Additionally, the active ingredients that drive the efficacy of non-pharmacological interventions are poorly specified and evaluated (Boutron et al., 2008). Active ingredients are the key components that are embedded in the interventions to change outcomes. Non-pharmacological interventions are often complex interventions, as defined by the Medical Research Council (Craig et al., 2008). A complex intervention is composed of more than one active ingredient (Michie,

Fixsen, Grimshaw, & Eccles, 2009). These active ingredients can be problem-solving, goal setting, exercise, or comprehensive geriatric assessment (Michie et al., 2013). The evaluation of active ingredients is critical because they may determine intervention efficacy in reducing disability in late life.

The purpose of this scoping review was to examine the effects of non-pharmacological interventions on disability in community-dwelling older adults participating in randomized controlled trials. The active ingredients of the interventions were also examined. We chose to include studies that recruited community-dwelling older adults to inform the development of future home-based programs. Information gleaned from this review may provide insights into how to optimize the effects of non-pharmacological interventions on disability for older adults.

2.2 Methods

2.2.1 Data sources and searches

We followed the scoping review methodological approach and provided the preferred reporting items for systematic review and meta-analysis (PRISMA) guidelines (Arksey & O'Malley, 2005; Moher, Liberati, Tetzlaff, & Altman, 2009) (**Appendix A**). An electronic search of PubMed, PsycINFO, and CINAHL databases was used to locate intervention studies. The terms used for the literature search were: older adults; disability; preclinical disability; activities of daily living; instrumental activities of daily living; intervention; social engagement; social participation; treatment outcome; clinical trial; clinical study. Terms were paired to search for eligible studies.

2.2.2 Study selection

We included studies that 1) recruited community-dwelling older adults aged ≥ 50 years old; 2) examined non-pharmacological interventions via randomized controlled trials (without the use of medication or substances); 3) measured ADL or IADL disability as primary or secondary outcomes; 4) included at least one follow-up, 5) were written in English, and 6) had sufficient data to calculate effect sizes. We excluded interventions that 1) focused on a specific diagnosis (e.g., cardiac arrest); 2) focused on one gender; 3) were not home-based; and 4) had follow-up longer than 3 years to minimize the influence of follow-up duration on results. Mendeley software (version 1.17) was used to manage the selection process (Mendeley Ltd, 2017).

A two-level screening process was performed to determine the inclusion eligibility: 1) title and abstract review, and 2) full-text review. One reviewer (C.Y.W.) reviewed abstracts and titles. Discrepancies in eligibility were determined through consensus by three authors (J.R., E.R.S., C.Y.W.).

2.2.3 Data extraction and management

Study characteristics (number of participants; age; gender; dosage; intervention session format; measure of disability; follow-up duration) and the means and standard deviations of disability were extracted for intervention and control groups. Baseline disability was categorized into four levels (negligible; mild; moderate; severe) using the cut-off points of measures of disability listed in the studies.

Active ingredients of interventions were identified and coded based on the descriptions of interventions within the manuscripts. Three independent authors coded the active ingredients separately (J.R., E.R.S., C.Y.W.). Discrepancies were discussed and resolved by three authors (J.R., E.R.S., C.Y.W.). Complex intervention (YES/NO) was characterized by more than one included active ingredient (Craig et al., 2008).

2.2.4 Data synthesis and analysis

Effect sizes were computed using standardized mean differences (SMDs), as known as Cohen's *d*. The Cohen's *d* was estimated by the differences between the mean changes of disability in the intervention and control groups divided by the pooled standard deviation (SD) of disability at baseline (Feingold, 2009). The effect sizes of the primary outcome were selected if multiple assessments were used to measure disability. The effect size of the longest follow-up was selected if there were multiple follow-ups.

STATA (version 15.0) (StataCorp, 2017) and SPSS (version 24.0) (IBM Corp., 2013) were used for statistical analysis. For each active ingredient, the heterogeneity of included studies was computed using the *I*-square statistics (I^2) (Higgins & Thompson, 2002). The magnitude of heterogeneity was followed by low (30.0%), moderate (50.0%), and high (75.0%). All the analyses were considered significant at the 0.05 two-tailed α level.

Cohen's *d* was used to categorize the four-level magnitude of effect sizes (< 0.2 = negligible; 0.2 - 0.5 = small; 0.5 - 0.8 = moderate; > 0.8 = large) (Lakens, 2013). We calculated the proportion of participants within each magnitude of effect size (negligible; small; moderate; large) across active ingredients. The greater proportion of participants in the studies with moderate

to large effect sizes, the more influence of an active ingredient on disability. This approach provided a visualization of magnitudes of effect sizes across studies, accounting for study sample sizes. Forest plots were generated for each active ingredient to visualize and synthesize the effect sizes of studies.

2.3 Results

2.3.1 Study characteristics

A total of 2,385 articles were identified; 363 articles were reviewed by full text. A total of 49 articles were eligible for this review (**Figure 1**). Sixteen authors were contacted and requested to provide means and SDs for studies that did not include necessary data. Means and SDs were obtained from 2 authors. There were 31 studies (included 33 interventions) with sufficient data (i.e., means and SDs) to be included in the analysis (**Table 1-2**; **Figure 2**).

A quarter of the studies (25.8%) had longer than 12 months follow-up. Nearly three-fourths studies (74.2%) listed disability as their primary outcome. Almost half of the studies (47.2%) examined complex interventions. Most of the studies (80.6%) had individual sessions in the interventions as opposed to group sessions. Intervention dosages varied from 2 sessions to 78 sessions (3 sessions per week for 26 weeks).

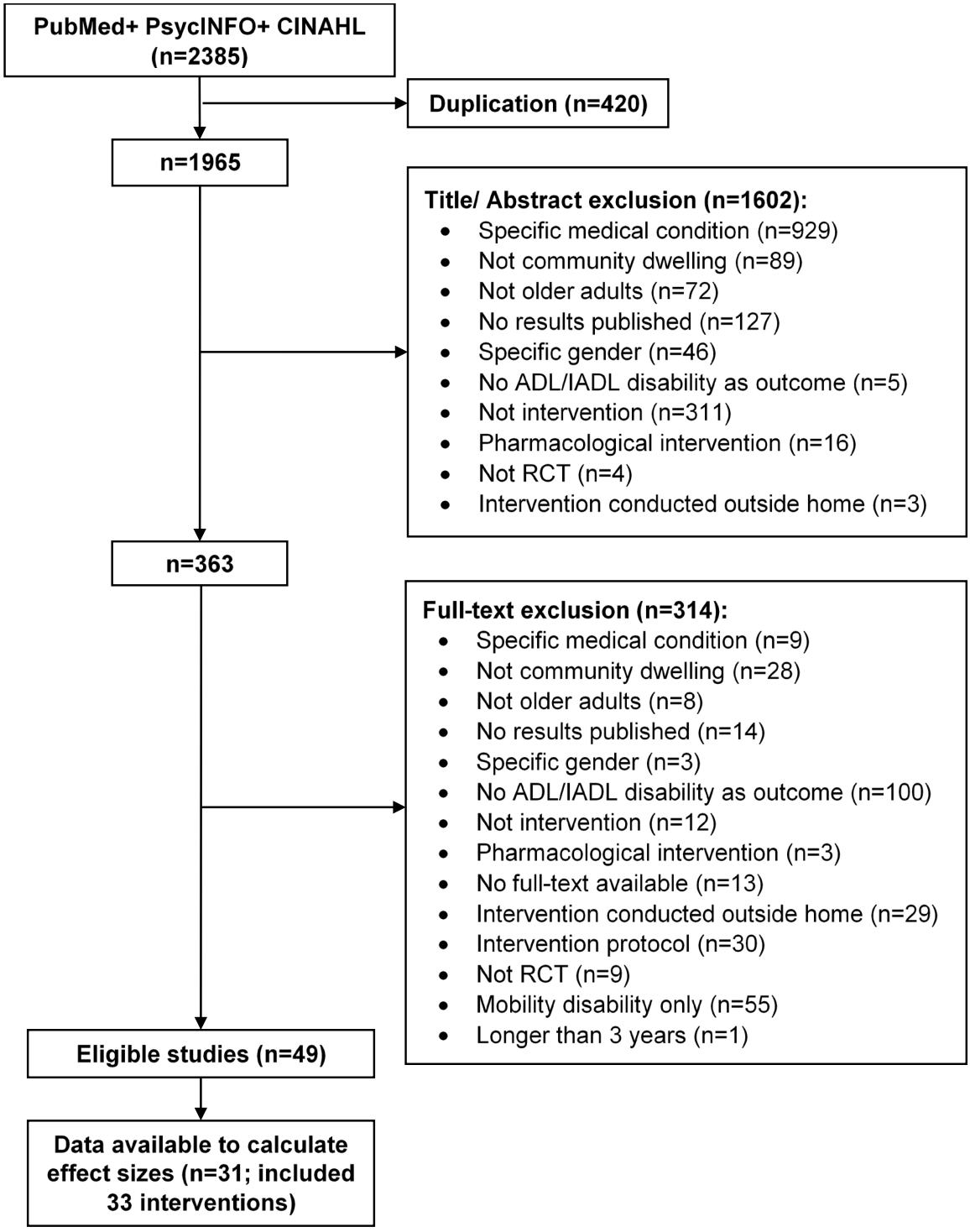


Figure 1 Review diagram

Table 1 Included studies (n = 31)

Authors, (year)	Population	No. allocated		Mean age (year)		Female (%)		Dosage	Session Format	Disability measure	Primary outcome	Follow-up month
		Intervention	Control	Intervention	Control	Intervention	Control					
Alexopoulos et al., (2011)	Major depressive disorder	110	111	72.8	73.2	N/A	N/A	12 weekly sessions	Individual	WHODAS	Yes	9
Binder et al., (2002)	Frailty	66	49	83.0	83.0	52.0	53.0	1 hour/3 times*12weeks	Group	FSQ	Yes	9
Bouman et al., (2008)	Poor health conditions	139	154	75.8	75.6	60.0	60.0	1-1.5 hours/ 8 sessions	Individual	GARS	Yes	24
Callahan et al., (2005)	Major depression or dysthymic disorder	906	895	71.0	71.4	64.1	65.6	6-8 sessions	Individual	7 IADL	Yes	12
Cameron et al., (2013)	Frailty	108	116	83.4	83.2	67.0	68.0	10 sessions	Individual	BI	Yes	12
Chin et al., (2001)	Physical inactivity	80	74	77.5	78.9	73.0	70.0	45 mins/2 times*17weeks	Group	16 ADL	Yes	3
Clare et al., (2015)	Without dementia or intellectual disability	22	27	68.2	70.2	79.2	85.2	A session and a follow-up call	Individual	FCAS	Yes	12
		21	27	67.5	70.2	95.8	85.2					
Clark et al., (1997)	Without dementia	101	202	N/A	N/A	64.0	65.5	2 hours per week/ 9 month	Group+ Individual	FSQ	Yes	9
Counsell et al., (2007)	Income < 200% of the federal poverty level	474	477	71.8	71.6	75.5	76.5	1 visit and 1 phone call	Individual	7 ADL+6 BADL	Yes	24
Day et al., (2012)	Preclinical disability	171	190	N/A	N/A	66.2	69.7	1 hour/ 2times*48 weeks	Group	LLFDI	Yes	6
Dorresteijn et al., (2016)	Concerns about falls and activity avoidance	141	171	78.4	78.3	68.0	72.3	3 sessions; 4 phone calls	Individual	GARS	No	12
Fairhall et al., (2012)	Frailty	111	121	83.4	83.2	67.0	68.0	1 hour/ 10 sessions	Individual	LSA-UAB	Yes	12
Foley et al., (2011)	Discharge from day rehabilitation	34	36	78.3	79.9	79.0	81.0	1 hour/ 24 sessions	Individual	BI	Yes	3
Gill et al., (2004)	Frailty	91	91	82.8	83.5	85.0	74.0	16 sessions*6 months	Individual	8 ADL	Yes	12
Gitlin et al., (2006)	Difficulty with two IADLs or one ADL	154	146	79.5	78.5	82.5	81.1	1.5 hours/ 6 sessions	Individual	6 ADL+6 IADL	Yes	12
Haines et al., (2009)	Discharged from hospital	19	34	80.9	80.5	74.0	53.0	8 weekly phone calls	Individual	FAI	Yes	6

Table 2 continued

Hendriks et al., (2008)	Fall	123	134	74.5	75.2	66.9	70.1	2 visits	Individual	FAI	No	12
Kerse et al., (2010)	Depressive symptoms	94	87	81.4	80.8	63.9	53.1	1 hour/ 8 sessions	Individual	NEADL	Yes	12
Kerse et al., (2014)	Participated in primary care practice	1787	1619	80.4	80.3	56.0	54.0	3 visits	Individual	NEADL	Yes	36
King et al., (2012)	Received assistance from the home care	82	82	80.5	78.4	77.4	69.9	At least 5 visits	Individual	NEADL	No	7
Kono et al., (2012)	Frailty	105	100	80.3	79.6	73.9	74.1	4 visits	Individual	BI	Yes	24
Lannin et al., (2007)	Mild to no cognitive impairments	5	5	80.0	82.4	100	60.0	55-85 minutes/ 1 session	Individual	NEADL	Yes	3
Liu et al., (2014)	Fall	64	58	74.5	74.5	87.5	86.2	1.5 hours/ 8 sessions	Group	5 social activities	No	3
Mahoney et al., (2007)	Fall	130	135	79.6	80.3	78.7	78.3	2 visits/ phone calls	Individual	BI	No	12
Pighills et al., (2011)	Fall	87	78	78.0	80.0	71.0	67.0	1 visit/ 2 phone calls	Individual	BI	No	12
		73	78	79.0	80.0	62.0	67.0					
Rockwood et al., (2003)	Frailty	85	80	81.4	82.2	56.8	57.5	1-6 visits/ 1 follow-up	Individual	Lawton IADL	N/A	12
Rydwik et al., (2010)	Frailty	20	19	83.5	82.9	47.8	69.6	1 hour/ 2 time*12 week	Group	FIM	No	24
Szanton et al., (2011)	Low income; difficulties in 1ADL or 2 IADL	20	15	79.0	77.0	96.0	94.0	1 hour/ 10 sessions	Individual	5 ADL+ 6 IADL	Yes	6
van Hout et al., (2010)	Frailty	331	330	81.3	81.5	72.2	68.8	3 visits/ phone contacts	Individual	GARS	Yes	18
Villareal et al., (2006)	Frail and obese	17	10	71.1	69.4	60.0	71.0	1.5 hour/ 3 days*26 weeks	Group	FSQ	Yes	24
von Bonsdorff et al., (2008)	Sedentary	310	306	77.6	77.6	74.5	75.2	1 hour/ every 4 months phone calls	Individual	Lawton IADL	Yes	24
Total		6081	5952	77.9	78.4	71.8	69.7					

Note: N/A (None applicable); WHODAS (World Health Organization Disability Assessment Schedule); FSQ (Functional Status Questionnaire); GARS (Groningen Activity Restriction Scale); BI (Barthel Index); FCAS (Florida Cognitive Activities Scale); LLFDI (Late-Life Function & Disability Instrument); LSA-UAB (University of Alabama at Birmingham Study of Aging Life-Space Assessment); FAI (Frenchay Activities Index); NEADL (Nottingham Extended Activities of Daily Living Scale); FIM (Functional Independence Measure)

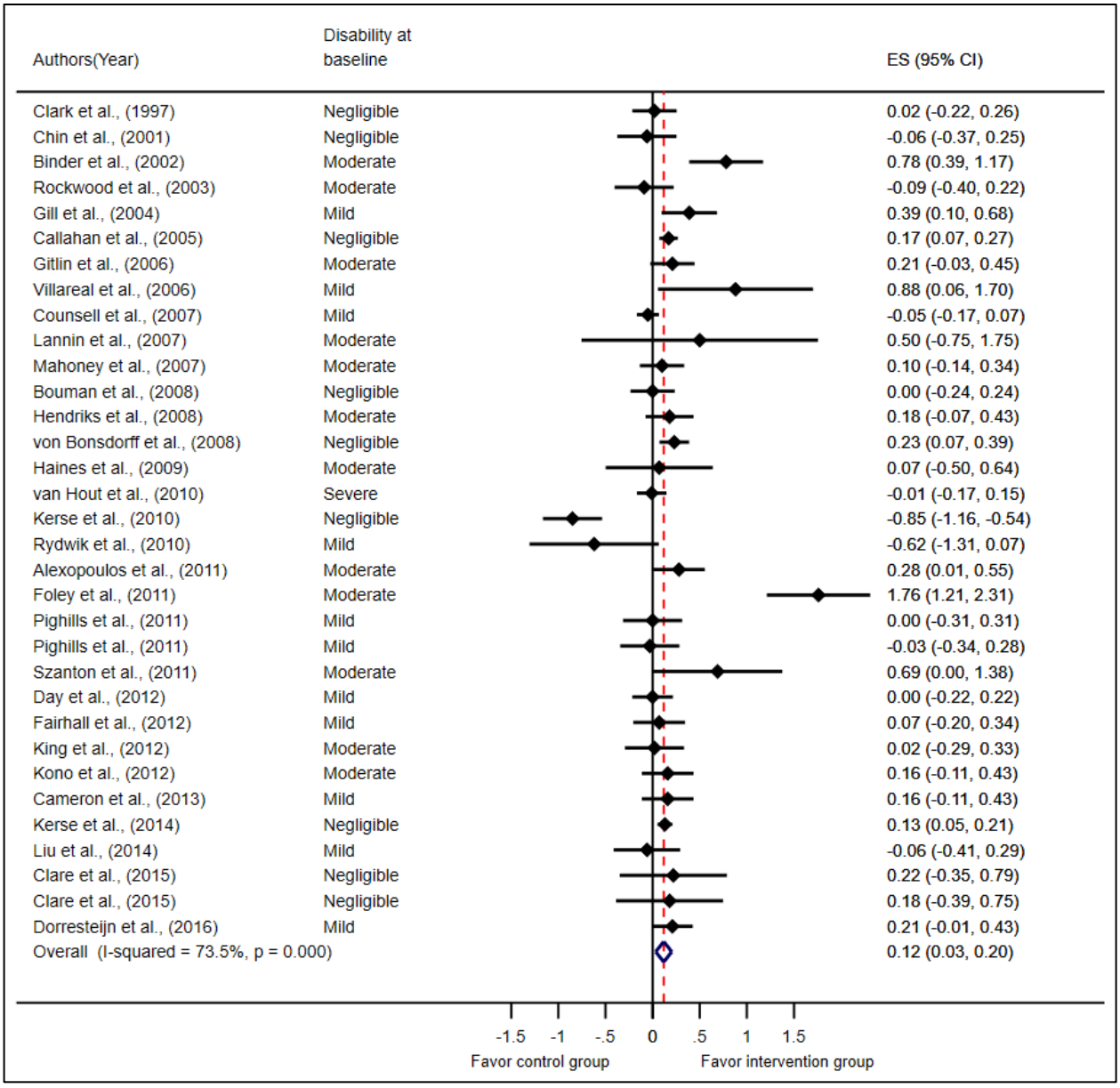


Figure 2 A forest plot of the effects of 31 studies on disabiliity

Eleven measurements were used to assess disability (**Table 1-2**). Several authors developed participant-reported measures of disability (n = 7). Barthel Index (n = 5) (Mahoney & Barthel, 1965) and Nottingham Extended Activities of Daily Living Scale (n = 4) (Nouri & Lincoln, 1987) were the most frequently used tools to assess ADL and IADL disabilities. Other studies used Groningen Activity Restriction Scale (n = 3) (Kempen & Suurmeijer, 1990), Functional Status Questionnaire (n = 3) (Jette et al., 1986), Frenchay Activities Index (n = 2) (Schuling, de Haan, Limburg, & Groenier, 1993), or Lawton IADL measures (n = 2) (Lawton & Brody, 1969).

2.3.2 Participant characteristics

Studies recruited participants with negligible (n = 9); mild (n = 11); moderate (n = 12), and severe disability (n = 1) (**Figure 2**).

2.3.3 Effects of intervention studies

There was a moderate to high heterogeneity among the 31 studies (I^2 = 73.5%, $p < .001$). **Figure 3** illustrates the effect size *d* ranged from -0.85 to 1.76 across studies, with 9 having statistically significant effect sizes (Alexopoulos et al., 2011; Binder et al., 2002; Callahan et al., 2005; Foley et al., 2011; Gill et al., 2004; Kerse et al., 2014; Szanton et al., 2011; Villareal, Banks, Sinacore, Siener, & Klein, 2006; von Bonsdorff et al., 2008). From the 31 studies, 22 had negligible effect sizes, accounting for 83.0% of total participants; 6 studies had mild effect sizes, accounting for 14.0% of total participants; 3 studies had moderate effect sizes, accounting for 2.0% of total participants; and 2 studies had large effect sizes, accounting for 1.0% of total participants.

Studies included measures of ADL disability, IADL disability, and ADL combined IADL disability had effect size *d* ranged from -0.62 to 1.76, -0.09 to 0.69, and -0.85 to 0.88.

2.3.4 Effects of active ingredients embedded in the interventions

Table 3-4 showed 8 active ingredients that were identified and defined: exercise; problem-solving; cognitive behavioral therapy; environmental modification; education; goal setting; comprehensive geriatric assessment; and cognitive training.

Table 3 Definitions of active ingredients

Active ingredient	Definition	Keywords
Exercise	Strengthen physical function, body structure, and physiological reserves	Exercise; physical activity; strengthening; walk; physical training; Tai-Chi; balance; mobility; agility; stretching
Problem-solving	Identify problems in daily activities, propose solutions to solve the problems, and implement solutions	Problem-solving; action plan, review solutions; identify strategies; refine strategies; design a plan; mutual problem-solving; overcome barriers; propose ways
Cognitive behavioral therapy	Discuss and identify patterns of thinking or behaviors. Change distorted thoughts to change behaviors and mood	Cognitive behavioral therapy; cognitive behavioral interventions
Environmental modification	Modify environmental factors, such as home, light, rug, handrail	Environmental modification; eliminate environmental hazards; home modification
Education	Deliver, shape, or instruct knowledge on how to perform a behavior or deal with situations	Education; impart knowledge; didactic teaching; educational videotape
Goal setting	Identify goals that are relevant to health professionals or participants	Goal setting; preview goals; identify goals; prioritize goals; set realistic goals
Comprehensive geriatric assessment	Evaluate medical, functional, psychological, social, or environmental domains	Comprehensive geriatric assessment; multidimensional geriatric instrument; standardized health assessment
Cognitive training	Train specific cognitive domains, including processing speed, memory, attention, or reasoning	Cognition training; mathematics; attention memory; visuospatial ability; processing speed; reasoning; visual search skill

Table 4 Effect sizes of active ingredients

Intervention characteristics	# of study	# of sample	I^2 (%)	Range of effect size *d*	The four-level magnitude of effect sizes[a] <0.2 Negligible	0.2-0.5 Small	0.5-0.8 Moderate	>0.8 Large
Active ingredient								
Exercise	13	2214	86.6*	-0.85~1.76	55%	36%	5%	4%
Problem-solving	8	3418	0.0	0.17~0.88	54%	44%	1%	1%
CBT	8	3196	0.0	-0.06~0.88	62%	37%		1%
Environment modification	4	778	26.2	0.10~0.69	34%	61%	4%	
Education	10	3361	0.0	0.02~0.69	75%	24%	1%	
Goal setting	9	2983	18.8	-0.09~0.88	78%	20%	2%	
CGA	15	6892	0.0	-0.09~0.69	94%		3%	3%
Complex intervention	15	4603	0.0	-0.09~0.88	62%	36%	1%	1%
Total	31	12033	73.5*	-0.85~1.76	83%		14%	2% 1%

Note: *Statistically significant ($p < 0.05$)

Note: [a]The proportions accounted for numbers of participants.

Note: CBT (cognitive behavioral therapy); CGA (comprehensive geriatric assessment)

2.3.4.1 Exercise

Exercise was an active ingredient of 13 interventions in 13 studies (Binder et al., 2002; Cameron et al., 2013; Chin A Paw, de Jong, Schouten, Hiddink, & Kok, 2001; Day et al., 2012; Dorresteijn et al., 2016; Fairhall et al., 2012; Foley et al., 2011; Gill et al., 2004; Gitlin et al., 2006; Haines et al., 2009; Kerse et al., 2010; Rydwik, Frandin, & Akner, 2010; Villareal et al., 2006) (**Table 4**; **Appendix B**). There was high heterogeneity among the 13 studies ($I^2 = 86.6\%$, $p < .001$). The effect size *d* ranged from -0.85 to 1.76 across studies, with 4 having statistically significant effect sizes (Binder et al., 2002; Foley et al., 2011; Gill et al., 2004; Villareal et al., 2006). Exercise programs focused on aerobic training, resistance training, balance, or Tai-Chi. Foley et al. conducted an aerobic exercise program for older adults with musculoskeletal impairments, surgeries, or falls. Results showed a large, statistically significant effect size ($d = 1.76$). Villareal et al. engaged older adults in flexibility, endurance, strength, and balance training. They found a large effect size ($d = 0.88$; baseline to 26 months). Gill et al. trained older adults in bed transfer, indoor and outdoor mobility. Results demonstrated a small to moderate effect size ($d = 0.39$; baseline to 12 months). There were negative effect sizes in favor of the control groups over time in Chin, Kerse and Rydwik et al.'s studies.

2.3.4.2 Problem-solving

Problem-solving was an active ingredient of 9 interventions in 8 studies (Alexopoulos et al., 2011; Callahan et al., 2005; Clare et al., 2015; Dorresteijn et al., 2016; Gitlin et al., 2006; Szanton et al., 2011; Villareal et al., 2006; von Bonsdorff et al., 2008) (**Table 4; Appendix C**). There was no statistically significant heterogeneity among the 8 studies ($I^2 = 0.0\%$, $p = 0.72$). Effect size *d* ranged from 0.21 to 0.88 across studies, with 5 having statistically significant effect

sizes (Alexopoulos et al., 2011; Callahan et al., 2005; Szanton et al., 2011; Villareal et al., 2006; von Bonsdorff et al., 2008). Alexopoulos et al. and Callahan et al. used problem-solving therapy to reduce disability for older adults with depressive symptoms. Alexopoulos et al. found a significant group difference in change in disability (d = 0.28; baseline to 36 weeks), but a non-significant group difference in Callahan et al.'s study (d = 0.17; baseline to 12 months). Villareal et al. applied problem-solving skills to modify eating habits and lifestyles in older adults who were obese. Results showed a large effect size (d = 0.88; baseline to 6 months). Szanton et al. used problem-solving techniques to resolve behavioral and environmental barriers for older adults. They found a moderate effect size (d = 0.69; baseline to 6 months).

2.3.4.3 Cognitive behavioral therapy

Cognitive behavioral therapy was an active ingredient of 8 interventions in 7 studies (Alexopoulos et al., 2011; Callahan et al., 2005; Clare et al., 2015; Dorresteijn et al., 2016; Liu & Tsui, 2014; Villareal et al., 2006; von Bonsdorff et al., 2008) (**Table 4**; **Appendix D**). There was no statistically significant heterogeneity among the 7 studies (I^2 = 0.0%, p = 0.60). The effect size d ranged from -0.06 to 0.88 across studies, with 4 having statistically significant effect sizes (Alexopoulos et al., 2011; Callahan et al., 2005; Villareal et al., 2006; von Bonsdorff et al., 2008). Two interventions incorporated cognitive behavioral therapy to reduce the fear of falling and promote re-engagement in ADL for older adults (Dorresteijn et al., 2016; Liu & Tsui, 2014). Zijlstra et al. and Dorresteijn et al. together developed "A Matter of Balance-Netherlands program" for frail older adults (Dorresteijn et al., 2016; Zijlstra et al., 2009). Results showed that the intervention group had more reductions in disabilities compared to the usual-care control (d = 0.21; baseline to 12 months). Liu et al. incorporated cognitive behavioral techniques to reduce the fear of falling. Results showed a negative effect size (d = -0.06). Alexopoulos et al. and Callahan et al.

both incorporated cognitive behavioral techniques to change older adults' distorted thoughts (e.g., Outdoor activities will make me fall.). Both studies found small to moderate effect sizes (d = 0.28; 0.17). Villareal et al. recruited frail older adults and adopted cognitive behavioral therapy to change diets, exercise, and functional status. Results showed a high magnitude effect size (d = 0.88).

2.3.4.4 Environmental modification

Environmental modification was an active ingredient of 4 interventions in 4 studies (Gill et al., 2004; Gitlin et al., 2006; Mahoney et al., 2007; Szanton et al., 2011) (**Table 4**; **Appendix E**). There was negligible heterogeneity among the 4 studies (I^2 = 26.2%, p = 0.25). The effect size d ranged from 0.10 to 0.69 across studies, with 2 having statistically significant effect sizes (Gill et al., 2004; Szanton et al., 2011). Environmental modification usually involved: 1) assessing environmental hazards; 2) removing environmental hazards; 3) installing equipment. Gitlin et al. and Szanton et al. designed environmental modification interventions to reduce disability for low-income older adults with mild disabilities. Szanton et al. found a significant group difference in change in disability (d = 0.69; baseline to 6 months), but a non-significant group difference in Gitlin et al.'s study (d = 0.21). Gill et al. had physical therapists evaluate the home environment and provide recommendations to remove cords, replace mats, and install adaptive equipment. Results showed a group difference in change in disability (d = 0.39; baseline to 12 months).

2.3.4.5 Education

Education was an active ingredient of 10 interventions in 10 studies (Callahan et al., 2005; Clark et al., 1997; Dorresteijn et al., 2016; Gill et al., 2004; Gitlin et al., 2006; King, Parsons, Robinson, & Jorgensen, 2012; Lannin et al., 2007; Mahoney et al., 2007; Szanton et al., 2011; von Bonsdorff et al., 2008) (**Table 4**; **Appendix F**). There was no statistically significant heterogeneity

among the 10 studies (I^2 = 0.0%, p = 0.52). The effect size d ranged from 0.02 to 0.69 across studies, with 4 having statistically significant effect sizes (Callahan et al., 2005; Gill et al., 2004; Szanton et al., 2011; von Bonsdorff et al., 2008). Education programs incorporated diverse modalities, including educational videotape, booklet, volunteer lecture, or homework. Three studies provided education on exercise (Gill et al., 2004; Mahoney et al., 2007; von Bonsdorff et al., 2008). von Bonsdorff et al. and Gill et al.'s exercise programs found small to moderate effect sizes (d = 0.23; 0.39), but a non-significant effect size was observed in Mahoney et al.'s program (d = 0.10). Callahan et al. provided educational videotapes for older adults with depressive symptoms. The intervention group reduced more disability than the control group (d = 0.17; baseline to 12 months). Lannin et al. educated older adults on safety precautions for performing ADL. Results showed a non-significant moderate effect size (d = 0.50; baseline to 3 months). Clark et al. applied a didactic teaching method to help older adults select healthy lifestyles. They found no group difference in change in disability (d = 0.02; baseline to 9 months).

2.3.4.6 Goal setting

Goal setting was an active ingredient of 9 interventions in 9 studies (Alexopoulos et al., 2011; Callahan et al., 2005; Clare et al., 2015; Dorresteijn et al., 2016; Fairhall et al., 2012; A. I. I. King et al., 2012; Rockwood et al., 2003; Szanton et al., 2011; Villareal et al., 2006) (**Table 4**; **Appendix G**). There was no statistically significant heterogeneity among the 9 studies (I^2 = 18.8%, p = 0.28).The effect size d ranged from -0.09 to 0.88 across studies, with 4 having statistically significant effect sizes (Alexopoulos et al., 2011; Callahan et al., 2005; Szanton et al., 2011; Villareal et al., 2006). Goals were described as either client-centered goals (e.g., go shopping myself) (Alexopoulos et al., 2011; Callahan et al., 2005; Clare et al., 2015; Dorresteijn et al., 2016; Fairhall et al., 2012; Szanton et al., 2011; Villareal et al., 2006) or practitioner-centered goals (e.g.

monitor blood sugar) (A. I. I. King et al., 2012; Rockwood et al., 2003) across the 9 included interventions. Three out of 7 client-centered goal setting interventions focused on physical activity goals (Dorresteijn et al., 2016; Fairhall et al., 2012; Villareal et al., 2006). Two out of 9 interventions used tools to facilitate goal setting processes (Clare et al., 2015; Rockwood et al., 2003). Clare et al. used the Bangor Goal Setting Interview to guide participants in selecting 5 goals: physical activity, cognitive activity, physical health, diet, and social engagement. Results showed a non-significant, small effect size (d = 0.22; baseline to 12 months). Rockwood et al. used the Goal Attainment Scale to facilitate goal selection and scaling processes. They found a non-significant, negative effect size (d = -0.09; baseline to 3 months).

2.3.4.7 Comprehensive geriatric assessment

Comprehensive geriatric assessment was an active ingredient of 15 interventions in 15 studies (Bouman, van Rossum, Ambergen, Kempen, & Knipschild, 2008; Cameron et al., 2013; Counsell et al., 2007; Fairhall et al., 2012; Gill et al., 2004; Hendriks et al., 2008; Kerse et al., 2014; King et al., 2012; Kono et al., 2012; Mahoney et al., 2007; Pighills, Torgerson, Sheldon, Drummond, & Bland, 2011; Rockwood et al., 2003; Szanton et al., 2011; van Hout et al., 2010) (**Table 4**; **Appendix H**). There was negligible heterogeneity among the 15 studies (I^2 = 0%, p = 0.46). The effect size d ranged from -0.09 to 0.69 across studies, with 3 having statistically significant effect sizes (Gill et al., 2004; Kerse et al., 2014; Szanton et al., 2011). The comprehensive geriatric assessment was often defined as a treatment process that incorporated medical, psychosocial or functional assessments to inform care plans for primary care teams. Older adults had less involvement in the development of care plans. Kerse et al. and Counsell et al. had multidisciplinary teams conduct the comprehensive geriatric assessment and provide suggestions to the primary care team for older adults. Results showed negligible effect sizes (d = 0.13; -0.05).

Gill et al.'s comprehensive geriatric assessment focused on impairments in physical abilities and home environments. Results showed a small to moderate effect size (d = 0.39; baseline to 12 months). Szanton et al. collected both client-report and clinician-observe data to identify problematic ADL and environmental features for older adults. Results demonstrated a moderate to large effect size (d = 0.69; baseline to 6 months). Pighills et al. conducted comprehensive assessments and sent recommendations to older adults. They found a negative effect size in favor of the control group (d = -0.03).

2.3.4.8 Cognitive training

Cognitive training was an active ingredient of 5 interventions in 3 studies (Ball et al., 2002; Corbett et al., 2015; Ng et al., 2015). Data were insufficient to calculate effect sizes.

2.3.4.9 Complex interventions

Fifteen interventions were complex interventions, as indicated by having more than one active ingredient in the intervention (**Table 4**; **Appendix I**). There was no statistically significant heterogeneity among the 15 studies (I^2 = 0.0%, p = 0.54). The effect size d ranged from -0.09 to 0.88 across studies, with 6 studies having statistically significant effect sizes (Alexopoulos et al., 2011; Callahan et al., 2005; Gill et al., 2004; Szanton et al., 2011; Villareal et al., 2006; von Bonsdorff et al., 2008). The number of active ingredients in the complex interventions was as followed: 2 (n = 3) (Cameron et al., 2013; Clare et al., 2015; Rockwood et al., 2003); 3 (n = 6) (Alexopoulos et al., 2011; Clare et al., 2015; Fairhall et al., 2012; King et al., 2012; Mahoney et al., 2007; von Bonsdorff et al., 2008); 4 (n = 4) (Callahan et al., 2005; Gill et al., 2004; Gitlin et al., 2006; Villareal et al., 2006); 5 (n = 2) (Dorresteijn et al., 2016; Szanton et al., 2011).

2.4 Discussion

This review examined the science related to non-pharmacological intervention studies to reduce disability in community-dwelling older adults. The majority of included studies showed negligible to small effect sizes in minimizing disability. Yet, this finding may be argued to be clinically meaningful. For example, a small reduction of disability may slow down the progression toward severe disability and potentially reduce the cost of healthcare programs since healthcare expenditures are positively correlated with the severity of disability in the aging population (Manton, Gu, & Lamb, 2006). Interventions that included exercise, problem-solving, cognitive behavioral therapy, and environmental modification as active ingredients were associated with stronger effect sizes in reducing disability. We urge caution when interpreting this finding, given that the active ingredients were not mutually exclusive among interventions. The results may not be confirmatory until a systematic review in comparing active ingredients is completed. Altogether, these findings may inform future intervention strategies and priorities to reduce disability in late life.

2.4.1 Negligible to small effect sizes across studies

Several possibilities may explain the negligible to small effect sizes across studies. The use of diverse eligibility criteria across studies resulted in a range of disability severity statuses among participants in the studies. Most of the included studies included older adults with negligible to moderate disability. As such, the effect sizes may not be as large as those interventions which aimed to reduce disability for older adults who have already developed severe disability. This explanation is based on the assumption that older adults with severe disability may have room to

gain greater improvements than those with negligible or mild disability. Another explanation is our use of a conservative approach to calculate effect sizes, which has been suggested to generate conservative estimates (Feingold, 2009). Negligible to small effect sizes may result from the psychometric properties of measures of disability. A measurement with low sensitivity to change may fail to detect the true effects of intervention studies (Fok & Henry, 2015). Last, certain control groups (e.g., nutrition interventions) may have had some influence on disability rather than attention control groups, thus reducing the magnitude of effect sizes.

Additionally, we found that the ranges of effect sizes varied from studies that focused on ADL, IADL, or ADL+IADL disabilities. Studies that focused on ADL disability had the widest range of effect sizes. Previous studies have suggested that ADL disability is more severe than IADL disability (Leibold et al., 2014). Thus, studies focused on reducing ADL disability may result in more changes than IADL disability. Future studies that aim to reduce disability may provide the rationale of how interventions may change ADL and IADL disability respectively.

2.4.2 The effects of active ingredients on disability

Many combinations of active ingredients were found in included interventions. The combination of problem-solving and environmental modification showed promise in reducing disability. This combination echoes current concept about the emergence of disability as a mismatch between personal strengths and environmental demands (World Health Organization, 2002). Problem-solving focuses on building individuals' problem-solving skills when facing barriers in ADL and IADL (D'Zurilla & Nezu, 2010). Whereas environmental modification changed contexture factors to match individuals' needs (Petersson, Lilja, Hammel, & Kottorp,

2008). The change of both personal and contextual factors helps older adults engage in ADL and IADL and thus, reduce disability.

Exercise showed promise in reducing disability; whereas comprehensive geriatric assessment found little or no effects on disability reduction. Interestingly, exercise and comprehensive geriatric assessment were often the only active ingredient in the interventions, comparing to goal setting and education that were often combined with other active ingredients. This suggests that active ingredients have different applicability and roles within interventions, and intervention effects are not determined by the number of active ingredients. Some active ingredients aim to initiate new behaviors while others aim to maintain preferred behaviors (Wood, Quinn, & Kashy, 2002). How to combine the most effective active ingredients to reduce disability require iterative case and pilot studies.

The mode of delivery could differ within the same active ingredient. For example, goal setting could be led by practitioners, older adults, or caregivers. In this review, we found that goals were mostly determined by practitioners, instead of older adults or caregivers. Since practitioner-selected goals may not always support an older adult autonomy and a family's expectation to change behaviors (Locke & Latham, 2002), future studies should separate those three perspectives while examining the effects of goal setting on disability.

Literature on comprehensive geriatric assessment has demonstrated its effectiveness for controlling disease progression and predicting mortality rates in late life (Stuck, Egger, Hammer, Minder, & Beck, 2002). While our ultimate goal was to reduce disability, the involvement of older adults and family in the care plan processes following the comprehensive geriatric assessment became critical to empower older adults and caregivers to drive behavioral changes (Krishnan et al., 2017). However, in our review, some interventions that incorporated comprehensive geriatric

assessment did not partner with older adults or their caregivers while making care plans. Thus, the potency of comprehensive geriatric assessment in reducing disability might not be as large as in controlling disease progression and mortality.

2.4.3 The effects of complex interventions on disability

The magnitudes of the effect sizes were not as large as we expected among studies that examined complex interventions. This might be due to a variety of possible reasons. First, complex interventions are "built up from more than one active ingredient, which may act both independently and interdependently. (p.455) (Campbell et al., 2007)" A clear understanding of how active ingredients worked with each other is a critical step. However, the effects of active ingredients were rarely compared or even described in the complex interventions. For example, does the combination of goal setting with exercise reduce more disability than the combination of goal setting with problem-solving? The unclarity of how active ingredients interacted with each other has impeded the design of optimal and efficacious interventions. Second, complex interventions might be inadequately applied (insufficient dosages) in an inappropriate environment (homes versus community settings) (Campbell et al., 2007; Craig et al., 2008).

2.4.4 Strengths and limitations

This study provided valuable insights. First, this review included studies that recruited older adults from negligible to severe disability, but this disability was not caused by acute medical conditions. The strategy provided a way to capture older adults at-risk for severe disability. Second, the active ingredients in driving the efficacy of non-pharmacological interventions were

explored. This information was critical to inform future intervention development and priorities. Third, disability was selected as the outcome, which was one of the top priorities to reduce the costly healthcare related to disability and sustain quality of life into old age.

The findings should be interpreted cautiously. First, the quality of studies was not evaluated, which may influence the potency of evidence. Second, research has shown that, often times, the active ingredients of non-pharmacological interventions were not well described in the contents of manuscripts (Abraham & Michie, 2008). This limitation might impede the finding. Third, the adherence rates of interventions were not evaluated, which might influence the reported effects. The study dosage might influence the effects of interventions, especially to make behavioral changes. Last, there was considerable heterogeneity across 31 studies. These variances might contribute to eligibility criteria used in the studies, quality of interventions, and the selection of outcome measures.

2.4.5 Future directions

Reducing disability among community-dwelling older adults relies on a clear understanding of problematic areas in their ADL and IADL. By comprehensively understanding these day-to-day activities, researchers can investigate the barriers older adults confront and further inform those who are at high risk of further disability.

Specifying and evaluating active ingredients in influencing intervention efficacy can provide valuable insights into why an intervention fails or succeeds, and how it can be optimized. For example, the multiphase optimization strategy (MOST) identifies active ingredients within interventions and optimizes dosages of each active ingredient to refine complex interventions (L.

M. Collins, Murphy, & Strecher, 2007). Future studies may adopt systematic protocols and methodologies to refine non-pharmacological interventions “prior to” the implementation phases. This, in turn, would help replication studies and support evidence-based practice.

The measurements that assess disability should obtain sensitivity to capture the change in older adults with minimal disability. Early decline in disability is usually silent and fluctuating. An assessment that captures the change in disability for older adults must assess the quality of their performance in ADL and IADL (Freedman et al., 2014).

In summary, non-pharmacological interventions involve many interacting active ingredients in mitigating disability for older adults. Future studies should specify and evaluate active ingredients within non-pharmacological interventions to optimize effects on disability in late life. This review identifies several research directions to reduce disability into old age.

3.0 Trajectory of Disability in Older Adults with Newly Diagnosed Diabetes Mellitus

In **Chapter 3**, we examine the association between selected indicators of brain health and disability in older adults with a newly-diagnosed chronic condition, using diabetes mellitus (DM) as an exemplar. We examined the longitudinal associations among elevated depressive symptoms, cognitive decline, and disability over a 10-year period in older adults with a new diagnosis of DM. A portion of the chapter has been published: Wu CY, Terhorst L, Karp J, Skidmore ER, Rodakowski J. Trajectory of Disability in Older Adults with Newly Diagnosed Diabetes: Role of Elevated Depressive Symptoms. *Diabetes Care.* 2018; 41(10), 2072-2078. The content was reprinted with permission (**Appendix J**).

3.1 Introduction

The number of older adults will increase by an estimated threefold by 2050, and the number of older adults with diabetes mellitus (DM) is expected to increase by 4.5-fold (Narayan, Boyle, Geiss, Saaddine, & Thompson, 2006). DM costs $245 billion per year ($176 billion in direct medical costs, $69 billion in reduced productivity) in the U.S. and is well-known for its complications and association with disability (American Diabetes Association, 2013; de Rekeneire et al., 2003).

Disability has been defined by the U.S. Census Bureau and National Institute on Disability, Independent Living, and Rehabilitation Research as the inability to perform activities of daily living (ADL) and instrumental ADL (IADL) (Kraus, 2017; Ortman et al., 2014). ADL is essential

to sustain self-care (e.g., dressing, eating), whereas IADL are critical for independent living (e.g., shopping, preparing a meal). Emerging evidence suggests that the prevalence of disability is growing in older adults with DM (J. P. Boyle, Thompson, Gregg, Barker, & Williamson, 2010). DM-related disability is problematic because it may lead to reduced quality of life, institutionalization, substantial health care costs, and early death (Dieleman et al., 2016; Selvin, Coresh, & Brancati, 2006). Identifying factors associated with DM-related disability early in the course of the disease may aid in the prevention of disability and save substantial health care costs.

Examining indicators of brain health may enhance our understanding of the disablement trajectory associated with DM in late life. Elevated depressive symptoms and cognitive decline were the indicators of brain health that are often comorbid with medical conditions in late life. Elevated depressive symptoms are often seen in older adults with newly diagnosed DM. Epidemiologic and clinical evidence suggests that 22.0% to 32.0% of older adults have DM (Black, Markides, & Ray, 2003; Kirkman et al., 2012), and 24.0% to 55.0% of these older adults have clinically significant depressive symptoms (Anderson, Freedland, Clouse, & Lustman, 2001; Roy & Lloyd, 2012). Depressive symptoms and DM have a bidirectional and mutually exacerbating relationship (Egede & Ellis, 2010) that may be mediated by behavioral and physiologic mechanisms (Lustman & Clouse, 2005). For example, after a new DM diagnosis, depressive symptoms may co-occur with metabolism dysregulation (Stuart & Baune, 2012). The somatic features of depressive symptoms (e.g., lack of energy, sleep disturbance) often interfere with adopting necessary healthy behaviors (e.g., medication management, exercise) (J. S. Gonzalez et al., 2008; Lin et al., 2004), worsening a vicious cycle of poor glucose control, inactivity, and low mood (Egede & Ellis, 2010; Nagelkerk, Reick, & Meengs, 2006). Symptoms of acute

hyperglycemia, including fatigue, nausea, frequent urination, and recurrent infections, also may cause or exacerbate depressive symptoms (Lustman & Clouse, 2005).

Subtle cognitive changes are often seen and reported in older adults with newly diagnosed DM (Rawlings et al., 2014). Cognitive decline is defined by the loss of cognitive domains, including memory, processing speed, or executive cognitive function. A systematic review suggests that individuals with a diagnosis of DM have 1.2 to 1.7 times odds of having cognitive decline (Cukierman, Gerstein, & Williamson, 2005). After a new DM diagnosis, brain imaging studies reveal brain volume reductions and these reductions mirror decline in cognitive function (Biessels, Strachan, Visseren, Kappelle, & Whitmer, 2014). Cognitive decline is problematic, because difficulties with remembering daily tasks, processing information, and switching between tasks may temper the ability to learn disease self-management and engage in everyday activities for those with newly-diagnosed DM. The less engagement in self-care and everyday activities may potentially lead to worsening health and function in late life.

Although it has been established that depressive symptoms and cognitive decline are associated with chronic diseases and worse health outcomes over time, we have little understanding of the influence of elevated depressive symptoms and cognitive decline on the disablement trajectory in older adults with newly diagnosed DM. Older adults who have a change in elevated depressive symptoms or cognitive decline after being diagnosed medical conditions (e.g., the onset of DM) are at risk of further psychiatric and neurological complications (E. I. Fried & Nesse, 2015; Jeffrey S. Gonzalez et al., 2007) and deteriorated health over time (Judd & Akiskal, 2000). The understanding of the similarities or differences in the trajectories of disability between older adults with and without elevated depressive symptoms and cognitive decline may aid in

current research through early identification of older adults at risk for disability. The timing and design of future interventions may be tailored based on this evidence.

The study examined whether the disablement trajectory before and after the diagnosis of DM was different between older adults with and without elevated depressive symptoms and cognitive decline. The Health and Retirement Study (HRS) dataset provided the opportunity to examine the longitudinal association among elevated depressive symptoms, cognitive decline with disability over a 10-year period in older adults with newly diagnosed DM.

3.2 Methods

3.2.1 Data and subjects

The HRS is a longitudinal dataset that was sponsored by the National Institute on Aging and was conducted by the University of Michigan (University of Michigan, 2016). The HRS dataset included a representative sample of 20,000 people age > 50 years. The HRS followed nationally representative samples of age-eligible respondents every 1–2 years. All the HRS survey data were collected by either phone or face-to-face interview by trained interviewers. The HRS survey data included demographics, work, health, functioning status, and disease conditions. The HRS dataset also included information about respondents' children and spouses.

We extracted survey data from the HRS cohorts from wave 8 (2004–2006) to wave 12 (2012–2014) because wave 12 had the most recent survey data. The response rates ranged from 87.9 to 88.6% among waves 8 to 12. Respondents who 1) self-reported being newly diagnosed with DM between waves 9 and 10, 2) were ≥ 55 years, and 3) had complete depressive symptoms,

cognitive function, and disability survey data were included in this study. In the HRS dataset, we identified eligible respondents in wave 10 to examine disablement before (waves 8 and 9) and after (waves 10–12) the onset of DM. A total of 512 respondents who met the inclusion criteria were identified in the HRS data. We excluded 93 and 248 who had missing values for depressive symptoms and cognitive function respectively; thus, 419 and 264 participants were included in the analyses separately.

3.2.2 Measures

3.2.2.1 Disability

Disability was measured by 5 ADL and 5 IADL tasks. Participants were asked whether they had difficulty with performing each task (yes/no). The total disability score ranged from 0 to 10, with a higher score indicating more disability. A cut point of 1 indicated the development of clinically meaningful, overt disability (Stenholm et al., 2015). In this study, separating two types of daily activities was important because ADL represented self-care tasks (e.g., bathing, eating), whereas IADL represented more complex tasks required for successful independent living (e.g., shopping, preparing meals) in older adults.

3.2.2.2 Depressive symptoms

Depressive symptoms were measured by the eight-item Center of Epidemiologic Studies Depression Scale (CESD) (Turvey, Carney, Arndt, Wallace, & Herzog, 1999), a self-report questionnaire with total scores ranging from 0 to 8, with a higher score indicating more somatic and mood symptoms. We measured depressive symptoms with the CESD after participants received a diagnosis of DM and separated these individuals into two groups: those who had

elevated depressive symptoms (elevated score on the CESD) from wave 9 to 10 and those who had the same or reduced depressive symptoms from wave 9 to 10. This approach would help to capture those with a tendency toward psychiatric complications and deteriorated health after the onset of DM (E. I. Fried & Nesse, 2015; Jeffrey S. Gonzalez et al., 2007).

3.2.2.3 Cognitive decline

Cognitive function was measured by survey questions addressing four cognitive domains: recall memory, working memory, processing speed, and naming. Recall memory was assessed by two-word recall tests: immediate and delayed. The two test scores were summed for a total score ranging from 0 to 20, with a higher score indicating better recall ability. Working memory was assessed by the serial sevens subtraction test. The total score ranged from 0 to 5, with a higher score indicating better working memory. Processing speed was assessed by counting backwards beginning with 20, a total score ranging from 0 to 2. Naming was assessed by an eight-item object, date, and President/Vice-President naming test (0 = incorrect and 1 = correct). The naming score was summed across items and ranged from 0 to 8. The summary cognition score ranged from 0 to 35, with a higher score indicating higher cognitive function. Prior research reported the summary cognition score had moderate internal consistency ($\alpha = 0.59$) (J. S. Gonzalez et al., 2008). We grouped older adults with DM into two groups: those with cognitive decline (reduced score on the summary cognition score from wave 9 to 10) and without cognitive decline (the same or increased summary cognition score from wave 9 to 10).

3.2.2.4 Demographic variables

We described the demographic and clinical characteristics of the sample by examining age, sex, years of education, race, ethnicity, marital status, comorbidity, and body mass index (BMI).

Comorbidity was measured by self-reported conditions (defined as high blood pressure, cancer or a malignant tumor, chronic lung disease, heart attack, stroke, psychiatric problems, or arthritis) before the onset of DM. We did not include health behaviors (e.g., smoking cessation, physical activity) and income variables because of the amount of missing data for those variables.

3.2.3 Statistical analysis

We used SPSS (version 22; IBM Corporation, Chicago, IL) and SAS (version 9.3; SAS Institute, Cary, NC) statistical software for data analysis. All the analyses were considered significant at the 0.05 two-tailed α-level. Disability was the dependent variable. Groups (with or without elevated depressive symptoms after the onset of DM; with or without cognitive decline after the onset of DM) and time (waves 8 to 12) were independent variables. We examined descriptive statistics, distribution plots, normality, and heterogeneity for the dependent variable (disability) over five waves to check the assumptions of the longitudinal linear mixed model (Singer, 1998). These assumptions were not met; therefore, we used the generalized linear mixed model with a Poisson distribution and an unstructured covariance matrix. The model included a group × time interaction as well as group (older adults with and without elevated depressive symptoms; cognitive decline) and time (waves 8 to 12) simple main effects. We treated the intercept of disability within participants as a random-effect variable. We controlled for wave 9 depressive symptoms (wave 9 cognitive function) in the model to take into account the severity of depressive symptoms (the level of cognitive function) before the onset of DM.

We conducted post hoc analysis and the Bonferroni correction for significance level adjustment after detecting a group × time interaction. Effect sizes were computed between groups for the five waves to determine the clinical meaningfulness of group differences. The magnitude

of effect sizes was followed by Cohen's *d* (0.2 = small, 0.5 = moderate, 0.8 = large). The χ^2 test was used to examine whether there were group differences in percentages of participants who experienced difficulties with the 10 ADL and IADL tasks at wave 10. Two steps were used to identify covariates in the model. First, group differences in demographic variables at wave 10 were examined by *t* and χ^2 statistics to identify potential covariates included in the model. Second, the relationships between disability and demographic variables were examined to identify variables with moderate associations (Pearson $r = 0.3$) to include as covariates in the model.

3.3 Results

3.3.1 Depressive symptoms

3.3.1.1 Subjects

A total of 419 participants with 1,956 observations (time points of data) were included in the analysis. Statistically significant differences were found between the two groups in years of education, marital status, and working memory at wave 10 (**Table 5**). No variable was moderately associated with disability (age [$r = 0.03$], sex [$r = 0.09$], race [$r = 0.10$], ethnicity [$r = 0.07$], years of education [$r = -0.19$], marital status [$r = 0.18$], self-report memory [$r = 0.18$], recall memory [$r = -0.20$], working memory [$r = -0.16$], and BMI [$r = 0.17$]).

Table 5 Descriptive statistics in older adults with new DM diagnosis at wave 10 (n = 419)

Characteristics [n (%)]	All	With elevated depressive symptoms	Without elevated depressive symptoms	*t*-statistics/ χ^2-statistics	*p*-value
	419 (100%)	113 (27.0)	306 (73.0)		
Age [mean (SD)]	70.30 (8.62)	71.05 (8.52)	70.02 (8.65)	$t_{(417)}$=-1.09	0.28
Gender [n (%)]				$\chi^2_{(1)}$=2.50	0.11
Male	199 (47.5%)	46 (40.7)	153 (50.0)		
Female	220 (52.5%)	67 (59.3)	153 (50.0)		
Race [n (%)]				$\chi^2_{(2)}$=5.49	0.06
White	329 (87.1%)	80 (70.8)	249 (81.4)		
Black	62 (14.8%)	23 (20.4)	39 (12.7)		
Other race	28 (6.7%)	10 (8.8)	18 (5.9)		
Ethnicity [n (%)]				$\chi^2_{(1)}$=3.80	0.05
Hispanic	54 (12.9%)	21 (18.6)	33 (10.8)		
Non-Hispanic	365 (87.1%)	92 (81.4)	273 (89.2)		
Year of education [mean (SD)]	12.48 (3.20)	11.85 (3.35)	12.71 (3.12)	$t_{(416)}$=2.46	0.01*
Marital status [n (%)]				$\chi^2_{(1)}$=8.41	<.001*
Married	250 (59.7%)	54 (47.8)	196 (64.1)		
Not married	169 (40.3%)	59 (52.2)	110 (35.9)		
Characteristics of comorbidity [n (%)]					
High blood pressure	316 (73%)	91 (80.5)	225 (73.5)	$\chi^2_{(1)}$=1.82	0.18
Cancer	87 (20.8%)	26 (23.0)	61 (19.9)	$\chi^2_{(1)}$=0.31	0.58
Lung disease	52 (12.4%)	16 (12.4)	36 (11.8)	$\chi^2_{(1)}$=0.24	0.62
Heart problems	142 (33.9%)	39 (34.5)	103 (33.7)	$\chi^2_{(1)}$ <0.01	0.96
Stroke	30 (7.2%)	10 (8.8)	20 (6.6)	$\chi^2_{(1)}$=0.35	0.55
Arthritis	288 (68.7%)	83 (73.5)	205 (67.0)	$\chi^2_{(1)}$=1.32	0.25
Psychiatric conditions [n (%)]	73 (17.4%)	25 (22.1)	48 (15.7)	$\chi^2_{(1)}$=1.95	0.16
Body Mass Index [mean (SD)]	29.83 (6.01)	29.80 (5.91)	29.84 (6.05)	$t_{(412)}$=0.05	0.96
Cognitive function [mean (SD)]					
Self-report memory	3.11 (0.94)	3.25 (0.95)	3.07 (0.94)	$t_{(417)}$=-1.76	0.08
Recall†	9.57 (3.44)	9.43 (3.46)	9.62 (3.44)	$t_{(417)}$=0.49	0.63
Working memory†	3.44 (1.70)	3.02 (1.87)	3.60 (1.61)	$t_{(417)}$=3.14	0.02*
Depressive symptoms [mean (SD)]	1.39 (1.89)	3.14 (2.10)	0.75 (1.31)	$t_{(417)}$=-13.93	<.001*
Acquired disability [n (%)]	102 (24.3%)	39 (34.5)	63 (20.6)	$\chi^2_{(1)}$=7.95	<.001*

† Higher scores indicate better cognitive function; *p-value < 0.05

3.3.1.2 Generalized linear mixed model

An interaction effect was found between time (waves) and group after controlling for years of education, marital status, working memory, and wave 9 depressive symptoms ($F_{4,4} = 3.52$; $p = 0.01$). This result indicated that the change in disability differed by groups over time (**Figure 3**).

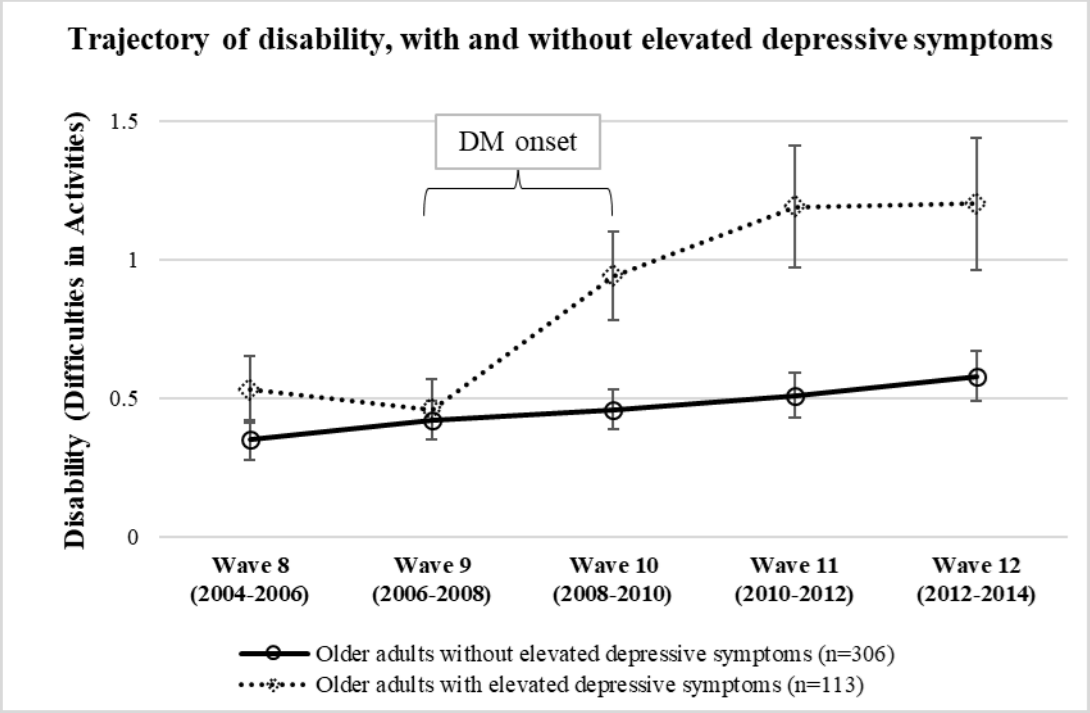


Figure 3 Trajectory of disability, with and without elevated depressive symptoms

3.3.1.3 Post hoc analysis – Between-group

We conducted post hoc tests for group differences from waves 8 to 12. Significant between-group differences were found in disability after the onset of DM at wave 10 ($t_{861.3} = -2.21$; $p = 0.03$) and wave 11 ($t_{829.6} = -2.53$; $p = 0.01$), but not at wave 12 ($t_{877.6} = -1.62$; $p = 0.11$). There was no significant difference in disability between groups before the onset of DM at wave 8 ($t_{1,277} = -0.61$; $p = 0.55$) and wave 9 ($t_{1,275} = 0.56$; $p = 0.58$). Small to moderate effect sizes were found from

waves 10 to 12 (d = 0.33 to 0.37), and negligible effect sizes were found at waves 8 and 9 (d = 0.13 and d = 0, respectively).

3.3.1.4 Post hoc analysis – Within-group

Among older adults with elevated depressive symptoms, post-DM diagnosis waves (10–12) had significantly more disability than pre-DM diagnosis wave 8 ([$t_{1,947}$ = -3.53, p < .001; $t_{1,947}$ = -4.99, p < .001; $t_{1,947}$ = -5.07, p < .001]); and wave 9 ([$t_{1,947}$ = 4.21, p < .001; $t_{1,947}$ = 5.63, p < 0.001; $t_{1,947}$ = 5.70, p < .001]). Clinically overt disability was found after the diagnosis of DM (wave 11 mean disability score 1.19, wave 12 mean disability score 1.20) in those who had elevated depressive symptoms at the time of DM diagnosis (**Table 6**).

Table 6 The level of disability at 5 waves

Disability	Participants	Wave 8 (2004-6)	Wave 9 (2006-8)	Wave 10 (2008-10)	Wave 11 (2010-12)	Wave 12 (2012-14)
ADL [mean (SD)]	All participants	0.25 (0.72)	0.26 (0.76)	0.31 (0.83)	0.39 (0.96)	0.42 (0.99)
	With elevated depressive symptoms	0.32 (0.81)	0.28 (0.82)	0.50 (1.05)	0.63 (1.22)	0.68 (1.29)
	Without elevated depressive symptoms	0.22 (0.68)	0.25 (0.73)	0.25 (0.72)	0.31 (0.83)	0.33 (0.85)
IADL [mean (SD)]	All participants	0.15 (0.57)	0.17 (0.54)	0.27 (0.75)	0.30 (0.88)	0.32 (0.87)
	With elevated depressive symptoms	0.20 (0.53)	0.18 (0.50)	0.44 (0.99)	0.55 (1.22)	0.52 (1.08)
	Without elevated depressive symptoms	0.14 (0.59)	0.17 (0.55)	0.21 (0.63)	0.21 (0.70)	0.26 (0.78)
ADL+IADL [mean (SD)]	All participant	0.40 (1.18)	0.43 (1.15)	0.59 (1.33)	0.69 (1.65)	0.74 (1.65)
	With elevated depressive symptoms	0.53 (1.20)	0.46 (1.14)	0.94 (1.72)	**1.19** (2.16)	**1.20** (2.21)
	Without elevated depressive symptoms	0.35 (1.17)	0.42 (1.15)	0.46 (1.13)	0.51 (1.38)	0.58 (1.38)

Note: The bold values suggested that there was an overt disability observed at wave 11 and 12 in older adults with elevated depressive symptoms.

Among older adults with elevated depressive symptoms, no significant difference was found in disability between pre-DM diagnosis waves (8 and 9) ($t_{1,947} = 0.69$; $p = 0.49$). There were no significant differences in disability among post-DM diagnosis waves (10 and 11 [$t_{1,947} = -1.70$; $p = 0.09$], 10 and 12 [$t_{1,947} = 1.92$; $p = 0.05$], 11 and 12 [$t_{1,947} = 0.31$; $p = 0.76$]).

3.3.1.5 Post hoc analysis – ADL and IADL disabilities between groups

No between-group differences were found in ADL or IADL disability over time ($F_{4,4} = 2.08$ [$p = 0.08$], $F_{4,4} = 1.66$ [$p = 0.16$], respectively), after controlling for years of education, marital status, working memory, and wave 9 depressive symptoms. There were significant group differences in the percentages of participants who experienced difficulties with eating [$\chi^2_{(1)} = 4.36$; $p = 0.04$], getting in/out of bed [$\chi^2_{(1)} = 4.79$; $p = 0.03$], managing medication [$\chi^2_{(1)} = 5.99$; $p = 0.01$], preparing meals [$\chi^2_{(1)} = 6.27$; $p = 0.01$], and shopping [$\chi^2_{(1)} = 5.65$; $p = 0.02$] at wave 10 (**Figure 4**).

The percentages of participants reporting difficulties with 10 ADL and IADL tasks were higher in those with elevated depressive symptoms (5.3% to 15.0%) than in those without elevated depressive symptoms (1.6% to 8.5%) at wave 10. Among those with elevated depressive symptoms, 1 in 7 older adults (15.0%) reported difficulties in dressing and shopping, and 1 in 10 older adults (10.0%) reported difficulties in walking and meal preparation (**Figure 4**).

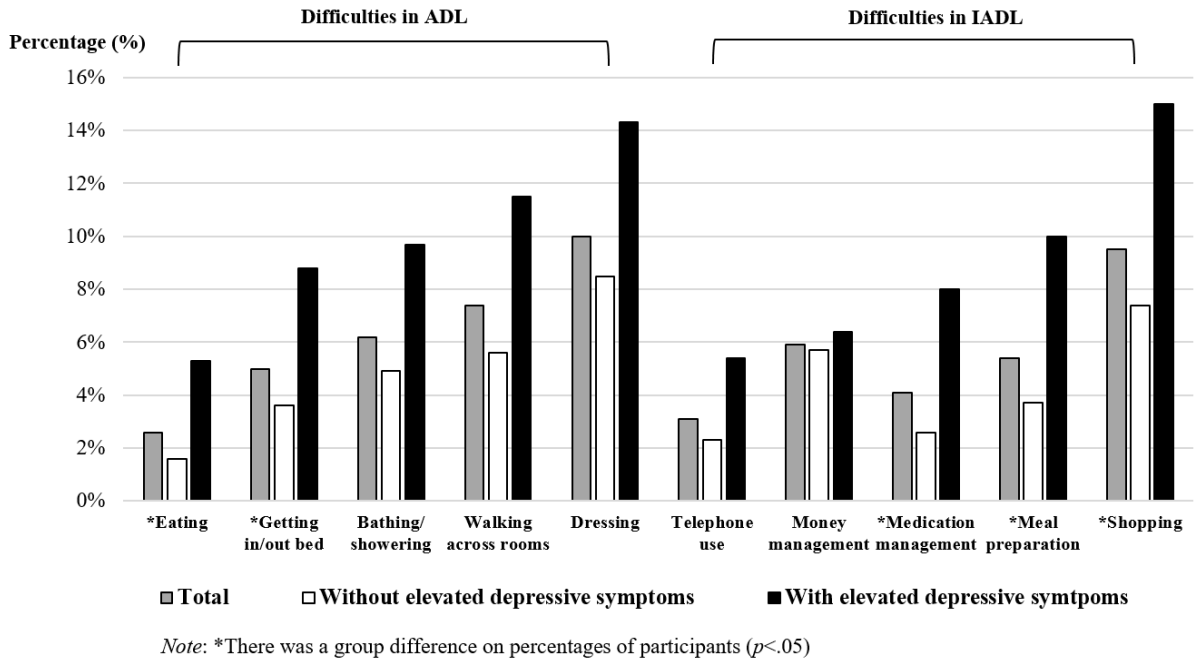


Figure 4 Percentages of participants experiencing difficulties in ADL and IADL at wave 10

3.3.2 Cognitive decline

3.3.2.1 Subject

A total of 264 participants with 1,320 observations (time points of data) were included in the analysis. A statistically significant difference was found in age between the two groups at wave 10 (**Table 7**). No variable was moderately associated with disability (age [$r = 0.03$], sex [$r = 0.09$], race [$r = 0.10$], ethnicity [$r = 0.07$], years of education [$r = -0.19$], marital status [$r = 0.18$], and BMI [$r = 0.17$]).

Table 7 Descriptive statistics in older adults with new DM diagnosis at wave 10 (n = 264)

Characteristics [n (%)]	All	With cognitive decline	Without cognitive decline	*t*-statistics/ χ^2-statistics	*p*-value
	264 (100.0)	147 (55.7)	117 (44.3)		
Age [mean (SD)]	75.51 (6.15)	76.29 (6.35)	74.53 (5.77)	t_{262}=2.32	0.02*
Gender [n (%)]				$\chi^2_{(1)}$=1.01	0.32
Male	124 (47.0)	65 (44.2)	59 (50.4)		
Female	140 (53.0)	82 (55.8)	58 (49.6)		
Race [n (%)]				$\chi^2_{(2)}$=0.13	0.94
White	212 (80.3)	117 (79.6)	95 (81.2)		
Black	43 (16.3)	25 (17.0)	18 (15.4)		
Other race	9 (3.4)	5 (3.4)	4 (3.4)		
Ethnicity [n (%)]				$\chi^2_{(1)}$=0.01	0.91
Hispanic	22 (8.3)	12 (8.2)	10 (8.5)		
Non-Hispanic	242 (91.7)	135 (91.8)	107 (91.5)		
Year of education [mean (SD)]	12.08 (3.29)	11.73 (3.47)	12.53 (2.99)	t_{262}=-1.98	0.05
Married [n (%)]	147 (55.7)	85 (57.8)	62 (53.0)	$\chi^2_{(1)}$=0.62	0.43
Characteristics of comorbidity [n (%)]					
High blood pressure	204 (77.3)	111 (75.5)	93 (79.5)	$\chi^2_{(1)}$=0.59	0.44
Cancer	63 (23.9)	35 (23.8)	28 (23.9)	$\chi^2_{(1)}$<0.01	0.98
Lung disease	38 (14.4)	21 (14.3)	17 (14.5)	$\chi^2_{(1)}$<0.01	0.96
Heart problems	98 (37.1)	58 (39.5)	40 (34.2)	$\chi^2_{(1)}$=0.78	0.38
Stroke	23 (8.7)	15 (10.2)	8 (6.8)	$\chi^2_{(1)}$=0.93	0.34
Arthritis	194 (73.5)	111 (75.5)	83 (70.9)	$\chi^2_{(1)}$=0.70	0.40
Psychiatric conditions	41 (15.5)	17 (11.6)	24 (20.5)	$\chi^2_{(1)}$=3.98	0.05
Body Mass Index [mean (SD)]	29.45 (5.46)	29.46 (5.16)	29.45 (5.83)	t_{259}=0.02	0.99
Cognitive function [mean (SD)]					
Self-report memory	3.14 (0.93)	3.20 (0.97)	3.08 (0.88)	t_{262}=1.04	0.30
Recall†	9.01 (3.50)	7.70 (3.33)	10.66 (2.99)	t_{262}=-7.50	<.001*
Working memory†	3.29 (1.77)	3.06 (1.82)	3.58 (1.67)	t_{262}=-2.39	0.02*
Depressive symptoms [mean (SD)]	1.37 (1.86)	1.22 (1.87)	1.56 (1.82)	t_{262}=-1.45	0.15
Acquired disability [n (%)]	68 (25.8)	38 (25.9)	30 (25.6)	$\chi^2_{(1)}$<0.01	0.97

† Higher scores indicate better cognitive function; *p-value < 0.05

3.3.2.2 Generalized linear mixed model

There was no significant interaction effect between time (waves) and group, after controlling for age and wave 9 cognitive function ($F_{4,1206} = 1.83$, $p = 0.12$). This result indicated that the change in disability did not differ by groups over time (**Figure 5**).

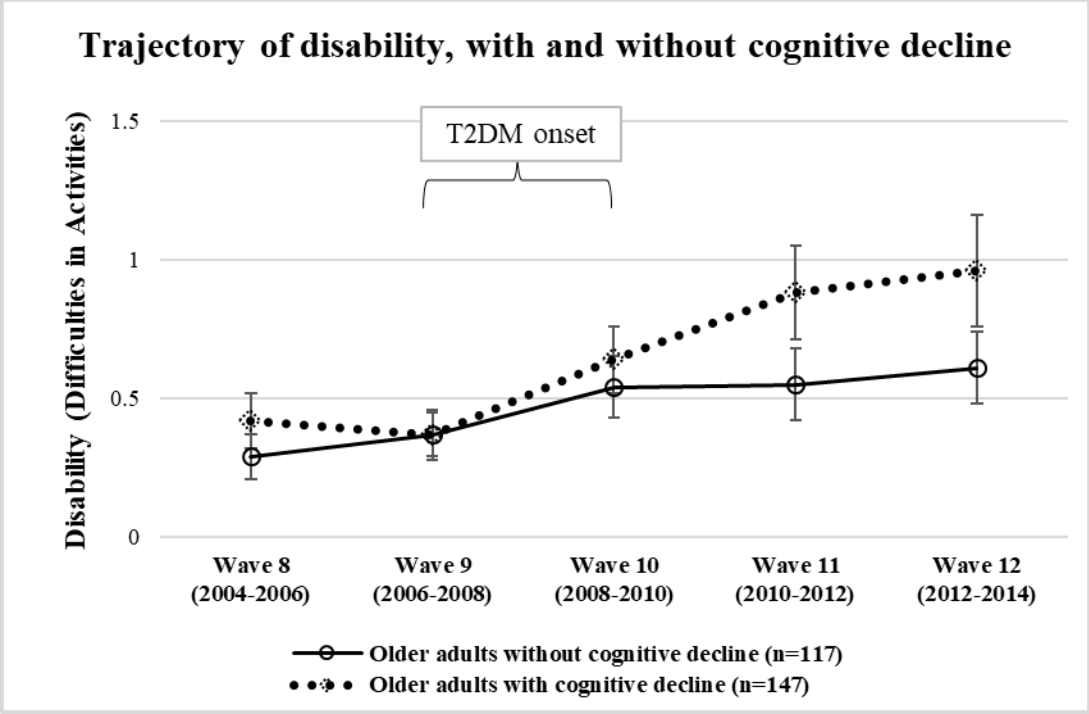


Figure 5 The trajectory of disability, with and without cognitive decline

3.3.2.3 Post hoc analysis – Between groups

There was no significant group effect on disability ($F_{1,305} = 3.44$, $p = 0.06$). Small effect sizes were found at wave 11 to 12 ($d = 0.20$; 0.21, respectively), and negligible effect sizes were found at wave 8, 9, and 10 ($d = 0 – 0.13$).

3.3.2.4 Post hoc analysis – Within groups

There was a significant time effect on disability ($F_{4,1206} = 16.52$, $p < .001$). Among older adults with cognitive decline, post-DM waves (11 and 12) had significantly more disability than pre-DM wave 8 ([$t_{1206} = -4.93$, $p < .001$; $t_{1206} = -5.95$, $p < .001$]) and wave 9 ([$t_{1206} = 5.65$, $p < .001$; $t_{1206} = 6063$, $p < .001$]). Clinically overt disability was found after the diagnosis of DM (wave 12 mean disability score 0.96) in those who had cognitive decline at the time of DM diagnosis (**Table 8**).

Table 8 The level of disability at 5 waves

Disability	Participants	Wave 8 (2004-6)	Wave 9 (2006-8)	Wave 10 (2008-10)	Wave 11 (2010-12)	Wave 12 (2012-14)
ADL [mean (SD)]	All participants	0.24 (0.65)	0.25 (0.71)	0.35 (0.88)	0.42 (0.98)	0.45 (1.01)
	With cognitive decline	0.27 (0.73)	0.22 (0.71)	0.34 (1.92)	0.49 (1.12)	0.52 (1.09)
	Without cognitive decline	0.20 (0.55)	0.28 (0.72)	0.37 (0.84)	0.34 (0.79)	0.37 (0.90)
IADL [mean (SD)]	All participants	0.13 (0.45)	0.12 (0.39)	0.24 (0.66)	0.31 (0.91)	0.35 (0.94)
	With cognitive decline	0.15 (0.52)	0.15 (0.41)	0.30 (0.75)	0.39 (1.06)	0.44 (1.13)
	Without cognitive decline	0.10 (0.35)	0.09 (0.36)	0.17 (0.51)	0.21 (0.69)	0.24 (0.60)
ADL+IADL [mean (SD)]	All participant	0.37 (1.01)	0.37 (0.95)	0.59 (1.31)	0.73 (1.67)	0.80 (1.74)
	With cognitive decline	0.42 (1.15)	0.37 (0.95)	0.64 (1.39)	0.88 (1.92)	**0.96** (2.04)
	Without cognitive decline	0.29 (0.79)	0.37 (0.94)	0.54 (1.20)	0.55 (1.29)	0.61 (1.25)

Note: The bold values suggested that there was an overt disability observed at wave 12 in older adults with cognitive decline

3.3.2.5 Post hoc analysis – ADL and IADL disabilities between groups

There were no between-group differences in ADL or IADL disability over time ($F_{4,1206}$ = 0.20, p = 0.94; $F_{4,1206}$ = 1.99, p = 0.09), after controlling for age and wave 9 cognitive function. There were no significant group differences in the percentages of participants who experienced difficulties in any activity tasks at wave 10 (**Figure 6**).

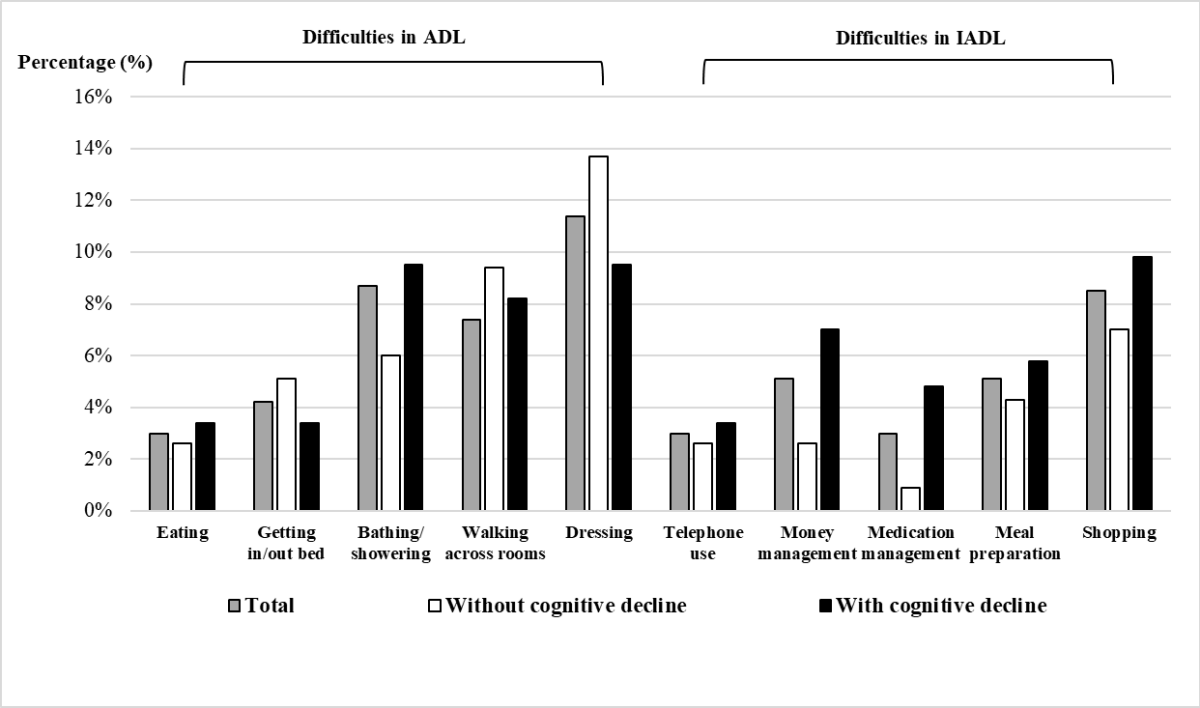


Figure 6 Percentages of participants experiencing difficulties in ADL and IADL at wave 10

3.4 Conclusion

Among older adults with newly diagnosed DM, those with elevated depressive symptoms had a clinically relevant and faster disablement trajectory than those without elevated depressive symptoms. Those with cognitive decline had an accelerated disablement trajectory, but this trajectory did not differ with those without cognitive decline. A disability score 1 is a threshold that suggests overt difficulties in performing ADL and IADL. The disability threshold was not crossed when disablement was examined across all the participants (n = 419) or in those with DM only. However, clinically overt disability was observed soon by 2 years (wave 11) and still presented at 4 years (wave 12) if elevated depressive symptoms were present at the time of DM diagnosis. Clinically overt disability was also observed at 4 years (wave 12) in those with cognitive decline. These findings suggested that elevated depressive symptoms and cognitive decline should be monitored and tracked after DM diagnosis to early prevent disablement progression for older adults.

The emergence of disability before clinically overt disability is a critical time to intervene. Usually, older adults with the emergence of disability are found to adjust their daily tasks or spend more time to complete daily tasks (L. P. Fried et al., 1991). For example, older adults with new-onset DM may carry fewer items than previously while shopping. Another example is that older adults may take a longer time to prepare meals than previously. These changes, although subtle, potentially suggest the emergence of disability. The emergence of disability may soon shift to overt disability, which is the incapability to complete ADL or IADL independently. In this study, we found that older adults showed signs of emerging disability upon new-onset DM and soon shifted to clinically overt disability within 4-year post-DM. Early identification of those with elevated

depressive symptoms and cognitive decline upon new DM is warranted to slow the accelerated disablement progression.

Many possible mechanisms may explain why elevated depressive symptoms were associated with a faster disability trajectory (Bruce, 2001). The literature indicates that older adults with depressive symptoms experience subtle changes in their daily activities. Perhaps due to anhedonia or apathy, these older adults may develop sedentary behaviors, give up social activities and healthy lifestyle practices (e.g., adherence to medication management, healthy meal preparation) (Kiosses & Alexopoulos, 2005; Leibold et al., 2014). More time spent being sedentary, socially isolated, and practicing unhealthy lifestyle behaviors is associated with an increased risk of incident disability among community-dwelling older adults (James, Boyle, Buchman, & Bennett, 2011). Elevated depressive symptoms also may be associated with biologic dysregulation (e.g., hormones, neurotransmitters) that leads to disability especially when DM is newly diagnosed (Pan et al., 2012). Elevated depressive symptoms may coexist with declines in memory and executive function, further decreasing the ability to perform IADL (Mehta et al., 2002), including medication management, meal preparation, and shopping. Older adults with elevated depressive symptoms may also sense a greater degree of disability than they actually experience (Bruce, 2001).

Interestingly, post-hoc analyses showed that the differences in disability were statistically reliable at waves 10 and 11 but not at wave 12 between depression groups. The differences in significance may be due to participant attrition from wave 10 to wave 12. The group with elevated depressive symptoms had a 23.0% attrition rate from wave 10 to wave 12, which was higher than the group without elevated depressive symptoms (16.6%). Those who dropped out might have experienced more disability, which may have contributed to the insignificant between-group

differences observed at wave 12. Of note, the small to moderate effect sizes throughout the post-DM diagnosis waves (10 – 12) were detected. These early distinct differences may be the determinant of long-term disability and high health care costs. For example, Fried et al. (L. P. Fried, Ferrucci, Darer, Williamson, & Anderson, 2004) found that older adults with disabilities spent $2,700 more per person on health care than those without disabilities. In addition, older adults with both DM and depressive symptoms had 4.5 times more health expenditures to manage their disability than those with DM only (Egede, Zheng, & Simpson, 2002).

Surprisingly, there was no significant difference in the disablement trajectories between those with and without cognitive decline. Although there was no group difference at any wave, we found small to moderate effect sizes at post-DM diagnosis waves (11 – 12). Previous studies suggested that cognitive decline progressed slowly over time in those with newly-diagnosed DM (Biessels et al., 2014). Plausibly, the slow cognitive decline may signal slight brain vascular damage and atrophy (Biessels et al., 2014); yet, this cognitive decline could be compensated until more accumulation of brain damage that could lead to clinically overt disability many years post DM diagnosis. In our study, we observed clinically overt disability in those with cognitive decline 4-year after DM diagnosis. This suggested that the effects of cognitive decline may not be evident until the follow-up duration was adequate. More, specific cognitive domains may accelerate disablement at the early stages of DM than the others. Spauwen and colleagues found that processing speed was the only cognitive domain declined after newly-diagnosed DM (Spauwen, Köhler, Verhey, Stehouwer, & van Boxtel, 2013). This reduced processing speed may be associated with reduced competency on managing medication, finance, and preparing meals, which ultimately lead to difficulties in ADL and IADL tasks (Owsley, Sloane, McGwin, & Ball, 2002). Additionally, the severity of DM upon newly diagnosed may contribute to accelerated

cognitive decline (Yaffe et al., 2012) . Our study did not examine the effects of specific cognitive domains and the severity of DM on disability due to limited secondary data. Future studies may examine the roles of cognitive domains and disease severity on disablement trajectories in older adults at risk for disability, especially for those with new medical conditions.

When we separated disability into ADL and IADL disabilities, no significant between-group differences were found in either depression or cognitive groups. Elevated depressive symptoms may be associated with disability in the spectrum of daily activities from basic (e.g., ambulation, eating) to complex (e.g., shopping) rather than with a specific type of daily activity. This finding may contribute to elevated depressive symptoms being associated with slower gait speed and movements, causing difficulties in ambulation and dressing (Brandler, Wang, Oh-Park, Holtzer, & Verghese, 2012). Elevated depressive symptoms also interacted with cognitive decline that contributes to difficulties in shopping and meal preparation (McGuire, Ford, & Ajani, 2006). These activities are critical self-management tasks to stabilize DM disease courses (Lin et al., 2004). The inability to go shopping, prepare meals, walk, and dress may lead to poor nutrition, an inactive life, and poor skin care, which may potentially deteriorate DM disease control and create a vicious cycle toward long-term disability (Volpato et al., 2003).

Among all the participants, one in four (24.3%) had disability. The risk of disability was higher when older adults had relapsing or remitting mood and cognitive changes. One in three and four older adults (34.5%; 25.9%) acquired disability if they had elevated depressive symptoms and cognitive decline respectively. In addition, nearly 15% of older adults with elevated depressive symptoms reported difficulties in dressing and shopping, which matched the results from other studies that recruited older adults with long-term DM (13.5% to 31.5%) (Maty et al., 2004). This finding suggested that older adults with new-onset DM and change in brain indicators may have

an accelerated path to disability that older adults with long-term DM had already experienced. This suggested an indicated approach to disability prevention for older adults with newly diagnosed DM.

We acknowledge limitations in this study. Because of the nature of secondary data analysis, we included older adults who self-reported that they were diagnosed with DM since their last study interview. We did not know the exact dates of the DM diagnosis or specific times of diagnosis to follow-up interviews of depressive symptoms and cognitive function. Our disability measurement was self-reported and may be influenced by the perceptions of participants instead of objective measures. We did not have a measure of DM severity in the data set, especially fasting glucose or hemoglobin A_{1c}, which may be associated with comorbidity and further complicate the relationship between elevated depressive symptoms, cognitive decline, and disablement trajectory. Plausibly, the trajectory of disability between groups may be driven by demographic characteristics (e.g., race, ethnicity) or comorbidity. We controlled for years of education, marital status, working memory, wave 9 depressive symptoms, and wave 9 cognitive function as covariates in our analysis, but no other variables met criteria for covariates.

This study had many strengths. First, we included five waves of data to examine a 10-year disablement trajectory in older adults with newly diagnosed DM. Often, the disablement trajectory was subtle and hard to identify within just a few years. These longitudinal data provided the opportunity to detect the transition of disability before and after DM diagnosis in older adults. Second, we found that elevated depressive symptoms were a determinant of steeper disablement in older adults with newly diagnosed DM, whereas those with cognitive decline was a risk population with more severe disability over time. In this study, we conceptualized depressive symptoms and cognitive function as a relapsing and remitting indicators of brain health in

influencing health over time. We took a different approach to capture severity change in depressive symptoms and cognitive function, which was different from a traditional approach that assessed a categorical diagnosis. Third, the time points when disability emerged (2 years from new onset of DM) and sustained (2 to 4 years from new onset of DM) also were captured through these longitudinal data, suggesting the need for early interventions for older adults with both new-onset DM and depression or cognitive decline. Future interventions should take an indicated approach to disability prevention in older adults with newly diagnosed DM, especially for those with a change in depression severity and cognition during the window before and after the diagnosis of DM.

4.0 Patterns of Everyday Activities in Older Adults At-risk for Disability

In **Chapter 4**, we studied patterns of everyday activities in older adults at-risk for disability. We examined the feasibility and usability of mobile technology to detect the patterns of everyday activities via a measurement burst design. The chapter has been developed into a manuscript, titled "Variability of Everyday Activities among Older Adults At-risk for Disability" for submission to a peer-reviewed journal to be named.

4.1 Introduction

Disability, the inability to sustain independence, has affected one-third of the aging population and led to extra out-of-pocket expenditures on long-term care in the United States (Kraus, 2017; Mitra et al., 2017; Ortman et al., 2014). To prevent or reduce disability, older adults have been urged to participate in healthy everyday activities (instrumental activities of daily living, IADL; exercise; leisure) (Fratiglioni, Paillard-Borg, & Winblad, 2004; D. E. King, Mainous, Carnemolla, & Everett, 2009). The health benefits of everyday activities were not merely derived from the "execution" of everyday activities; rather, "repeated and regular execution" of these activities over time. Studies have recommended the optimal intensity and dosage of healthy activities, such as participating in aerobic exercise 30 minutes three times per week (Haskell et al., 2007). Yet, little research has described the real-world situation – older adults' patterns (or regularity) in participating in these activities (Eckel et al., 2014). For example, leisure activities (e.g., visiting friends) are critical to older adults but the patterns of visiting friends is rarely

explored, specifically how well an older adult stick to visiting friends over a period of time. This information is of great importance because any changes in patterns of everyday activities may herald reduced competences and skills in navigating daily tasks, further compound the risk of health decline (L. P. Fried et al., 1991). This information may also inform the development of preventative acts to support a health periodicity of everyday activities for older adults.

In previous studies, patterns of everyday activities are defined as "the day-to-day variability in the 1) variety of activities and 2) time spent on activities" over time (Carlson et al., 2012). Variety of activities has been derived from the types of activities that older adults chose to complete (e.g., shopping, paying bills). The time spent on activities has been defined by the interval of minutes spent on activities. The patterns of everyday activities are of interest because they illustrate the capability of initiating, sustaining, and navigating activities over time (Law, 2002). From the patterns of everyday activities, we may potentially grasp insights into who may be demonstrating declines in capabilities, and as well as when we should intervene to early prevent disability.

Examining the patterns of everyday activities is challenging. Oftentimes, the understanding of everyday activities is based on a snapshot, which ignores the fact that older adults participate in different activities day-to-day. Second, older adults are often asked to recall past experiences, which is not ideal when assessing everyday activities (Shiffman, Stone, & Hufford, 2008). Last, data collection might be conducted in laboratory settings, which limit the ecological validity of data (Kanning & Schlicht, 2010; Wegner et al., 2002). Altogether, these challenges have hindered the examination of the patterns of everyday activities in older adults.

Capitalizing on new methods offers the opportunity to examine the patterns of everyday activities via a measurement burst design. The measurement burst design delivers a form of

assessments (e.g., surveys, diaries, sensors) that collect data in a short period of time in real-world settings (A. Stone, Shiffman, Atienza, & Nebeling, 2007). This mode of delivery minimizes the temporal and spatial influence of information validity via the use of mobile technology. The assessments can be delivered intensively, longitudinally, and remotely to understand the patterns of everyday activities. Research suggests, 40% of adults aged 50 and older are interested in using mobile technology to record health (Christopoulos et al., 2014). While older adults have started to embrace new technologies, we were still unclear whether it was feasible and useful to use mobile devices to detect the patterns of everyday activities, nor did we understand whether older adults had sufficient digital adherence to report the information over time. The feasibility of assessing the patterns of everyday activities via mobile devices was worth exploring because it may be adapted to signal the risk for disability in community settings, rather than clinical settings.

The aim of this study was to examine the feasibility and usability of a measurement burst design in detecting the patterns of everyday activities in at-risk older adults. Everyday activities were categorized into IADL, exercise, and leisure activities. Within each category, the variability of variety (types) and time (minutes) were separately examined. The information gleaned from this study may provide valuable insights into preventative strategies and structure to support a healthy periodicity of participation in late life.

4.2 Method

4.2.1 Participants

This study was approved by the University of Pittsburgh Institutional Review Board. Participants were recruited from month 2017 to month 2018. Older adults aged ≥ 55 and were at-risk of disability were recruited using the following criteria: 1) self-report of "slowing down or changing ways in performing daily tasks" (Freedman et al., 2014; L. P. Fried et al., 2001) and 2) the Barthel Index (BI) (F. I. Mahoney & Barthel, 1965). Self-report change in daily tasks has been used to identify older adults at-risk for disability (L. P. Fried et al., 2001). The BI was used to exclude older adults who already had disability. The BI had 8 items, measuring the assistance needed to perform self-care or mobility activities. Older adults who needed help on more than two activities in the BI were excluded. Those who were previously diagnosed with major depressive disorder, bipolar, mania, and drug or alcohol abused were excluded because of the inherent difficulty in discerning whether the disability was substance or depressive symptoms induced.

4.2.2 Measurement burst design

A mobile device was provided to every participant to ensure the consistency of assessment delivery. Assessments were sent through Short Message Service (SMS) via Qualtrics software (**Appendix K**) (Qualtrics, 2017). Participants received the same assessment every day for 14 days (van Hooff, Geurts, Kompier, & Taris, 2007b). The time of the assessment was selected by participants from 9:00 pm to 10:30 pm. The mobile devices emitted up to 5 reminder signals at 5-minute intervals until responses were entered. All data were uploaded automatically to the

computer once the assessment was completed. In order to accommodate participants' life routines, we offered mobile device flashlights or vibrations to replace ringtones. Participants were trained to complete assessments via mobile devices prior to the start of the study.

4.2.3 Measurement

4.2.3.1 Everyday activities

The contents within assessments were developed based on the Lawton Instrumental Activities Of Daily Living Scale (Lawton IADL scale) and the Lifestyle Activities Questionnaire (LAQ) (Carlson et al., 2012; Lawton & Brody, 1969). The Lawton IADL scale included IADL and maintenance activities for older adults. The LAQ included leisure activities that older adults value and perform. Twenty-six activity choices were validated in older adults by a previous study (**Table 9**). The 26 activities were categorized based on the International Classification of Functioning, Disability, and Health (ICF), including IADL (9 items), exercise (1 item), and leisure activities (16 items) (World Health Organization, 2002). The guiding question was "Select all the activities you did today."

Table 9 The 26 everyday activities

Category	Variety
IADL	Groom; Dress; Medication management; Bath/ Shower; Laundry; Housekeeping or home maintenance; Telephone use; Shopping; Prepare/cook a meal; Manage finances
Exercise	Exercise (except walking)
Leisure activity	Church; Garden; Watch TV; Listen to music/ radio; Go to a movie; Attend events/ clubs; Visit friends/family; Assist others; Attend class; Volunteer; Play game/cards; Read newspaper; Sing; Art Activities; Read books; Crossword puzzles

Each category had its "variety" and "time." For example, IADL variety was the different types of IADL activities that older adults performed per day. IADL time was calculated by the intervals of minutes older adults spent on a particular IADL per day. The guiding question was "How much time did you spend on this activity?" The response choices were 5 to 55 minutes (5-minute intervals) and 1 to 10 hours (1-hour intervals). This approach, which has been used in prior research, has been shown to be a reliable method for assessing everyday activities (A. A. Stone et al., 2003).

4.2.3.2 Feasibility and usability indices

Five indices were calculated to assess the feasibility of measurement burst design: 1) participant attrition rate, 2) survey response rate, 3) missing data rate, 4) time to open the survey, and 5) time spent on the survey. The participant attrition rate was the number of participants lost divided by the total number of participants. The survey response rate was the number of answered survey divided by deployed surveys. A benchmark of at least 80.0% survey response rate was set based on a review examining the averaged survey response rate in the aging population (Cain, Depp, & Jeste, 2009). The missing data rate was the number of missing data divided by the number of answered surveys. A 5.0% missing data rate was set (Fritz, Tarraf, Saleh, & Cutchin, 2017). The time to open the surveys was calculated by the time difference between a survey was sent and opened. The time spent on answering the survey was recorded.

The 19-item Post-Study System Usability Questionnaire (PSSUQ) was used to assess the usability of the mobile device (Lewis, 1995). It assessed whether the interface of the mobile device covered all the functionality and whether the mobile device was easy to learn and use. The PSSUQ assessed three subdomains: function usefulness, information quality, and interface quality. All the items were scored on a 7-point ordinal scale (1 = strongly agree, 7 = strongly disagree). The 8-

item function usefulness assessed whether the functionality was adequate. Item scores were averaged, with a score ≥ 2.8 representing low satisfaction of function usefulness. The 7-item information quality evaluated whether the system was easy to learn. Item scores were averaged, with a score ≥ 3.0 representing disagreements of easiness to learn (Lewis, 2002). The 3-item interface quality assessed whether the interface was easy to use. Item scores were averaged, with a score ≥ 2.5 representing lower agreements of easiness to use. The PSSUQ has been validated in older adults, with excellent reliability, reasonable concurrent validity, and sensitivity (Lewis, 2002).

We collected mobile device user experiences, including whether participants had a smartphone before the study, what activities they performed via a mobile device, and in what frequency did they use the mobile device.

4.2.3.3 Demographic and health variables

Age, gender, race, years of education, income, comorbidity, cognitive function, depressive symptoms, and independence were collected. Comorbidity was assessed via the Charlson Comorbidity Index (CCI), with a higher score suggesting more comorbidity (19 items, score range: 0 to 35) (Frenkel, Jongerius, Mandjes-van Uitert, van Munster, & de Rooij, 2014). Cognitive function was assessed via the National Institution of Health Toolbox (NIH Toolbox), with a mean score of 50 and a standard deviation of 10. Depressive symptoms were assessed via the Patient Health Questionnaire-9 (PHQ-9), with a higher score indicating more severe depressive symptoms (9 items; range: 0 to 27) (Kroenke, Spitzer, & Williams, 2001). Independence was assessed via the Performance Assessment of Self-Care Skills (PASS). The PASS was an observational-based tool to assess the independence of completing daily tasks (shopping for groceries; medication management; sweeping). Every task has been scored by how many verbal and physical cues are

needed to complete the task. The more assistance older adults needed to complete a task, the lower the independence of the older adult.

4.2.4 Data analysis

Descriptive statistics were used to examine the feasibility and usability of the measurement burst design. The reasons for attrition were documented. The SPSS (version 24) was used for data analysis (IBM Corp., 2013).

Six dependent variables were separately examined (IADL variety, IADL time, exercise (Yes/No), exercise time, leisure variety, leisure time). Spaghetti plots were plotted to visualize the trajectory of six dependent variables over 14 days among participants. Plots of residuals, normality, and heterogeneity were examined for each dependent variable to check the assumptions of the individual growth model (Singer, 1998). The assumption of the normality was not met; therefore, the generalized linear mixed model was adopted with an appropriate distribution. An unconditional model was used to examine how much variability in the dependent variable was explained by between-individual and within-individual differences (Singer, 1998). SAS (version 9.3) was used for data analysis (SAS Institution, 2015). All the analyses were considered significant at the .05 two-tailed α level.

4.3 Results

4.3.1 Participants

We recruited a sample of 50 older adults living in the community, with a mean age of 66.6 (SD = 8.27) (**Figure 7**). Most were female, white, lived alone, and had a college degree (**Table 10-11**).

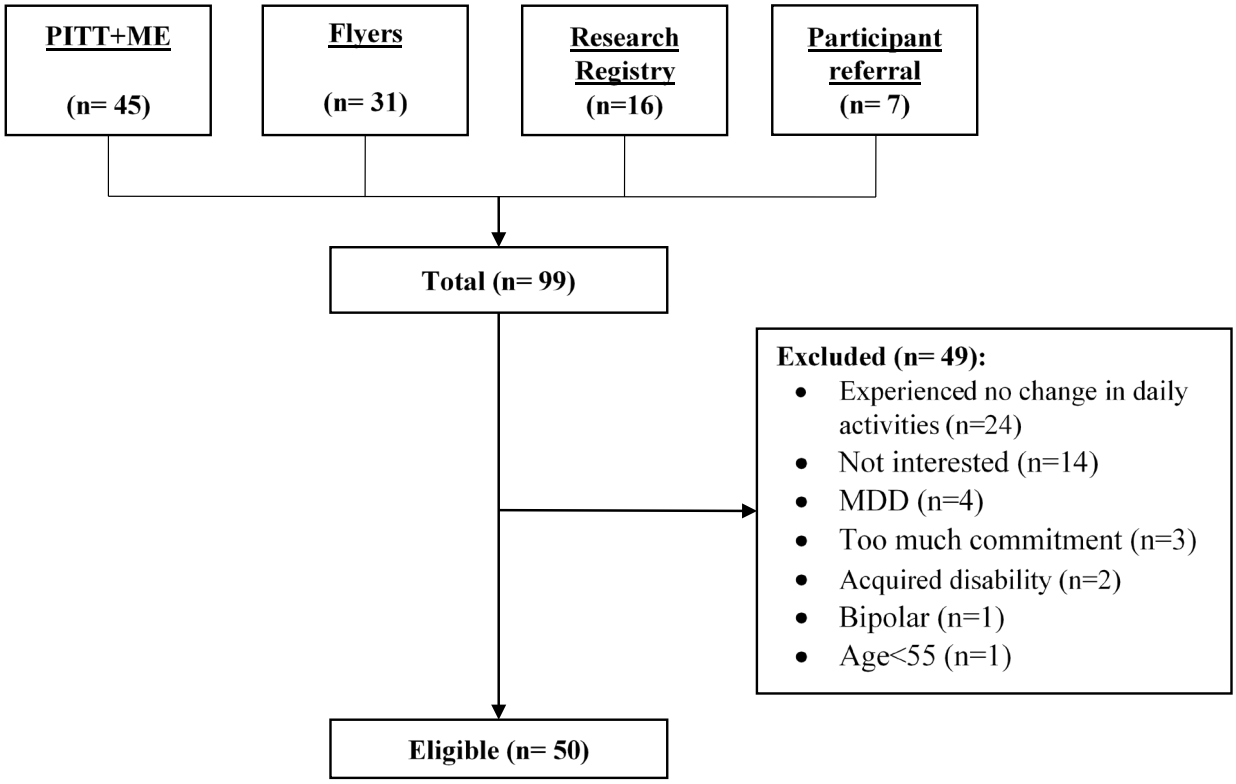


Figure 7 Recruitment diagram

Table 10 Participant characteristics

Characteristics	All (n=50)	Theoretical range
Age [mean (SD), range]	66.60 (8.27), 56-87	≥ 55
Female [n (%)]	31 (62.0)	
Race [n (%)]		
White	42 (84.0)	
Black	7 (14.0)	
Asian	1 (2.0)	
Non-Hispanic [n (%)]	48 (96.0)	
Year of education [mean (SD), range] †	15.85 (2.48), 11-22	
Level of education [n (%)]		
High school	11 (22.0)	
Associates	8 (16.0)	
Bachelors	13 (26.0)	
Master	17 (34.0)	
PhD	1 (2.0)	
Marital status [n (%)]		
Married	19 (38.0)	
Never married	7 (14.0)	
Divorced	13 (26.0)	
Widowed	7 (14.0)	
Separated	2 (4.0)	
Partner, not married	1 (2.0)	
Living status		
Alone	27 (54.0)	
With spouse	19 (38.0)	
With an adult child	3 (6.0)	
With an adult child	1 (2.0)	
Others	4 (8.0)	
Employment status		
Full-time job	8 (16.0)	
Part-time job_ not retire	3 (6.0)	
Part-time job_ retire	6 (12.0)	
No job_ retire	24 (48.0)	
No job_ not retire	9 (18.0)	

Table 11 continued

Income		
< 5,000	2 (4.0)	
5,000-9,999	1 (2.0)	
10,000-14,999	8 (16.0)	
15,000-19,999	1 (2.0)	
20,000-24,999	1 (2.0)	
25,000-34,999	9 (18.0)	
35,000-49,999	2 (4.0)	
50,000-74,999	14 (28.0)	
75,000-99,999	4 (8.0)	
100,000-119,999	2 (4.0)	
>120,000	2 (4.0)	
Prefer not to answer	4 (8.0)	
PASS [mean (SD), range]		
Shopping	4.79 (4.51), 0-17	≥ 0
Medication management	1.79 (2.84), 0-14	≥ 0
Sweeping	0.04 (0.20), 0-1	≥ 0
Comorbidity [mean (SD), range]	2.04 (2.32), 0-12	≥ 0
NIH Toolbox [*t* score (SD), range] †		0-100
Picture vocabulary test	54.88 (8.22), 33-72	
Oral reading recognition test	53.23 (10.48), 28-78	
List sorting working memory test	50.66 (9.06), 26-73	
Pattern comparison processing test	44.25 (16.15), 11-74	
Picture sequence memory test	47.77 (9.80), 28-72	
Inhibitory control and attention test	44.85 (6.77), 33-65	
Dimensional change card sort test	54.23 (9.74), 34-77	
Fluid composite	47.72 (9.85), 27-86	
Crystallized composite	54.42 (8.56), 30-74	
Total score	51.09 (9.38), 30-72	
PHQ-9 [mean (SD), range]	4.42 (3.95), 0-16	0-27

4.3.2 Feasibility and usability

The participant attrition rate was 6.0% (1 deceased and 2 withdrew). Of the two participants who withdrew, one did not want to carry a phone and withdrew on day 3, the other did not have time for the study and withdrew on day 2. All feasibility indices met the benchmarks; the survey response rate was 89.0%, and the missing data rate was 1.1%. The average time to open the assessment was 10.1 minutes (SD = 73.73). The average time spent on answering the assessment was 7.8 minutes (SD = 46.20).

Twenty-two percent of the participants (9 out of 41 participants) did not have a smartphone before participating in the study. For those who had a smartphone before the study, smartphones were used daily (100.0%) for phone calls (100.0%), texting (98.0%) and emails (83.0%). Participants reported great function usefulness (mean = 1.20, SD = 0.59), information quality (mean = 1.69, SD = 1.38), and interface quality (mean = 1.54, SD = 1.51) of our mobile devices. Participants reported high usability answering surveys (PSSUQ total score mean = 25.43, SD = 11.59).

Among 686 deployed assessments, 54 were unanswered, and 8 had missing data. A total of 624 time points of data were valid and included in the analysis (**Figure 8**).

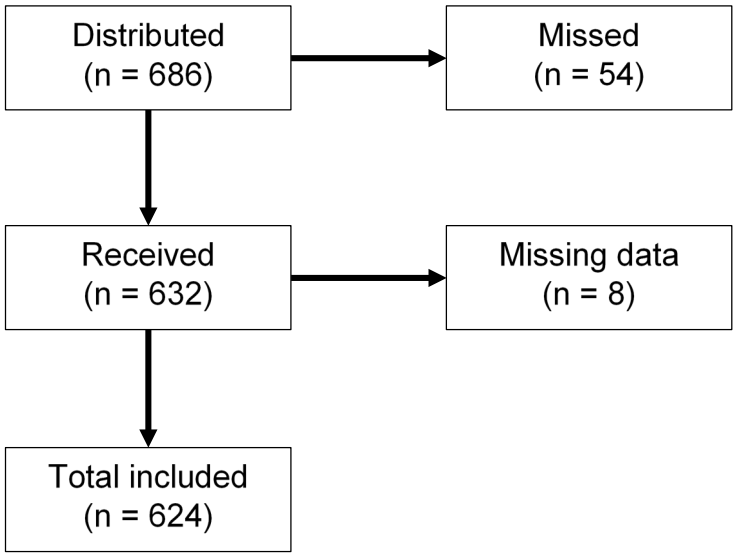


Figure 8 Flow diagram of the end-of-day questionnaire

4.3.3 Patterns of everyday activities

4.3.3.1 IADL

On average, participants participated in 4.21 IADL per day, with a mean time of 194.8 minutes. Fifty-nine percent of the variability in IADL variety was explained by within-individual differences, suggesting that the numbers of IADL activities varied within participants (**Table 12**; **Figure 9**). Forty-one percent of the variability in IADL variety was explained by between-individual differences, suggesting that the numbers of IADL activities varied among participants.

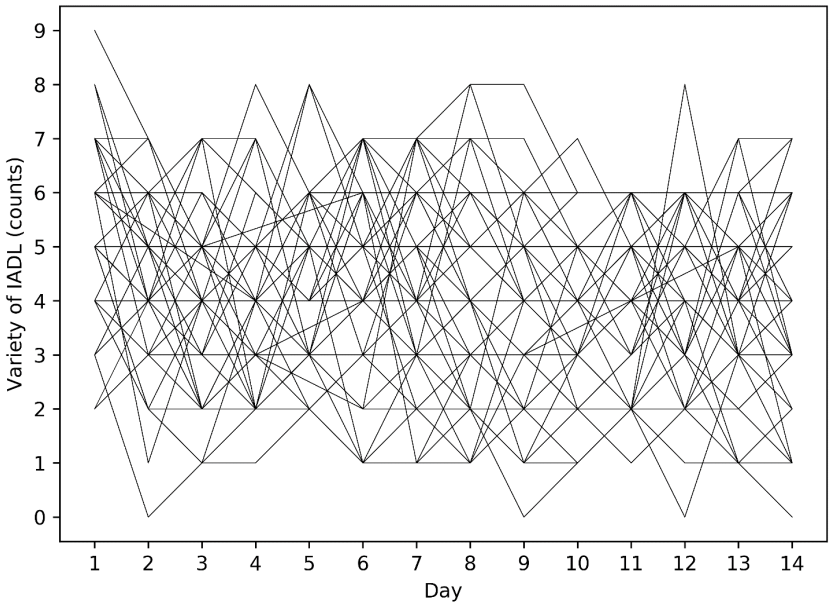


Figure 9 Spaghetti plot of IADL variety

Table 12 The intraclass correlation coefficient (ICC)

Category	Items	Intercept estimate	Residual estimate	Between-individual ICC	Within-individual ICC
Variety					
IADL	9	1.12	1.64	0.41	0.59
Exercise	1	0.08	0.13	0.39	0.61
Leisure	16	2.16	1.43	0.60	0.40
Time					
IADL	9	11208.00	10726.00	0.51	0.49
Exercise	1	127.00	440.00	0.22	0.78
Leisure	16	14945.00	29197.00	0.34	0.66

Forty-nine percent of the variability in IADL time was explained by within-individual differences, suggesting that the minutes spent on IADL varied within participants (**Table 10**; **Figure 10**). Fifty-one percent of the variability in IADL time was explained by between-individual differences, suggesting that the minutes spent on IADL varied among participants.

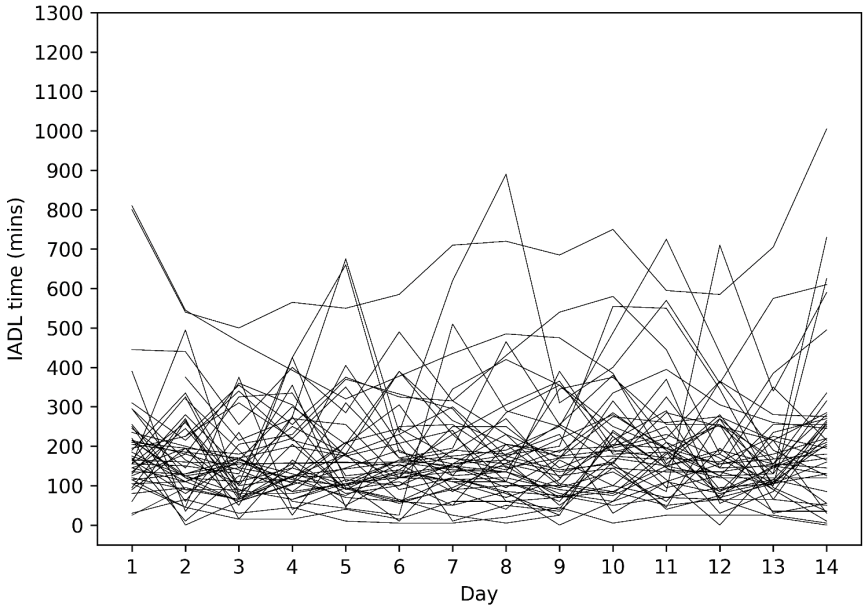


Figure 10 Spaghetti plot of IADL time

4.3.3.2 Exercise

Only 30 participants had variability in exercise (Yes/No) since 18 participants reported they did not exercise during the study period. On average, participants participated in 0.29 exercises per day, with a mean time of 11.3 minutes. Sixty-one percent of the variability in exercise (Yes/No) was explained by within-individual differences, suggesting that the decision to exercise varied within participants (**Table 10)**. Thirty-nine percent of the variability in exercise (Yes/No) was explained by between-individual differences, suggesting that the decision to exercise varied among participants.

Seventy-eight percent of the variability in exercise time was explained by within-individual differences, suggesting that the minutes spent on exercise varied within participants (**Table 10**; **Figure 11**). Twenty-two percent of the variability in exercise time was explained by between-individual differences, suggesting that the minutes spent on exercise varied among participants.

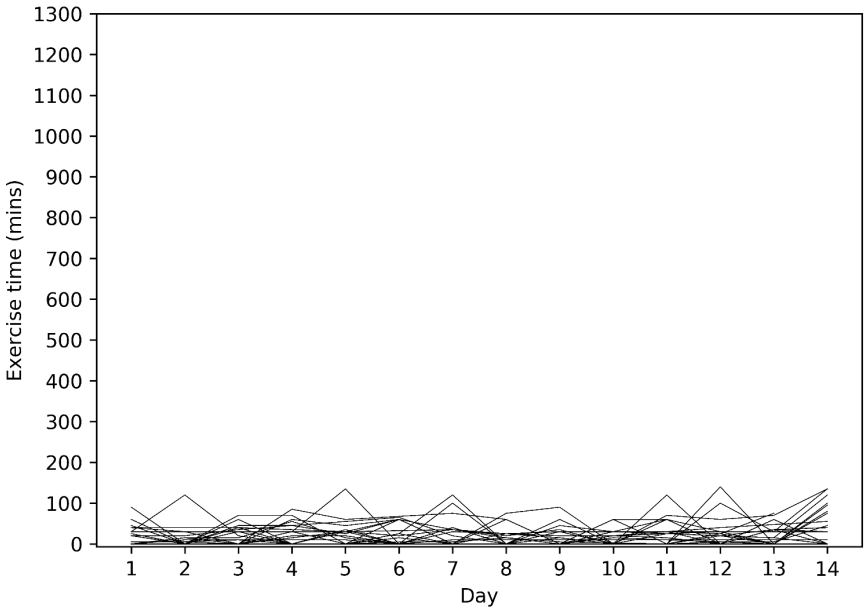


Figure 11 Spaghetti plot of exercise time

4.3.3.3 Leisure activities

On average, participants participated in 3.67 leisure activities per day, with a mean time of 374 minutes. Forty percent of the variability in leisure variety was explained by within-individual differences, suggesting that the numbers of leisure activities varied within participants (**Table 10**; **Figure 12**). Sixty percent of the variability in leisure variety was explained by between-individual differences, suggesting that the numbers of leisure activities varied among participants.

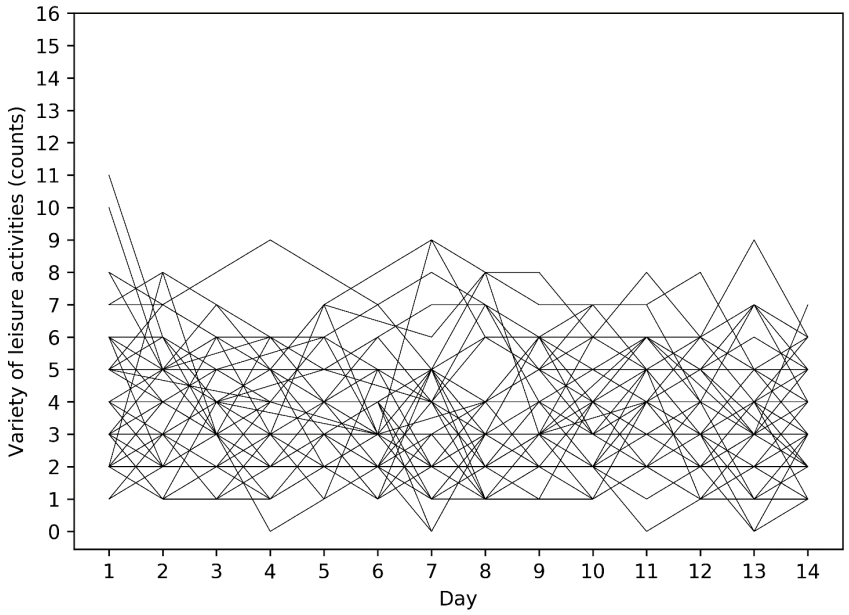


Figure 12 Spaghetti plot of leisure variety

Sixty-six percent of the variability in leisure time was explained by within-individual differences, suggesting that the minutes spent on leisure varied within participants (**Table 10**; **Figure 13**). Thirty-four percent of the variability in leisure time was explained by between-individual differences, suggesting that the minutes spent on leisure varied among participants.

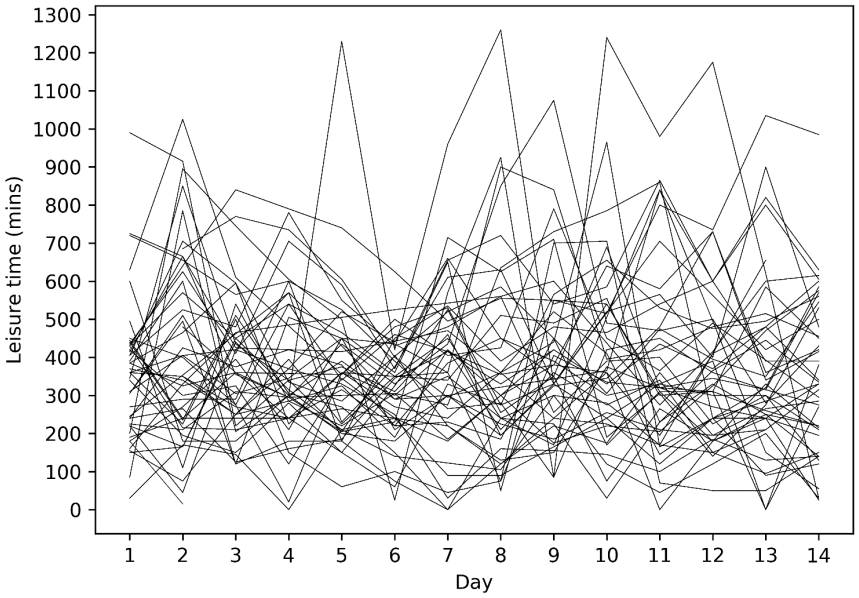


Figure 13 Spaghetti plot of leisure time

4.4 Discussion

The study examined the feasibility of the measurement burst design to detect the patterns of everyday activities among older adults at-risk for disability. Findings suggested that the measurement burst design was a feasible and usable approach to detect the patterns of everyday activities. The variability in everyday activities contributed to between and within individual differences. We were able to calculate the amount of IADL, exercise, and leisure activities in at-risk older adults. The feasible measurement burse design provided a fine-grained analysis of everyday activities. Although the data may not generalize to the full aging population and the 26 sampled activities might not represent the full range of activities of daily living, this study was the first step toward evaluating methods for quantifying patterns of everyday activities in older adults

at-risk for disability. The study methodologies may inform future studies aiming to develop preventative strategies to support healthy activity patterns in late life.

Older adults without prior experience of smartphones did learn to use mobile devices and respond to assessments with a high adherence rate. Participants reported that the amount of time spent on assessments was manageable and appropriate. Interestingly, participants reported that this design made them more aware of how they spent time. However, few suggested that this design had changed their daily activities or routines. The results matched previous findings, rejecting the "reactivity effect" on answering assessments intensively in a short period of time (Shiffman et al., 2008).

Our response rate was similar to previous studies using a measurement burst design, which was usually higher than 80.0% if there were no technical issues and if participants were trained (Cain et al., 2009). One participant had lost the device during the study. We were able to trace its location and find the device. Two participants tried to respond surveys for few days and decided it was too burdensome to continue. They reported that the perceived burden was not related to the length of the study design (14 days), but the willingness to carry a second phone. While many studies suggested technical issues (e.g., devices did not ring, surveys could not open, the Internet was disconnected), we encountered few errors with survey distribution. There was a day that a few surveys were not sent out. However, the issue was quickly fixed by the specialist. In general, the survey dissemination portal (Qualtrics) was reliable and usable in collecting surveys within an intensive period of time.

There were limitations in this study. The primary drawback was the validity of self-report time spent on activities. Although the assessments were sent day-to-day to minimize the need to recall memory, self-report time spent on activities was probably not the most optimal

methodologies in examining everyday activities. So far, however, it was a better way to examine complex human behaviors compared to traditional ways of assessing activities via a one-time questionnaire. Strategies must be developed to estimate everyday activities, with minimal threats to personal privacy (as in the case of camera monitoring). Additionally, the small sample size and highly-educated participants hindered the generalizability of results.

The study was novel in understanding the patterns of everyday activities. The study showed that the measurement burst design was a feasible approach to detect the patterns of everyday activities. Future studies that aim to promote changes in human behaviors and routines should consider assessing the patterns of everyday activities in evaluating the effects of preventative strategies in reducing disability for older adults.

5.0 Patterns of Everyday Activities in Older Adults At-risk for Disability: Depressive Symptoms and Cognitive Complaints

In **Chapter 5**, we studied the association between indicators of brain-health and everyday activity patterns in older adults at-risk for disability. We examined the interactions among depressive symptoms, cognitive complaints with the patterns of everyday activities via a measurement burst design. The chapter has been developed into a manuscript, titled "Patterns of Everyday Activities in Older Adults At-risk for Disability: Depressive Symptoms and Cognitive Complaints" for submission to a peer-reviewed journal to be named.

5.1 Introduction

Periodic engagement in everyday activities (instrumental activities of daily living, exercise, leisure) reduces the risk of chronic diseases and mortality from all causes in late life (Elwood et al., 2013). Emerging evidence suggested that routine participation in these activities could reduce the risk of disability by 7%-43% in older adults (P. A. Boyle, Buchman, Wilson, Bienias, & Bennett, 2007; Fratiglioni et al., 2004; James et al., 2011). Consequently, current research seeks to better understand the patterns of participating in everyday activities, as illustrated by 1) the types of activities older adults select and 2) the minutes they spend on activities "during a period of time (e.g., weekly, monthly)" (Carlson et al., 2012). Unfortunately, an estimated half of older adults do not routinely participate in these activities over time, exposing themselves to risks of poor health, cardiovascular events, and increased healthcare costs in late life (D. E. King et al., 2009).

Identifying risk factors for unhealthy patterns of everyday activities may inform timely prevention-oriented interventions to maintain healthy patterns of activities in late life.

Subtle changes in thinking and feeling often reflect changes in brain health (Saykin et al., 2006). These brain health changes may be noticed by older adults without triggering clinical intervention, however, these changes may be associated with subtle changes in decision making on everyday activities. Depressive symptoms and cognitive complaints and were commonly reported in late life, especially for those who were at-risk for disability (T. L. Hayes et al., 2008). The estimated prevalence of depressive symptoms is reported to be 27.5%, and estimated prevalence of cognitive complaints in late life ranges from 21.7% to 61.4% (Fritsch et al., 2014; Laborde-Lahoz et al., 2014; Westoby et al., 2009). Depressive symptoms include feelings of sadness, hopelessness, or loss of interest but not necessarily qualified a medical diagnosis. Cognitive complaints may include perceptions of inefficient thinking, coordinating information and making decisions that may proceed beyond objective cognitive impairments. These two categories of symptoms, though not formal medical diagnoses, may represent a dysregulation in the brain networks due to underlying neurodegenerative changes (Saykin et al., 2006), and potentially sway everyday activities over time.

Yet, the interactions among depressive symptoms, cognitive complaints with the patterns of everyday activities have not been fully understood. Potentially due to the difficulties in assessing the patterns of everyday activities over time, research findings have been based on one-time assessments, asking older adults to recall past experiences in clinical or laboratory settings. This approach is problematic because a snapshot overlooks the fluctuating nature of human activity, and recalling thinking and feeling in a controlled environment threatens information validity. Most importantly, associations among brain health changes and patterns of everyday activities have not

been studies at such an early stage – that is, among older adults at-risk for disability. To identify the risk factors for unhealthy patterns of everyday activities, we need to study older adults who are beginning to experience a change in patterns of everyday activities, but are still able to perform everyday activities.

Thus, the aim of the study was to use intensive, real-time assessments to understand the associations among depressive symptoms, cognitive complaints, and activities for 14 days in older adults at-risk for disability (self-reported changes in daily activities but without difficulties performing activities). We first examined the feasibility of delivering 4 questionnaires throughout a day for 14 days. We investigated whether the patterns of three categories of everyday activities (instrumental activities of daily living; exercise; leisure) differed by depressive symptoms and cognitive complaints. The findings derived from the study may inform timely interventions that aim to promote healthy patterns of everyday activities to prevent adverse health outcomes in late life.

5.2 Method

5.2.1 Participants

Older adults aged ≥ 55 were recruited. Older adults at-risk for disability were screened via two criteria: 1) self-reported change in life routines or take more time in daily activities than they used to do; 2) absence of difficulties in performing basic activities, as indicated by a score ≥ 95 on the Barthel Index (F. I. Mahoney & Barthel, 1965). Older adults who were previously diagnosed with major depressive disorder, bipolar, mania or dementia were excluded. Older adults with drug

and alcohol abuse history were excluded to ensure that depressive symptoms were not induced via the consumption of substance or drug. Participants provided informed consent approved by the University of Pittsburgh Institutional Review Board.

5.2.2 Study procedure

Upon enrollment, participants were trained to use a mobile device to answer questionnaires. Questionnaires were disseminated through Qualtrics software via the Short Message Service (SMS) (Qualtrics, 2017). Participants were asked to carry the mobile device with them and answer questionnaires throughout waking hours for 14 consecutive days.

A measurement burst design approach was adopted to intensively collect the outcome of interest. Participants received 4 questionnaires throughout a day [one in the morning block (9 am -12 pm); afternoon block (12 pm – 6 pm); evening block (6 pm – 9 pm); and end-of-day] (**Table 13**). Morning and afternoon questionnaires assessed depressive symptoms, evening questionnaires assessed depressive symptoms and cognitive complaints, and the end-of-day questionnaire assessed everyday activities. Cognitive complaints were assessed once per day due to the stability of cognition (Weaver Cargin, Collie, Masters, & Maruff, 2008), whereas depressive symptoms were assessed three times per day due to the instability of mood throughout the day (Wichers et al., 2010). Morning, afternoon, and evening questionnaires were randomly-scheduled within time blocks to ensure representative and unbiased data compared to planned, scheduled questionnaires (Shiffman et al., 2008; A. Stone et al., 2007). The end-of-day diary was scheduled based on participants' preferred time to prevent unreported daily activities after the questionnaires. Participants were audibly prompted up to five times to complete the questionnaire. Questionnaires answered 30 minutes after delivery were treated as expired data.

Table 13 Measurement schedule

Sampling	Time	Variables	Items	Total items
Random scheduled questionnaires	9 am – 12 pm	Depressive symptoms	2	2
	12 pm – 6 pm	Depressive symptoms	2	2
	6 pm – 9 pm	Depressive symptoms	2	8
		Cognitive complaints	4	
		Pain	1	
		Fatigue	1	
End-of-day questionnaire	9 pm – 10:30 pm	Everyday activities (variety and time)	≈20	≈20

5.2.3 Measures

5.2.3.1 Everyday activities

The repertoire of activities included three categories: 1) instrumental activities of daily living (IADL), 2) exercise and 3) leisure activities. The Lawton instrumental activities of daily living scale (Lawton IADL scale) and the Lifestyle Activities Questionnaire (LAQ) were used to develop the repertoire of activities (Carlson et al., 2012; Lawton & Brody, 1969). The IADL category included 9 IADL, which were necessary for independent living. The exercise category included 1 item, asking whether older adults had exercised except for walking. The leisure category included 16 leisure activities that were often chosen by older adults.

Each category had "variety" and "time" scores. The scores were collected per day for 14 days. IADL variety was scored from 0 to 9, with a higher score representing more types of IADL were chosen by participants. Exercise (Yes/No) was scored from 0 to 1, with 0 meaning the participant did not exercise. Leisure variety was scored from 0 to 16, with a higher score indicating more types of leisure activities were chosen by participants. IADL time, exercise time, and leisure time were scored based on the sum of the minutes they reported on the activities within each category.

5.2.3.2 Depressive symptoms

The PHQ-2 was a self-report measure that assessed the anhedonia and somatic aspects of depressive symptoms (Li, Friedman, Conwell, & Fiscella, 2007). The wording of 2 items was converted to reflect the present state. It had 2 items, with item score ranging from 1 (not at all) to 5 (very much). The total score ranged from 2 to 10, with a higher score representing a higher severity of depressive symptoms.

5.2.3.3 Cognitive complaints

Self-perceived cognitive complaints were measured via the Patient-Reported Outcomes Measurement Information System (PROMIS) – Cognitive abilities (Howland, Tatsuoka, Smyth, & Sajatovic, 2017). It had 4 items, with item score ranging from 1 (not at all) to 5 (very much). The wording of 4 items has been converted to reflect the present state. The total score was translated to *t* score, with a population mean of 50 and a standard deviation of 10. A higher score represented lower cognitive complaints.

5.2.3.4 Covariates

Perceived social support was assessed once by the Multidimensional Scale of Perceived Social Support (MSPSS) (Zimet, Dahlem, Zimet, & Farley, 1988). The MSPSS had 12 items (1 = very strongly disagree, 7 = very strongly agree); item scores were summed and ranged from 7 to 84, with a higher score indicating higher perceived social support.

Fatigue was assessed daily for 14 days. The fatigue severity was assessed by a numeric rating scale (0-10), with 0 indicating “no fatigue at all” and 10 indicating “extremely fatigued” (van Hooff, Geurts, Kompier, & Taris, 2007a).

5.2.3.5 Feasibility indices

Feasibility was assessed via seven indices: 1) participant attrition rate (number of withdrew/ total participants), 2) mobile device user experiences (whether the participant had a smartphone before the study), 3) survey response rate (number of answered surveys/ total deployed surveys), 4) survey expired rate (number of surveys answered after 30 minutes/ total answered surveys), 5) missing data rate (number of surveys with missing data/ total answered surveys), 6) time to open the survey (minutes), and 7) time spent on the survey (minutes).

Benchmarks were set for three indices: 1) survey response rate (≥ 80.0%) (Cain et al., 2009), 2) survey expired rate (≤ 20.0%) (Shiffman et al., 2008), and 3) missing data rate (≤ 5.0%) (Fritz et al., 2017).

5.2.4 Statistical analysis

Descriptive statistics (mean; standard deviation; percentage) were used to assess the feasibility indices. Depressive symptoms score was averaged from the morning, afternoon, and evening questionnaires for each day for each participant.

A series of separate generalized linear mixed models were used to examine whether the patterns of everyday activities differed by cognitive complaints and depressive symptoms over 14 days. The patterns of six dependent variables (IADL variety; IADL time; exercise (Yes/No); exercise time; leisure variety; leisure time) were separately examined with depressive symptoms and cognitive complaints.

The generalized linear mixed model included a “depressive symptoms × day” interaction as well as depressive symptoms and day main effects as fixed effect variables. The intercept and

slope of a dependent variable within participants were treated as random-effect variables. Covariates that were moderately associated with the dependent variables (Spearman $r \geq 0.3$) were treated as fixed-effect variables (Barbara & Linda, 2007). The means of continuous variables were centered to eliminate the scaling differences among variables. If the interaction term was not statistically significant, the main effect was used to examine the relationship between depressive symptoms and dependent variables. The structure of the estimated covariance matrix for the repeated measures was examined to determine the appropriate covariance structure. The same model structure was used for cognitive complaints.

To visualize interaction effects, participants were dichotomized into two groups by the cut-off of depressive symptoms (cognitive complaints). Participants were dichotomized into high depressive symptoms (mean PHQ-2 score over 14 days ≥ 3) and low depressive symptoms (< 3) groups (Li et al., 2007); high cognitive complaints (mean *t*-score over 14 days < 50) and low cognitive complaints (≥ 50) groups. Additionally, *t*-statistics was conducted to examine whether there was a group difference in the dependent variables. A Cohen's *d* was calculated to estimate the magnitude of between-group differences on dependent variables.

The SAS (version 9.4) PROC GLIMMIX procedure and the SPSS (version 24.0) were used for data analysis. Analyses were considered statistically significant at the 0.05 α level.

5.3 Results

5.3.1 Participants

A total of 99 participants were screened; 50 participants were eligible and enrolled. One participant died, and two participants withdrew. **Table 14** described the characteristics of participants. The response rate was 89.1% among delivered assessments. Among 2,744 surveys, 211 were not answered, 452 were expired (answered ≥ 30 minutes), and 36 had missing data. A total of 2,045 data were valid and included in the analysis.

Table 14 Participant characteristics

Characteristics	All (n = 50)
Age [mean (SD), range]	66.6 (8.27), 56-87
Male [n (%)]	19 (38.0)
White [n (%)]	42 (84.0)
Level of education [n (%)]	
High school	11 (22.0)
Associates	8 (16.0)
Bachelors	13 (26.0)
Master	17 (34.0)
PhD	1 (2.0)
Married [n (%)]	19 (38.0)
Comorbidity [mean (SD), range]	2.04 (2.32), 0-12
Lived alone [n (%)]	27 (54.0)
Retired [n (%)]	24 (48.0)

5.3.2 Measurement burst design feasibility indices

The flow diagrams of the morning, afternoon, and evening questionnaires were presented in **Figure 14**, **15**, and **16**. Participants averagely spent less than 10 minutes on the four

questionnaires per day. The response rates were high (88.1% to 93.1%), and missing data rates were low (0.9% to 4.0%) among the four questionnaires (**Table 15**). Morning and afternoon survey expire rates did not meet the benchmark.

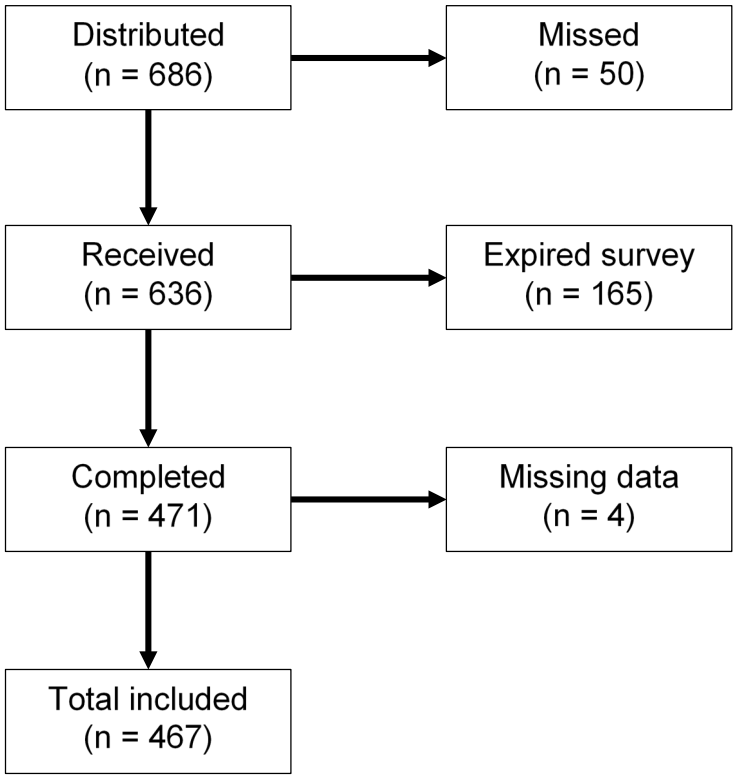


Figure 14 Flow diagram of the morning questionnaire

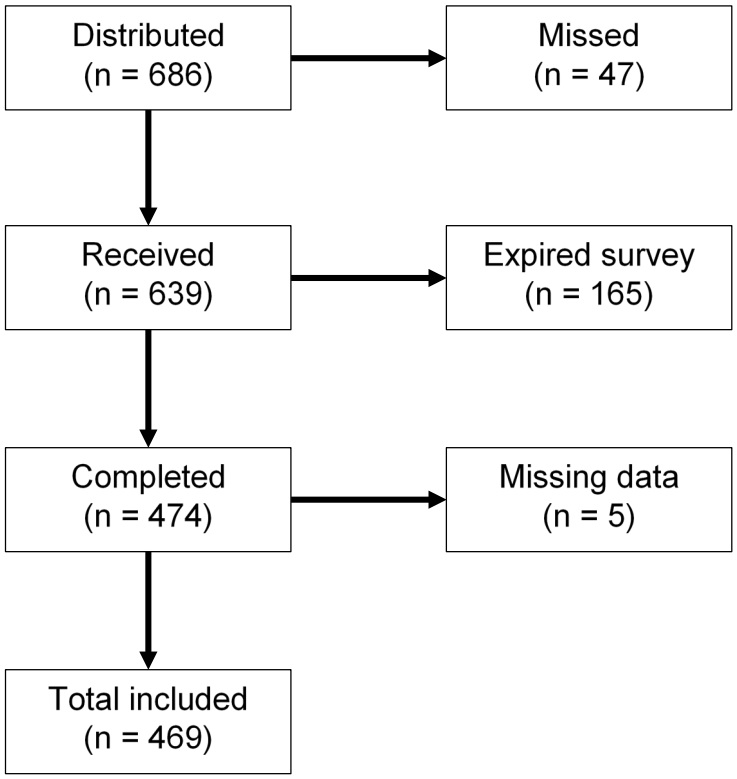


Figure 15 Flow diagram of the afternoon questionnaire

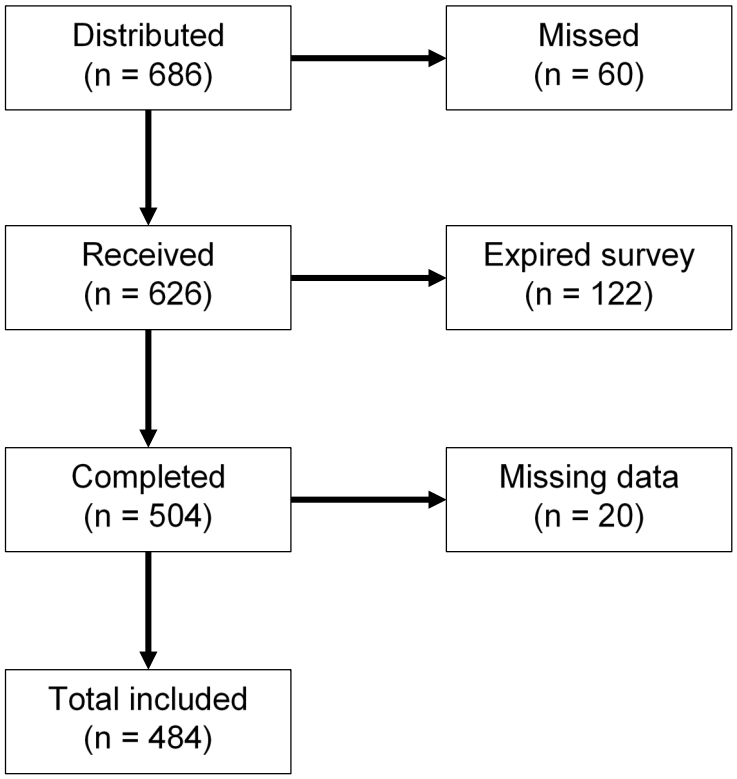


Figure 16 Flow diagram of the evening questionnaire

Table 15 Feasibility indices

Feasibility indices	Benchmarks	Results	Achieved
Participant attrition rate [(n (%)]	< 10.0	3 (6.0)	Yes
Mobile device experience			
Had a smartphone before the study [n (%)]		41 (78.0)	
Morning survey			
Response rate (%)	> 80.0	92.7	Yes
Expire rate (%)	< 20.0	25.9	No
Missing data rate (%)	< 5.0	0.9	Yes
Time to open surveys [mean (SD)]	< 30	36.2 (83.8)	Yes
Time spent on surveys [mean (SD)]	N/A	2.1 (17.1)	N/A
Afternoon survey			
Response rate (%)	> 80.0	93.1	Yes
Expire rate (%)	< 20.0	25.8	No
Missing data rate (%)	< 5.0	1.1	Yes
Time to open surveys [mean (SD)]	< 30	45.7 (120.0)	Yes
Time spent on surveys [mean (SD)]	N/A	4.8 (75.0)	N/A
Evening survey			
Response rate (%)	> 80.0	88.1	Yes
Expire rate (%)	< 20.0	19.5	Yes
Missing data rate (%)	< 5.0	4.0	Yes
Time to open surveys [mean (SD)]	< 30	38.1 (133.5)	Yes
Time spent on surveys [mean (SD)]	N/A	4.1 (47.3)	N/A
End-of-Day survey			
Response rate (%)	> 80.0	89.0	Yes
Missing data rate (%)	< 5.0	1.1	Yes
Time to open surveys [mean (SD)]	N/A	10.1 (73.7)	N/A
Time spent on surveys [mean (SD)]	N/A	7.8 (46.2)	N/A

Note: Time was reported in minutes.

5.3.3 IADL variety

There was no interaction effect between depressive symptoms and time ($F_{13,514} = 1.64$, $p = .07$) (**Figure 17**). The main effect of depressive symptoms showed that higher depressive symptoms were statistically associated with less IADL variety ($F_{1,514} = 10.29$, $p = .001$). The main effect of time showed that days were statistically associated with IADL variety ($F_{13,514} = 3.09$, $p < .001$).

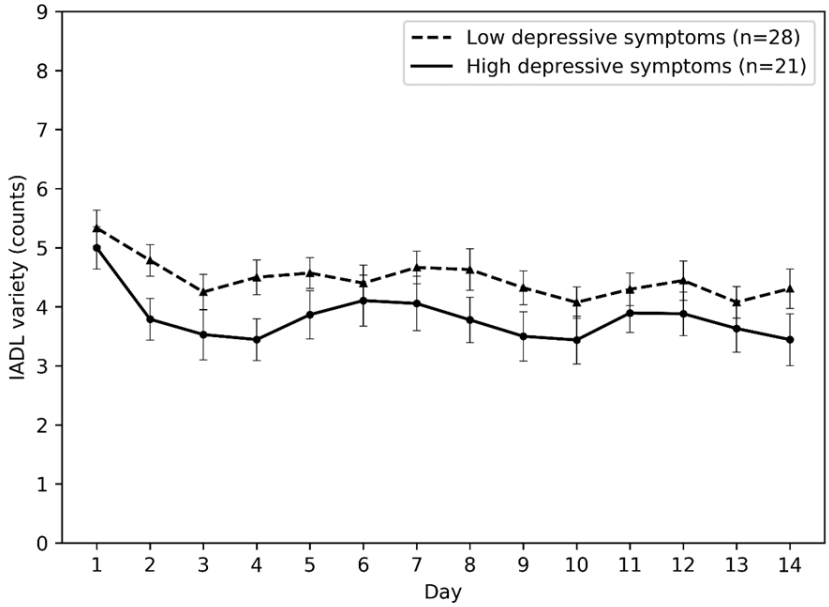


Figure 17 IADL variety - The interaction between depressive symptoms and time

There was no interaction effect between cognitive complaints and day ($F_{13,405} = 0.88$, $p = .57$) (**Figure 18**). The main effect of cognitive complaints showed that higher cognitive complaints were not statistically associated with IADL variety ($F_{1,405} = 0.02$, $p = .89$). The main effect of time showed that days were statistically associated with IADL variety ($F_{13,405} = 2.19$, $p < .001$).

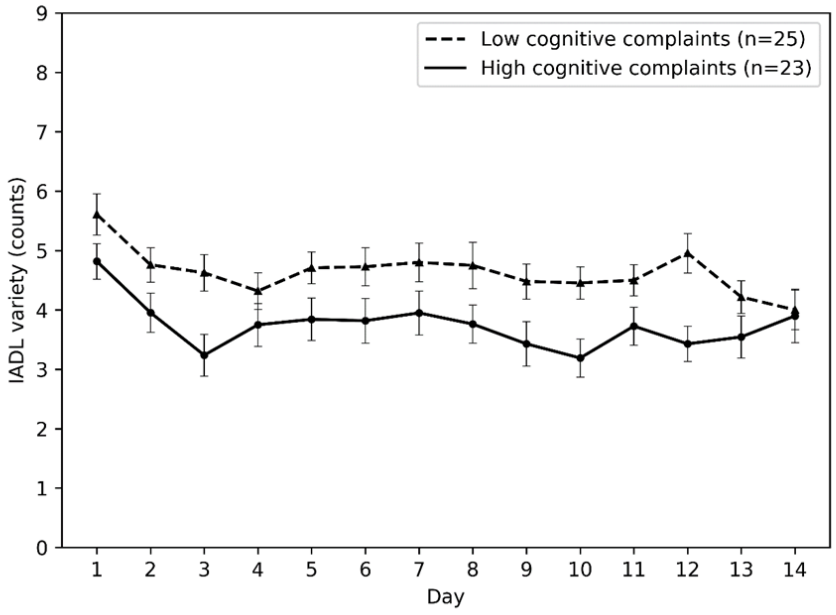


Figure 18 IADL variety - The interaction between cognitive complaints and time

5.3.4 IADL time

There was no interaction effect between depressive symptoms and time ($F_{13,515} = 0.98$, $p = .47$) (**Figure 19**). The main effect of depressive symptoms showed that higher depressive symptoms were statistically associated with lower IADL time ($F_{1,515} = 4.75$, $p = .03$). The main effect of time showed that days were not statistically associated with IADL time ($F_{1,515} = 1.15$, $p = .31$).

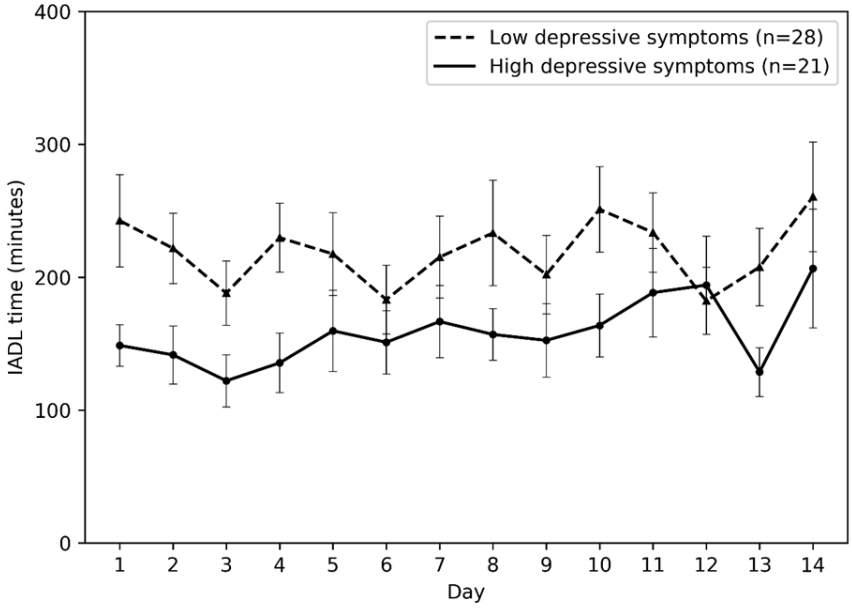


Figure 19 IADL time - The interaction between depressive symptoms and time

There was no interaction effect between cognitive complaints and time ($F_{13,406} = 0.45$, $p = .95$) (**Figure 20**). The main effect of cognitive complaints showed that higher cognitive complaints were not statistically associated with IADL time ($F_{1,406} = 0.04$, $p = .85$). The main effect of time showed that days were statistically associated with IADL variety ($F_{13,514} = 3.09$, $p < .001$).

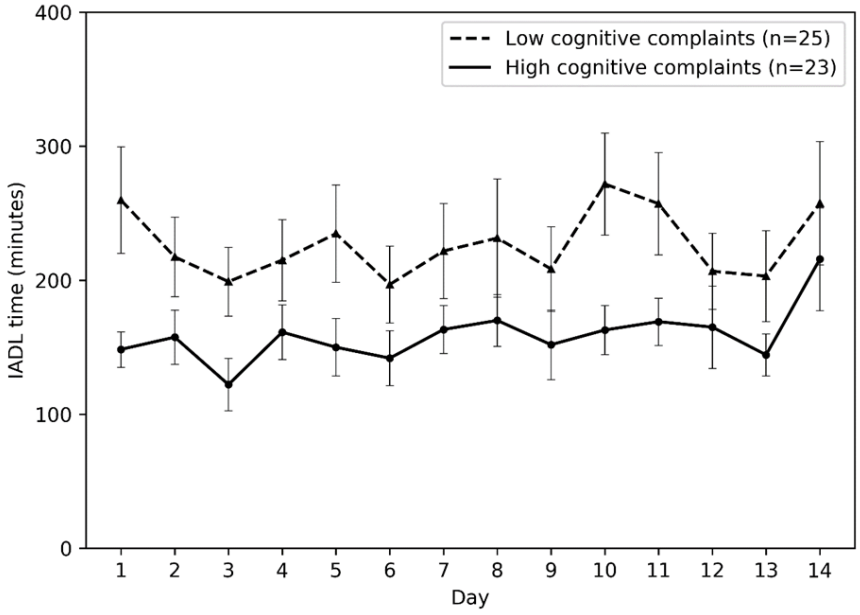


Figure 20 IADL time - The interaction between cognitive complaints and time

5.3.5 Exercise (Yes/No)

There was no interaction effect between depressive symptoms and time ($F_{13,518} = 0.66$, $p = 0.81$) (**Figure 21**). The main effect of depressive symptoms showed that higher depressive symptoms were not statistically associated with exercise (Yes/No) ($F_{1,518} = 0.28$, $p = .60$). The main effect of time showed that days were not statistically associated with exercise (Yes/No) ($F_{13,518} = 0.51$, $p = .92$).

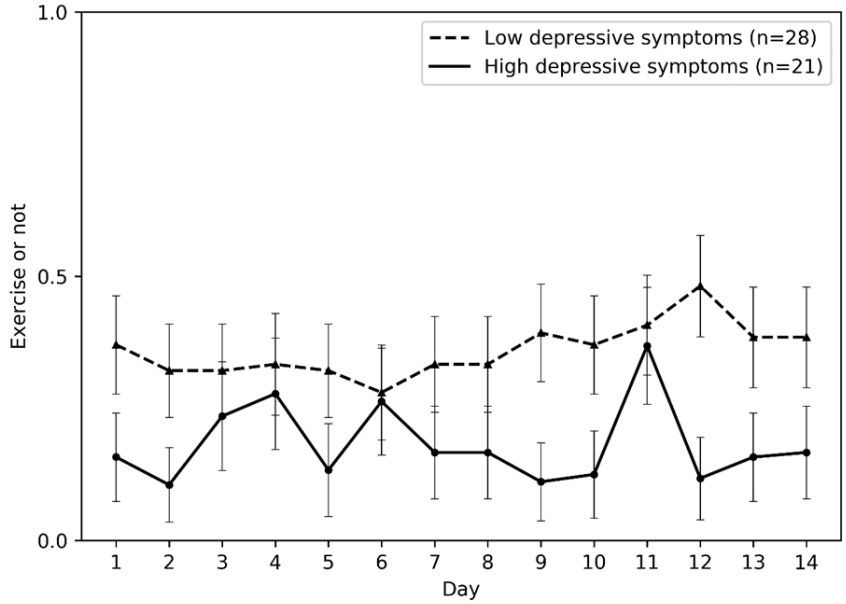


Figure 21 Exercise (Yes/No) - The interaction between depressive symptoms and time

There was no interaction effect between cognitive complaints and day ($F_{13,408} = 0.50$, $p = .92$) (**Figure 22**). The main effect of cognitive complaints showed that higher cognitive complaints were not statistically associated with exercise (Yes/No) ($F_{1,408} = 1.02$, $p = .31$). The main effect of time showed that days were statistically associated with exercise (Yes/No) ($F_{13,408} = 0.46$, $p = .94$).

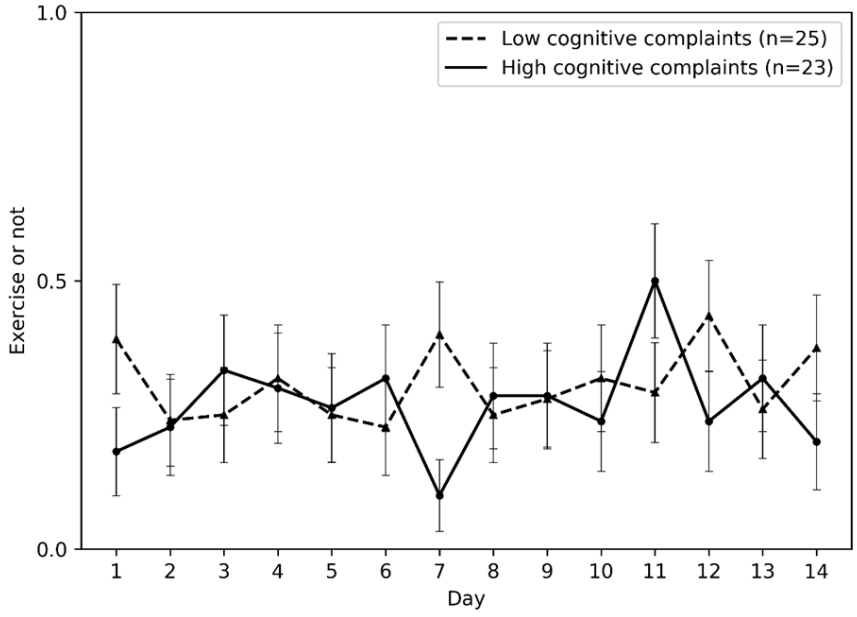


Figure 22 Exercise (Yes/No) - The interaction between cognitive complaints and time

5.3.6 Exercise time

There was an interaction effect between depressive symptoms and day, indicating that the patterns of exercise time varied by depressive symptoms ($F_{13,519} = 26.28$, $p < .001$) (**Figure 23**).

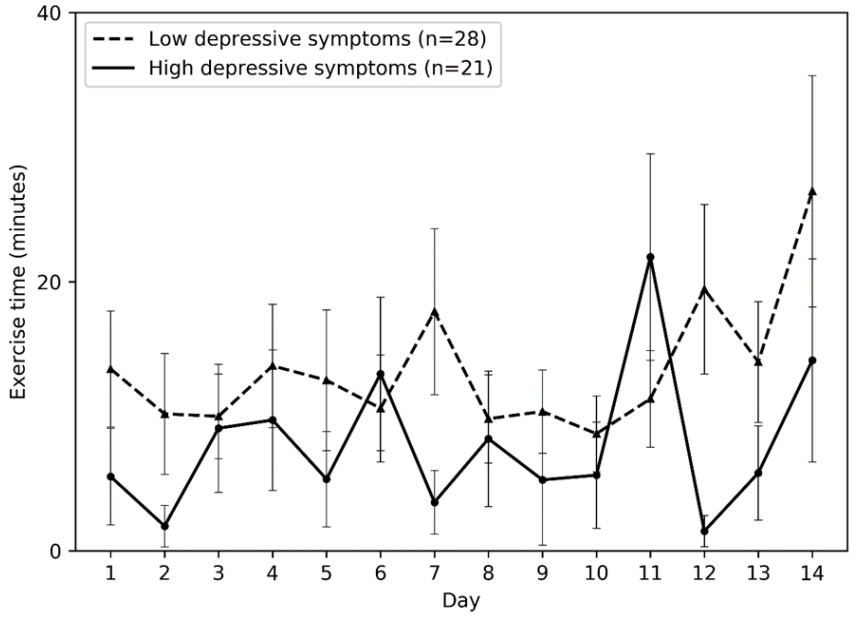


Figure 23 Exercise time - The interaction between depressive symptoms and time

There was an interaction effect between cognitive complaints and time, indicating that the patterns of exercise time varied by cognitive complaints ($F_{13,409} = 28.51$, $p < .001$) (**Figure 24**).

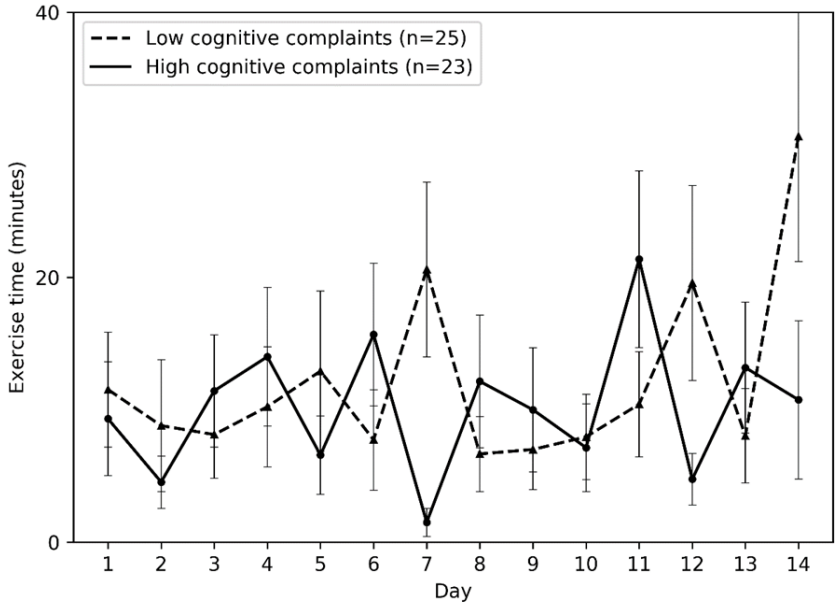


Figure 24 Exercise time - The interaction between cognitive complaints and time

5.3.7 Leisure variety

There was no interaction effect between depressive symptoms and day ($F_{13,397} = 1.43$, $p = .14$) (**Figure 25**). The main effect of depressive symptoms showed that higher depressive symptoms were not associated with leisure variety ($F_{1,397} = 0.01$, $p = .91$). The main effect of time showed that days were not statistically associated with leisure variety ($F_{13,397} = 1.66$, $p = .06$).

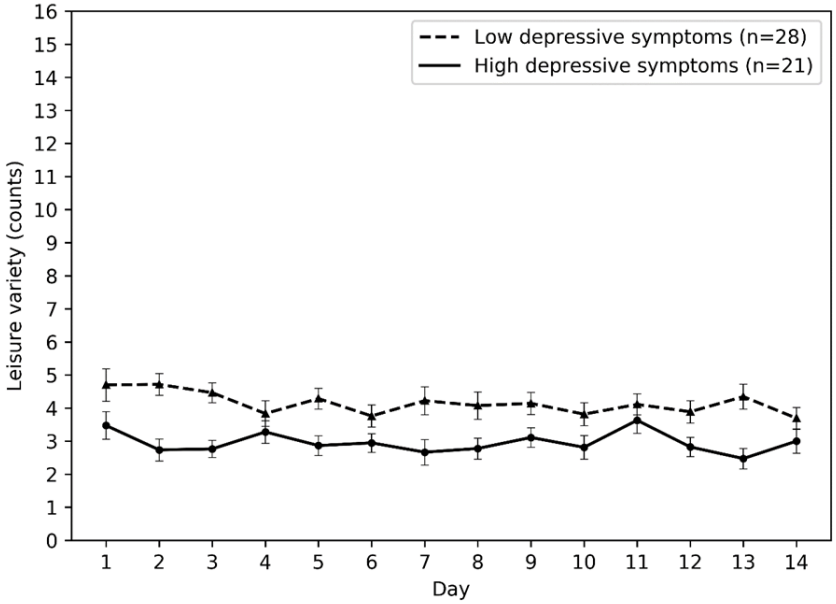


Figure 25 Leisure variety - The interaction between depressive symptoms and time

There was no interaction effect between cognitive complaints and day ($F_{1,397} = 1.53$, $p = .10$) (**Figure 26**). The main effect of cognitive complaints showed that higher cognitive complaints were statistically associated with less leisure variety ($F_{1,397} = 5.84$, $p = .02$). The main effect of time showed that days were not statistically associated with leisure variety ($F_{13,397} = 1.70$, $p = .06$).

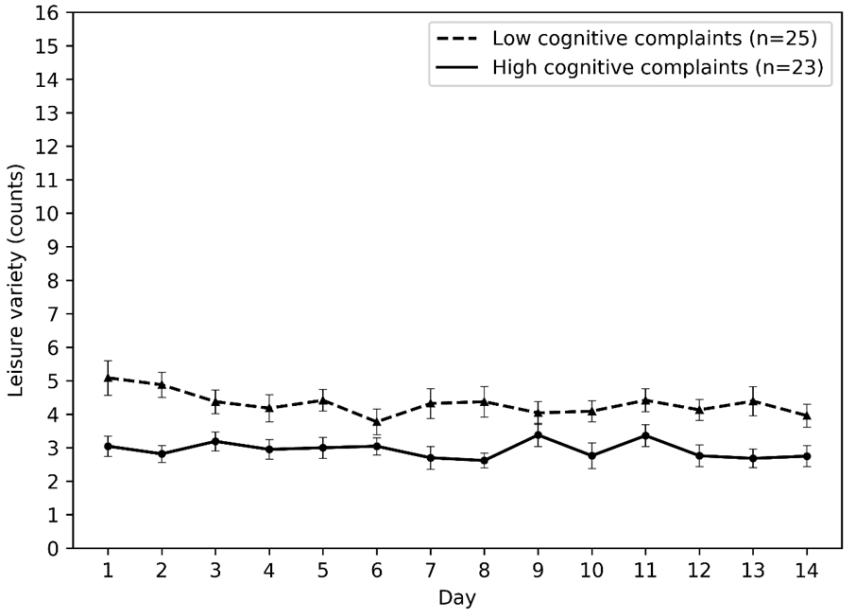


Figure 26 Leisure variety - The interaction between cognitive complaints and time

5.3.8 Leisure time

There was no interaction effect between depressive symptoms and time ($F_{13,403} = 0.77$, $p = 0.70$) (**Figure 27**). The main effect of depressive symptoms showed that higher depressive symptoms were not associated with leisure time ($F_{1,403} = 0.09$, $p = .76$). The main effect of time showed that days were not statistically associated with leisure time ($F_{13,403} = 1.48$, $p = .12$).

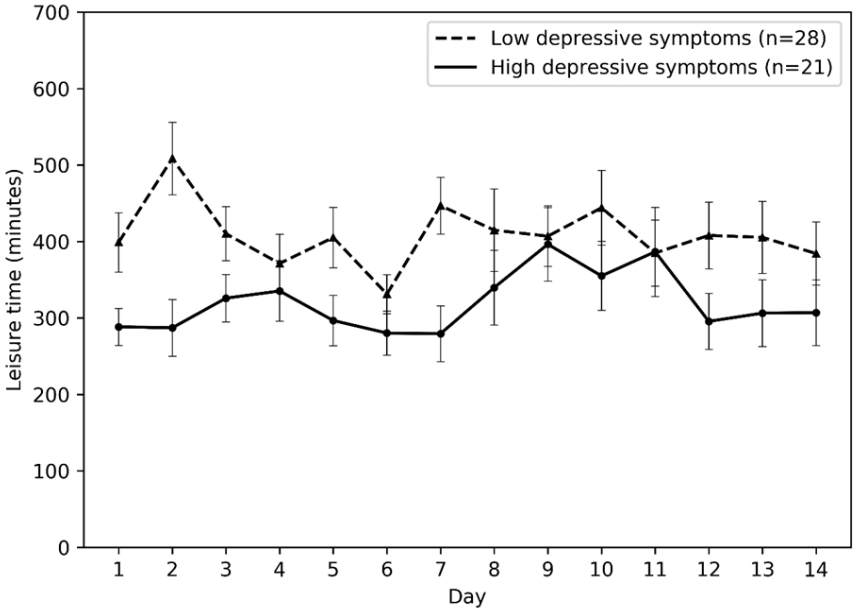


Figure 27 Leisure time - The interaction between depressive symptoms and time

There was an interaction effect between cognitive complaints and time, indicating that the patterns of leisure time varied by cognitive complaints ($F_{13,404} = 2.48$, $p = .003$) (**Figure 28**).

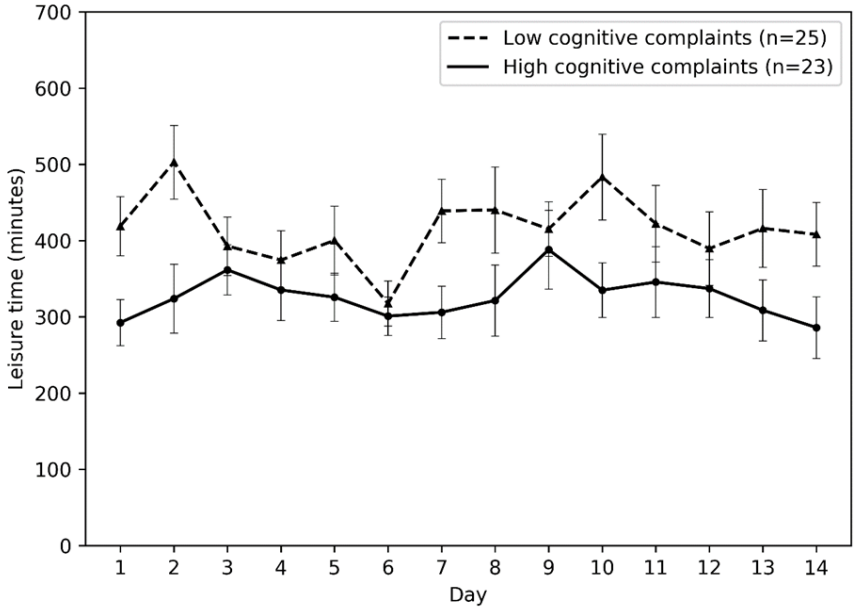


Figure 28 Leisure time - The interaction between cognitive complaints and time

5.3.9 High and low depressive symptoms and cognitive complaints groups

High and low depressive symptoms groups had significant differences in IADL variety, exercise (Yes/No), leisure variety, and leisure time (**Table 16**). High and low cognitive groups had significant differences in IADL variety, IADL time, leisure variety, and leisure time (**Table 16**).

Table 16 Effect sizes for older adults with high and low depressive symptoms and cognitive complaints

Characteristics [mean (SD)]	All	Cognitive complaints					Depressive symptoms				
		Low	High	*t*-statistics	*p*-value	Effect size	Low	High	*t*-statistics	*p*-value	Effect size
		25 (52.1)	23 (47.9)				28 (57.1)	21 (42.9)			
IADL variety	4.21 (1.66)	4.62 (1.00)	3.72 (1.08)	$t_{(46)}$=2.97	*<.001	0.86	4.46 (1.01)	3.81 (1.15)	$t_{(47)}$=2.09	*0.04	0.60
IADL time	194.80 (148.52)	226.09 (134.90)	156.82 (60.30)	$t_{(34)}$=2.33	*0.03	0.66	217.60 (127.00)	157.20 (70.12)	$t_{(47)}$=1.96	0.06	0.59
Exercise (Yes/No)	0.29 (0.45)	0.30 (0.32)	0.26 (0.29)	$t_{(46)}$=0.42	0.68	0.13	0.36 (0.32)	0.17 (0.24)	$t_{(47)}$=2.40	*0.02	0.67
Exercise time	11.29 (23.79)	11.99 (13.69)	10.23 (11.84)	$t_{(46)}$=0.48	0.64	0.14	13.43 (12.94)	7.57 (11.84)	$t_{(47)}$=1.63	0.11	0.47
Leisure variety	3.67 (1.83)	4.32 (1.44)	2.90 (1.04)	$t_{(46)}$=3.87	*<.001	1.13	4.15 (1.53)	3.21 (1.62)	$t_{(47)}$=2.06	*0.04	0.60
Leisure time	374.04 (209.30)	416.18 (132.76)	320.81 (119.78)	$t_{(46)}$=2.61	*0.01	0.75	409.54 (137.08)	309.33 (112.97)	$t_{(47)}$=2.73	*0.01	0.80

5.4 Discussion

Findings suggest that the patterns of everyday activities were strongly associated with thinking and feeling in day-to-day lives for older adults at-risk for disability. We found that the patterns of exercise time varied by depressive symptoms and cognitive complaints, whereas the patterns of leisure time varied by cognitive complaints. Less IADL variety and IADL time were associated with higher depressive symptoms, whereas less leisure variety and leisure time were associated with higher cognitive complaints. These findings may suggest that brain health changes signal changes in everyday activities, or that patterns of everyday activities may herald brain health changes. Additional investigation is warranted to understand the causal nature of these associations if we are to use these data potentially mitigate disability in late life. As of now, our data would suggest that in patterns of everyday activities may be useful in identifying at-risk aging populations.

The variations in patterns of exercise time, as associated with depressive symptoms and cognitive complaints, may be interpreted in several ways. First, the variability of exercise time was high, and this may have contributed or be caused by day-by-depression (cognition) interaction effects. Second, the relationship between depression (cognition) and exercise time may be confounded by other variables, such as weather and holidays. Third, the relationship between depressive symptoms and exercise could be both positively and negatively correlated. For example, an older adult may be too depressed to exercise; reversely, an older adult may be depressed and decided to exercise to lighten her depressed mood. This hypothesis had been examined (Taquet, Quoidbach, de Montjoye, Desseilles, & Gross, 2016), suggesting that

individuals may force themselves in doing unpleasant but necessary activities, in trading off a positive affect.

The patterns of leisure time varied by cognitive complaints. Visually, we observed a trend where older adults with high cognitive complaints had a lower variability in patterns of leisure time, comparing to those with low cognitive complaints having a higher variability pattern. This could be explained by the nature of leisure activities. Unlike basic activities (e.g., bathing or dressing), the participation of leisure required the exposure to cognitive-demanding environments, which relied on higher-level cognitive processes (e.g., language, task switching, and executive functioning). For older adults with low cognitive complaints, they may flexibly utilize these cognitive operations, sustain participating in leisure activities, and organize lives in a reasonable manner. However, for older adults with high cognitive complaints, sustaining leisure activities in a certain amount of time may be difficult. Also, organizing and switching between leisure tasks may be cognitively burdensome. This may explain why older adults with high cognitive complaints had a more consistent and less time spent on leisure activities comparing to those with low cognitive complaints. Averagely, older adults with high cognitive complaints performed fewer leisure activities (1.4 counts less; 90 minutes less) than low cognitive complaints peers. These differences happened day-to-day, revealing the clinical importance in re-engaging those with cognitive complaints into leisure events.

We found that older adults with high depressive symptoms had less participation in IADL (0.6 counts less; 60 minutes less) than less depressed peers. However, the patterns of IADL variety and time did not vary by depressive symptoms. These findings suggested three things. First, one-point of anhedonia and symptomatic of depression was potent to sway everyday tasks and routines. Second, the relationship between depressive symptoms and IADL was stable and consistent. Third,

a one-time screening tool of depressive symptoms may be helpful for identifying those who have low participation in IADL in the primary care or clinics.

The associations among depressive symptoms, cognitive complaints, and patterns of everyday activities inferred treatment strategies to reduce disability for older adults. Several recommendations were provided for future studies. First, those with depressive symptoms and cognitive complaints were a risk population to be recruited and intervened to prevent further adverse health outcomes. Second, intervention studies that aim to reduce disability should evaluate the patterns of everyday activities, both variety and time. Third, effective approaches should be developed to "initiate" and "sustain" the participation in everyday activities. For example, interventions that utilized goal-setting, problem-solving strategies may be helpful to increase the participation in everyday activities in older adults (Clare et al., 2013; Rodakowski et al., 2016). The use of time management and scheduling is critical to supporting the periodicity in participating in everyday activities (Cuijpers, van Straten, & Warmerdam, 2007; Kanter et al., 2010). Last, while older adults are implementing the above strategies to elicit behavioral changes, depressive symptoms and cognitive complaints should be monitored in the meantime.

Cautiously, the relationship between depressive symptoms and cognitive complaints with everyday activity could be explained in two directions since the study had a cross-sectional design. Depressive symptoms and cognitive complaints may influence the patterns of everyday activities. Reversely, the patterns of everyday activities may also influence the perception of depressive symptoms and cognitive complaints. Thus, the benefits of IADL, exercise, and leisure should be examined via higher level evidence studies (e.g., randomized controlled trials, systematic reviews). Last, the participants were well-educated; the results may not be generalized to the aging population.

This study is innovative in its prevention-oriented research question, the real-time, real-world assessment study design, and the examination of thinking, feeling, and activities from an intra-individual perspective. Older adults with a change in patterns of everyday activities should be flagged for further evaluation, and carefully monitored on with respect to mood and cognition. We urge future intervention studies to evaluate the patterns of activities from intensive, real-time assessments, thus may truly estimate the behavioral changes made via intervention studies to mitigate disability in late life.

6.0 Summary

Preventing disability is a necessary public health goal for individuals, family units, and the whole society. This dissertation sought to advance the state of science by summarizing current gaps in prevent-oriented interventions and exploring the associations among indicators of brain health and everyday activity patterns to inform the risk architecture of disability in late life. The findings gleaned from **Chapter 2** to **5** suggested that existing interventions demonstrated limited effects on reducing disability due to the lack of the specification of active ingredients and mechanisms of change. The modest effects of these interventions may also be due to limited knowledge about indications for intervention, particularly in vulnerable populations who have not yet manifested disability. We explored potential indications for prevention-oriented interventions by examining associations among selected indicators of brain health and changes in disability, and patterns of everyday activities. Subtle changes in mood and cognition were potent enough to sway everyday activity patterns and accelerate disablement progression in selected at-risk older adults. Furthermore, these same indicators of brain health were associated with variations in patterns of everyday activities, which may herald an early phase in the disablement trajectory heretofore unmeasured. These findings inform future prevention-oriented interventions to consider the complexity of active ingredients to address changes in feeling, thinking, and activities to attenuate early stage disablement in late life. Efforts to prevent or slow the disablement progression have the potential to reduce associated health care cost, and support well-being in late life.

6.1 Implications and Future Directions

The identification of active ingredients is essential to understanding the mechanisms and pathways that led to the prevention of disability. Reviewing existing non-pharmacological interventions, we learned that interventions are often complex interventions composed of various active ingredients. Active ingredients have differing levels of potency in their ability to reduce disability. Since the combination of active ingredients varied among interventions, we did not have the opportunity to compare the effects of the various combinations of active ingredients to reduce disability. Future randomized controlled trials that comparing two or more active ingredients are warranted to differentiate the levels of effectiveness. We also learned that, the understanding of the mechanisms among active ingredients should complement early-phase intervention development. An understanding of mechanisms has potential to expedite the effectiveness of prevention-oriented interventions and enhance our understanding of why they are effective.

The nuances in feeling, thinking, and activities that precede overt disability are critical to identifying risk population in late life. We found a subtle elevation of depressive symptoms and cognitive complaints signaled differing activity patterns and accelerated disablement in selected at-risk older adults. For older adults with changes in depressive symptoms and cognitive complaints, everyday activity patterns may be used as a phenotype of early disablement, such as low variety and time spent on IADL and leisure activities. This phenotype offers a window of opportunity to early identify at-risk older adults for more extensive evaluations and treatments to mitigate disability.

The strong linkage between indicators of brain health and everyday activity patterns informs intervention opportunities. We suspected that intervening upon the interactions among indicators of brain health and everyday activity patterns may show promise in mitigating disability

in late life. However, the optimal strategies in changing their interaction are unclear, nor do we understand whether intervening upon one is better than the other. We recommend future intervention studies to 1) intervene upon either indicators of brain health or everyday activity patterns, 2) compare their effectiveness in addressing these outcomes and their interactions, and 3) link the observed changes with models that explicate the disablement trajectory in at-risk older adults.

While our findings from the mobile health study are promising, they were based on small sample sizes and limited to at-risk older adults. Future studies should assess everyday activities patterns in larger population-based samples and examine the health consequences of everyday activity patterns via multiple public health outcomes, including the risk of disability, hospitalization, and mortality. Also, the measurement burst design gives us a feasible approach to understand the nuance of feeling, thinking, and activity patterns from a day-to-day perspective via self-report questionnaires. Future studies should develop innovative methods to estimate mood, cognition, and everyday activity patterns other than self-report approaches, such as the use of wearable devices and unobtrusive environmental sensors. By evaluating feeling, thinking, and activity patterns in various settings (e.g., home, community) and population, we vision that early identification of risk population may be feasible and accessible in the future.

Finally, a closer of examination of specific biological and environmental factors to inform early disablement is warranted. Disability may be related to biological risks and environmental determinants, including dopaminergic systems, weather, social support, and community services. However, we did not examine these known risk factors and their associations with the disablement progressions in at-risk older adults. Future studies should establish predictive algorisms to identify at-risk population based on a variety of health indicators (i.e., indicators of brain health, activity

patterns, biological risks, and environmental determinants), in the hope to provide the most optimal and tailored services for the aging population.

6.2 Conclusion

The dissertation identifies critical elements to inform future prevention-oriented interventions for the aging population. This dissertation advances knowledge in the field of gerontology to better understand the mechanisms that lead to early changes in disability in late life. We hope the findings may inform future intervention studies to slow down millions of health care cost related to late life disability.

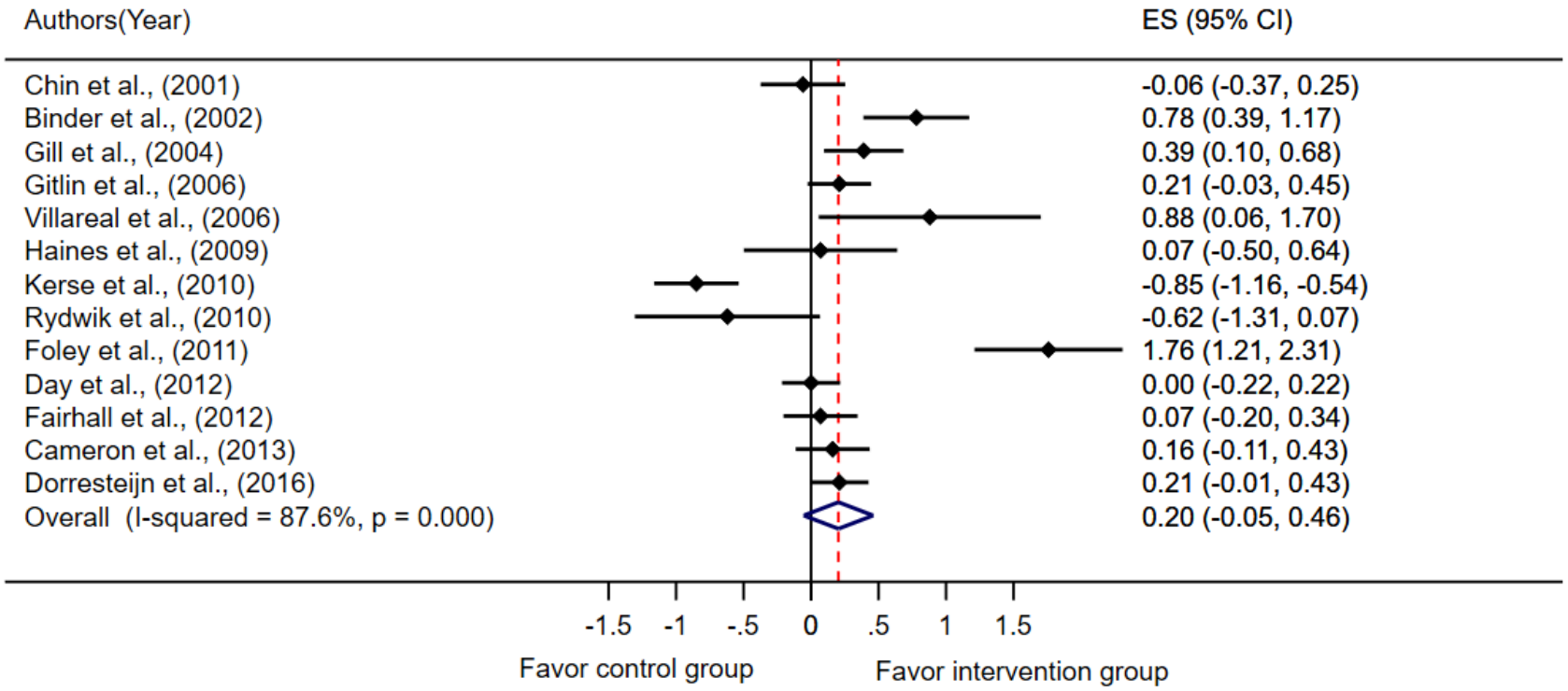
Appendix A **A Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) checklist**

Section/topic	#	Checklist item	Reported on page #
TITLE			
Title	1	Identify the report as a systematic review, meta-analysis, or both.	p.1
ABSTRACT			
Structured summary	2	Provide a structured summary including, as applicable: background; objectives; data sources; study eligibility criteria, participants, and interventions; study appraisal and synthesis methods; results; limitations; conclusions and implications of key findings; systematic review registration number.	p.2
INTRODUCTION			
Rationale	3	Describe the rationale for the review in the context of what is already known.	p.3-4
Objectives	4	Provide an explicit statement of questions being addressed with reference to participants, interventions, comparisons, outcomes, and study design (PICOS).	p.4
METHODS			
Protocol and registration	5	Indicate if a review protocol exists, if and where it can be accessed (e.g., Web address), and, if available, provide registration information including registration number.	Table 2; Figure 1
Eligibility criteria	6	Specify study characteristics (e.g., PICOS, length of follow-up) and report characteristics (e.g., years considered, language, publication status) used as criteria for eligibility, giving rationale.	p.5
Information sources	7	Describe all information sources (e.g., databases with dates of coverage, contact with study authors to identify additional studies) in the search and date last searched.	p.5-6
Search	8	Present full electronic search strategy for at least one database, including any limits used, such that it could be repeated.	p.5
Study selection	9	State the process for selecting studies (i.e., screening, eligibility, included in systematic review, and, if applicable, included in the meta-analysis).	p.5
Data collection process	10	Describe method of data extraction from reports (e.g., piloted forms, independently, in duplicate) and any processes for obtaining and confirming data from investigators.	p.5-6

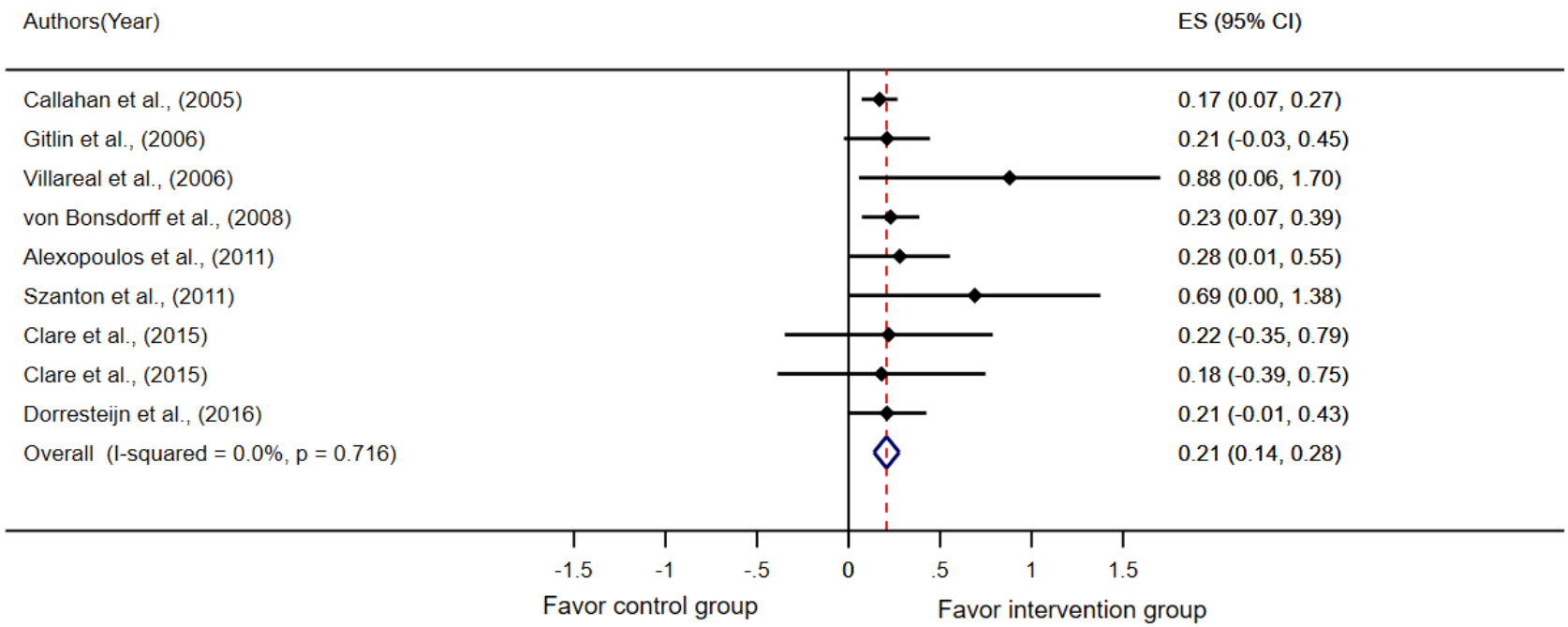
Data items	11	List and define all variables for which data were sought (e.g., PICOS, funding sources) and any assumptions and simplifications made.	p.6; Table 2
Risk of bias in individual studies	12	Describe methods used for assessing risk of bias of individual studies (including specification of whether this was done at the study or outcome level), and how this information is to be used in any data synthesis.	N/A
Summary measures	13	State the principal summary measures (e.g., risk ratio, difference in means).	p.6-7
Synthesis of results	14	Describe the methods of handling data and combining results of studies, if done, including measures of consistency (e.g., I^2) for each meta-analysis.	p.6-7
Risk of bias across studies	15	Specify any assessment of risk of bias that may affect the cumulative evidence (e.g., publication bias, selective reporting within studies).	N/A
Additional analyses	16	Describe methods of additional analyses (e.g., sensitivity or subgroup analyses, meta-regression), if done, indicating which were pre-specified.	Figure 1; Appendix B-I
RESULTS			
Study selection	17	Give numbers of studies screened, assessed for eligibility, and included in the review, with reasons for exclusions at each stage, ideally with a flow diagram.	p.7; Figure 1
Study characteristics	18	For each study, present characteristics for which data were extracted (e.g., study size, PICOS, follow-up period) and provide the citations.	p.7-8
Risk of bias within studies	19	Present data on risk of bias of each study and, if available, any outcome level assessment (see item 12).	p.7-8
Results of individual studies	20	For all outcomes considered (benefits or harms), present, for each study: (a) simple summary data for each intervention group (b) effect estimates and confidence intervals, ideally with a forest plot.	p.8-14; Figure 2, Appendix B-I
Synthesis of results	21	Present results of each meta-analysis done, including confidence intervals and measures of consistency.	Table 3; Appendix B-I
Risk of bias across studies	22	Present results of any assessment of risk of bias across studies (see Item 15).	N/A
Additional analysis	23	Give results of additional analyses, if done (e.g., sensitivity or subgroup analyses, meta-regression [see Item 16]).	Table 3; Appendix B-I
DISCUSSION			
Summary of evidence	24	Summarize the main findings including the strength of evidence for each main outcome; consider their relevance to key groups (e.g., healthcare providers, users, and policy makers).	p.14-18

Limitations	25	Discuss limitations at study and outcome level (e.g., risk of bias), and at review-level (e.g., incomplete retrieval of identified research, reporting bias).	p.18
Conclusions	26	Provide a general interpretation of the results in the context of other evidence, and implications for future research.	p.18-19
FUNDING			
Funding	27	Describe sources of funding for the systematic review and other support (e.g., supply of data); role of funders for the systematic review.	p.20

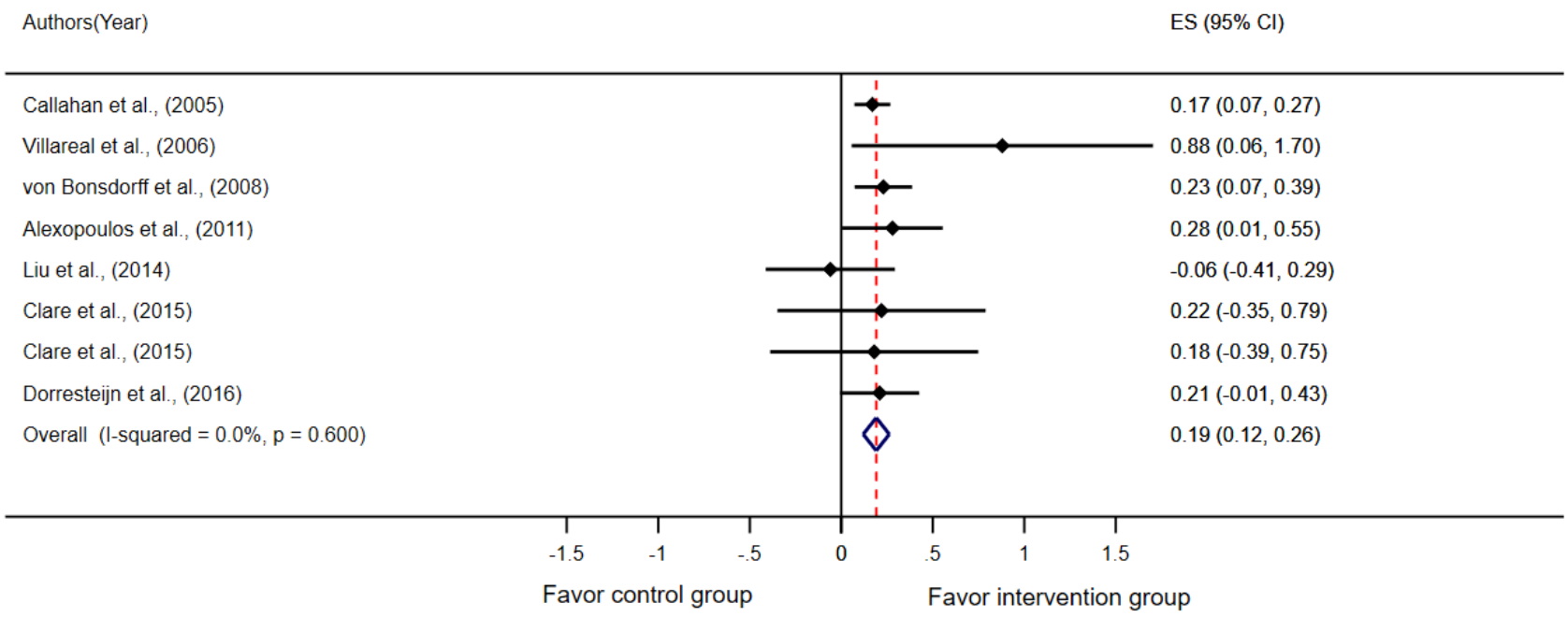
Appendix B **A forest plot of the effect of exercise on disability**



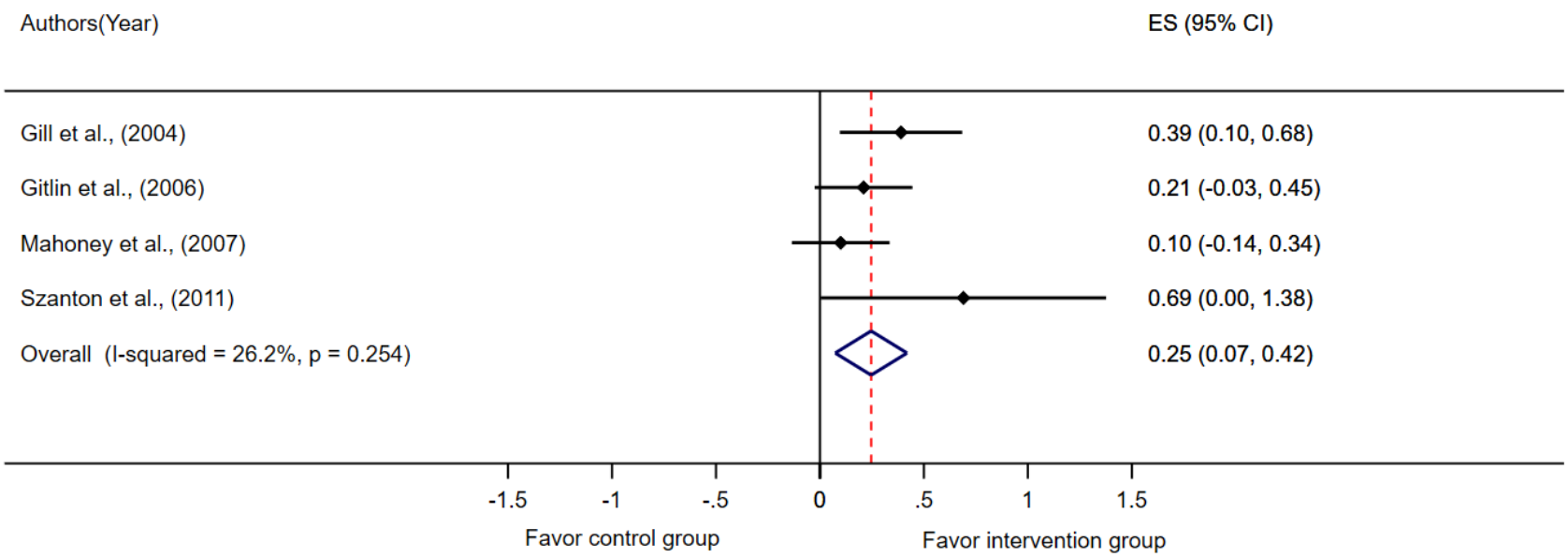
Appendix C **A forest plot of the effect of problem-solving on disability**



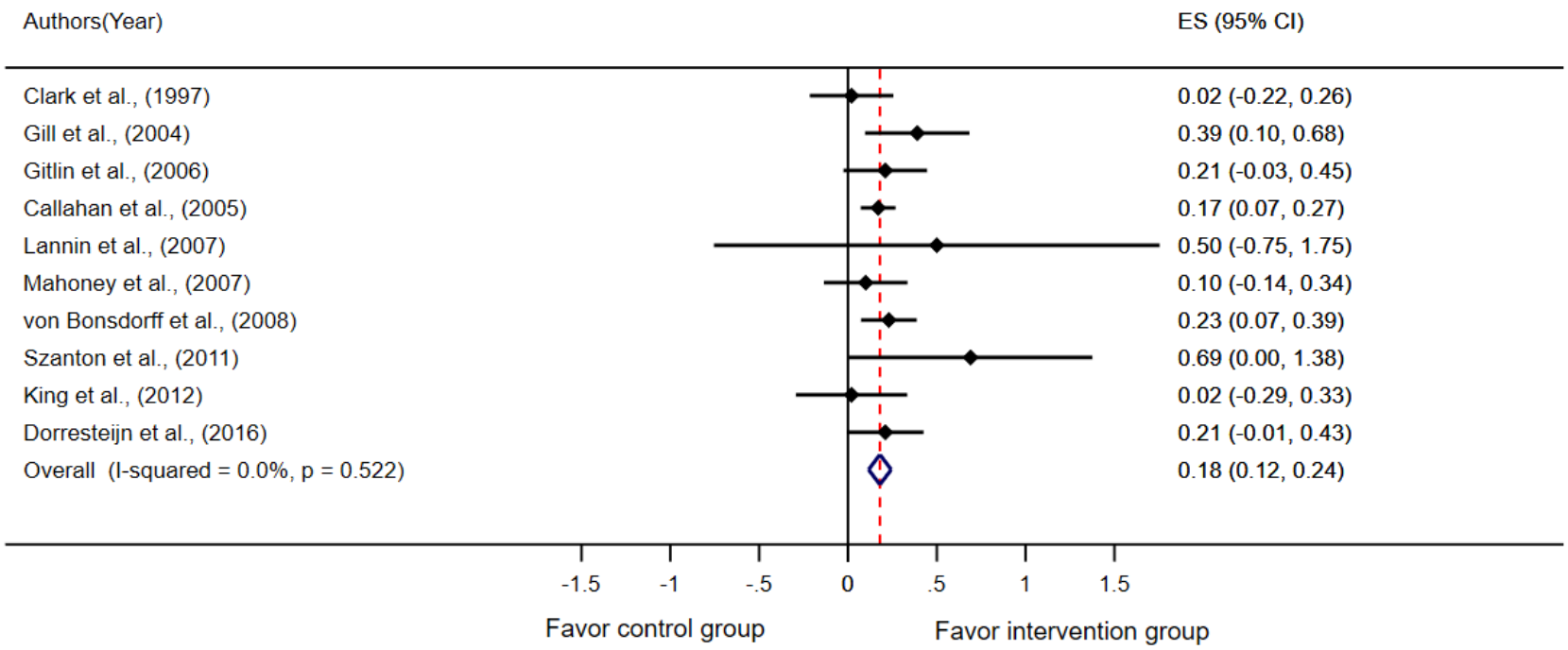
Appendix D **A forest plot of the effect of cognitive behavioral therapy on disability**



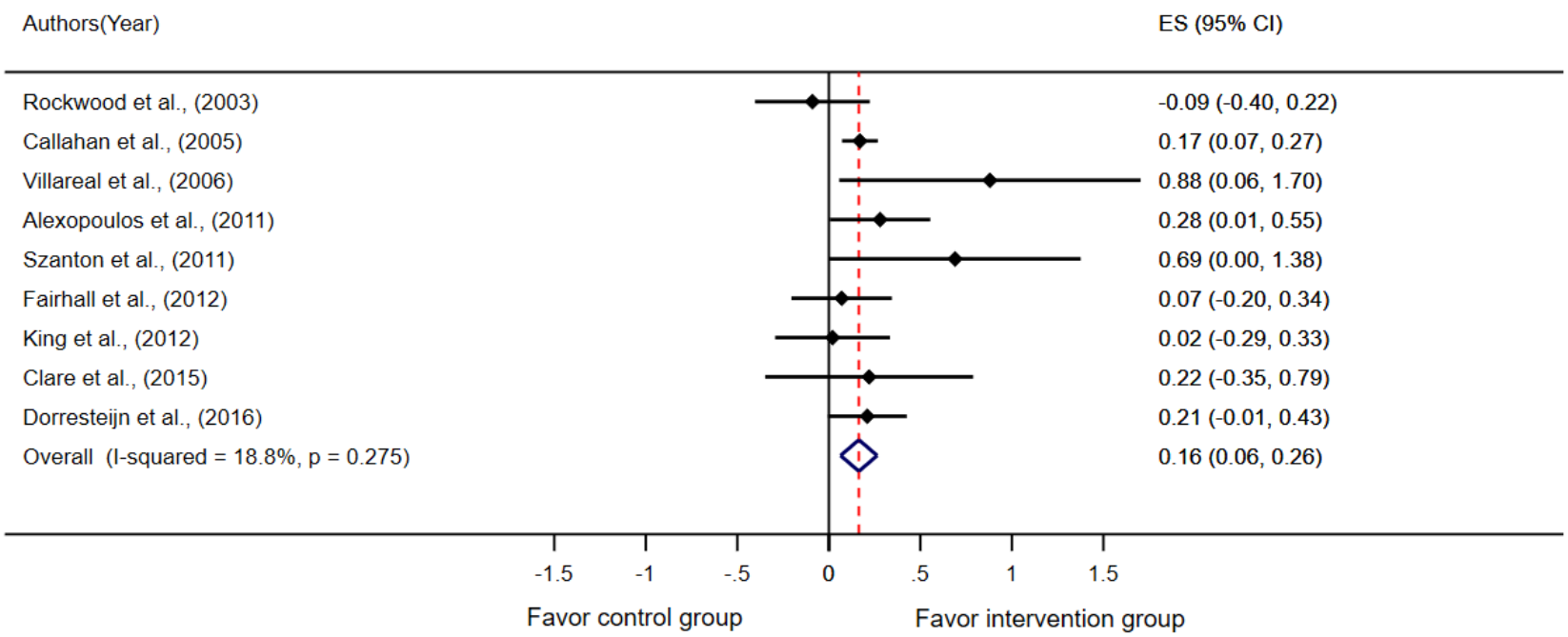
Appendix E **A forest plot of the effect of environmental modification on disability**



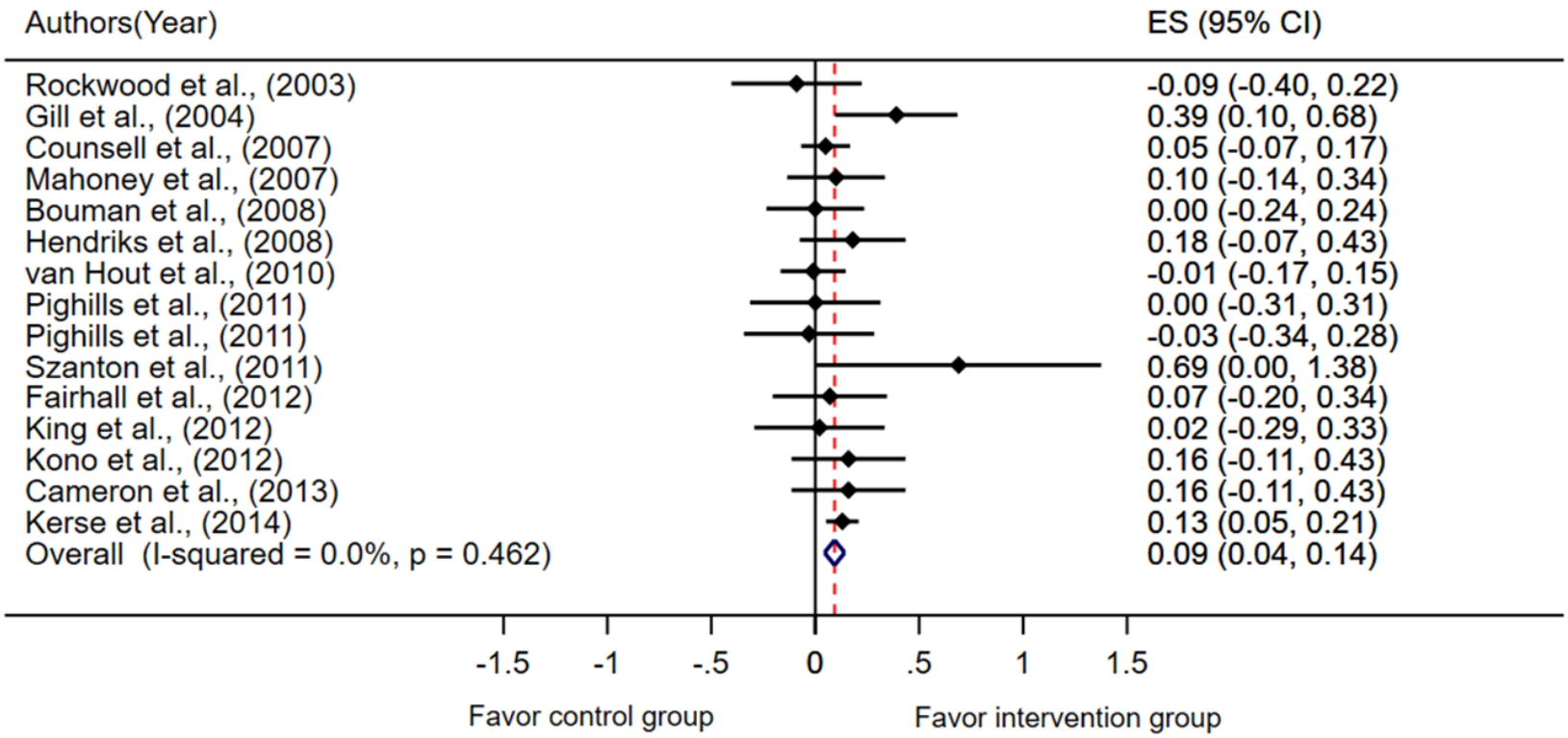
Appendix F **A forest plot of the effect of education on disability**



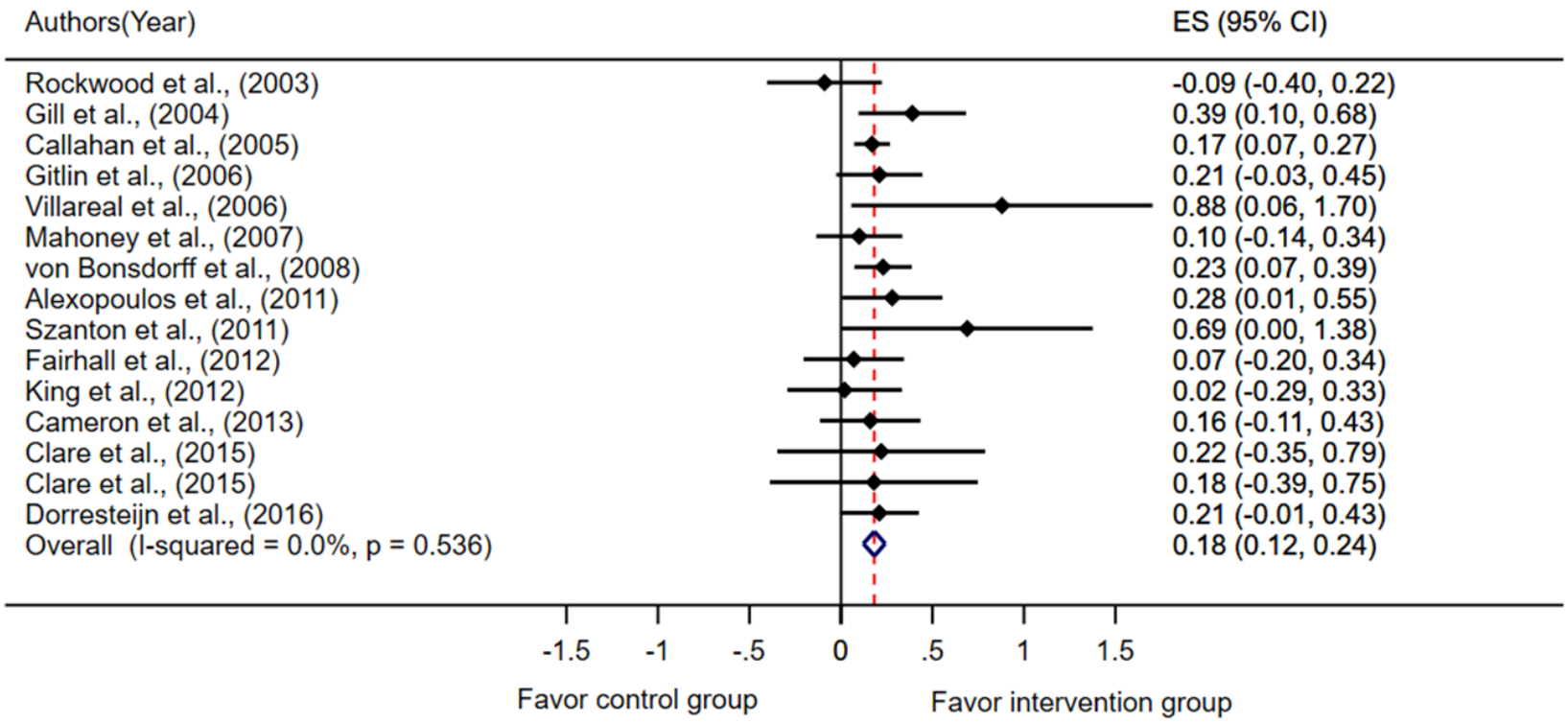
Appendix G **A forest plot of the effect of goal-setting on disability**



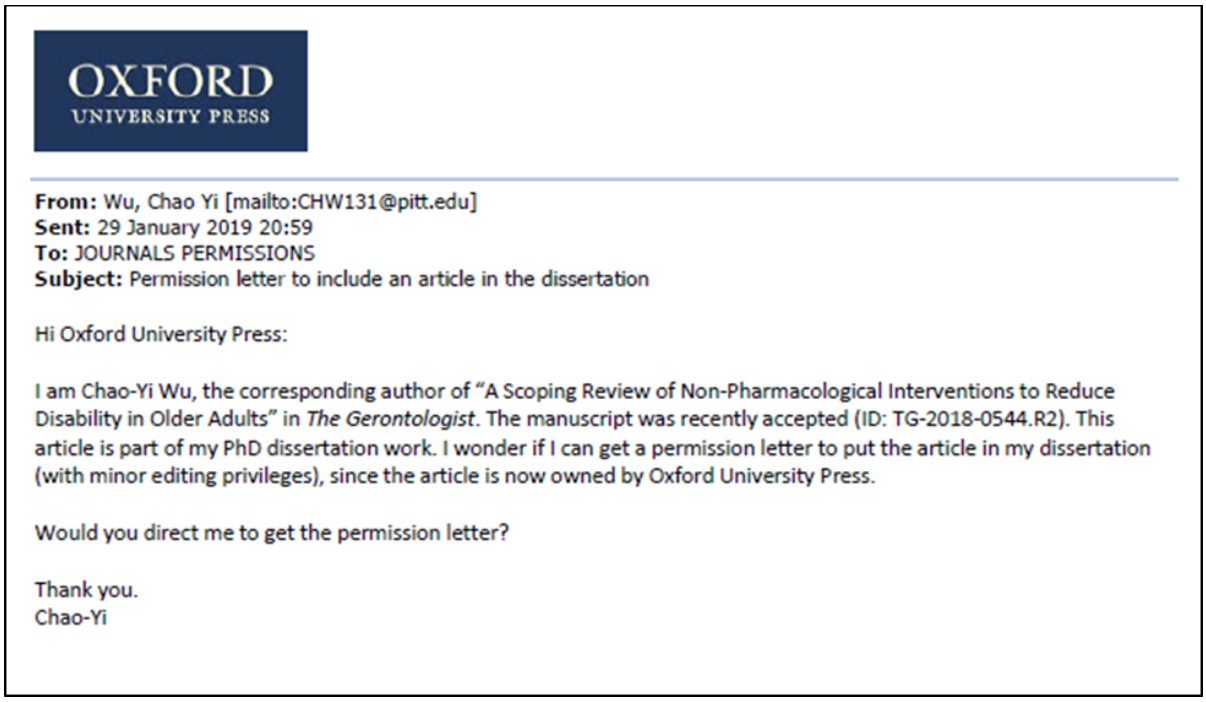
Appendix H **A forest plot of the effect of comprehensive geriatric assessment on disability**



Appendix I **A forest plot of the effect of complex interventions on disability**



Appendix J **Permission letters**



OXFORD
UNIVERSITY PRESS

From: Wu, Chao Yi [mailto:CHW131@pitt.edu]
Sent: 29 January 2019 20:59
To: JOURNALS PERMISSIONS
Subject: Permission letter to include an article in the dissertation

Hi Oxford University Press:

I am Chao-Yi Wu, the corresponding author of "A Scoping Review of Non-Pharmacological Interventions to Reduce Disability in Older Adults" in *The Gerontologist*. The manuscript was recently accepted (ID: TG-2018-0544.R2). This article is part of my PhD dissertation work. I wonder if I can get a permission letter to put the article in my dissertation (with minor editing privileges), since the article is now owned by Oxford University Press.

Would you direct me to get the permission letter?

Thank you.
Chao-Yi

Wu, Chao Yi

From: JOURNALS PERMISSIONS <Journals.Permissions@oup.com>
Sent: Wednesday, January 30, 2019 4:37 AM
To: Wu, Chao Yi
Subject: RE: Permission letter to include an article in the dissertation

Self-Archiving Policy B

Dear Chao-Yi,

RE. Manuscript accepted in *The Gerontologist*

Thank you for your email requesting permission to reuse all of your article in a thesis/dissertation.

As part of your copyright agreement with Oxford University Press you have retained the right, after publication, to use all or part of the article and abstract, in the preparation of derivative works, extension of the article into a booklength work, in a thesis/dissertation, or in another works collection, provided that a full acknowledgement is made to the original publication in the journal. As a result, you should not require direct permission from Oxford University Press to reuse your article.

As your article has not yet been published, you are permitted to include the **Author's Original Version (AOV)** in your thesis on the proviso that you inlcude the following acknowledgement:

"This article has been accepted for publication in *The Gerontologist*. Published by Oxford University Press."

Once your article has been published online, you should update the AOV to the **Accepted Manuscript (AM)** in your thesis/dissertation, however in line with the journal self-archiving policy, public availability must be delayed until **12 months** after first online publication in the journal. You should include the following acknowledgment as well as a link to the version of record.

This is a pre-copyedited, author-produced version of an article accepted for publication in [insert journal title] following peer review. The version of record [insert complete citation information here] is available online at: xxxxxxx [insert URL and DOI of the article on the OUP website].

Please Note: Inclusion under a Creative Commons license or any other open-access license allowing onward reuse is prohibited.

For full details of our publication and rights policy please see the attached link to our website:
http://www.oxfordjournals.org/en/access-purchase/rights-and-permissions/self-archiving-policyb.html

If you have any other queries, please feel free to contact us.

Kind regards,
Katie

Katie Randall | Permissions Assistant | Rights Department
Academic and Journals Divisions | Global Business Development
Oxford University Press | Great Clarendon Street | Oxford | OX2 6DP

AMERICAN DIABETES ASSOCIATION ORDER DETAILS

Feb 08, 2019

This Agreement between Chao-Yi Wu ("You") and American Diabetes Association ("American Diabetes Association") consists of your order details and the terms and conditions provided by American Diabetes Association and Copyright Clearance Center.

Order Number	501460150
Order date	Jan 29, 2019
Licensed Content Publisher	American Diabetes Association
Licensed Content Publication	Diabetes Care
Licensed Content Title	Trajectory of Disability in Older Adults With Newly Diagnosed Diabetes: Role of Elevated Depressive Symptoms
Licensed Content Author	Chao-Yi Wu,Lauren Terhorst,Jordan F. Karp,Elizabeth R. Skidmore,Juleen Rodakowski
Licensed Content Date	Aug 2, 2018
Type of Use	Thesis/Dissertation
Requestor type	Academic institution
Format	Electronic
Portion	chapter/article
Number of pages in chapter/article	7
Page range of chapter/article	1-7
Rights for	Main product
Duration of use	Life of current edition
Creation of copies for the disabled	no
With minor editing privileges	yes
For distribution to	Worldwide
In the following language(s)	Original language of publication
With incidental promotional use	no
The lifetime unit quantity of new product	0 to 499
Title	EMERGENCE OF DISABILITY IN LATE LIFE
Institution name	University of Pittsburgh
Expected presentation date	Apr 2019
Requestor Location	University of Pittsburgh Bridgeside Point I 100 Technology Drive Suite 370 PITTSBURGH, PA 15219 United States Attn: University of Pittsburgh

Billing Type	Invoice
Billing Address	University of Pittsburgh Bridgeside Point I 100 Technology Drive Suite 370 PITTSBURGH, PA 15219 United States Attn: University of Pittsburgh
Total	0.00 USD

Terms and Conditions

STANDARD TERMS AND CONDITIONS FOR REPRODUCTION OF MATERIAL

Introduction

The publisher for this copyrighted content is American Diabetes Association. By clicking "accept" in connection with completing this licensing transaction, you agree that the following terms and conditions apply to this transaction (along with the Billing and Payment terms and conditions established by Copyright Clearance Center, Inc. ("CCC"), at the time that you opened your CCC account and that are available at any time at http://myaccount.copyright.com).

Limited License

Publisher hereby grants to you a non-exclusive license to use this material. Licenses are for one-time use only with a maximum distribution equal to the number that you identified in the licensing process; any form of granted republication must be completed within one (1) year from the date hereof (although copies prepared before then may be distributed thereafter); and any electronic posting is limited to a period of one (1) year. This permission shall automatically terminate if fail to comply with the terms of this license.

Geographic Rights: Scope

Licenses may be exercised anywhere in the world.

Altering/Modifying Material: Not Permitted

You may not alter or modify the material in any manner (except that you may use, within the scope of the license granted, one or more excerpts from the copyrighted material, provided that the process of excerpting does not alter the meaning of the material or in any way reflect negatively on the publisher or any writer of the material), nor may you translate the material into another language.

Reservation of Rights

Publisher reserves all rights not specifically granted in the combination of (i) the license details provided by you and accepted in the course of this licensing transaction, (ii) these terms and conditions and (iii) CCC's Billing and Payment terms and conditions.

License Contingent on Payment

While you may exercise the rights licensed immediately upon issuance of the license at the end of the licensing process for the transaction, provided that you have disclosed complete and accurate details of your proposed use, no license is finally effective unless and until full payment is received from you (either by publisher or by CCC) as provided in CCC's Billing and Payment terms and conditions. If full payment is not received on a timely basis, then any license preliminarily granted shall be deemed automatically revoked and shall be void as if never granted. Further, in the event that you breach any of these terms and conditions or any of CCC's Billing and Payment terms and conditions, the license is automatically revoked and shall be void as if never granted. Use of materials as described in a revoked license, as well as any use of the materials beyond the scope of an unrevoked license, may constitute

copyright infringement and publisher reserves the right to take any and all action to protect its copyright in the materials.

Copyright Notice: Disclaimer

You _____ must include the following copyright and permission notice in connection with any reproduction of the licensed material: "American Diabetes Association [Insert Title of Publication, American Diabetes Association, [Insert Year of Publication]. Copyright and all rights reserved. Material from this publication has been used with the permission of American Diabetes Association."

Warranties: None

Publisher makes no representations or warranties with respect to the licensed material and adopts on its own behalf the limitations and disclaimers established by CCC on its behalf in its Billing and Payment terms and conditions for this licensing transaction.

Indemnity

You hereby indemnify and agree to hold harmless publisher and CCC, and their respective officers, directors, employees and agents, from and against any and all claims arising out of your use of the licensed material other than as specifically authorized pursuant to this license.

No Transfer of License

This license is only granted you and your company (if noted in the license) and may not be sublicensed, assigned, or transferred by you to any other person without publisher's written permission.

No Amendment Except in Writing

This license may not be amended except in a writing and signed by both parties (or, in the case of publisher, by CCC on publisher's behalf).

Objection to Contrary Terms

Publisher hereby objects to any terms contained in any purchase order, acknowledgment, check endorsement or other writing prepared by you, which terms are inconsistent with these terms and conditions or CCC's Billing and Payment terms and conditions. These terms and conditions, together with CCC's Billing and Payment terms and conditions (which are incorporated herein), comprise the entire agreement between you and publisher (and CCC) concerning this licensing transaction. In the event of any conflict between your obligations established by these terms and conditions and those established by CCC's Billing and Payment terms and conditions, these terms and conditions shall control.

Jurisdiction:

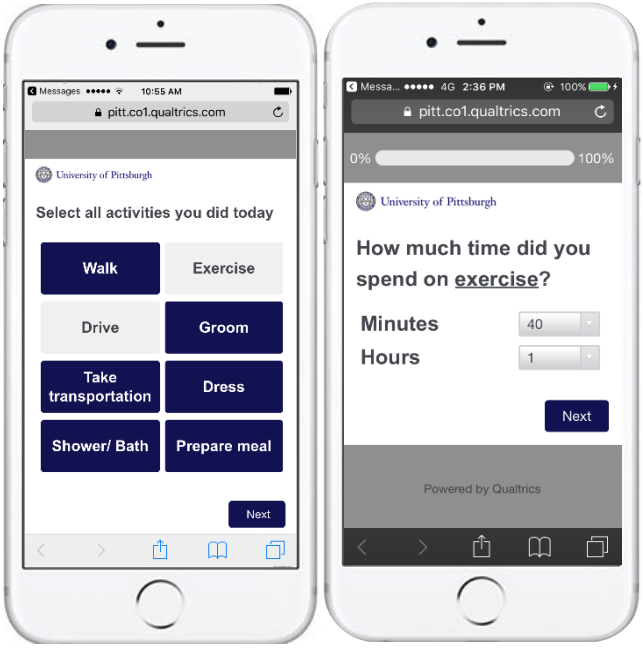
This license transaction shall be governed by and construed in accordance with the laws of the Commonwealth of Virginia. You hereby agree to submit to the jurisdiction of the federal and state courts located in the Commonwealth of Virginia for purposes of resolving any disputes that may arise in connection with this licensing transaction.

Other Terms and Conditions:

None

v1.0

Appendix K **Measurement burst design in mobile devices**



Bibliography

Abraham, C., & Michie, S. (2008). A taxonomy of behavior change techniques used in interventions. *Health Psychology*, *27*, 379–387.

Agahi, N., Silverstein, M., & Parker, M. G. (2011). Late-life and earlier participation in leisure activities: Their importance for survival among older persons. *Activities, Adaptation & Aging*, *35*, 210–222.

Alexopoulos, G. S., Raue, P. J., Kiosses, D. N., Mackin, R. S., Kanellopoulos, D., McCulloch, C., & Arean, P. A. (2011). Problem-solving therapy and supportive therapy in older adults with major depression and executive dysfunction: Effect on disability. *Archives of General Psychiatry*, *68*, 33–41.

Alexopoulos, G. S., Raue, P. J., Kiosses, D. N., Seirup, J. K., Banerjee, S., & Arean, P. A. (2015). Comparing engage with PST in late-life major depression: A preliminary report. *The American Journal of Geriatric Psychiatry : Official Journal of the American Association for Geriatric Psychiatry*, *23*, 506–513.

American Diabetes Association. (2013). Economic costs of diabetes in the U.S. in 2012. *Diabetes Care*, *36*, 1033–1046.

Anderson, R. J., Freedland, K. E., Clouse, R. E., & Lustman, P. J. (2001). The prevalence of comorbid depression in adults with diabetes: A meta-analysis. *Diabetes Care*, *24*, 1069–1078.

Arksey, H., & O'Malley, L. (2005). Scoping studies: Towards a methodological framework. *International Journal of Social Research Methodology*, *8*, 19–32.

Asch, D. A., Muller, R. W., & Volpp, K. G. (2012). Automated hovering in health vare - Watching over the 5000 hours. *New England Journal of Medicine*, *367*, 1–3.

Ball, K., Berch, D. B., Helmers, K. F., Jobe, J. B., Leveck, M. D., Marsiske, M., … Willis, S. L. (2002). Effects of cognitive training interventions with older adults: A randomized controlled trial. *JAMA*, *288*, 2271–2281.

Barbara, T. G., & Linda, F. S. (2007). *Using multivariate statistics* (5th ed.). Boston, MA: Allyn & Bacon/Pearson Education.

Biessels, G. J., Strachan, M. W. J., Visseren, F. L. J., Kappelle, L. J., & Whitmer, R. A. (2014). Dementia and cognitive decline in type 2 diabetes and prediabetic stages: Towards targeted interventions. *The Lancet Diabetes & Endocrinology*, *2*, 246–255.

Binder, E. F., Schechtman, K. B., Ehsani, A. A., Steger-May, K., Brown, M., Sinacore, D. R., … Holloszy, J. O. (2002). Effects of exercise training on frailty in community-dwelling older

adults: Results of a randomized, controlled trial. *Journal of the American Geriatrics Society*, *50*, 1921–1928.

Black, S. A., Markides, K. S., & Ray, L. A. (2003). Depression predicts increased incidence of adverse health outcomes in older Mexican Americans with type 2 diabetes. *Diabetes Care*, *26*, 2822–2828.

Bouman, A., van Rossum, E., Ambergen, T., Kempen, G., & Knipschild, P. (2008). Effects of a home visiting program for older people with poor health status: A randomized, clinical trial in The Netherlands. *Journal of the American Geriatrics Society*, *56*, 397–404.

Boutron, I., Moher, D., Altman, D. G., Schulz, K. F., & Ravaud, P. (2008). Extending the CONSORT statement to randomized trials of nonpharmacologic treatment: Explanation and elaboration. *Annals of Internal Medicine*, *148*, 295.

Boyce, L. W., Reinders, C. C., Volker, G., Los, E., van Exel, H. J., Vliet Vlieland, T. P. M., & Goossens, P. H. (2017). Out-of-hospital cardiac arrest survivors with cognitive impairments have lower exercise capacity. *Resuscitation*, *115*, 90–95.

Boyle, J. P., Thompson, T. J., Gregg, E. W., Barker, L. E., & Williamson, D. F. (2010). Projection of the year 2050 burden of diabetes in the US adult population: Dynamic modeling of incidence, mortality, and prediabetes prevalence. *Population Health Metrics*, *8*, 29.

Boyle, P. A., Buchman, A. S., Wilson, R. S., Bienias, J. L., & Bennett, D. A. (2007). Physical activity Is associated with incident disability in community-based older persons. *Journal of the American Geriatrics Society*, *55*, 195–201.

Brandler, T. C., Wang, C., Oh-Park, M., Holtzer, R., & Verghese, J. (2012). Depressive symptoms and gait dysfunction in the elderly. *The American Journal of Geriatric Psychiatry*, *20*, 425–432.

Brown, C. J., Roth, D. L., Allman, R. M., Sawyer, P., Ritchie, C. S., & Roseman, J. M. (2009). Trajectories of life-space mobility after hospitalization. *Annals of Internal Medicine*, *150*, 372.

Bruce, M. L. (2001). Depression and disability in late life: Directions for future research. *The American Journal of Geriatric Psychiatry : Official Journal of the American Association for Geriatric Psychiatry*, *9*, 102–112.

Cain, A. E., Depp, C. A., & Jeste, D. V. (2009). Ecological momentary assessment in aging research: A critical review. *Journal of Psychiatric Research*, *43*, 987–996.

Callahan, C. M., Kroenke, K., Counsell, S. R., Hendrie, H. C., Perkins, A. J., Katon, W., … Unutzer, J. (2005). Treatment of depression improves physical functioning in older adults. *Journal of the American Geriatrics Society*, *53*, 367–373.

Cameron, I. D., Fairhall, N., Langron, C., Lockwood, K., Monaghan, N., Aggar, C., … Kurrle, S. E. (2013). A multifactorial interdisciplinary intervention reduces frailty in older people:

Randomized trial. *BMC Medicine*, *11*, 65.

Campbell, N. C., Murray, E., Darbyshire, J., Emery, J., Farmer, A., Griffiths, F., … Kinmonth, A. L. (2007). Designing and evaluating complex interventions to improve health care. *BMJ: British Medical Journal*, *334*, 455–459.

Capistrant, B. D., Mejia, N. I., Liu, S. Y., Wang, Q., Glymour, M. M., & PA, W. (2014). The disability burden associated with stroke emerges before stroke onset and differentially affects blacks: Results from the health and retirement study cohort. *The Journals of Gerontology Series A: Biological Sciences and Medical Sciences*, *69*, 860–870.

Carlson, M. C., Parisi, J. M., Xia, J., Xue, Q.-L., Rebok, G. W., Bandeen-Roche, K., & Fried, L. P. (2012). Lifestyle activities and memory: Variety may be the spice of life. The women's health and aging study II. *Journal of the International Neuropsychological Society : JINS*, *18*, 286–294.

Centers for Disease Control and Prevention. (2011). Cognitive impairment: A call for action, now!, pp. 1–4.

Chin A Paw, M. J., de Jong, N., Schouten, E. G., Hiddink, G. J., & Kok, F. J. (2001). Physical exercise and/or enriched foods for functional improvement in frail, independently living elderly: A randomized controlled trial. *Archives of Physical Medicine and Rehabilitation*, *82*, 811–817.

Christopoulos, K. A., Riley, E. D., Tulsky, J., Carrico, A. W., Moskowitz, J. T., Wilson, L., … Hilton, J. F. (2014). A text messaging intervention to improve retention in care and virologic suppression in a U.S. urban safety-net HIV clinic: study protocol for the Connect4Care (C4C) randomized controlled trial. *BMC Infectious Diseases*, *14*, 718.

Cigolle, C. T., Langa, K. M., Kabeto, M. U., Tian, Z., & Blaum, C. S. (2007). Geriatric conditions and disability: The health and retirement study. *Annals of Internal Medicine*, *147*, 156.

Clare, L., Bayer, A., Burns, A., Corbett, A., Jones, R., Knapp, M., … Whitaker, R. (2013). Goal-oriented cognitive rehabilitation in early-stage dementia: study protocol for a multi-centre single-blind randomised controlled trial (GREAT). *Trials*, *14*, 152.

Clare, L., Nelis, S. M., Jones, I. R., Hindle, J. V, Thom, J. M., Nixon, J. A., … Whitaker, C. J. (2015). The Agewell trial: A pilot randomised controlled trial of a behaviour change intervention to promote healthy ageing and reduce risk of dementia in later life. *BMC Psychiatry*, *15*, 25.

Clark, F., Azen, S. P., Zemke, R., Jackson, J., Carlson, M., Mandel, D., … Lipson, L. (1997). Occupational therapy for independent-living older adults. A randomized controlled trial. *JAMA*, *278*, 1321–1326.

Collins, D., Downer, B., Kumar, A., Krishnan, S., Li, C.-Y., Markides, K. S., & Karmarkar, A. M. (2018). Impact of multiple chronic conditions on activity limitations among older Mexican-American care recipients. *Preventing Chronic Disease*, *15*, 170358.

Collins, L. M., Murphy, S. A., & Strecher, V. (2007). The Multiphase Optimization Strategy (MOST) and the Sequential Multiple Assignment Randomized Trial (SMART). *American Journal of Preventive Medicine*, *32*, S112–S118.

Corbett, A., Owen, A., Hampshire, A., Grahn, J., Stenton, R., Dajani, S., … Ballard, C. (2015). The effect of an online cognitive training package in healthy older adults: An online randomized controlled trial. *Journal of the American Medical Directors Association*, *16*, 990–997.

Counsell, S. R., Callahan, C. M., Clark, D. O., Tu, W., Buttar, A. B., Stump, T. E., & Ricketts, G. D. (2007). Geriatric care management for low-income seniors: A randomized controlled trial. *JAMA*, *298*, 2623–2633.

Craig, P., Dieppe, P., Macintyre, S., Michie, S., Nazareth, I., Petticrew, M., & Medical Research Council Guidance. (2008). Developing and evaluating complex interventions: The new Medical Research Council guidance. *BMJ: British Medical Journal*, *337*, a1655.

Cuijpers, P., van Straten, A., & Warmerdam, L. (2007). Behavioral activation treatments of depression: A meta-analysis. *Clinical Psychology Review*, *27*, 318–326.

Cukierman, T., Gerstein, H. C., & Williamson, J. D. (2005). Cognitive decline and dementia in diabetes—systematic overview of prospective observational studies. *Diabetologia*, *48*, 2460–2469.

D'Zurilla, T. J., & Nezu, A. M. (2010). Problem-solving therapy. In K. S. Dobson (Ed.), *Handbook of cognitive-behavioral therapies* (pp. 197–225). Guilford Press.

Day, L., Hill, K. D., Jolley, D., Cicuttini, F., Flicker, L., & Segal, L. (2012). Impact of tai chi on impairment, functional limitation, and disability among preclinically disabled older people: A randomized controlled trial. *Archives of Physical Medicine and Rehabilitation*, *93*, 1400–1407.

de Rekeneire, N., Resnick, H. E., Schwartz, A. V, Shorr, R. I., Kuller, L. H., Simonsick, E. M., … Harris, T. B. (2003). Diabetes is associated with subclinical functional limitation in nondisabled older individuals: The health, aging, and body composition study. *Diabetes Care*, *26*, 3257–3263.

Dieleman, J. L., Baral, R., Birger, M., Bui, A. L., Bulchis, A., Chapin, A., … Murray, C. J. L. (2016). US spending on personal health care and public health, 1996-2013. *JAMA*, *316*, 2627–2646.

Dorresteijn, T. A. C., Zijlstra, G. A. R., Ambergen, A. W., Delbaere, K., Vlaeyen, J. W. S., & Kempen, G. I. J. M. (2016). Effectiveness of a home-based cognitive behavioral program to manage concerns about falls in community-dwelling, frail older people: Results of a randomized controlled trial. *BMC Geriatrics*, *16*, 1–11.

Eckel, R. H., John Jakicic, C.-C. M., Jamy Ard, C.-C. D., de Jesus, J. M., Houston Miller, N., Van Hubbard, F. S., … Win-Kuang Shen, F. (2014). 2013 AHA/ACC guideline on lifestyle

management to reduce cardiovascular risk: A report of the American College of Cardiology/American Heart Association task force on practice guidelines. *Journal of American College of Cardiology*, *63*, 2960–2984.

Egede, L. E., & Ellis, C. (2010). Diabetes and depression: Global perspectives. *Diabetes Research and Clinical Practice*, *87*, 302–312.

Egede, L. E., Zheng, D., & Simpson, K. (2002). Comorbid depression is associated with increased health care use and expenditures in individuals with diabetes. *Diabetes Care*, *25*, 464–470.

Elwood, P., Galante, J., Pickering, J., Palmer, S., Bayer, A., Ben-Shlomo, Y., … Gallacher, J. (2013). Healthy lifestyles reduce the incidence of chronic diseases and dementia: Evidence from the Caerphilly cohort study. *PloS One*, *8*, e81877.

Fairhall, N., Sherrington, C., Kurrle, S. E., Lord, S. R., Lockwood, K., & Cameron, I. D. (2012). Effect of a multifactorial interdisciplinary intervention on mobility-related disability in frail older people: Randomised controlled trial. *BMC Medicine*, *10*, 1–13.

Feingold, A. (2009). Effect sizes for growth-modeling analysis for controlled clinical trials in the same metric as for classical analysis. *Psychological Methods*, *14*, 43–53.

Ferrucci, L., Guralnik, J. M., Studenski, S., Fried, L. P., Cutler, G. B., & Walston, J. D. (2004). Designing randomized, controlled trials aimed at preventing or delaying functional decline and disability in frail, older persons: A consensus report. *Journal of the American Geriatrics Society*, *52*, 625–634.

Fok, C. C. T., & Henry, D. (2015). Increasing the sensitivity of measures to change. *Prevention Science : The Official Journal of the Society for Prevention Research*, *16*, 978–986.

Foley, A., Hillier, S., & Barnard, R. (2011). Effectiveness of once-weekly gym-based exercise programmes for older adults post discharge from day rehabilitation: A randomised controlled trial. *British Journal of Sports Medicine*, *45*, 978–986.

Fratiglioni, L., Paillard-Borg, S., & Winblad, B. (2004). An active and socially integrated lifestyle in late life might protect against dementia. *The Lancet Neurology*, *3*, 343–353.

Freedman, V. A., Kasper, J. D., Spillman, B. C., Agree, E. M., Mor, V., Wallace, R. B., & Wolf, D. A. (2014). Behavioral adaptation and late-life disability: A new spectrum for assessing public health impacts. *American Journal of Public Health*, *104*, e88-94.

Freedman, V. A., & Spillman, B. C. (2014). Disability and care needs among older americans. *Milbank Quarterly*, *92*, 509–541.

Frenkel, W. J., Jongerius, E. J., Mandjes-van Uitert, M. J., van Munster, B. C., & de Rooij, S. E. (2014). Validation of the Charlson comorbidity index in acutely hospitalized elderly adults: A prospective cohort study. *Journal of the American Geriatrics Society*, *62*, 342–346.

Fried, E. I., & Nesse, R. M. (2015). Depression sum-scores don’t add up: Why analyzing specific

depression symptoms is essential. *BMC Medicine*, *13*, 72.

Fried, L. P., Ferrucci, L., Darer, J., Williamson, J. D., & Anderson, G. (2004). Untangling the concepts of disability, frailty, and comorbidity: Implications for improved targeting and care. *The Journals of Gerontology Series A: Biological Sciences and Medical Sciences*, *59*, M255–M263.

Fried, L. P., Herdman, S., Kuhn, K., Rubin, G., & Turano, K. (1991). Preclinical disability hypotheses about the bottom of the iceberg. *Journal of Aging and Health*, *3*, 285–300.

Fried, L. P., Young, Y., Rubin, G., Bandeen-Roche, K., WHAS II Collaborative Research Group, WHAS II Collaborative Research Group, P., … Horwitz, R. I. (2001). Self-reported preclinical disability identifies older women with early declines in performance and early disease. *Journal of Clinical Epidemiology*, *54*, 889–901.

Fritsch, T., McClendon, M. J., Wallendal, M. S., Hyde, T. F., & Larsen, J. D. (2014). Prevalence and cognitive bases of subjective memory complaints in older adults: Evidence from a community sample. *Journal of Neurodegenerative Diseases*, *2014*, 1–9.

Fritz, H., Tarraf, W., Saleh, D. J., & Cutchin, M. P. (2017). Using a smartphone-based ecological momentary assessment protocol with community dwelling older African Americans. *The Journals of Gerontology Series B: Psychological Sciences and Social Sciences*, *72*, 876–887.

Gill, T. M., Baker, D. I., Gottschalk, M., Peduzzi, P. N., Allore, H., Van Ness, P. H., … Maraldi, C. (2004). A prehabilitation program for the prevention of functional decline: Effect on higher-level physical function. *Archives of Physical Medicine and Rehabilitation*, *85*, 1043–1049.

Gitlin, L. N., Winter, L., Dennis, M. P., Corcoran, M., Schinfeld, S., & Hauck, W. W. (2006). A randomized trial of a multicomponent home intervention to reduce functional difficulties in older adults. *Journal of the American Geriatrics Society*, *54*, 809–816.

Gonzalez, J. S., Safren, S. A., Cagliero, E., Wexler, D. J., Delahanty, L., Wittenberg, E., … Grant, R. W. (2007). Depression, self-care, and medication adherence in type 2 diabetes. *Diabetes Care*, *30*, 2222–2227.

Gonzalez, J. S., Safren, S. A., Delahanty, L. M., Cagliero, E., Wexler, D. J., Meigs, J. B., & Grant, R. W. (2008). Symptoms of depression prospectively predict poorer self-care in patients with type 2 diabetes. *Diabetic Medicine*, *25*, 1102–1107.

Gorwood, P., Corruble, E., Falissard, B., & Goodwin, G. M. (2008). Toxic effects of depression on brain function: Impairment of delayed recall and the cumulative length of depressive disorder in a large sample of depressed outpatients. *American Journal of Psychiatry*, *165*, 731–739.

Groessl, E. J., Kaplan, R. M., Rejeski, W. J., Katula, J. A., King, A. C., Frierson, G., … Pahor, M. (2007). Health-related quality of life in older adults at risk for disability. *American Journal of Preventive Medicine*, *33*, 214–218.

Haines, T. P., Russell, T., Brauer, S. G., Erwin, S., Lane, P., Urry, S., … Condie, P. (2009). Effectiveness of a video-based exercise programme to reduce falls and improve health-related quality of life among older adults discharged from hospital: A pilot randomized controlled trial. *Clinical Rehabilitation*, *23*, 973–985.

Haskell, W., Lee, I.-M., Pate, R., Powell, K., Blair, S., Franklin, B., … Bauman, A. (2007). Physical activity and public health: Updated recommendation for adults from the American College of Sports Medicine and the American Heart Association. *Circulation*, *116*, 1081.

Hayes, S., Salzberg, C. A., McCarthy, D., Radley, D. C., Abrams, M. K., Shah, T., & Anderson, G. F. (2016). High-need, high-cost patients: Who are they and how do they use health care? A population-based comparison of demographics, health care use, and expenditures. *Issue Brief (Commonwealth Fund)*, *26*, 1–14.

Hayes, T. L., Abendroth, F., Adami, A., Pavel, M., Zitzelberger, T. A., & Kaye, J. A. (2008). Unobtrusive assessment of activity patterns associated with mild cognitive impairment. *Alzheimer's and Dementia*, *4*, 395–405.

Hendriks, M. R. C., Evers, S. M. A. A., Bleijlevens, M. H. C., van Haastregt, J. C. M., Crebolder, H. F. J. M., & van Eijk, J. T. M. (2008). Cost-effectiveness of a multidisciplinary fall prevention program in community-dwelling elderly people: A randomized controlled trial (ISRCTN 64716113). *International Journal of Technology Assessment in Health Care*, *24*, 193–202.

Higgins, J. P. T., & Thompson, S. G. (2002). Quantifying heterogeneity in a meta-analysis. *Statistics in Medicine*, *21*, 1539–1558.

Howland, M., Tatsuoka, C., Smyth, K. A., & Sajatovic, M. (2017). Evaluating PROMIS® applied cognition items in a sample of older adults at risk for cognitive decline. *Psychiatry Research*, *247*, 39–42.

IBM Corp. (2013). IBM SPSS statistics for Windows. Armonk, NY: IBM Corp.

Iwasa, H., Yoshida, Y., Kai, I., Suzuki, T., Kim, H., & Yoshida, H. (2012). Leisure activities and cognitive function in elderly community-dwelling individuals in Japan: A 5-year prospective cohort study. *Journal of Psychosomatic Research*, *72*, 159–164.

James, B. D., Boyle, P. A., Buchman, A. S., & Bennett, D. A. (2011). Relation of late-life social activity with incident disability among community-dwelling older adults. *The Journals of Gerontology Series A: Biological Sciences and Medical Sciences*, *66A*, 467–473.

Jette, A. M., Davies, A. R., Cleary, P. D., Calkins, D. R., Rubenstein, L. V, Fink, A., … Delbanco, T. L. (1986). The Functional Status Questionnaire: Reliability and validity when used in primary care. *Journal of General Internal Medicine*, *1*, 143–149.

Judd, L., & Akiskal, H. (2000). Delineating the longitudinal structure of depressive illness: Beyond clinical subtypes and duration thresholds. *Pharmacopsychiatry*, *33*, 3–7.

Kanning, M., & Schlicht, W. (2010). Be active and become happy: An ecological momentary assessment of physical activity and mood. *Journal of Sport and Exercise Psychology*, *32*, 253–261.

Kanter, J. W., Manos, R. C., Bowe, W. M., Baruch, D. E., Busch, A. M., & Rusch, L. C. (2010). What is behavioral activation? A review of the empirical literature. *Clinical Psychology Review*, *30*, 608–620.

Karp, J. F., Skidmore, E., Lotz, M., Lenze, E., Dew, M. A., & Reynolds, C. F. (2009). Use of the late-life function and disability instrument to assess disability in major depression. *Journal of the American Geriatrics Society*, *57*, 1612–1619.

Kempen, G. I. J. M., & Suurmeijer, T. P. B. M. (1990). The development of a hierarchical polychotomous ADL-IADL scale for noninstitutionalized elders. *The Gerontologist*, *30*, 497–502.

Kerse, N., Hayman, K. J., Moyes, S. A., Peri, K., Robinson, E., Dowell, A., … Arroll, B. (2010). Home-based activity program for older people with depressive symptoms: DeLLITE--A randomized controlled trial. *Annals of Family Medicine*, *8*, 214–223.

Kerse, N., McLean, C., Moyes, S. A., Peri, K., Ng, T., Wilkinson-Meyers, L., … Connolly, M. (2014). The cluster-randomized BRIGHT trial: Proactive case finding for community-dwelling older adults. *Annals of Family Medicine*, *12*, 514–524.

King, A. I. I., Parsons, M., Robinson, E., & Jorgensen, D. (2012). Assessing the impact of a restorative home care service in New Zealand: A cluster randomised controlled trial. *Health & Social Care in the Community*, *20*, 365–374.

King, D. E., Mainous, A. G., Carnemolla, M., & Everett, C. J. (2009). Adherence to healthy lifestyle habits in US adults, 1988-2006. *The American Journal of Medicine*, *122*, 528–534.

Kiosses, D. N., & Alexopoulos, G. S. (2005). IADL functions, cognitive deficits, and severity of depression: A preliminary study. *The American Journal of Geriatric Psychiatry*, *13*, 244–249.

Kirkman, M. S., Briscoe, V. J., Clark, N., Florez, H., Haas, L. B., Halter, J. B., … Swift, C. S. (2012). Diabetes in older adults. *Diabetes Care*, *35*, 2650–2664.

Kono, A., Kanaya, Y., Fujita, T., Tsumura, C., Kondo, T., Kushiyama, K., & Rubenstein, L. Z. (2012). Effects of a preventive home visit program in ambulatory frail older people: A randomized controlled trial. *The Journals of Gerontology. Series A, Biological Sciences and Medical Sciences*, *67*, 302–309.

Kraus, L. (2017). *2016 Disability statistics annual report*. Durham, NH: University of New Hampshire.

Krishnan, S., Anderson, D., Chan, S., Kim, S., Reistetter, T., Sood, P., … Heyn, P. C. (2018). Overview of common complementary and integrative approaches to managing chronic pain:

A guide for patients with chronic pain. *Archives of Physical Medicine and Rehabilitation*, *99*, 2393–2394.

Krishnan, S., Pappadis, M. R., Weller, S. C., Stearnes, M., Kumar, A., Ottenbacher, K. J., & Reistetter, T. A. (2017). Needs of stroke survivors as perceived by their caregivers. *American Journal of Physical Medicine & Rehabilitation*, *96*, 487–505.

Kroenke, K., Spitzer, R. L., & Williams, J. B. (2001). The PHQ-9: Validity of a brief depression severity measure. *Journal of General Internal Medicine*, *16*, 606–613.

Laborde-Lahoz, P., El-Gabalawy, R., Kinley, J., Kirwin, P. D., Sareen, J., & Pietrzak, R. H. (2014). Subsyndromal depression among older adults in the USA: Prevalence, comorbidity, and risk for new-onset psychiatric disorders in late life. *International Journal of Geriatric Psychiatry*, *30*, 677–685.

Lakens, D. (2013). Calculating and reporting effect sizes to facilitate cumulative science: A practical primer for t-tests and ANOVAs. *Frontiers in Psychology*, *4*, 863.

Lannin, N. A., Clemson, L., McCluskey, A., Lin, C.-W. C., Cameron, I. D., & Barras, S. (2007). Feasibility and results of a randomised pilot-study of pre-discharge occupational therapy home visits. *BMC Health Services Research*, *7*, 1–8.

Law, M. (2002). Participation in the occupations of everyday life. *American Journal of Occupational Therapy*, *56*, 640–649.

Lawton, M. P., & Brody, E. M. (1969). Assessment of older people: Self-maintaining and instrumental activities of daily living. *The Gerontologist*, *9*, 179–186.

Leibold, M. L., Holm, M. B., Raina, K. D., Reynolds III, C. F., & Rogers, J. C. (2014). Activities and adaptation in late-life depression: A qualitative study. *American Journal of Occupational Therapy*, *68*, 570–577.

Lewis, J. R. (1995). IBM computer usability satisfaction questionnaires: Psychometric evaluation and instructions for use. *International Journal of Human-Computer Interaction*, *7*, 57–78.

Lewis, J. R. (2002). Psychometric evaluation of the PSSUQ using data from five years of usability studies. *International Journal of Human-Computer Interaction*, *14*, 463–488.

Li, C., Friedman, B., Conwell, Y., & Fiscella, K. (2007). Validity of the patient health questionnaire 2 (PHQ-2) in identifying major depression in older people. *Journal of the American Geriatrics Society*, *55*, 596–602.

Lin, E. H., Katon, W., Von Korff, M., Rutter, C., Simon, G. E., Oliver, M., … Young, B. (2004). Relationship of depression and diabetes self-care, medication adherence, and preventive care. *Diabetes Care*, *27*, 2154–2160.

Liu, Y. W. J., & Tsui, C. M. (2014). A randomized trial comparing Tai Chi with and without cognitive-behavioral intervention (CBI) to reduce fear of falling in community-dwelling

elderly people. *Archives of Gerontology and Geriatrics*, *59*, 317–325.

Locke, E. A., & Latham, G. P. (2002). Building a practically useful theory of goal setting and task motivation: A 35-year odyssey. *American Psychologist*, *57*, 705–717.

Lubitz, J., Cai, L., Kramarow, E., & Lentzner, H. (2003). Health, life expectancy, and health care spending among the elderly. *New England Journal of Medicine*, *349*, 1048–1055.

Lustman, P. J., & Clouse, R. E. (2005). Depression in diabetic patients: The relationship between mood and glycemic control. *Journal of Diabetes and Its Complications*, *19*, 113–122.

Mahoney, F. I., & Barthel, D. W. (1965). Functional evaluation: The Barthel index: A simple index of independence useful in scoring improvement in the rehabilitation of the chronically ill. *Maryland State Medical Journal*, *14*, 56–61.

Mahoney, J. E., Shea, T. A., Przybelski, R., Jaros, L., Gangnon, R., Cech, S., & Schwalbe, A. (2007). Kenosha county falls prevention study: A randomized, controlled trial of an intermediate-intensity, community-based multifactorial falls intervention. *Journal of the American Geriatrics Society*, *55*, 489–498.

Manton, K. G., Gu, X., & Lamb, V. L. (2006). Change in chronic disability from 1982 to 2004/2005 as measured by long-term changes in function and health in the U.S. elderly population. *Proceedings of the National Academy of Sciences of the United States of America*, *103*, 18374–18379.

Maty, S. C., Fried, L. P., Volpato, S., Williamson, J., Brancati, F. L., & Blaum, C. S. (2004). Patterns of disability related to diabetes mellitus in older women. *The Journals of Gerontology. Series A, Biological Sciences and Medical Sciences*, *59*, 148–153.

McGuire, L. C., Ford, E. S., & Ajani, U. A. (2006). The impact of cognitive functioning on mortality and the development of functional disability in older adults with diabetes: The second longitudinal study on aging. *BMC Geriatrics*, *6*, 8.

Mehta, K. M., Yaffe, K., & Covinsky, K. E. (2002). Cognitive impairment, depressive symptoms, and functional decline in older people. *Journal of the American Geriatrics Society*, *50*, 1045–1050.

Mendeley Ltd. (2017). Mendeley. London, United Kingdom.

Michie, S., Fixsen, D., Grimshaw, J. M., & Eccles, M. P. (2009). Specifying and reporting complex behaviour change interventions: The need for a scientific method. *Implementation Science*, *4*, 1–6.

Michie, S., Richardson, M., Johnston, M., Abraham, C., Francis, J., Hardeman, W., … Wood, C. E. (2013). The behavior change technique taxonomy (v1) of 93 hierarchically clustered techniques: Building an international consensus for the reporting of behavior change interventions. *Annals of Behavioral Medicine*, *46*, 81–95.

Mitra, S., Palmer, M., Kim, H., Mont, D., & Groce, N. (2017). Extra costs of living with a disability: A review and agenda for research. *Disability and Health Journal*, *10*, 475–484.

Moher, D., Liberati, A., Tetzlaff, J., & Altman, D. G. (2009). Preferred reporting items for systematic reviews and meta-analyses: The PRISMA statement. *Annals of Internal Medicine*, *151*, 264.

Morley, J. E., Morris, J. C., Berg-Weger, M., Borson, S., Carpenter, B. D., del Campo, N., … Vellas, B. (2015). Brain health: The importance of recognizing cognitive impairment: An IAGG consensus conference. *Journal of the American Medical Directors Association*, *16*, 731–739.

Nagelkerk, J., Reick, K., & Meengs, L. (2006). Perceived barriers and effective strategies to diabetes self-management. *Journal of Advanced Nursing*, *54*, 151–158.

Narayan, K. V., Boyle, J. P., Geiss, L. S., Saaddine, J. B., & Thompson, T. J. (2006). Impact of recent increase in incidence on future diabetes burden: U.S., 2005-2050. *Diabetes Care*, *29*, 2114–2116.

National Alliance on Mental Illness. (2009). *Depression in older persons: Fact sheet.*

Ng, T. P., Feng, L., Nyunt, M. S. Z., Feng, L., Niti, M., Tan, B. Y., … Yap, K. B. (2015). Nutritional, physical, cognitive, and combination interventions and frailty reversal among older adults: A randomized controlled trial. *The American Journal of Medicine*, *128*, 1225–1236.e1.

Nouri, F., & Lincoln, N. (1987). An extended activities of daily living scale for stroke patients. *Clinical Rehabilitation*, *1*, 301–305.

Ortman, J. M., Velkoff, V. A., & Hogan, H. (2014). *An aging nation: The older population in the United States*. United States Census Bureau, Economics and Statistics Administration, US Department of Commerce.

Owsley, C., Sloane, M., McGwin, G., & Ball, K. (2002). Timed instrumental activities of daily living tasks: Relationship to cognitive function and everyday performance assessments in older adults. *Gerontology*, *48*, 254–265.

Pan, A., Sun, Q., Okereke, O. I., Rexrode, K. M., Rubin, R. R., Lucas, M., … Hu, F. B. (2012). Use of antidepressant medication and risk of type 2 diabetes: Results from three cohorts of US adults. *Diabetologia*, *55*, 63–72.

Peixoto, T. C. A., Begot, I., Bolzan, D. W., Machado, L., Reis, M. S., Papa, V., … Guizilini, S. (2015). Early exercise-based rehabilitation improves health-related quality of life and functional capacity after acute myocardial infarction: A randomized controlled trial. *Canadian Journal of Cardiology*, *31*, 308–313.

Petersson, I., Lilja, M., Hammel, J., & Kottorp, A. (2008). Impact of home modification services on ability in everyday life for people ageing with disabilities. *Journal of Rehabilitation*

Medicine, *40*, 253–260.

Pighills, A. C., Torgerson, D. J., Sheldon, T. A., Drummond, A. E., & Bland, J. M. (2011). Environmental assessment and modification to prevent falls in older people. *Journal of the American Geriatrics Society*, *59*, 26–33.

Qualtrics. (2017). The data collection for this paper is generated using Qualtrics software. Provo, Utah, USA.

Rawlings, A. M., Sharrett, A. R., Schneider, A. L. C., Coresh, J., Albert, M., Couper, D., … Selvin, E. (2014). Diabetes in midlife and cognitive change over 20 years. *Annals of Internal Medicine*, *161*, 785.

Reynolds, S. L., & Silverstein, M. (2003). Observing the onset of disability in older adults. *Social Science & Medicine*, *57*, 1875–1889.

Robertson, D. A., Savva, G. M., & Kenny, R. A. (2013). Frailty and cognitive impairment—A review of the evidence and causal mechanisms. *Ageing Research Reviews*, *12*, 840–851.

Rockwood, K., Howlett, S., Stadnyk, K., Carver, D., Powell, C., & Stolee, P. (2003). Responsiveness of goal attainment scaling in a randomized controlled trial of comprehensive geriatric assessment. *Journal of Clinical Epidemiology*, *56*, 736–743.

Rodakowski, J., Reynolds, C. F., Lopez, O. L., Butters, M. A., Dew, M. A., & Skidmore, E. R. (2016). Developing a non-pharmacological intervention for individuals with mild cognitive impairment. *Journal of Applied Gerontology*, *37*, 665–676.

Roy, T., & Lloyd, C. E. (2012). Epidemiology of depression and diabetes: A systematic review. *Journal of Affective Disorders*, *142*, S8–S21.

Rydwik, E., Frandin, K., & Akner, G. (2010). Effects of a physical training and nutritional intervention program in frail elderly people regarding habitual physical activity level and activities of daily living--A randomized controlled pilot study. *Archives of Gerontology and Geriatrics*, *51*, 283–289.

SAS Institution. (2015). The SAS system for Windows. SAS Institute Inc.

Saykin, A. J., Wishart, H. A., Rabin, L. A., Santulli, R. B., Flashman, L. A., West, J. D., … Mamourian, A. C. (2006). Older adults with cognitive complaints show brain atrophy similar to that of amnestic MCI. *Neurology*, *67*, 834–842.

Schuling, J., de Haan, R., Limburg, M., & Groenier, K. H. (1993). The Frenchay Activities Index. Assessment of functional status in stroke patients. *Stroke*, *24*, 1173–1177.

Selvin, E., Coresh, J., & Brancati, F. L. (2006). The burden and treatment of diabetes in elderly individuals in the U.S. *Diabetes Care*, *29*, 2415–2419.

Shiffman, S., Stone, A. A., & Hufford, M. R. (2008). Ecological momentary assessment. *Annual*

Review of Clinical Psychology, *4*, 1–32.

Singer, J. D. (1998). Using SAS PROC MIXED to fit multilevel models, hierarchical models, and individual growth models. *Journal of Educational and Behavioral Statistics*, *23*, 323–355.

Singh-Manoux, A., Kivimaki, M., Glymour, M. M., Elbaz, A., Berr, C., Ebmeier, K. P., … Dugravot, A. (2012). Timing of onset of cognitive decline: Results from Whitehall II prospective cohort study. *BMJ*, *344*, d7622.

Spauwen, P. J. J., Köhler, S., Verhey, F. R. J., Stehouwer, C. D. A., & van Boxtel, M. P. J. (2013). Effects of type 2 diabetes on 12-year cognitive change: Results from the Maastricht Aging Study. *Diabetes Care*, *36*, 1554–1561.

Springer, J. F., & Phillips, J. (2007). The Institute of Medicine framework and its implication for the advancement of prevention policy, programs and practice. *California, Community Prevention Initiative*.

StataCorp. (2017). STATA Statistical Software: Release 15. College Station, TX: StataCorp LLC.

Stenholm, S., Westerlund, H., Head, J., Hyde, M., Kawachi, I., Pentti, J., … Vahtera, J. (2015). Comorbidity and functional trajectories from midlife to old age: The health and retirement study. *The Journals of Gerontology Series A: Biological Sciences and Medical Sciences*, *70*, 332–338.

Stone, A. A., Broderick, J. E., Schwartz, J. E., Shiffman, S., Litcher-Kelly, L., & Calvanese, P. (2003). Intensive momentary reporting of pain with an electronic diary: Reactivity, compliance, and patient satisfaction. *Pain*, *104*, 343–351.

Stone, A., Shiffman, S., Atienza, A., & Nebeling, L. (2007). *The science of real-time data capture: Self-reports in health research*. Oxford University Press.

Stuart, M. J., & Baune, B. T. (2012). Depression and type 2 diabetes: Inflammatory mechanisms of a psychoneuroendocrine co-morbidity. *Neuroscience & Biobehavioral Reviews*, *36*, 658–676.

Stuck, A. E., Egger, M., Hammer, A., Minder, C. E., & Beck, J. C. (2002). Home visits to prevent nursing home admission and functional decline in elderly people. *JAMA*, *287*, 1022–1028.

Szanton, S. L., Thorpe, R. J., Boyd, C., Tanner, E. K., Leff, B., Agree, E., … Gitlin, L. N. (2011). Community aging in place, advancing better living for elders: A bio-behavioral-environmental intervention to improve function and health-related quality of life in disabled older adults. *Journal of the American Geriatrics Society*, *59*, 2314–2320.

Taquet, M., Quoidbach, J., de Montjoye, Y.-A., Desseilles, M., & Gross, J. J. (2016). Hedonism and the choice of everyday activities. *Proceedings of the National Academy of Sciences of the United States of America*, *113*, 9769–9773.

Turvey, C. L., Carney, C., Arndt, S., Wallace, R. B., & Herzog, R. (1999). Conjugal loss and

syndromal depression in a sample of elders aged 70 years or older. *The American Journal of Psychiatry*, *156*, 1596–1601.

University of Michigan. (2016). Health and Retirement Study. Retrieved July 26, 2018, from http://hrsonline.isr.umich.edu

van Hooff, M. L. M., Geurts, S. A. E., Kompier, M. A. J., & Taris, T. W. (2007a). "How fatigued do you currently feel?" Convergent and discriminant validity of a single-item fatigue measure. *Journal of Occupational Health*, *49*, 224–234.

van Hooff, M. L. M., Geurts, S. A. E., Kompier, M. A. J., & Taris, T. W. (2007b). Workdays, in-between workdays and the weekend: A diary study on effort and recovery. *International Archives of Occupational and Environmental Health*, *80*, 599–613.

van Hout, H. P. J., Jansen, A. P. D., van Marwijk, H. W. J., Pronk, M., Frijters, D. F., & Nijpels, G. (2010). Prevention of adverse health trajectories in a vulnerable elderly population through nurse home visits: A randomized controlled trial [ISRCTN05358495]. *The Journals of Gerontology. Series A, Biological Sciences and Medical Sciences*, *65*, 734–742.

Villareal, D. T., Banks, M., Sinacore, D. R., Siener, C., & Klein, S. (2006). Effect of weight loss and exercise on frailty in obese older adults. *Archives of Internal Medicine*, *166*, 860–866.

Villareal, D. T., Chode, S., Parimi, N., Sinacore, D. R., Hilton, T., Armamento-Villareal, R., … Shah, K. (2011). Weight loss, exercise, or both and physical function in obese older adults. *The New England Journal of Medicine*, *364*, 1218–1229.

Volpato, S., Ferrucci, L., Blaum, C., Ostir, G., Cappola, A., Fried, L. P., … Guralnik, J. M. (2003). Progression of lower-extremity disability in older women with diabetes. *Diabetes Care*, *26*, 70–75.

von Bonsdorff, M. B., Leinonen, R., Kujala, U. M., Heikkinen, E., Tormakangas, T., Hirvensalo, M., … Rantanen, T. (2008). Effect of physical activity counseling on disability in older people: A 2-year randomized controlled trial. *Journal of the American Geriatrics Society*, *56*, 2188–2194.

Weaver Cargin, J., Collie, A., Masters, C., & Maruff, P. (2008). The nature of cognitive complaints in healthy older adults with and without objective memory decline. *Journal of Clinical and Experimental Neuropsychology*, *30*, 245–257.

Wegner, K. E., Smyth, J. M., Crosby, R. D., Wittrock, D., Wonderlich, S. A., & Mitchell, J. E. (2002). An evaluation of the relationship between mood and binge eating in the natural environment using ecological momentary assessment. *International Journal of Eating Disorders*, *32*, 352–361.

Westoby, C. J., Mallen, C. D., & Thomas, E. (2009). Cognitive complaints in a general population of older adults: Prevalence, association with pain and the influence of concurrent affective disorders. *European Journal of Pain*, *13*, 970–976.

Wichers, M., Peeters, F., Geschwind, N., Jacobs, N., Simons, C. J. P., Derom, C., … van Os, J. (2010). Unveiling patterns of affective responses in daily life may improve outcome prediction in depression: A momentary assessment study. *Journal of Affective Disorders*, *124*, 191–195.

Wood, W., Quinn, J. M., & Kashy, D. A. (2002). Habits in everyday life: Thought, emotion, and action. *Journal of Personality and Social Psychology*, *83*, 1281–1297.

World Health Organization. (2002). *Towards a common language for functioning, disability and health (ICF)*. Geneva.

Yaffe, K., Falvey, C., Hamilton, N., Schwartz, A. V., Simonsick, E. M., Satterfield, S., … Harris, T. B. (2012). Diabetes, glucose control, and 9-year cognitive decline among older adults without dementia. *Archives of Neurology*, *69*, 1170–1175.

Zijlstra, G. A. R., van Haastregt, J. C. M., Ambergen, T., van Rossum, E., van Eijk, J. T. M., Tennstedt, S. L., & Kempen, G. I. J. M. (2009). Effects of a multicomponent cognitive behavioral group intervention on fear of falling and activity avoidance in community-dwelling older adults: Results of a randomized controlled trial. *Journal of the American Geriatrics Society*, *57*, 2020–2028.

Zimet, G. D., Dahlem, N. W., Zimet, S. G., & Farley, G. K. (1988). The multidimensional scale of perceived social support. *Journal of Personality Assessment*, *52*, 30–41.