Abstract

Longitudinal Associations between Balance Confidence and Cognitive Performance in Community-Residing Older Adults

Objective: The current study examined the moderating effects of balance confidence on the relationship between time and cognitive performance over 7 years in a cohort of non-demented, community-residing older adults.

Participants and Methods: A sample of 519 older adults (65 years and older, 55% female) provided information regarding balance confidence via completion of the Activities-specific Balance Confidence (ABC) Scale. Participants also completed neuropsychological testing annually, for up to 7 years, to assess their cognitive functioning globally and in specific domains of memory and attention/executive functioning.

Results: Adjusted linear mixed effects models revealed that, within the context of an overall tendency to learn over repeated sessions, participants with low baseline balance confidence demonstrated an attenuated improvement in performance on measures of global cognition and memory, but not attention/executive functioning over 7 years. When models were stratified by gender, balance confidence more strongly moderated the effect of time on cognitive performance in females compared to males. However, sensitivity analyses revealed mixed findings, which should be considered when interpreting these results. Furthermore, when growth trajectories of balance confidence and each cognitive outcome were compared, changes over time in balance confidence significantly covaried with changes over time in cognitive performance.

Conclusion: Findings from the present study suggest that those with lower balance confidence have worse cognitive outcomes compared to those with higher balance confidence and that those with greater decreases in balance confidence over time also show less improvement in cognitive performance over repeated sessions. As balance confidence is a modifiable risk factor for gait impairment, treated successfully with balance-based exercises and psychotherapy, it may be a useful marker to target for treatment within the clinical setting. Given the known associations between mobility decline and cognitive decline, future studies might investigate the potential longitudinal benefits of improved balance confidence on cognitive functioning.

LONGITUDINAL ASSOCIATIONS BETWEEN BALANCE CONFIDENCE AND COGNITIVE PERFORMANCE IN COMMUNITY-RESIDING OLDER ADULTS

Dissertation Project

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Dedication

This dissertation is dedicated to:

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Key Term Abbreviations

Fear of Falling: FOF

Activities-specific Balance Confidence Scale: ABC Scale

Attention/Executive Functioning: Attention/EF

Chapter 1

<u>Introduction</u>

Background Information

Concern about falling, a known risk factor for falls (Landers, Oscar, Sasaoka, & Vaughn, 2016) and other negative health outcomes (Whipple, Hamel, & Talley, 2018) is endorsed by 20-83% of older adults (Friedman, Munoz, West, Rubin, & Fried, 2002). Concern about falling is commonly referred to as fear of falling (FOF) in the literature when in fact FOF, falls efficacy and balance confidence all refer to this construct of concern about falling (Thurman, Stevens, Rao, & Quality Standards Subcommittee of the American Academy of, 2008). Falls efficacy is generally operationalized using the Falls-Efficacy Scale (Tinetti, Richman, & Powell, 1990) and balance confidence with the Activities-specific Balance Confidence (ABC) scale (Myers, Fletcher, Myers, & Sherk, 1998). FOF is commonly used as a label independent of operationalization but is frequently assessed as a dichotomous variable using a single question "Do you have a fear of falling?". Throughout this document "FOF" will be used to refer to the construct broadly, independent of operationalization, while "balance confidence" will refer to the specific construct measured by the ABC scale.

FOF was first identified by Murphy & Isaacs (1982) as a specific health problem when it was recognized as part of *post-fall syndrome*, a condition marked by a cautious and unstable gait that would develop after an incident fall. However, FOF has since also been recognized in the literature as an independent risk factor for falling (Cumming, Salkeld, Thomas, & Szonyi, 2000; Friedman et al., 2002; Landers et al., 2016). Specifically, falls history, FOF and functional decline all serve as independent risk factors for one another (Friedman et al., 2002). While moderate levels of FOF may prevent fall-related injuries, excessive amounts of FOF are associated with activity restriction that can lead to adverse health outcomes (Zijlstra et al., 2007). Moreover, the coexistence of FOF and falls history is more strongly linked to disability incidence (*disability* was defined by the nationally uniform criteria for long-term care need certification established by the Japanese government) than each is independently (Makino et al., 2017). This emphasizes the interrelationships between physical and psychological risk factors for disability incidence, which includes both physical and functional decline.

The literature on the relationships between mobility declines and cognition in older adults is robust. Incident falls (O. Jayakody et al., 2022; Liu, Chan, & Yan, 2014) and gait impairment (Cohen, Verghese, & Zwerling, 2016; Grande et al., 2019; Sekhon et al., 2019) in older adults serve as independent risk factors for cognitive decline. However, the mechanisms underlying these relationships are not well understood. As described above, FOF can result from past falls but can also develop independent of falls history and increase the risk of future falls (Cumming et al., 2000; Friedman et al., 2002; Landers et al., 2016). Given the widely recognized relationship between falls and cognition in this population, associations between FOF and cognition have been considered as well. While limited, there is evidence to suggest that FOF impacts cognition both globally (Kraut & Holtzer, 2021; Noh, Roh, Song, & Park, 2019; Peeters, Leahy, Kennelly, & Kenny, 2018; Sakurai et al., 2017) and in specific domains of memory and attention/executive functioning (Holtzer, Kraut, Izzetoglu, & Ye, 2019; Kraut & Holtzer, 2021). However, the relationship between balance confidence assessed via the ABC scale and cognition in older adults has never been studied. The ABC scale is sensitive to level of physical functioning and performance on balance-based tasks (Myers et al., 1998) and is sensitive to low balance confidence even in high functioning individuals (Hatch, Gill-Body, & Portney, 2003). Gender differences in rates of incident falls, FOF endorsement and balance confidence are notable, with significantly more females being affected than males (Chang, Chen, & Chou, 2016; Lavedan et al., 2018; LeBouthillier, Thibodeau, & Asmundson, 2013).

The current study was based on the notion that fall-related psychological factors as well as gender differences in these psychological factors might help explain a portion of the variance observed in cognitive performance over time in community-residing older adults. Clarifying the role of these factors in performance on cognitive tasks might facilitate the identification of older adults at risk of cognitive decline. Moreover, this information can be incorporated into the development of fall risk assessments and therapeutic options for community-residing older adults.

Overview of Topics Discussed

The following introduction will provide an overview of the experimental components and theoretical constructs within this study. First the literature on mobility, incident falls, and cognitive decline in non-demented older adults will be reviewed. This will clarify the underlying principle of the current study and the need to further identify factors that account for individual differences in cognitive decline among older adults. Then, to provide justification for our choice of specific factors examined, we will describe the issue of FOF in aging as a public health concern that has been well documented among the older adult community, how it is assessed, and findings of potential gender differences related to the construct. We will define and describe the specific fall-related psychological construct (i.e., balance confidence) as well as specific cognitive outcomes (i.e., global cognition, memory, and attention/executive functioning) investigated in the present study. Lastly, we will summarize the study's rationale, aims and corresponding hypotheses, and the methods used for statistical analysis, which will contextualize our findings and interpretations in following sections of the document.

Review of Literature on Mobility and Falls

According to U.S. census data, individuals aged 65 or older comprise about 15% of the U.S. population and the number is rapidly growing. 15-50% of older adults in the U.S. reported serious difficulty walking or climbing stairs (Roberts, Ogunwole, Blakeslee, & Rabe, 2018), 20-40% reported falling at least once per year (Peel, 2011) and 20-83% of older adults reported a FOF (Friedman et al., 2002; Scheffer et al., 2008). Even highly functional older adults demonstrate declines in mobility which put them at risk for negative outcomes including incident falls, cognitive decline, and functional decline (Montero-Odasso et al., 2005; Shinkai et al., 2000). Gait performance has been identified as a strong predictor of falls risk (Montero-Odasso et al., 2005) as well as functional decline (Shinkai et al., 2000). Decreased gait velocity and increased variability have also been identified as risk factors for developing both clinical and non-clinical dementia (Verghese et al., 2002; Waite et al., 2005; Verghese et al., 2007; Marquis et al., 2002). Functional decline in older adults can lead to disability, characterized by inability to independently complete activities of daily living (ADLs); disability, in turn, is a risk factor for other adverse outcomes such as admission to a nursing home (Gill, Robison, & Tinetti, 1998) and earlier mortality (Hjaltadóttir, Hallberg, Ekwall, & Nyberg, 2011). Importantly, screening within the primary care setting to identify those at risk for falling and intervention (exercise focused on strength and balance has been shown to be most effective) can improve mobility and significantly reduce fall risk (Phelan & Ritchey, 2018).

Review of Literature on FOF and Balance Confidence

With high, yet variable prevalence (Friedman et al., 2002; Scheffer, Schuurmans, van Dijk, van der Hooft, & de Rooij, 2008), FOF is reported more often by females (Vellas, Wayne, Romero, Baumgartner, & Garry, 1997) and is a common challenge faced by older adults that is associated with a reduced sense of self-efficacy, ability to perform activities of daily living, and overall quality of life (Donoghue, Setti, O'Leary, & Kenny, 2017; Whipple et al., 2018). Balance confidence can be used as a proxy for FOF, a broader concept referred to in the older adult and mobility literature. FOF can develop because of a fall but is also an independent risk factor for falling. FOF was first identified by Murphy & Isaacs (1982) as a specific health problem when it was recognized as part of a *post-fall syndrome*, a condition marked by cautious and unstable gait that would develop after an incident fall. However, FOF has since also been recognized in the literature as an independent risk factor for falling (Cumming, Stalkeld, Thomas & Szonyi, 2000; Friedman et al., 2002; Landers, Oscar, Sasaoka & Vaughn, 2016). Specifically, falls history, FOF and functional decline all serve as independent risk factors for one another (Friedman et al., 2002). While moderate levels of FOF may prevent fall-related injuries, excessive amounts of FOF are associated with activity restriction that can lead to adverse health outcomes (Zijlstra et al., 2007).

Balance confidence, specifically, has been defined as a cognitive component of FOF where older adults subjectively estimate their ability to avoid a fall or maintain their balance (Hadjistavropoulos, Delbaere, & Fitzgerald, 2011). In a group of older women ($\geq$ 70 years) at risk for falling (determined based on postural instability in addition to at least one other physical or cognitive risk factor), balance confidence decreased by 5% on average over two years (Talley, Wyman, Gross, Lindquist, & Gaugler, 2014). In this same cohort of older women, these decreasing balance confidence scores were associated with worse balance as well as other measures of physical performance such as scores on the TUG (Podsiadlo & Richardson, 1991) and repeated chair stands, decreased physical activity levels and increased activity restriction, and decreased social networks (Talley et al., 2014). Encouragingly, both physical balance performance as well as balance confidence levels in older adults improve in response to balance training (Myers et al., 1998, Rendon et al., 2012).

Assessment of FOF and Balance Confidence

FOF is commonly assessed via a single question: "Do you have a fear of falling?". However, more comprehensive questionnaires such as the Falls Efficacy Scale (Tinetti et al., 1990) and the Activities-Specific Balance Confidence (ABC) Scale (Powell & Myers, 1995) were developed to capture FOF on a continuum, rather than as a dichotomous variable, due to concern that dichotomous assessment of a global trait (i.e., FOF) may not be a sensitive measure. Both scales discriminated between mobility groups (high vs low defined as requiring assistance aside from transportation to leave their homes) while the dichotomous assessment of FOF did not (Powell & Myers, 1995). Still, the ABC scale demonstrated even greater sensitivity than the FES, thereby capturing high functioning individuals who are still at increased risk of falling due to poor balance confidence (Powell & Myers, 1995). Balance confidence, the construct assessed by the ABC scale, will be used as a proxy for FOF in this project.

Balance confidence assessed by the ABC scale is strongly linked with physical functioning and falls history and has been shown to predict falls in older adults at least as well as physical measures (Landers et al., 2016). More than 50% of the variance in balance confidence in a group of older adults was explained by performance on physical balance tasks (Hatch et al., 2003). Clinical cut-points for the ABC scale have been established to discriminate groups based on functional status with regard to physical activity. In a sample ranging from home-care clients to highly functional individuals, Myers and colleagues (1998) determined that a mean score below 50 was associated with a "low" level of physical functioning, a mean score between 50-80 was associated with a "moderate" level of physical functioning, and a mean score above 80 was associated with a "high" level of physical functioning. Using the Hindi version of the ABC scale (ABC-H), Moiz and colleagues (2017) determined that 58.13 was the optimal cutoff to discriminate between fallers and non-fallers. In sum, balance confidence assessed by the ABC scale is associated with worse gait impairment (Herman, Giladi, Gurevich, & Hausdorff, 2005), more incident falls (Moiz et al., 2017), and worse overall physical functioning (Myers et al., 1998), which are all significantly linked with cognitive decline (Cohen et al., 2016; Montero-Odasso & Speechley, 2018).

Review of Literature on Gender Differences in Mobility and FOF

Significant gender differences exist in FOF. Females have been shown to endorse FOF more often than males and also have a higher number of incident falls (Chang et al., 2016; Myers et al., 1996). Specifically, females report lower balance confidence than males and in turn demonstrate associated impairments in functional performance (Ko, Park, Lim, Kim, & Paik, 2009; LeBouthillier et al., 2013). Females also demonstrate higher gait variability under dual task conditions, associated with increased falls risk (Johansson, Nordström, & Nordström, 2016). In sum, females have higher rates of incident falls, gait variability, and FOF, as well as lower balance confidence. Therefore, the possible moderating role of gender in the relationship between balance confidence and cognition would be important to examine.

Review of Literature on Cognitive Decline in Aging

Cognitive decline is prevalent in the aging population, however there is still much to be learned about how different factors impact upon individual cognitive domains as well as global cognitive function. According to a report from the institute of medicine (Blazer, Yaffe, & Karlawish, 2015), cognitive aging is not a disease and is distinct from Alzheimer's disease or other neurocognitive disorders. Rather, performance across multiple cognitive domains decline as a function of age in healthy individuals, with the exception of vocabulary knowledge, which has been shown to remain relatively stable across the lifespan (Salthouse, 2010). One aspect of cognitive aging is increased difficulty with quick, efficient decision-making which puts older adults at greater risk for losing money to financial fraud and for more dangerous driving (Blazer et al., 2015). While the study of cognitive change over the lifespan is relatively young, researchers are eager to understand the natural course of cognition in the healthy brain over the lifespan as well as how this natural course may differ from changes in cognition that precede the manifestation of a neurocognitive disorder. Broadly, cognitive function across the lifespan can be impacted by genetics, increased physical and social activity, cognitive reserve, and cognitive training (brain exercises) (Harada, Love, & Triebel, 2013). However, there are individual differences both within and outside these broad categories that put some at greater risk for worsening cognitive decline.

Memory and attention/executive functions (EF) are two cognitive domains shown to change as a function of age in a cohort of healthy older adults (Van Hooren et al., 2007). EF refers to higher order cognitive processes that rely on basic, as well as more complex attention; consequently, EF and attention are commonly examined as one domain. Memory, specifically the ability to acquire and retrieve new information, declines significantly in non-demented older adults (Park & Festini, 2017). EF declines in healthy older adults may explain the age-related decline in everyday multitasking abilities (Caballero, McFall, Wiebe, & Dixon, 2020; McAlister & Schmitter-Edgecombe, 2013). The literature suggests that memory and executive functioning are independently linked to falls risk (Martin et al., 2009). Since these domains are two areas of common decline in our population of interest, and are often impacted in non-demented older adults, it would be informative to learn about how balance confidence might predict decline in these areas.

Review of Literature on FOF and Balance Confidence, Mobility, and Cognition

Review (Cohen et al., 2016) and meta-analytic (Peel, Alapatt, Jones, & Hubbard, 2019) studies demonstrate meaningful associations between cognition and gait in aging but the directionality of this relationship, as assessed in longitudinal investigation, is not clear. Some studies propose that baseline cognitive functions predict decline in gait (Holtzer, Wang, Lipton, & Verghese, 2012; Soumaré, Tavernier, Alpérovitch, Tzourio, & Elbaz, 2009; Watson et al., 2010) while others show that poor gait predicts cognitive decline (Oshadi Jayakody, Breslin, Srikanth, & Callisaya, 2019; Mielke et al., 2013; J. Verghese, Wang, Lipton, Holtzer, & Xue, 2007). The literature also suggests that memory and executive functioning are associated with greater falls risk (Holtzer et al., 2007; Martin et al., 2009; Montero-Odasso & Speechley, 2018). While these associations may be bidirectional, there is evidence showing that incident falls (Padubidri et al., 2014) as well as gait impairments (Cohen et al., 2016) predict cognitive decline in older adults. In this study we are interested in understanding predictors of cognitive decline rather than effects of cognitive decline.

Since FOF has been shown to predict both incident falls and gait impairment in this population (Cumming et al., 2000; Friedman et al., 2002; Landers et al., 2016), it might serve as a risk factor for decline in cognition as well. Memory (Park & Festini, 2017) and executive functions (Caballero et al., 2020) often decline in older adults. Hence, it would be informative to determine if the presence of FOF might predict decline in these cognitive domains. Specifically, if FOF is an early expression of neuropathological changes, memory and attention/executive functions are likely to be impacted.

FOF is associated with subjective memory complaints in older adults (Sakurai et al., 2017) and weakly predicts cognitive decline as determined by the MoCA and MMSE (Noh et al., 2019; Peeters et al., 2018). In these studies, however, cognitive screeners with relatively weak sensitivity to subtle cognitive changes were used to assess cognitive function and none assessed specific domains of cognitive functioning. Additionally, none of these studies examined the role of frequency of FOF endorsement in its association with cognition. Recent work in our lab has begun to address gaps in the literature by examining frequency of FOF report as a predictor of cognitive performance and by assessing specific cognitive domains as outcome measures. In a sample of 421 non-demented, community-residing older adults, we found that persistent, but not transient, FOF significantly predicts cognitive decline (over 6 years of follow-up) in areas of global cognitive function, memory, and attention/executive functions (Kraut & Holtzer, 2021). As well we found that, in a subset of the same study cohort (n=75), FOF directly impacts metabolic activity in the prefrontal cortex under dual-task walking conditions as well as learning trajectory across trials (Holtzer, Kraut, Izzetoglu & Ye, 2019). In the latter study, dual-task walking served as a proxy for executive functioning. In both studies FOF was assessed via a single question "Do you have a fear of falling?". While neither study examined potential interactions of gender with primary predictor or outcome variables, significantly more females than males endorsed FOF in both studies, consistent with relevant literature (Chang et al., 2016; Myers et al., 1996).

Using the FES to assess FOF, one study found that increased FOF was associated with greater attention variability (O'Halloran et al., 2011). Furthermore, one study showed improved performance in memory and spatial orientation in response to a balance training intervention (Rogge et al., 2017). Balance training has also been shown to improve both balance confidence and physical balance performance (Myers et al., 1998). Still, to our knowledge, the relationship between balance confidence, assessed via the ABC scale, and cognition in older adults has never been studied.

Rationale for Current Study

Mobility decline in older adults has been widely studied, has a high prevalence (Roberts et al., 2018; Verghese et al., 2006) and is associated with functional (Rodríguez-Molinero et al., 2019) and cognitive (Cohen et al., 2016) decline. Yet reasons for individual differences that exist among these phenomena require further clarification. FOF has been established as both a consequence of (Murphy & Isaacs, 1982) and risk factor for mobility decline (Cumming et al., 2000; Friedman et al., 2002; Landers et al., 2016). FOF may explain a portion of the variance in the relationship between mobility decline and associated outcomes of functional and cognitive decline. While the literature provides robust support for FOF as a predictor of poor functional outcomes (Donoghue et al., 2017; Whipple et al., 2018), literature describing the relationship between FOF and cognitive decline is limited (Holtzer et al., 2019; Noh et al., 2019; Peeters et al., 2018; Sakurai et al., 2017). Furthermore, no studies to our knowledge have examined balance confidence, a reliable and valid proxy for physical performance (Powell & Myers, 1995), as a predictor of cognitive function.

Notably, preliminary work has demonstrated that frequency of FOF report moderated the effect of FOF on cognitive decline in non-demented older adults (Kraut & Holtzer, 2021). Moreover, when FOF was examined in the context of other outcome measures such as gait variability, meta-analytic review showed that FOF only significantly predicted this type of functional decline when it was assessed using a comprehensive measure (e.g., FES, ABC scale), and not when assessed via a single question "Are you afraid of falling?" (Ayoubi, Launay, Annweiler, & Beauchet, 2015).

This work emphasizes that the method used to assess FOF may impact the significance of its association with various outcomes. Since the ABC scale is a comprehensive measure of FOF with high sensitivity, examining the relationship between balance confidence assessed by the ABC scale and cognitive decline might offer an avenue to understand not only how persistence of FOF endorsement impacts cognitive outcomes but also how severity of FOF impacts cognitive outcomes. Moreover, it would be useful to understand not only whether balance confidence predicts cognitive decline but also how change over time in balance confidence might correlate with change over time in cognition to better understand the nature of the association between the two constructs. Since memory and attention/EF are implicated in cognitive decline associated with normal aging (Oschwald et al., 2019) these would be important to examine in addition to global cognition. Furthermore, the current study will investigate the potential moderating role of gender in the relationship between balance confidence and cognition given endorsement of lower balance confidence (Myers et al., 1996), increased FOF, and increased incident falls among females compared to males (LeBouthillier et al., 2013).

Aims and Hypotheses

Overview. The current study aimed to characterize the balance confidence distribution in a sample of healthy aging, community-dwelling older adults ≥ 65 years in age. We investigated the effects of balance confidence on longitudinal cognitive performance in older adults. Furthermore, given the gender differences described in the older adult literature related to falls and FOF indicating higher prevalence in females (Chang et al., 2016; Myers et al., 1996), we investigated the potential moderating effect of gender on this relationship. Additionally, as dementia appears to be an insidious disease process (Cheng, Chen, & Chiu, 2017), it would be useful to understand the temporal relationship between changes in balance confidence and changes in cognition, even in older adults that appear cognitively normal. This might provide us with more nuanced insight into the predictive role of fall-related psychological factors (i.e., balance confidence). Therefore, we also examined the trajectories of change in balance confidence and cognition over time. For all models, change over time in global cognition as well as specific domains of memory and attention/executive functions were examined.

Aim 1: To determine whether balance confidence (mean score on ABC scale) predicts decline in global cognitive functioning, memory, and attention/EF over time.

> Hypothesis 1: Lower balance confidence at baseline will be associated with worse decline in overall cognitive functioning, memory, and attention/EF assessed over a longitudinal follow, up to 7 years.

Aim 2: To determine whether gender moderates the relationship between baseline balance confidence and decline in global cognitive functioning, memory, and attention/EF.

Hypothesis 2: Females will demonstrate a stronger association between balance confidence at baseline and subsequent decline (longitudinally, up to 7 years) in overall cognitive functioning, memory, and attention/EF than males.

Exploratory Aim 3A: To determine whether change in balance confidence over time correlates with changes in global cognitive function, memory, and attention/EF.

Innovativeness

Few studies to date have investigated the relationship between fall-related psychological factors and cognition in community-dwelling older adults and none have examined how balance confidence, assessed using a comprehensive self-report measure, might predict change in cognitive function in this cohort. Early intervention for cognitive decline is key to improving outcomes for older adults at risk for dementia (Robinson, Tang, & Taylor, 2015) and in order to provide appropriate guidelines for monitoring and management of symptoms, it is important to understand how individual differences may put some older adults at greater risk for cognitive decline than others. Therefore, this study aims to examine the relationship between balance confidence and cognitive performance, two clinically relevant and likely related domains in a population that is steadily growing (Roberts et al., 2018). Moreover, this study will be the first to examine whether balance confidence differentially predicts cognitive decline in females compared to males. To better understand the relationship between balance confidence and cognition, we will also be the first to implement growth curve models to see not only whether baseline balance confidence predicts linear change in cognition but also whether changes in balance confidence over time forecast changes in cognition, too.

Chapter 2

Methods

Participants

Participants in this study were recruited from a longitudinal cohort study of older adults entitled Central Control of Mobility in Aging (CCMA) (PI: Roee Holtzer, Ph.D., Project #5R01AG036921-05; Holtzer, Wang & Verghese, 2014; Holtzer et al., 2015). The primary aims of the parent study were to determine cognitive and brain predictors of mobility performance, decline, and disability in aging. Potential participants were identified from a population list of individuals aged 65 and older in Yonkers and Mount Vernon, New York. These individuals were first contacted by mail and then by telephone inviting them to participate. A structured telephone interview (Holtzer, Wang, & Verghese, 2014) was then administered to screen potential participants for eligibility. The telephone interview consisted of verbal consent, medical history, mobility questions, and validated cognitive screens (Buschke et al., 1999; Galvin et al., 2005) to exclude dementia. Exclusion criteria were inability to speak English, inability to ambulate independently, dementia, significant loss of vision and/or hearing, history of neurological or psychiatric disorders, recent or anticipated medical procedures that may affect mobility, and receiving hemodialysis. Eligible participants were screened for bilateral hearing (≥ 20db at 400hz) and visual acuity (≥ 20/100) at the first in-house visit. Participants were asked to return for annual in-house visits for up to 7 years. Based on diagnostic consensus during monthly interdisciplinary case conferences, subjects with evidence of dementia were excluded from the current data analyses. Written informed consents were obtained on site according to study protocols and were approved by the Albert Einstein College of Medicine institutional review board.

Risks and Benefits

Potential risks of participation were minimal: performance anxiety, feeling frustrated or stressed when completing complex tasks, and/or fatigue. Benefits of participating in the study were also described: helping the scientific community better understand underlying mechanisms for declines in mobility and cognition among community-dwelling older adults.

Power Analysis

We conducted a power analysis for linear mixed effects models examining the moderating effects of balance confidence on the relationship between time and a single cognitive outcome which will incorporate a within-subjects variable (cognitive performance) and a continuous between-subjects variable. Using General Linear Mixed Model Power and Sample Size (GLIMMPSE) software, a Hotelling Lawley Trace test was used to assess the necessary sample size to achieve sufficient power for the study. Using a standard significance level, $\alpha = .05$, with application of unstructured correlation matrix, and assumption of a medium effect size and equal number of participants across groups, to achieve power of 0.8 the minimum sample size required for the present study was 218 individuals. Since we had a sample of more than 500 participants, we estimate sufficient statistical power for the proposed study. Power estimates for stratified data were not extracted as analyses are based on existing data and power analyses were conducted for aim 1. Support for power analysis of growth curve models is limited.

Ethics

Participants for this study were included as part of the CCMA longitudinal cohort study described above. Informed consent was obtained from each participant prior to study enrollment. Research assistants administering consent emphasized the voluntary nature of the study and that participants could discontinue at any point. Participants were also informed about the confidentiality of data and that a unique number was assigned to each participant for deidentification of data. Moreover, collected data was stored in a locked file cabinet in a secure medical building. Study risks and possible benefits were also discussed prior to enrollment (see above for details). Additionally, participants were informed that they would be contacted by phone for bi-monthly follow-up telephone calls. Participants were provided with a copy of the informed consent form and an opportunity to ask questions.

All research protocols were conducted by trained graduate students authorized to work with human subjects by the HIPPA Collaborative Institutional Training Initiative. The study was reviewed and approved by the Committee on Clinical Investigation of the Albert Einstein College of Medicine (protocol # 2010-224).

Study Procedures

Eligible participants, based on phone screen described above, were scheduled for two in-person visits (1 – 4 weeks apart) at the research center which served as their “baseline” during this longitudinal study. Visits lasted two to three hours and included comprehensive neuropsychological, cognitive, psychological, and mobility assessments as well as a structured neurological examination. CCMA participants received $25, complimentary transportation to our study center, and refreshments for each visit. They were followed by phone at two-month intervals and returned annually for in-person assessments for up to 7 years. Written informed consents were obtained on site according to study protocols and were approved by the institutional review board. Study protocols have been described in detail in previous work (Holtzer et al., 2014).

Measures

Balance Confidence. Balance confidence was assessed annually during in-person visits using the Activities-specific Balance Confidence (ABC) scale (Powell & Myers, 1995), a 16-item questionnaire designed to assess the respondent's level of confidence in his/her ability to perform specific physical activities without becoming unsteady. For each item, respondents are asked to rate his/her level of confidence on a scale from 0-100% and an overall score is obtained by calculating the average of individual item responses. Higher percentages reflect higher levels of confidence. This scale has been shown to have good reliability (stable over a two-week period ($r = .92$, $p < .001$)) and high internal consistency (Cronbach's alpha = .96) in community residing older adults, age 65 or older (Powell & Myers, 1995). The ABC scale has been validated against the FES ($r = .84$) (Jørstad, Hauer, Becker, Lamb, & Group, 2005) as well as the physical abilities subscale score ($r = .63$, $p <.001$) (Powell & Myers, 1995). Balance confidence was assessed as a continuous variable. Previously established cut-points for low (<50), moderate (50-80), and high (>80) balance confidence scores, associated with the respective levels of physical functioning, are available for qualitative description of our sample (Myers, A. M., Fletcher, Myers, A. H. & Sherk, 1998).

Global Cognitive Assessment. Repeatable Battery for the Assessment of Neuropsychological Status (RBANS) has been validated as a useful measure of global cognition that is sensitive in detecting dementia (Duff et al., 2008; Randolph, Tierney, Mohr, & Chase, 1998). The overall index standard score, comprised of subscale scores for domains of immediate and delayed memory, language, visuospatial skills and attention, was used as a measure of overall cognitive function. The RBANS overall index score has a reported sensitivity and specificity of 90% (Randolph et al., 1998) and good test-retest reliability ($r = .58$ to $r = .83$).

Memory. Memory was measured using a composite score consisting of six averaged z-scores based on sample distribution. All measures were subtests from the RBANS (Randolph et al., 1998). Measures of verbal memory included immediate and delayed recall scores on list learning and story recall tasks, respectively, as well as a recognition trial score for list learning. Visual memory was assessed using delayed reconstruction of a figure copied earlier on.

Attention and Executive Functions. Attention/executive functions was measured using a composite score consisting of averaged z-scores, calculated based on sample distribution, from five different neuropsychological assessments associated with attention/executive functioning: Trail Making Test A and Trail Making Test B (Reitan, 1958); Letter Fluency and Category Fluency (Bolla, Gray, Resnick, Galante, & Kawas, 1998; Borkowski, Benton, & Spreen, 1967); Digit Symbol Substitution Test (Wechsler, 1981).

The trail making test (TMT) consists of two parts, part A and part B. TMT A is a visuomotor sequencing task in which a person is asked to draw a line connecting numbers 1 – 25 in order as quickly as possible. TMT B is similar to TMT A but with a set-switching condition that involves alternating between numbers and letters. For TMT B, the individual is asked to draw a line connecting numbers (1 – 13) and letters (A – L) in order as quickly as they can, alternating between numbers and letters, until they reach the final number on the page. The TMT was developed in 1938 as part of the Army Individual Test Battery (Partington & Leiter, 1949), but its psychometric properties were first documented by Ralph M. Reitan in 1958. This initial validation study found that the TMT significantly differentiates between individuals with and without brain damage ($p < .001$) (Reitan, 1958). The tests' clinical utility has since been examined in the context of older adult samples at risk for physical decline (Vazzana et al., 2010) as well as in multiple clinical samples (Llinàs-Reglà et al., 2017). A review paper (Llinàs-Reglà et al., 2017) noted that most studies suggest that both graphomotor speed and visual scanning are key to both parts A and B of the TMT, while abilities specifically related to executive functioning such as working memory, inhibitory control, and set-switching, are critical for part B, but less so for part A.

The letter and category fluency tests used in the current study are from the Controlled Oral Word Association Test (COWAT) (Borkowski et al., 1967). For the letter fluency test, a person is asked to say as many words as they can think of that begin with a given letter (F, A, and S over three separate trials) in one minute. For the category fluency test, the person is asked to say as many words as they can think of that belong to a given category (fruits, vegetables, and animals over three separate trials) in one minute. These fluency tests have high sensitivity but low specificity; for example, in older adults, poor performance is associated with an increased risk of dementia but cannot reliably differentiate (in absence of other assessment measures) between subtypes of dementia (Pasquier, Lebert, Grymonprez, & Petit, 1995). The literature suggests that while both tests rely on aspects of language and executive functioning abilities

(Aita et al., 2019; Patt et al., 2017), the category fluency test relies more heavily on use of semantic knowledge, associated with highest neural activation levels in the left temporal region, and the letter fluency test relies more heavily on use of executive functioning and is linked with brain activation in the left frontal and temporal regions (Henry & Crawford, 2004; Zhang et al., 2013).

Digit Symbol Substitution Test (DSST) (Wechsler, 1944) is a paper-and-pencil cognitive test in which an individual is asked to use a visual key pairing unique symbols with numbers 1 – 9 in order to transcribe the correct symbol for each number presented on the page as quickly as possible. The score is based on the number of correct symbols drawn within the time limit (120 seconds). This test assesses processing speed and visuomotor coordination, as well as working memory, depending on the strategy used to complete the task (Wechsler & De Lemos, 1981). It has been shown to have high test-retest reliability (Matarazzo & Herman, 1984) and was also found to be the most sensitive measure among the WAIS subtests to discriminate between those with and without brain damage (Russell, 1972; Tsatali et al., 2021).

Gender. Female vs male status was assessed via self-report.

Covariates. Covariates in the models examining the effects of balance confidence over time on global cognitive function, memory, and attention/executive functions included age, education, gender, falls history, health status, depression, and anxiety. Gender was not included as a covariate in models where it served as a primary predictor. Years of education were included as a continuous variable. Falls history was measured as a dichotomous variable based on “yes”/ “no” responses to “Have you ever fallen [in older adulthood]?”. Overall health status was measured using the Global Health Status (GHS) score- a comorbidity summary score (range 0–10) including the presence of diabetes, chronic heart failure, arthritis, hypertension, depression, stroke, Parkinson's disease, chronic obstructive lung disease, angina, and myocardial infarction was used to characterize disease burden (Holtzer, Verghese, Wang, Hall, & Lipton, 2008). The Geriatric Depression Scale (GDS) was used to assess depression (J. A. Yesavage et al., 1982). The Beck Anxiety Inventory (Gana, Bailly, Broc, Cazauvieilh, & Boudouda) was used to assess anxiety (Beck, Epstein, Brown, & Steer, 1988).

The GHS scale was developed as a proxy for disease burden to assess comorbid medical conditions that may affect outcomes for participants in the CCMA study (Holtzer et al., 2007; Holtzer, Verghese, Xue, & Lipton, 2006; Verghese et al., 2007). The GHS score serves as an illness summary score (0 – 10), calculated based on dichotomous rating (present or absent) of diabetes, chronic heart failure, arthritis, hypertension, depression, stroke, Parkinson disease, chronic obstructive pulmonary disease, angina, and myocardial infarction.

The GDS (Brink et al., 1982) is a 30-item questionnaire designed to screen for depression within the older adult population. An individual is asked to respond yes/no to each item based on whether the statement reflects how they have felt over the past week. The scale was specifically developed for and validated within a geriatric sample, with targeted items based on characteristics of depression in the elderly (Brink et al., 1982; Yesavage et al., 1982). The GDS has high internal consistency and validity, discriminating between normal, mildly depressed, and severely depressed groups (Yesavage et al., 1982). A cut-off score of 11 had an 84% sensitivity rate and a 95% specificity rate, while a cut-off score of 14 had an 80% sensitivity rate but yielded an 100% specificity rate (Yesavage et al., 1982). A more recent, longitudinal study demonstrated that the GDS captures trait depression, reflecting a stable and enduring depressive trait rather than a transient depressive affect (Gana et al., 2017), which further supports its construct validity.

The BAI (Beck et al., 1988) is a 21-item scale in which an individual is asked to rate how bothered they are by each listed anxiety symptom (0=Not at all, 1=Mildly, but didn't bother me much, 2= Moderately, it wasn't pleasant at times, 3=Severely, it bothered me a lot) over the past week. Total score ranges from 0 – 63 and cut-off scores associated with clinical severity have been established (0–7 = normal/minimal anxiety, 8–15 = mild anxiety, 16–25 = moderate anxiety, and 26–63 = severe anxiety) (Beck, Epstein, Brown, & Steer, 1993). The BAI discriminated individuals with anxiety from those with depression and demonstrated high internal consistency as well as test-retest reliability (Beck et al., 1988). Moreover, the BAI has been shown to be a valid measure of anxiety within a non-clinical sample (Osman, Kopper, Barrios, Osman, & Wade, 1997) and also specifically in older adults (Morin et al., 1999).

Statistical Analyses

Descriptive statistics were calculated for demographic variables, depression, anxiety, GHS score, falls history, ABC score, and cognitive performance variables. Linear Mixed Effects Models (LMEMs) were used to examine whether baseline balance confidence predicts cognitive decline as well as to examine gender differences in the effect of balance confidence on cognition over time. LMEMs were also used to examine the temporal relationship between changes in balance confidence and cognition over time. Separate models examined balance confidence as a continuous predictor. For Aims 1 and 2, time and subject were entered into the model as fixed variables. Compound symmetry was the selected covariance type. For Aim 3, outcome and covariates were entered as fixed effects, and time along with the interaction between outcome and time were entered as random effects. Covariance structure for the random effects was unstructured and the repeated effects covariance structure was diagonal. Due to the complexity of our data, the diagonal covariance structure was the only covariance structure that allowed the model to converge. Though in many instances a diagonal covariance structure is applied under the assumption of statistically uncorrelated covariance of the repeated effects, in the current study the unstructured covariance structure used for the random effects accounts for the non-independence of the data within persons over time; the repeated effects covariance structure then accounts for the residual variability left after accounting for within person variability.

Aim 1. To determine whether balance confidence (mean score on ABC scale) predicts decline in global cognitive functioning as well as in specific domains of memory and attention/EF. Three separate LMEMs were conducted, one for each cognitive outcome. Time (year of study) served as a within-person repeated measure, while performance on measures of global cognitive function, memory, and attention/EF served as the dependent variables, respectively. Balance confidence served as a between-subjects variable and was examined as a continuous variable. The moderating effects of balance confidence were tested in separate LMEMs via two-way interactions of time x balance confidence.

Aim 2. To determine whether gender moderates the relationship between balance confidence and decline in global cognitive functioning as well as in specific domains of memory and attention/EF. Six separate LMEMs were conducted: two for each cognitive outcome, one including only males and the other including only females. Time (year of study) served as a within-person repeated measure, while performance on measures of global cognitive function, memory, and attention/EF served as the dependent variables, respectively. Balance confidence served as a between-subjects variable and was examined as a continuous variable. The moderating effects of balance confidence were tested in six separate LMEMs via two-way interactions of time x balance confidence.

Aim 3. To determine whether change in balance confidence over time correlates with changes in global cognitive function, memory, and attention/EF. A multivariate growth model using the linear mixed effects commands in SPSS was conducted to compare the growth curves of balance confidence and each of the three cognitive outcomes. Time (year of study) served as a within-person repeated measure. Performance on measures of balance confidence, global cognitive function, memory, and attention/EF served as the dependent variables. Using the method described by Hoffman (Hoffman, 2015) and Curran, McGinley, Serrano and Burfeind (Curran, McGinley, Serrano, & Burfeind, 2012), multiple outcomes (balance confidence and the three composite measures of cognitive functioning, respectively) were represented by dummy variables which enabled computation of the covariance of the two growth curves, leading to calculation of the correlation between the two curves. Covariance structures used were unstructured for the random effects of time and time x outcome, and diagonal for the within subjects repeated effect of time.

Supplementary Analyses

Sensitivity analyses for attrition. Nearly 160 participants were lost to attrition over the final two years of this study (see *Participant Characteristics* below for detail). In order to assess the impact of attrition on the interaction effects between balance confidence and time on cognitive outcomes, we ran sensitivity analyses in which models were restricted to 5 years of follow-up, rather than 7 years. These sensitivity analyses were conducted in Aims 1, 2, and 3 and mirrored all other aspects of the primary analyses for each aim.

Sensitivity analyses for incident dementia cases. We further conducted sensitivity analyses to understand whether incident dementia cases might be driving the significant moderation effects found in the primary analyses conducted for Aims 1, 2, and 3. Cases were excluded from year of diagnosis and onward (e.g., if dementia diagnosed at year 3, data from years 1 and 2 still included in model). Again, after incident dementia cases were excluded from the dataset, these sensitivity analyses mirrored all other aspects of the LMEMs run for primary analyses.

Sensitivity analyses for potential outliers. Finally, we conducted sensitivity analyses to address non-normal sample distribution of balance confidence scores, presented in Figure 1. Initially, data was log-transformed; however, log-transformation did not mitigate the non-normal distribution, as shown in Figure 2, and importantly, did not significantly impact outcomes of the models. Therefore, we also conducted sensitivity analyses in which we excluded outliers from the model. This would help us understand whether significant moderation effects of balance confidence in primary analyses were driven by outliers in the data. Outliers were defined as participants with a balance confidence score of 30% or lower. This was based on visual inspection of the data as use of a standardized outlier threshold such as ≥ 2 SDs below mean would have excluded 31 participants (~6% of the sample). After outliers were excluded from the dataset, these sensitivity analyses mirrored all other aspects of the LMEMs run for primary analyses.

Chapter 3

Results

Participant Characteristics

Five-hundred and ninety-two participants were assessed for eligibility; 64 were excluded for missing data at baseline; 9 were excluded for dementia diagnosis at baseline (year one visit), diagnosed during case conference (N = 519). Therefore, 519 non-demented older adults were included in the analysis for this study. Attrition was gradual over the first 5 years of the study and increased in the last two years of the study, with 191 individuals included in the fifth year of follow-up, 131 in year six, and 33 in year 7. Participants were predominantly female (N = 295/519, 55.66%), with some college education (M=14.57, SD=2.93) (Table 1). Baseline cognitive performance of the total sample was within the normal range (M = 91.71, SD = 11.80). Balance confidence scores of the total sample were high (average of 90.60/100%) based on cut-points established in previous work (Myers et al., 1998). Data was collected for this study from June 2011 to August 2018.

Group differences between females and males for each variable in the study were examined to provide context for Aim 2 models in which gender is a primary predictor variable. Males (M = 15.04, SD = 3.13) had significantly more years of education than females (M = 14.32, SD = 2.61), P =.005. 62.94% of females (180/286) reported fall history compared to 52.36% of males (122/233), P =.015. Females (Mdn = 88.35, IQR = [76.20-94.55]) also endorsed lower balance confidence than males (Mdn = 93.10, IQR = [85.60-97.500]), P <.001. Females (Mdn = 3.00, IQR = [1.00-7.00]) endorsed more symptoms of anxiety than males (Mdn = 2.00, IQR = [0.00-4.00]), P <.001. However, females (M = 96.68, SD = 10.35) had higher baseline memory performance than males (M = 93.90, SD = 9.12), P =.001 as well as higher baseline performance on three measures of attention/EF as follows. On a letter fluency test, females (M = 0.22, SD = 1.16) performed better than males (M = -0.01, SD = 1.13), *P* =.023; on a category fluency test, females (M = 0.39 SD = 1.27) performed better than males (M = -0.04 SD = 1.25), *P* <.001; and on a digit symbol substitution test, females (M = -0.00, SD = 0.99) performed better than males (M = -0.21, SD = 1.02), *P* =.021. Males and females did not significantly differ in age, depression score (GDS), physical health (GHS), global cognition (RBANS total index), or in performance on two cognitive test scores (Trails A & B). Demographics for the entire sample as well as group demographics for males and females, respectively, are summarized in Table 1.

Insert Table 1

Outcomes

Impact of Balance Confidence on Cognitive Functioning Over Time

Results Aim 1: Impact of baseline balance confidence on global cognitive performance and on performance in specific domains of memory and attention/EF over 7 years of follow-up. In Aim 1 we aimed to examine the effect of balance confidence on change in cognitive performance over time. Results of the adjusted LMEMs used to examine the potential moderating effects of balance confidence on the relationship between time and cognitive performance are presented in Table 2. There was a main effect of time on global cognition (estimate = 0.03, $p < .001$) and memory (estimate = 0.06, $p < .001$) such that, on average, participants tended to improve their performance in these domains over time. There was also a significant main effect of age on global cognition (estimate = -0.03, $p < .001$), memory (estimate = -0.04, $p < .001$), and attention/EF (estimate = -0.02, $p < .001$) indicating that older participants tended to have worse cognitive performance. Main effects of education also showed that those with fewer years of education had worse performance across cognitive outcomes of global cognition (estimate = 0.07, $p < .001$), memory (estimate = 0.07, $p < .001$), and attention/EF (estimate = 0.07, $p < .001$). There was a main effect of gender indicating that females performed better in global cognition (estimate = 0.12, $p = .015$), memory (estimate = 0.27, $p < .001$) and attention/EF (estimate = 0.17, $p = .001$). Additionally, main effects of depression were evident indicating that those with more depressive symptoms had lower performance in global cognition (estimate = -0.01, $p = .004$) and memory (estimate = -0.01, $p = .010$) performances but not attention/EF. A significant two-way interaction between time and balance confidence partially confirmed our hypothesis for two of the three cognitive outcomes; balance confidence moderated the effect of time on global cognition (estimate < 0.01, $p = .023$) and the effect of time on memory (estimate < 0.01, $p = .036$) but not on attention/EF. However, while our hypothesis suggested that low balance confidence would predict worse cognitive decline, we found that in the context of a positive main effect of time in which participants learned over repeated sessions, those with lower balance confidence showed an attenuated improvement in their global cognition and memory performances compared to those with higher balance confidence. On average, decline in cognitive performance over time was not evident.

Insert Table 2

Results of sensitivity analyses for the impact of baseline balance confidence on global cognitive performance and on performance in specific domains of memory and attention/EF

<u>Attrition</u>. We conducted sensitivity analyses for Aim 1 to address significant attrition over the last two years of the study described above. Results of the adjusted LMEMs used to examine the potential moderating effects of balance confidence on the relationship between time and cognitive performance over 5 years are presented in Table 3. When models were restricted to 5 years of follow-up, there was again a significant positive main effect of time on global cognition (estimate = 0.03, $p < .001$), memory (estimate = 0.06, $p < .001$), and attention/EF (estimate = 0.01, $p = .029$) indicating improved cognitive performance over time. Significant main effects of age on global cognition (estimate = -0.03, $p < .001$), memory (estimate = -0.04, $p < .001$), and attention/EF (estimate = -0.02, $p < .001$) show that older participants have lower cognitive performance. Significant main effects of education across global cognition (estimate = 0.07, $p < .001$), memory (estimate = 0.07, $p < .001$), and attention/EF (estimate = 0.07, $p < .001$) show that those with fewer years of education also had worse cognitive outcomes. Significant main effects of gender indicated that females performed better on tests of global cognition (estimate = 0.11, $p = .017$), memory (estimate = 0.27, $p < .001$), and attention/EF (estimate = 0.16, $p = .001$) compared to males. Additionally, main effects of depression were evident indicating that those with more depressive symptoms had lower performance in global cognition (estimate = -0.01, $p = .003$) and memory (estimate = -0.01, $p = .008$) performances but not attention/EF. There was a significant two-way interaction between time and balance confidence for global cognition and memory, respectively, indicating that balance confidence moderated the effect of time on global cognition (estimate < 0.01, $p = .007$) and memory (estimate < 0.01, $p = .014$), but not attention/EF. Again, within the context of a positive main effect of time, those with lower balance confidence showed an attenuated increase in cognitive performance in global cognition and memory over time. In sum, results from primary analyses persisted when models were restricted to 5 years and significant interaction effects strengthened.

Insert Table 3

***Incident Dementia*.** We further conducted sensitivity analyses to understand whether incident dementia cases might be driving the significant moderation effects found in Aim 1. Cases were excluded from year of diagnosis and onward (e.g., if dementia diagnosed at year 3, data from years 1 and 2 still included in model). Results of the adjusted LMEMs used to examine the potential moderating effects of balance confidence on the relationship between time and cognitive performance over 7 years after excluding incident cases of dementia are presented in Table 4. When models excluded incident dementia cases, there was a main effect of time indicating that in general, participants improved their performance on measures of global cognition (estimate = 0.04, $p < .001$) and memory (estimate = 0.07, $p < .001$) over time, but not on measures of attention/EF. Significant main effects of age on global cognition (estimate = -0.03, $p < .001$), memory (estimate = -0.04, $p < .001$), and attention/EF (estimate = -0.02, $p < .001$) show that older participants have worse cognitive performance. Significant main effects of education across global cognition (estimate = 0.07, $p < .001$), memory (estimate = 0.07, $p < .001$), and attention/EF (estimate = 0.07, $p < .001$) show that those with fewer years of education also had worse cognitive outcomes. Significant main effects of gender indicated that females tended to perform better on tests of global cognition (estimate = 0.12, $p = .009$), memory (estimate = 0.23, $p = .001$), and attention/EF (estimate = 0.17, $p < .001$) compared to males. Additionally, main effects of depression were evident indicating that those with more depressive symptoms had lower performance in global cognition (estimate = -0.01, $p = .022$) and memory (estimate = -0.01, $p = .055$) performances but not attention/EF. While main effects from primary analyses persisted, there was no significant two-way interaction between time and balance confidence for any cognitive outcome in this set of sensitivity analyses.

Insert Table 4

Outliers. Finally, we conducted sensitivity analyses to address the non-normal sample distribution of balance confidence scores, presented in Figure 1. Outliers were defined as participants with a balance confidence score of 30% or lower. This was based on visual inspection of the data as use of a standardized outlier threshold, such as ≥ 2 SDs below the mean, would have excluded 31 participants (~6% of the sample). As shown in Figure 3, exclusion of outliers improved the sample distribution though did not make it normally distributed. Results of the adjusted LMEMs used to examine the potential moderating effects of balance confidence on the relationship between time and cognitive performance over 7 years after excluding participants with ABC scores of 30 or lower are presented in Table 5. Three participants were considered outliers in these sensitivity analyses.

When models excluded outliers, there was a main effect of time indicating that participants tended to improve their performance over repeated sessions on measures of global cognition (estimate = 0.03, $p < .001$) and memory (estimate = 0.06, $p < .001$), but not attention/EF. Significant main effects of age on global cognition (estimate = -0.03, $p < .001$), memory (estimate = -0.05, $p < .001$), and attention/EF (estimate = -0.02, $p < .001$) show that older participants have worse cognitive performance. Significant main effects of education across global cognition (estimate = 0.07, $p < .001$), memory (estimate = 0.07, $P < .001$), and attention/EF (estimate = 0.07, $P < .001$) show that those with fewer years of education also had worse cognitive performance. Significant main effects of gender indicated that females tended to perform better on tests of global cognition (estimate = 0.12, $p = .009$), memory (estimate = 0.28, $p < .001$), and attention/EF (estimate = 0.17, $p = .001$) compared to males. Main effects of depression were also evident indicating that participants with more depressive symptoms performed worse on measures of global cognition (estimate = -0.01, $p = .004$) but not on measures of memory or attention/EF. Consistent with findings from primary analyses, there was a significant two-way interaction between time and balance confidence for global cognition and memory, respectively, indicating that, even after outliers were excluded from the models, balance confidence moderated the effect of time on global cognition (estimate < 0.01, $p = .031$) and memory (estimate < 0.01, $p = .038$), but not attention/EF. Again, within the context of a positive main effect of time, those with lower balance confidence showed an attenuated increase in cognitive performance in global cognition and memory over time. Results from these analyses did not significantly differ from primary analyses.

Insert Figure 1

Insert Figure 2

Insert Figure 3

Insert Table 5

Impact of Balance Confidence on Cognitive Functioning Over Time, Stratified by Gender

Results Aim 2: Effect of Gender on the relationship between baseline balance confidence and global cognitive performance and performance in specific domains of memory and attention/EF over 7 years of follow up.

In Aim 2 we aimed to determine whether gender moderates the effect of balance confidence on cognitive performance over time. Data was stratified by gender and separate LMEMs were run for males and females. Results of the adjusted LMEMs used to examine potential gender differences in the impact of balance confidence on cognition over time are presented in Tables 6A (females) and 6B (males).

Results from models including only females are presented first (Table 6A). Consistent with the results of non-stratified models reported in Aim 1, there was a significant positive main effect of time on global cognition (estimate = 0.05, $p = .001$) and memory (estimate = 2.58, $p < .001$) such that females tended to improve their performance in these domains over time. There was also a significant main effect of age on global cognition (estimate = -0.03, $p < .001$), memory (estimate = -0.04, $p < .001$), and attention/EF (estimate = -0.02, $p < .001$) indicating that older females tended to have worse cognitive performance. Main effects of education also showed that those with fewer years of education had worse performance across cognitive outcomes of global cognition (estimate = 0.06, $p < .001$), memory (estimate = 0.06, $p < .001$), and attention/EF (estimate = 0.06, $p < .001$). Females showed significant main effects of depressive symptoms indicating that those endorsing more symptoms of depression tended to perform worse on measures of global cognition (estimate = -0.01, $p = .039$) and memory (estimate = -0.01, $p = .034$), but not attention/EF. A significant two-way interaction indicated that in females, balance confidence moderated the effect of time on global cognition (estimate = 0.00, $p = .002$), on memory (estimate < 0.01, $p = .027$) and on attention/EF (estimate < 0.01, $p = .003$). Of note, this moderation effect is again within the context of a positive main effect of time indicating that, consistent with results from the total sample in Aim 1, females with worse balance confidence showed an attenuated improvement in cognitive performance over time compared to those with higher balance confidence but, on average, did not show decline from baseline.

Results from models including only males are presented second (Table 6B). A significant positive main effect of time was seen only on memory (estimate = 0.04, $p = .001$) for males. There was a significant main effect of age on global cognition (estimate = -0.03, $p < .001$), memory (estimate = -0.04, $p < .001$), and attention/EF (estimate = -0.02, $p = .002$) indicating that older males tended to have worse cognitive performance. Main effects of education also showed that those with fewer years of education had worse performance across cognitive outcomes of global cognition (estimate = 0.08, $p < .001$), memory (estimate = 0.08, $p < .001$), and attention/EF (estimate = 0.08, $p < .001$). For males, there was no significant two-way interaction between balance confidence and time for any cognitive outcome. This provides evidence in support of our hypothesis that the moderating effect of balance confidence on the relationship between time and cognition was stronger in females than in males.

Insert Table 6A

Insert Table 6B

Results of sensitivity analyses for the effect of gender on the relationship between balance confidence and cognitive performance on measures of global cognition, memory, and attention/EF

Attrition. We conducted sensitivity analyses for Aim 2 in symmetry with those conducted for Aim 1. The first set of sensitivity analyses addresses significant attrition over the last two years of the study described earlier. Results of the adjusted LMEMs used to examine the potential moderating effects of balance confidence on the relationship between time and cognitive performance over 5 years in females and males are presented in Tables 7A and 7B, respectively. Results for females will be described first.

In females, when models were restricted to 5 years of follow-up, there was a significant positive main effect of time on global cognition (estimate = 0.05, $p < .001$), memory (estimate = 0.08, $p < .001$), and attention/EF (estimate = 0.02, $p = .017$) indicating improved cognitive performance over time. Significant effects of age on global cognition (estimate = -0.03, $p < .001$), memory (estimate = -0.04, $p < .001$), and attention/EF (-0.02, $p < .001$) show that older participants have worse cognitive performance. Significant main effects of education across global cognition (estimate = 0.06, $p < .001$), memory (estimate = 0.06, $p < .001$), and attention/EF (estimate = 0.06, $p < .001$) show that those with fewer years of education also had worse cognitive outcomes. There was a significant two-way interaction between time and balance confidence for global cognition (estimate < 0.01, $p = .013$) and attention/EF (estimate < 0.01, $p = .047$) indicating that in females, balance confidence moderated the effect of time on cognitive performance in these domains. The interaction did not reach the significance threshold for memory but was approaching significance (estimate < 0.01, $p = .066$).

In males, when models were restricted to 5 years of follow up, there was a main effect of time on memory only (estimate = 0.04, $p = .006$) indicating improved memory performance over time. There was also a slightly significant main effect of balance confidence on attention/EF in males (estimate < 0.01, $p = .046$). Main effects of age were significant for global cognition (estimate = -0.03, $p < .001$), memory (estimate = -0.04, $p < .001$), and attention/EF (estimate = -0.02, $p = .005$), again indicating that older participants had worse cognitive performance. Main effects of education demonstrated that males with more years of education had higher scores on measures of global cognition (estimate = 0.08, $p < .001$), memory (estimate = 0.08, $p < .001$), and attention/EF (estimate = 0.08, $p < .001$). Those with increased symptoms of depression had worse outcomes for global cognition (estimate = -0.01, $p = .030$) but not for memory or attention/EF. There was a significant two-way interaction between time and balance confidence for global cognition (estimate < 0.01, p = .026) and memory (estimate < 0.01, p = .005) indicating that in males, balance confidence moderated the effect of time on cognitive performance in these domains. These significant two-way interactions are discrepant from the non-significant findings in primary analyses described above and provide less support for our hypothesis that moderation effects of balance confidence on the relationship between time and cognition would be stronger in females.

In sum, results from models restricted to 5 years were inconsistent with those from primary analysese. Significant interaction effects in females weakened for all cognitive outcomes and lost significance for memory and interaction effects in males now met the threshold for significance for global cognition and memory outcomes.

Insert Table 7A

Insert Table 7B

Incident Dementia. We also conducted sensitivity analyses to examine whether incident dementia cases were impacting the strength of significance in the two-way interactions found in Aim 2 (for females). Results of the adjusted LMEMs used to examine the potential moderating effects of balance confidence on the relationship between time and cognitive performance after excluding incident cases of dementia in males and females are presented in Tables 8A and 8B, respectively. Results from models including only female participants will be reported first.

In females, when models excluded incident dementia cases, there was a main effect of time indicating that participants tended to improve their performance on measures of global cognition (estimate = 0.05, $p < .001$), memory (estimate = 0.08, $p < .001$), and attention/EF (estimate = 0.02, $p = .010$) over repeated sessions. Significant main effects of age on global cognition (estimate = -0.03, $p < .001$), memory (estimate = -0.04, $p < .001$), and attention/EF (estimate = -0.02, $p < .001$) show that older participants have reduced cognitive performance. Significant main effects of education across global cognition (estimate = 0.06, $p < .001$), memory (estimate = 0.06, $p < .001$), and attention/EF (estimate = 0.06, $p < .001$) show that those with fewer years of education also had worse cognitive outcomes. Those with increased symptoms of depression tended to perform worse on measures of global cognition and memory but not at the significance level of $P \leq .05$. There was a significant two-way interaction between time and balance confidence for global cognition (estimate < 0.01, $p = .031$) and attention/EF (estimate < 0.01, $p = .035$) indicating that, in females, balance confidence moderated the effect of time on cognitive performance in these domains even after incident dementia cases were excluded. However, in contrast to Aim 2 primary analyses, the two-way interaction was not significant for memory.

In males, when models excluded incident dementia cases, there was a significant main effect of time on global cognition (estimate = 0.02, $p = .009$) and memory (estimate = 0.05, $p < .001$) but not on attention/EF. Significant main effects of age on global cognition (estimate = -0.03, $p < .001$), memory (estimate = -0.04, $p < .001$) and attention/EF (estimate = -0.02, $p = .002$) indicated that older participants had worse cognitive performance. Significant main effects of education across global cognition (estimate = 0.08, $p < .001$), memory (estimate = 0.08, $p < .001$), and attention/EF (estimate = 0.08, $p < .001$) show that those with more years of education also had better cognitive performance. There were no significant effects of depressive symptoms on cognition in these models. In males, when models excluded incident dementia cases, there were no significant two-way interactions between balance confidence and time for any cognitive outcome.

In sum, when models excluded incident dementia cases, significant interaction effects in females from primary analyses persisted for global cognition and attention/EF, but not memory, while all interaction effects remained non-significant in males.

Insert Table 8A

Insert Table 8B

Outliers. We lastly conducted sensitivity analyses to examine whether outlier balance confidence scores (ABC≤ 30) were impacting the strength of significance in the two-way interaction found in Aim 2 (for females). Results of the adjusted LMEMs used to examine the potential moderating effects of balance confidence on the relationship between time and cognitive performance over 7 years in males and females after excluding participants with ABC scores of 30 or lower are presented in Tables 9A and 9B, respectively. Results for models including only females are reported first.

In females, when models excluded participants with balance confidence scores of 30 or lower, there was a main effect of time indicating that participants tended to improve their performance over repeated sessions in global cognition (estimate = 0.05, $p < .001$), memory (estimate = 0.08, $p < .001$), and attention/EF (estimate = 0.02, $p = .045$). Significant main effects of age on global cognition (estimate = -0.03, $p < .001$), memory (estimate = -0.04, $p < .001$), and attention/EF (estimate = -0.02, $p < .001$) show that older participants have worse cognitive performance. Significant main effects of education across global cognition (estimate = 0.07, $p < .001$), memory (estimate = 0.07, $P < .001$), and attention/EF (estimate = 0.06, $P < .001$) show that those with more years of education also had better cognitive performance. Main effects of depression were also evident indicating that participants with more depressive symptoms performed worse on measures of global cognition (estimate = -0.01, $p = .042$) and memory (estimate = -0.01, $p = .034$) but not attention/EF. There was a significant two-way interaction between time and balance confidence for global cognition (estimate < 0.01, $p = .004$), memory (estimate < 0.01, $p = .027$), and attention/EF (estimate < 0.01, $p = .004$) indicating that, in females, balance confidence moderated the effect of time on cognitive performance in these domains even after outliers were excluded.

In males, results were the same as those reported in the primary analysis as all outlier participants were female; there were no significant two-way interactions between balance confidence and time for any cognitive outcome.

In sum, results from models excluding outliers did not significantly differ from primary analyses.

Insert Table 9A

Insert Table 9B

Linear Growth Trajectories of Balance Confidence and Cognitive Functioning

Results Aim 3: Comparison of growth trajectories of balance confidence with global cognitive performance and with performance in specific domains of memory and attention/EF over 7 years of follow-up.

In Aim 3 we aimed to examine whether change in balance confidence over time correlates with changes in cognitive performance. Results of the adjusted multivariate growth models used to examine the covariances between rates of change in balance confidence and in each cognitive measure over 7 years are presented in Supplementary Table 1. Correlation (*r*) values were calculated from covariance and variance values extracted from model. A linear, as opposed to a quadratic, equation best fit the longitudinal data and so growth trajectories of the two variables were measured linearly. There was a positive correlation between the slopes of balance confidence scores and slopes of global cognitive ($r = .36$, $p < .001$), memory ($r = .29$, $p < .001$), and attention/EF ($r = .31$, $p < .001$) scores over 7 years. However, since balance confidence was decreasing over time and cognitive performance tended to improve over time, a straightforward interpretation of ‘positive correlation’ does not quite explain the data. Instead, the positive correlation can be understood as an association between the rates of change in each variable; those with the most positive slope in balance confidence have the most positive slope in cognitive performance. In other words, a lesser decrease in balance confidence over 7 years is significantly associated with a greater increase in cognitive performance. Within the context of the positive main effect of time we saw in previous aims, these findings demonstrate that not only is baseline balance confidence predictive of change in cognitive performance over time but that the growth trajectory of balance confidence over time covaries with that of cognitive performance.

Insert Supplementary Table 1

Results of sensitivity analyses for the comparison of growth trajectories of balance confidence with global cognitive performance and with performance in specific domains of memory and attention/EF

***Attrition*.** We conducted sensitivity analyses in symmetry with Aims 1 and 2 to address significant attrition in the final two years of the study. Results of the adjusted multivariate growth model used to examine the covariances of the slopes for balance confidence and cognitive performance over 5 years are presented in Supplementary Table 2. When models were restricted to 5 years of follow-up, there was again a significant positive correlation between the slopes of balance confidence scores and slopes of global cognitive (r = .35, p < .001), memory (r = .29, p < .001), and attention/EF (r = .32, p < .001) scores.

Insert Supplementary Table 2

***Incident Dementia*.** We further conducted sensitivity analyses to understand whether significant effects found in the primary analyses were influenced by individuals diagnosed with dementia over the course of the study. Results of the adjusted multivariate growth model used to examine the covariances of the slopes for balance confidence and cognitive performance after excluding incident dementia cases are presented in Supplementary Table 3. Significant associations persisted even after excluding these participants from the model. There was a significant positive correlation between the slopes of balance confidence scores and slopes of global cognitive (r = .31, $p < .001$), memory (r = .24, p = .004), and attention/EF (r = .24, p = .003) scores over 7 years.

Insert Supplementary Table 3

***Outliers*.** Sensitivity analyses were also conducted to address non-normal distribution of balance confidence scores in our sample. Results of the adjusted multivariate growth model used to examine the covariances of the slopes for balance confidence and cognitive performance after excluding outliers are presented in Supplementary Table 4. After excluding outliers from the model, significant positive correlations between the slopes of balance confidence scores and the slopes of global cognitive (r = .36, p < .001), memory (r = .29, p < .001), and attention/EF (r = .31, p < .001) scores remained.

In sum, results from all sensitivity analyses were consistent with findings from primary analyses.

Insert Supplementary Table 4

Chapter 4

Discussion

Balance confidence is introduced in the older adult literature as a means of operationalizing fear of falling (FOF), a construct associated with reduced sense of self-efficacy, ability to perform activities of daily living, and overall quality of life for older adults both with and without a falls history (Donoghue et al., 2017; Whipple et al., 2018). Balance confidence is assessed using the Activities-specific Balance Confidence (ABC) Scale (Powell & Myers, 1995) which has been shown to be the most sensitive measure of FOF, capturing high functioning individuals who are still at increased risk of falling due to poor balance confidence (Powell & Myers, 1995). Balance confidence assessed by the ABC scale is strongly linked with physical functioning and falls history and has been shown to predict falls in older adults at least as well as physical measures (Landers et al., 2016). Notably, balance confidence assessed by the ABC scale is strongly linked with gait impairment (Herman et al., 2005), incident falls (Moiz et al., 2017), and overall physical functioning (Myers et al., 1998), which are significantly linked with cognitive decline (Cohen et al., 2016; Montero-Odasso & Speechley, 2018).

Our recent work (Kraut & Holtzer, 2021) demonstrated that persistent, but not single report, of FOF significantly predicts cognitive decline in healthy older adults in areas of global cognitive function, memory, and attention/executive functions. These findings emphasized that how FOF is assessed can impact study outcomes. In that study, FOF was assessed via a single question “Do you have a fear of falling?”. Additionally, falls efficacy assessed by the Falls Efficacy Scale (FES) (Tinetti et al., 1990) was associated with greater attention variability (O'Halloran et al., 2011) and balance training has been shown to improve performance in cognitive domains of memory and spatial orientations in adults (Rogge et al., 2017).

To our knowledge, no study has examined the relationship between balance confidence assessed with the ABC scale and cognitive functioning in healthy older adults. Given that persistence of FOF endorsement moderated the relationship between FOF and cognitive decline, and since the ABC scale captures severity of FOF, examining the relationship between balance confidence assessed by the ABC scale and cognitive decline might offer an avenue to understand not only how persistence of FOF endorsement impacts cognitive outcomes but also how severity of FOF impacts cognitive outcomes. Moreover, it would be useful to understand not only whether balance confidence predicts cognitive decline but also how change over time in balance confidence might correlate with change over time in cognition to better understand the nature of the association between the two constructs. Since memory and attention/executive functions are implicated in cognitive decline associated with normal aging (Oschwald et al., 2019) these would be important to examine in addition to global cognition.

Notably, significant gender differences exist in FOF. Females have been shown to endorse FOF more often than males and also have a higher number of incident falls (Chang et al., 2016; Myers et al., 1996). Specifically, females report lower balance confidence and in turn demonstrate associated impairments in functional performance (Ko et al., 2009; LeBouthillier et al., 2013). Females also demonstrate higher gait variability under dual task conditions, associated with increased falls risk (Johansson et al., 2016). In sum, females have higher rates of incident falls and gait variability and higher rates of FOF as well as lower balance confidence. Therefore, the possible moderating role of gender in the relationship between balance confidence and cognition was investigated as well. Thus, the present study aimed to examine how individual differences related to gender and balance confidence may put some older adults at greater risk for cognitive decline than others.

Summary of General Findings

The study sample included 519 non-demented, community-dwelling older adults (≥65 years of age) from the Central Control of Mobility in Aging (CCMA) study at Albert Einstein College of Medicine in Bronx, New York. Participants completed a questionnaire assessing confidence in their ability to perform specific physical activities without losing their balance (ABC scale; Powell, 1995), neuropsychological and psychological assessments, as well as questionnaires about their medical and fall history. Baseline cognitive performance of the total sample was within the normal range (M = 91.71, SD = 11.80). Balance confidence scores of the total sample were high (average of 90.60/100%) based on clinical cut-points established in previous work (Myers et al., 1998). Our results showed that over repeated annual visits, participants tended to improve their performance on measures of global cognition and memory, but that those with lower balance confidence demonstrated an attenuated improvement compared to those with higher balance confidence over 7 years of follow-up. Consistent with previous studies (Chang et al., 2016; Myers et al., 1996), females in our sample endorsed significantly lower balance confidence than males. As predicted, when models were stratified by gender, the moderation effect of balance confidence on the relationship between time and cognition seen in the total sample was stronger in females than in males; however, mixed findings seen in sensitivity analyses warrant further investigation. Per our exploratory aim, when the growth trajectories of balance confidence and the three respective cognitive outcomes were compared within individual models, changes over time in balance confidence significantly correlated with changes over time in cognitive performance.

Summary of Results: Moderating Effect of Balance Confidence on Relationship Between Time and Cognitive Functioning

Overall, we found significant moderating effects of balance confidence on the relationship between time and global cognition and memory, but not attention/EF, over 7 years of follow-up. Positive main effects of time on global cognition and memory indicated that all participants tended to improve their cognitive performance over time and significant interaction effects between time and balance confidence demonstrated that participants with lower baseline balance confidence improved significantly less than those with higher baseline balance confidence. These results partially supported our hypotheses regarding the impact of balance confidence on cognitive outcomes; firstly, we expected balance confidence to impact performance on attention/EF measures and it did not, and secondly, we predicted cognitive decline in those with lower balance confidence whereas, on average, they still improved their performance over time, just with an attenuated increase compared to those with higher balance confidence. Findings from our previous work (Kraut & Holtzer, 2021) showed that, in a slightly smaller sample (N=421) from the same cohort of older adults, when FOF was assessed using a single question “Do you have a fear of falling?”, those with persistent FOF endorsement demonstrated cognitive decline over 6 years of follow-up. To that end, we expected a similar trend of decline when FOF was assessed using the ABC-scale, which has been shown to be a more sensitive measure of FOF compared to a single question, especially in high-functioning older adults like those in our sample (Hatch et al., 2003).

Sensitivity analyses were designed to investigate possible effects of attrition, incident dementia, and non-normal distribution of balance confidence scores on longitudinal associations between balance confidence and cognitive function. Results were not materially different when models were restricted to 5 years of follow-up. Moderation effects were non-significant for all cognitive outcomes in models that excluded incident dementia cases. These findings suggest that those converting to dementia over the course of the study may be driving the significant moderation effects of balance confidence. Lastly, moderation effects of balance confidence in global cognition and memory remained significant in models that excluded outliers. It should be noted that there is no evidence to suggest that outlier data was erroneous but rather outlier ABC scores were well below the mean, and we wanted to understand whether these three much lower scores were significantly affecting significant interaction effects in the model. Given the attrition in the last two years of the study, we further investigated whether outliers impacted longitudinal associations between balance confidence and cognition over 5, rather than 7 years. We found that when we excluded outliers after restricting models to 5 years of follow-up, significant moderation effects found in primary analyses persisted, indicating that outlier scores were likely not driving the longitudinal associations between balance confidence and cognition in primary analyses.

With regard to potential mechanisms underlying the effect of balance confidence on cognition we should consider the shared neural networks involved in cognition and mobility. The same frontal networks of the brain recruited for ambulation and postural stability are key for aspects of higher order cognitive functions. Impaired cognitive functioning, specifically frontally mediated activity, impedes the necessary allocation of attentional resources to meet the demands of postural and gait stability and can lead to an increased risk of falling (Woollacott & Shumway-Cook, 2002). The increased gait variability and decreased control of gait can further result in a person feeling less stable while walking and developing FOF, without having ever fallen (Ayoubi et al., 2015). The theory here is that FOF is an early expression of gait and mobility decline. In our rationale for the current study, we described reasons to believe this relationship may be bidirectional, suggesting that not only is cognitive decline a risk factor for FOF but that FOF may be a risk factor for cognitive decline. To that end, and given the literature showing frontal network involvement in aspects of both cognition and mobility, perhaps FOF is also an early expression of frontal network changes associated with risk for cognitive decline. Neuroimaging and gait assessment was beyond the scope of the current study but would provide helpful context to shed light on potential mechanisms for our findings.

Alternatively, the potential etiologic contribution of activity restriction to the effect of balance confidence on cognition should be considered. As described earlier, increased FOF is associated with increased activity restriction which is in turn associated with worse cognitive (Cunningham, O'Sullivan, Caserotti & Tully, 2020) and functional (Donoghue et al., 2017) outcomes. Relatedly, participants in our sample with more baseline depressive symptoms, also associated with activity restriction (Smith, Gardner, Fisher & Hamer, 2015), tended to have worse cognitive outcomes. In that vein, it would also be important to consider activity restriction, not accounted for in the current study, as a possible mechanism for our findings.

Summary of Results: Differential Effects of Balance Confidence on Cognitive Functioning Over Time in Males Vs Females

Given increased frequency of FOF endorsement (Chang et al., 2016) and incident falls (Stenhagen, Nordell, & Elmståhl, 2013) in females compared to males, in addition to report of lower balance confidence (Ko et al., 2009) and increased gait variability associated with fall risk (Johansson et al., 2016) in females, the second aim of the study examined whether balance confidence differentially affected cognitive performance in females versus males over time. In the context of a general trend of improved cognitive performance over time also seen in Aim 1, we found that females, but not males, with lower balance confidence demonstrated an attenuated improvement in global cognition, memory, and attention/EF over 7 years of follow-up, compared to those with higher balance confidence.

We conducted sensitivity analyses in symmetry with those described for Aim 1, above. To our surprise, when models were restricted to 5 years of follow-up to address possible effects of attrition, significance of interaction effects in females weakened and, for the memory outcome, fell below the threshold for significance. In contrast, significance of interaction effects in males strengthened and, for global cognition and memory, surpassed the threshold for significance. The ratio of females to males did not change significantly in the final two years of the study excluded from these analyses. We do not have an explanation for why exclusion of data from years 6 and 7 minimized the gender differences seen in primary analyses. Of note, males did have significantly lower baseline memory performance compared to females.

When models excluded incident dementia cases, we saw a similar trend in females, where the longitudinal association between balance confidence and memory was no longer significant. However, as seen in primary analyses, interaction effects for all cognitive outcomes remained non-significant for males. Finally, moderation effects remained significant for all cognitive outcomes in females when outliers were excluded from models. All three outlier participants were female and so male models were the same as those in primary analyses with all interaction effects remaining non-significant.

Together, these findings suggest that balance confidence does more strongly moderate the effect of time on cognitive functioning in females compared to males. This moderation effect persisted even after those converting to dementia were excluded from the analyses, where lower balance confidence remained a significant risk factor for decline in global cognition and attention/EF in females. While our findings are consistent with previously described literature demonstrating female gender as a risk factor for incident falls and FOF (Chang et al., 2016; Myers et al., 1996), literature exploring gender differences that may underlie these findings is limited. One study suggested that limited postural control of females under conditions that stress balance (e.g., deprivation of visual or somatosensory inputs) might explain their greater incident falls frequency (Wolfson, Whipple, Derby, Amerman & Nashner, 1994). If future studies were to confirm these findings, perhaps a difference in postural control would contribute to a difference in FOF, too.

Summary of Results: Covariance of Balance Confidence and Cognitive Functioning Over Time

To better understand the nature of the relationship between balance confidence and cognition in older adults we examined whether changes over time that occurred in the two variables were correlated. Overall, we found that there was a positive correlation between the slope of balance confidence scores and slopes of global cognitive functioning, memory, and attention/EF, respectively, over 7 years. As this was an exploratory aim, we did not have a hypothesis regarding the outcome. However, results from these analyses fit well into the narrative from our Aim 1 findings. Given that over the course of this longitudinal study we see a learning effect, a bigger change in cognitive performance over time means greater improvement; those with the most positive slopes for cognitive performance over time showed the biggest improvement. At the same time, a smaller change in balance confidence score indicates less decline; those with the most positive slopes for balance confidence scores over time showed the least decreases in balance confidence. Consistent with our Aim 1 findings indicating that those with lower baseline balance confidence show attenuated improvement in cognitive performance over time, these findings suggest that those who decreased the most in balance confidence over time improved the least in cognitive performance over time.

Limitations, Strengths, and Future Directions

Strengths of this study include the relatively large sample size and the length of follow-up, as well as multivariate analyses accounting for several possible confounders including but not limited to history of falls and anxiety. Clinical characterization of population was carefully considered and balance confidence, used as a proxy for FOF, was assessed using the ABC scale, shown to be sensitive in even high functioning older adults (Powell & Myers, 1995). Moreover, in contrast to previous studies that have examined the effect of FOF on global cognition, this study examined the effect of balance confidence on global cognitive functioning as well as in specific cognitive domains known to be sensitive to aging effects, namely memory and attention/executive functions (Caballero et al., 2020; Park & Festini, 2017). We used a structured and comprehensive battery of neuropsychological tests to characterize cognitive functions in this cohort of community-residing older adults. Normative test scores revealed that, on average, participants performed well within the normal range on multiple cognitive domains. In addition, established diagnostic case conference procedures (Holtzer et al., 2008) were used to exclude dementia cases. Hence, it is unlikely that the longitudinal associations between balance confidence and decline in cognitive functions reported herein were attributable to undiagnosed dementia.

There were also notable limitations of the study. While attrition is common in longitudinal studies and was accounted for in the statistical model used to analyze the data, the drop-off of participants in the later years of the study is a limitation that should be acknowledged. Still, sensitivity analyses demonstrated that most findings remained significant when the last two years of the study were excluded. Our study sample consisted of high functioning individuals who endorsed high balance confidence and as a result the ABC scale scores had a non-normal distribution. Logarithmic transformation did not significantly improve the distribution. Therefore, we also conducted sensitivity analyses in which we excluded outliers from the model and significant results from primary analyses persisted. Future studies should aim to include a sample with a broader range (and ideally a normal distribution) of balance confidence scores. Relatedly, our sample meant to represent the population of community-residing older adults is likely biased toward a higher-functioning subset who not only meet eligibility criteria for the study but who are interested and able to come to our study center to participate. Longitudinal findings indicated a learning effect for cognitive tasks over repeated sessions. As a result, we were unable to characterize cognitive decline that might be occurring in our sample. While our findings show important effects of balance confidence on learning in older adults, future studies might use alternative versions of cognitive tasks across visits to decrease learning effects which would allow for description of cognitive patterns independent of learning. We also note that our findings may have been impacted by a subset of our sample who were diagnosed with dementia over the course of the study. To address this concern, we conducted sensitivity analyses in which incident dementia cases were excluded from the sample. Findings showed that indeed incident dementia cases were driving some significant interaction effects of time and balance confidence on cognitive performance. It would be clarifying to examine in a sample with a broader range of balance confidence scores, whether balance confidence differentially predicts cognitive change in those converting from normal to an MCI vs dementia diagnosis. This would shed light on the clinical utility of balance confidence as a predictor of cognitive outcomes.

Clinical Implications

Balance confidence is a modifiable risk factor. A combination of balance-based exercises and psychotherapy has been shown to most effectively improve balance confidence (Whipple et al., 2018), though isolated balance training shows similarly encouraging results (Myers et al., 1998). Findings from the present study suggest that those with lower balance confidence have worse cognitive outcomes compared to those with higher balance confidence and that those with greater decreases in balance confidence over time also show less improvement in cognitive performance over repeated sessions. In addition to our findings, balance confidence is a useful proxy for physical functioning (Landers et al., 2016) and is a predictor of fall risk (Moiz et al., 2017), both of which are recognized as risk factors for cognitive decline (Cohen et al., 2016; Montero-Odasso & Speechley, 2018). Furthermore, our findings confirm findings from previous studies (Ko et al., 2009) showing lower balance confidence in females compared to males and contribute new findings to suggest that balance confidence predicts worse cognitive outcomes in females but not males. It may be that use of balance confidence assessment to identify individuals that might benefit from targeted interventions would be of greater utility in females than in males. To our knowledge, only one study has examined the effect of balance training on cognition and found that balance-based exercises can improve aspects of spatial cognition and memory (Rogge et al., 2017). Further investigation is needed to clarify the possible effect of balance training on cognitive function as this type of targeted training might serve as a useful early intervention for both physical and cognitive decline.

Conclusion

In sum, findings from the current study contribute to the literature on FOF, balance confidence, and cognitive functioning in several ways. First, our results support existing literature suggesting that females tend to endorse significantly lower balance confidence than males (Ko et al., 2009) and that females are more likely to have history of incident falls compared to males (LeBouthillier et al., 2013). These findings are of clinical significance because both balance confidence (Herman et al., 2005) and incident falls (Moiz et al., 2017) predict gait impairment which, in turn, is associated with cognitive decline (Cohen et al., 2016). Though cognition tends to decline as a function of age (Salthouse, 2010), we seek to better understand the individual differences that put some individuals at greater risk for decline than others. Preliminary findings suggested that FOF assessment may be an important predictor of cognitive decline but that a single question ("do you have a fear of falling?") in isolation may not be a sensitive measure; rather, persistence of FOF endorsement moderated the relationship between time and cognition (Kraut & Holtzer, 2021). As the ABC scale was developed to more sensitively assess FOF (Powell & Myers, 1995), we used this measure to capture balance confidence as a proxy for FOF in the current study and found that balance confidence did in fact moderate the relationship between time and cognition. Not only did baseline balance confidence predict cognitive performance but the growth trajectories of the two variables also covaried over time.

We had mixed findings regarding gender differences in the effect of balance confidence on the relationship between time and cognitive performance. While primary analyses showed that balance confidence significantly predicted cognitive performance in females but not males, results were inconsistent across sensitivity analyses. Still, there does appear to be a trend indicating that balance confidence more significantly contributes to cognitive functioning in females compared to their male peers. Our findings provide evidence to suggest that in addition to being an important clinical indicator of physical functioning (Hatch et al., 2003; Landers et al., 2016), balance confidence is a predictor of cognitive functioning. As a modifiable risk factor (Myers et al., 1998), balance confidence may be a useful construct to assess and treat within the clinical setting.

References

Aita, S. L., Beach, J. D., Taylor, S. E., Borgogna, N. C., Harrell, M. N., & Hill, B. D. (2019). Executive, language, or both? An examination of the construct validity of verbal fluency measures. *Appl Neuropsychol Adult, 26*(5), 441-451. doi:10.1080/23279095.2018.1439830

Ayoubi, F., Launay, C. P., Annweiler, C., & Beauchet, O. (2015). Fear of falling and gait variability in older adults: a systematic review and meta-analysis. *J Am Med Dir Assoc, 16*(1), 14-19. doi:10.1016/j.jamda.2014.06.020

Beck, A. T., Epstein, N., Brown, G., & Steer, R. (1993). Beck anxiety inventory. *Journal of consulting and clinical psychology*.

Beck, A. T., Epstein, N., Brown, G., & Steer, R. A. (1988). An inventory for measuring clinical anxiety: psychometric properties. *J Consult Clin Psychol, 56*(6), 893-897. doi:10.1037//0022-006x.56.6.893

Blazer, D. G., Yaffe, K., & Karlawish, J. (2015). Cognitive Aging: A Report From the Institute of Medicine. *Jama, 313*(21), 2121-2122. doi:10.1001/jama.2015.4380

Bolla, K. I., Gray, S., Resnick, S. M., Galante, R., & Kawas, C. (1998). Category and letter fluency in highly educated older adults. *Clinical Neuropsychologist, 12*(3), 330-338. doi:DOI 10.1076/clin.12.3.330.1986

Borkowski, J. G., Benton, A. L., & Spreen, O. (1967). Word fluency and brain damage. *Neuropsychologia, 5*(2), 135-140.

Brink, T. L., Yesavage, J. A., Lum, O., Heersema, P. H., Adey, M., & Rose, T. L. (1982). Screening tests for geriatric depression. *Clinical gerontologist, 1*(1), 37-43.

Buschke, H., Kuslansky, G., Katz, M., Stewart, W. F., Sliwinski, M. J., Eckholdt, H. M., & Lipton, R. B. (1999). Screening for dementia with the memory impairment screen. *Neurology, 52*(2), 231-231.

Caballero, H. S., McFall, G. P., Wiebe, S. A., & Dixon, R. A. (2020). Integrating Three Characteristics of Executive Function in Non-Demented Aging: Trajectories, Classification, and Biomarker Predictors. *Journal of the International Neuropsychological Society*, 1-14. doi:10.1017/S1355617720000703

Chang, H.-T., Chen, H.-C., & Chou, P. (2016). Factors associated with fear of falling among community-dwelling older adults in the Shih-Pai study in Taiwan. *PLoS One, 11*(3), e0150612.

Cheng, Y.-W., Chen, T.-F., & Chiu, M.-J. (2017). From mild cognitive impairment to subjective cognitive decline: conceptual and methodological evolution. *Neuropsychiatric disease and treatment, 13*, 491-498. doi:10.2147/NDT.S123428

Cohen, J. A., Verghese, J., & Zwerling, J. L. (2016). Cognition and gait in older people. *Maturitas, 93*, 73-77.

Cumming, R. G., Salkeld, G., Thomas, M., & Szonyi, G. (2000). Prospective study of the impact of fear of falling on activities of daily living, SF-36 scores, and nursing home admission. *J Gerontol A Biol Sci Med Sci, 55*(5), M299-305. doi:10.1093/gerona/55.5.m299

Cunningham, C., O'Sullivan, R., Caserotti, P., & Tully, M. A. (2020). Consequences of physical inactivity in older adults: A systematic review of reviews and meta-analyses. Scandinavian journal of medicine & science in sports, 30(5), 816-827.

Curran, P. J., McGinley, J. S., Serrano, D., & Burfeind, C. (2012). A multivariate growth curve model for three-level data.

Donoghue, O. A., Setti, A., O'Leary, N., & Kenny, R. A. (2017). Self-Reported Unsteadiness Predicts Fear of Falling, Activity Restriction, Falls, and Disability. *J Am Med Dir Assoc, 18*(7), 597-602. doi:10.1016/j.jamda.2017.01.022

Duff, K., Humphreys Clark, J. D., O'Bryant, S. E., Mold, J. W., Schiffer, R. B., & Sutker, P. B. (2008). Utility of the RBANS in detecting cognitive impairment associated with Alzheimer's disease: sensitivity, specificity, and positive and negative predictive powers. *Arch Clin Neuropsychol, 23*(5), 603-612. doi:10.1016/j.acn.2008.06.004

Friedman, S. M., Munoz, B., West, S. K., Rubin, G. S., & Fried, L. P. (2002). Falls and fear of falling: which comes first? A longitudinal prediction model suggests strategies for primary and secondary prevention. *J Am Geriatr Soc, 50*(8), 1329-1335. doi:10.1046/j.1532-5415.2002.50352.x

Galvin, J., Roe, C., Powlishta, K., Coats, M., Muich, S., Grant, E., . . . Morris, J. (2005). The AD8: a brief informant interview to detect dementia. *Neurology, 65*(4), 559-564.

Gana, K., Bailly, N., Broc, G., Cazauvieilh, C., & Boudouda, N. E. (2017). The Geriatric Depression Scale: does it measure depressive mood, depressive affect, or both? *Int J Geriatr Psychiatry, 32*(10), 1150-1157. doi:10.1002/gps.4582

Gill, T. M., Robison, J. T., & Tinetti, M. E. (1998). Difficulty and dependence: two components of the disability continuum among community-living older persons. *Annals of Internal Medicine, 128*(2), 96-101.

Grande, G., Triolo, F., Nuara, A., Welmer, A.-K., Fratiglioni, L., & Vetrano, D. L. (2019). Measuring gait speed to better identify prodromal dementia. *Experimental gerontology, 124*, 110625.

Hadjistavropoulos, T., Delbaere, K., & Fitzgerald, T. D. (2011). Reconceptualizing the Role of Fear of Falling and Balance Confidence in Fall Risk. *Journal of aging and health, 23*(1), 3-23. doi:10.1177/0898264310378039

Harada, C. N., Love, M. C. N., & Triebel, K. L. (2013). Normal cognitive aging. *Clinics in geriatric medicine, 29*(4), 737-752.

Hatch, J., Gill-Body, K. M., & Portney, L. G. (2003). Determinants of balance confidence in community-dwelling elderly people. *Phys Ther, 83*(12), 1072-1079.

Henry, J. D., & Crawford, J. R. (2004). A meta-analytic review of verbal fluency performance following focal cortical lesions. *Neuropsychology, 18*(2), 284.

Herman, T., Giladi, N., Gurevich, T., & Hausdorff, J. (2005). Gait instability and fractal dynamics of older adults with a "cautious" gait: why do certain older adults walk fearfully? *Gait Posture, 21*(2), 178-185.

Hjaltadóttir, I., Hallberg, I. R., Ekwall, A. K., & Nyberg, P. (2011). Predicting mortality of residents at admission to nursing home: A longitudinal cohort study. *BMC Health Services Research, 11*(1), 1-11.

Hoffman, L. (2015). *Longitudinal analysis: Modeling within-person fluctuation and change*: Routledge.

Holtzer, R., Friedman, R., Lipton, R. B., Katz, M., Xue, X., & Verghese, J. (2007). The relationship between specific cognitive functions and falls in aging. *Neuropsychology, 21*(5), 540-548. doi:10.1037/0894-4105.21.5.540

Holtzer, R., Kraut, R., Izzetoglu, M., & Ye, K. (2019). The effect of fear of falling on prefrontal cortex activation and efficiency during walking in older adults. *GeroScience, 41*(1), 89-100. doi:10.1007/s11357-019-00056-4

Holtzer, R., Mahoney, J. R., Izzetoglu, M., Wang, C., England, S., & Verghese, J. (2015). Online fronto-cortical control of simple and attention-demanding locomotion in humans. Neuroimage, 112, 152-159.

Holtzer, R., Verghese, J., Wang, C., Hall, C. B., & Lipton, R. B. (2008). Within-person across-neuropsychological test variability and incident dementia. *Jama, 300*(7), 823-830. doi:10.1001/jama.300.7.823

Holtzer, R., Verghese, J., Xue, X., & Lipton, R. B. (2006). Cognitive processes related to gait velocity: results from the Einstein Aging Study. *Neuropsychology, 20*(2), 215-223. doi:10.1037/0894-4105.20.2.215

Holtzer, R., Wang, C., Lipton, R., & Verghese, J. (2012). The protective effects of executive functions and episodic memory on gait speed decline in aging defined in the context of cognitive reserve. *J Am Geriatr Soc, 60*(11), 2093-2098.

Holtzer, R., Wang, C., & Verghese, J. (2014). Performance variance on walking while talking tasks: theory, findings, and clinical implications. *Age, 36*(1), 373-381.

Jayakody, O., Blumen, H. M., Breslin, M., Ayers, E., Lipton, R. B., Verghese, J., & Callisaya, M. L. (2022). Longitudinal associations between falls and future risk of cognitive decline, the Motoric Cognitive Risk syndrome and dementia: the Einstein Ageing Study. *Age Ageing, 51*(3). doi:10.1093/ageing/afac058

Jayakody, O., Breslin, M., Srikanth, V. K., & Callisaya, M. L. (2019). Gait Characteristics and Cognitive Decline: A Longitudinal Population-Based Study. *Journal of Alzheimer's Disease, 71*, S5-S14. doi:10.3233/JAD-181157

Johansson, J., Nordström, A., & Nordström, P. (2016). Greater fall risk in elderly women than in men is associated with increased gait variability during multitasking. *J Am Med Dir Assoc, 17*(6), 535-540.

Jørstad, E. C., Hauer, K., Becker, C., Lamb, S. E., & Group, P. (2005). Measuring the psychological outcomes of falling: a systematic review. *J Am Geriatr Soc, 53*(3), 501-510.

Ko, Y.-M., Park, W.-B., Lim, J.-Y., Kim, K. W., & Paik, N.-J. (2009). Discrepancies between balance confidence and physical performance among community-dwelling Korean elders: a population-based study. *International psychogeriatrics, 21*(4), 738-747. doi:10.1017/S1041610209009077

Kraut, R., & Holtzer, R. (2021). Recurrent but not single report of fear of falling predicts cognitive decline in community-residing older adults. *Aging & Mental Health*, 1-7. doi:10.1080/13607863.2021.1916878

Landers, M. R., Oscar, S., Sasaoka, J., & Vaughn, K. (2016). Balance Confidence and Fear of Falling Avoidance Behavior Are Most Predictive of Falling in Older Adults: Prospective Analysis. *Phys Ther, 96*(4), 433-442. doi:10.2522/ptj.20150184

Lavedan, A., Viladrosa, M., Jurschik, P., Botigue, T., Nuin, C., Masot, O., & Lavedan, R. (2018). Fear of falling in community-dwelling older adults: A cause of falls, a consequence, or both? *PLoS One, 13*(3), e0194967. doi:10.1371/journal.pone.0194967

LeBouthillier, D. M., Thibodeau, M. A., & Asmundson, G. J. (2013). Severity of fall-based injuries, fear of falling, and activity restriction: sex differences in a population-based sample of older Canadian adults. *Journal of aging and health, 25*(8), 1378-1387.

Liu, Y., Chan, J. S., & Yan, J. H. (2014). Neuropsychological mechanisms of falls in older adults. *Frontiers in aging neuroscience, 6*, 64.

Llinàs-Reglà, J., Vilalta-Franch, J., López-Pousa, S., Calvó-Perxas, L., Torrents Rodas, D., & Garre-Olmo, J. (2017). The Trail Making Test:Association With Other Neuropsychological Measures and Normative Values for Adults Aged 55 Years and Older From a Spanish-Speaking Population-Based Sample. *Assessment, 24*(2), 183-196. doi:10.1177/1073191115602552

Makino, K., Makizako, H., Doi, T., Tsutsumimoto, K., Hotta, R., Nakakubo, S., . . . Shimada, H. (2017). Fear of falling and gait parameters in older adults with and without fall history. *Geriatr Gerontol Int, 17*(12), 2455-2459. doi:10.1111/ggi.13102

Martin, K., Thomson, R., Blizzard, L., Wood, A., Garry, M., & Srikanth, V. (2009). Visuospatial ability and memory are associated with falls risk in older people: a population-based study. *Dement Geriatr Cogn Disord, 27*(5), 451-457. doi:10.1159/000216840

Matarazzo, J. D., & Herman, D. O. (1984). Base rate data for the WAIS-R: test-retest stability and VIQ-PIQ differences. *J Clin Neuropsychol, 6*(4), 351-366. doi:10.1080/01688638408401227

McAlister, C., & Schmitter-Edgecombe, M. (2013). Naturalistic assessment of executive function and everyday multitasking in healthy older adults. *Neuropsychol Dev Cogn B Aging Neuropsychol Cogn, 20*(6), 735-756. doi:10.1080/13825585.2013.781990

Mielke, M. M., Roberts, R. O., Savica, R., Cha, R., Drubach, D. I., Christianson, T., . . . Ivnik, R. J. (2013). Assessing the temporal relationship between cognition and gait: slow gait predicts cognitive decline in the Mayo Clinic Study of Aging. *Journals of Gerontology Series A: Biomedical Sciences and Medical Sciences, 68*(8), 929-937.

Moiz, J. A., Bansal, V., Noohu, M. M., Gaur, S. N., Hussain, M. E., Anwer, S., & Alghadir, A. (2017). Activities-specific balance confidence scale for predicting future falls in Indian older adults. *Clinical interventions in aging, 12*, 645.

Montero-Odasso, M., Schapira, M., Soriano, E. R., Varela, M., Kaplan, R., Camera, L. A., & Mayorga, L. M. (2005). Gait velocity as a single predictor of adverse events in healthy seniors aged 75 years and older. *J Gerontol A Biol Sci Med Sci, 60*(10), 1304-1309. doi:10.1093/gerona/60.10.1304

Montero-Odasso, M., & Speechley, M. (2018). Falls in cognitively impaired older adults: implications for risk assessment and prevention. *J Am Geriatr Soc, 66*(2), 367-375.

Morin, C. M., Landreville, P., Colecchi, C., McDonald, K., Stone, J., & Ling, W. (1999). The Beck Anxiety Inventory: psychometric properties with older adults. *Journal of Clinical Geropsychology, 5*(1), 19-29.

Murphy, J., & Isaacs, B. (1982). The post-fall syndrome. A study of 36 elderly patients. *Gerontology, 28*(4), 265-270. doi:10.1159/000212543

Myers, A. M., Fletcher, P. C., Myers, A. H., & Sherk, W. (1998). Discriminative and evaluative properties of the activities-specific balance confidence (ABC) scale. *The Journals of Gerontology Series A: Biological Sciences and Medical Sciences, 53*(4), M287-M294.

Myers, A. M., Powell, L. E., Maki, B. E., Holliday, P. J., Brawley, L. R., & Sherk, W. (1996). Psychological indicators of balance confidence: relationship to actual and perceived abilities. *The Journals of Gerontology Series A: Biological Sciences and Medical Sciences, 51*(1), M37-M43.

Noh, H. M., Roh, Y. K., Song, H. J., & Park, Y. S. (2019). Severe Fear of Falling Is Associated With Cognitive Decline in Older Adults: A 3-Year Prospective Study. *J Am Med Dir Assoc, 20*(12), 1540-1547. doi:10.1016/j.jamda.2019.06.008

O'Halloran, A. M., Pénard, N., Galli, A., Fan, C. W., Robertson, I. H., & Kenny, R. A. (2011). Falls and falls efficacy: the role of sustained attention in older adults. *BMC geriatrics, 11*(1), 1-10.

Oschwald, J., Guye, S., Liem, F., Rast, P., Willis, S., Röcke, C., . . . Mérillat, S. (2019). Brain structure and cognitive ability in healthy aging: a review on longitudinal correlated change. *Reviews in the Neurosciences, 31*(1), 1-57.

Osman, A., Kopper, B. A., Barrios, F. X., Osman, J. R., & Wade, T. (1997). The Beck Anxiety Inventory: reexamination of factor structure and psychometric properties. *J Clin Psychol, 53*(1), 7-14. doi:10.1002/(sici)1097-4679(199701)53:1<7::aid-jclp2>3.0.co;2-s

Padubidri, A., Al Snih, S., Samper-Ternent, R., Markides, K. S., Ottenbacher, K. J., & Raji, M. A. (2014). Falls and cognitive decline in Mexican Americans 75 years and older. *Clinical interventions in aging, 9*, 719.

Park, D. C., & Festini, S. B. (2017). Theories of memory and aging: A look at the past and a glimpse of the future. *The Journals of Gerontology: Series B, 72*(1), 82-90.

Partington, J. E., & Leiter, R. G. (1949). Partington's Pathways Test. *Psychological Service Center Journal*.

Pasquier, F., Lebert, F., Grymonprez, L., & Petit, H. (1995). Verbal fluency in dementia of frontal lobe type and dementia of Alzheimer type. *Journal of Neurology, Neurosurgery & Psychiatry, 58*(1), 81-84.

Patt, V. M., Brown, G. G., Thomas, M. L., Roesch, S. C., Taylor, M. J., & Heaton, R. K. (2017). Factor Analysis of an Expanded Halstead-Reitan Battery and the Structure of Neurocognition. *Archives of Clinical Neuropsychology, 33*(1), 79-101. doi:10.1093/arclin/acx043

Peel, N. M. (2011). Epidemiology of falls in older age. *Canadian Journal on Aging/La Revue canadienne du vieillissement, 30*(1), 7-19.

Peel, N. M., Alapatt, L. J., Jones, L. V., & Hubbard, R. E. (2019). The association between gait speed and cognitive status in community-dwelling older people: a systematic review and meta-analysis. *The Journals of Gerontology: Series A, 74*(6), 943-948.

Peeters, G., Leahy, S., Kennelly, S., & Kenny, R. A. (2018). Is Fear of Falling Associated With Decline in Global Cognitive Functioning in Older Adults: Findings From the Irish Longitudinal Study on Ageing. *J Am Med Dir Assoc, 19*(3), 248-254 e243. doi:10.1016/j.jamda.2017.09.012

Phelan, E. A., & Ritchey, K. (2018). Fall prevention in community-dwelling older adults. *Annals of Internal Medicine, 169*(11), ITC81-ITC96.

Podsiadlo, D., & Richardson, S. (1991). The timed "Up & Go": a test of basic functional mobility for frail elderly persons. *J Am Geriatr Soc, 39*(2), 142-148. doi:10.1111/j.1532-5415.1991.tb01616.x

Powell, L. E., & Myers, A. M. (1995). The Activities-specific Balance Confidence (ABC) Scale. *The Journals of Gerontology: Series A, 50A*(1), M28-M34. doi:10.1093/gerona/50A.1.M28

Randolph, C., Tierney, M. C., Mohr, E., & Chase, T. N. (1998). The Repeatable Battery for the Assessment of Neuropsychological Status (RBANS): preliminary clinical validity. *J Clin Exp Neuropsychol, 20*(3), 310-319. doi:10.1076/jcen.20.3.310.823

Rendon, A. A., Lohman, E. B., Thorpe, D., Johnson, E. G., Medina, E., & Bradley, B. (2012). The effect of virtual reality gaming on dynamic balance in older adults. Age Ageing, 41(4), 549-552. doi:10.1093/ageing/afs053

Reitan, R. M. (1958). Validity of the Trail Making Test as an indicator of organic brain damage. *Perceptual and motor skills, 8*(3), 271-276.

Roberts, A. W., Ogunwole, S. U., Blakeslee, L., & Rabe, M. A. (2018). *The population 65 years and older in the United States: 2016*: US Department of Commerce, Economics and Statistics Administration, US ….

Robinson, L., Tang, E., & Taylor, J.-P. (2015). Dementia: timely diagnosis and early intervention. *Bmj, 350*.

Rodríguez-Molinero, A., Herrero-Larrea, A., Miñarro, A., Narvaiza, L., Gálvez-Barrón, C., León, N. G., . . . Aivar, D. (2019). The spatial parameters of gait and their association with falls, functional decline and death in older adults: a prospective study. *Scientific reports, 9*(1), 1-9.

Rogge, A.-K., Röder, B., Zech, A., Nagel, V., Hollander, K., Braumann, K.-M., & Hötting, K. (2017). Balance training improves memory and spatial cognition in healthy adults. *Scientific reports, 7*(1), 1-10.

Russell, E. W. (1972). WAIS factor analysis with brain-damaged subjects using criterion measures. *Journal of consulting and clinical psychology, 39*(1), 133.

Sakurai, R., Suzuki, H., Ogawa, S., Kawai, H., Yoshida, H., Hirano, H., . . . Fujiwara, Y. (2017). Fear of falling, but not gait impairment, predicts subjective memory complaints in cognitively intact older adults. *Geriatr Gerontol Int, 17*(7), 1125-1131. doi:10.1111/ggi.12829

Salthouse, T. A. (2010). Selective review of cognitive aging. *J Int Neuropsychol Soc, 16*(5), 754-760. doi:10.1017/S1355617710000706

Scheffer, A. C., Schuurmans, M. J., van Dijk, N., van der Hooft, T., & de Rooij, S. E. (2008). Fear of falling: measurement strategy, prevalence, risk factors and consequences among older persons. *Age Ageing, 37*(1), 19-24. doi:10.1093/ageing/afm169

Sekhon, H., Allali, G., Launay, C. P., Barden, J., Szturm, T., Liu-Ambrose, T., . . . Consortium, C. G. (2019). Motoric cognitive risk syndrome, incident cognitive impairment and morphological brain abnormalities: systematic review and meta-analysis. *Maturitas, 123*, 45-54.

Shinkai, S., Watanabe, S., Kumagai, S., Fujiwara, Y., Amano, H., Yoshida, H., . . . Shibata, H. (2000). Walking speed as a good predictor for the onset of functional dependence in a Japanese rural community population. *Age Ageing, 29*(5), 441-446. doi:10.1093/ageing/29.5.441

Smith, L., Gardner, B., Fisher, A., & Hamer, M. (2015). Patterns and correlates of physical activity behaviour over 10 years in older adults: prospective analyses from the English Longitudinal Study of Ageing. BMJ open, 5(4), e007423.

Soumaré, A., Tavernier, B., Alpérovitch, A., Tzourio, C., & Elbaz, A. (2009). A cross-sectional and longitudinal study of the relationship between walking speed and cognitive function in community-dwelling elderly people. *Journals of Gerontology Series A: Biomedical Sciences and Medical Sciences, 64*(10), 1058-1065.

Stenhagen, M., Nordell, E., & Elmståhl, S. (2013). Falls in elderly people: a multifactorial analysis of risk markers using data from the Swedish general population study ‘Good Ageing in Skåne’. *Aging clinical and experimental research, 25*(1), 59-67.

Talley, K. M., Wyman, J. F., Gross, C. R., Lindquist, R. A., & Gaugler, J. E. (2014). Change in balance confidence and its associations with increasing disability in older community-dwelling women at risk for falling. *Journal of aging and health, 26*(4), 616-636.

Thurman, D. J., Stevens, J. A., Rao, J. K., & Quality Standards Subcommittee of the American Academy of, N. (2008). Practice parameter: Assessing patients in a neurology practice for risk of falls (an evidence-based review): report of the Quality Standards Subcommittee of the American Academy of Neurology. *Neurology, 70*(6), 473-479. doi:10.1212/01.wnl.0000299085.18976.20

Tinetti, M. E., Richman, D., & Powell, L. (1990). Falls Efficacy as a Measure of Fear of Falling. *Journals of Gerontology, 45*(6), P239-P243. doi:DOI 10.1093/geronj/45.6.P239

Tsatali, M., Poptsi, E., Moraitou, D., Agogiatou, C., Bakoglidou, E., Gialaouzidis, M., . . . Tsolaki, M. (2021). Discriminant validity of the WAIS-R digit symbol substitution test in subjective cognitive decline, mild cognitive impairment (amnestic subtype) and Alzheimer's disease dementia (ADD) in Greece. *Brain Sciences, 11*(7), 881.

Van Hooren, S., Valentijn, A., Bosma, H., Ponds, R., Van Boxtel, M., Jolles, J. J. A., Neuropsychology,, & Cognition. (2007). Cognitive functioning in healthy older adults aged 64–81: a cohort study into the effects of age, sex, and education. *14*(1), 40-54.

Vazzana, R., Bandinelli, S., Lauretani, F., Volpato, S., Lauretani, F., Di Iorio, A., . . . Guralnik, J. M. (2010). Trail Making Test predicts physical impairment and mortality in older persons. *J Am Geriatr Soc, 58*(4), 719-723.

Vellas, B. J., Wayne, S. J., Romero, L. J., Baumgartner, R. N., & Garry, P. J. (1997). Fear of falling and restriction of mobility in elderly fallers. *Age Ageing, 26*(3), 189-193. doi:10.1093/ageing/26.3.189

Verghese, J., LeValley, A., Hall, C. B., Katz, M. J., Ambrose, A. F., & Lipton, R. B. (2006). Epidemiology of gait disorders in community-residing older adults. *J Am Geriatr Soc, 54*(2), 255-261.

Verghese, J., Wang, C., Lipton, R. B., Holtzer, R., & Xue, X. (2007). Quantitative gait dysfunction and risk of cognitive decline and dementia. *J Neurol Neurosurg Psychiatry, 78*(9), 929-935. doi:10.1136/jnnp.2006.106914

Watson, N., Rosano, C., Boudreau, R., Simonsick, E. M., Ferrucci, L., Sutton-Tyrrell, K., . . . Satterfield, S. (2010). Executive function, memory, and gait speed decline in well-functioning older adults. *Journals of Gerontology Series A: Biomedical Sciences and Medical Sciences, 65*(10), 1093-1100.

Wechsler, D. (1944). The measurement of adult intelligence.

Wechsler, D. (1981). *Wechsler adult intelligence scale-revised (WAIS-R)*: Psychological Corporation.

Wechsler, D., & De Lemos, M. M. (1981). Wechsler adult intelligence scale-revised.

Whipple, M. O., Hamel, A. V., & Talley, K. M. C. (2018). Fear of falling among community-dwelling older adults: A scoping review to identify effective evidence-based interventions. *Geriatr Nurs, 39*(2), 170-177. doi:10.1016/j.gerinurse.2017.08.005

Wolfson, L., Whipple, R., Derby, C. A., Amerman, P., & Nashner, L. (1994). Gender differences in the balance of healthy elderly as demonstrated by dynamic posturography. Journal of gerontology, 49(4), M160–M167. https://doi.org/10.1093/geronj/49.4.m160

Yesavage, J. A., Brink, T. L., Rose, T. L., Lum, O., Huang, V., Adey, M., & Leirer, V. O. (1982). Development and validation of a geriatric depression screening scale: A preliminary report. *Journal of Psychiatric Research, 17*(1), 37-49. doi:https://doi.org/10.1016/0022-3956(82)90033-4

Yesavage, J. A., Brink, T. L., Rose, T. L., Lum, O., Huang, V., Adey, M., & Leirer, V. O. (1982). Development and validation of a geriatric depression screening scale: a preliminary report. *J Psychiatr Res, 17*(1), 37-49. doi:10.1016/0022-3956(82)90033-4

Zhang, H., Sachdev, P. S., Wen, W., Kochan, N. A., Crawford, J. D., Brodaty, H., . . . Trollor, J. N. (2013). Grey matter correlates of three language tests in non-demented older adults. *PLoS One, 8*(11), e80215.

Zijlstra, G. A., van Haastregt, J. C., van Eijk, J. T., van Rossum, E., Stalenhoef, P. A., & Kempen, G. I. (2007). Prevalence and correlates of fear of falling, and associated avoidance of activity in the general population of community-living older people. *Age Ageing, 36*(3), 304-309. doi:10.1093/ageing/afm021

Tables

Table 1. Descriptive Statistics of Demographic Information Stratified by Gender

Variable	Total Sample (519) M (SD) or N (%) or Mdn [IQR]	Females (286) M (SD) or N (%) or Mdn [IQR]	Males (233) M (SD) or N (%) or Mdn [IQR]	P-value
Age (years)	75.99 (6.47)	76.22 (6.37)	75.70 (6.58)	.362
Gender	--	--	--	--
Female	286 (55.10%)	--	--	--
Male	233 (44.90%)	--	--	--
Education (years)	14.64 (2.88)	14.32 (2.61)	15.04 (3.13)	.005
Falls History	--	--	--	.015
Yes	302 (58.20%)	180 (62.94%)	122 (52.36%)	--
No	217 (41.80%)	106 (37.06%)	111 (46.64%)	--
Balance Confidence Score	90.60 [80.60-96.20]	88.35 [76.20-94.55]	93.10 [85.60-97.500]	<.001
Beck Anxiety Inventory (Gana et al.) Score	3.00 [0.00-6.00]	3.00 [1.00-7.00]	2.00 [0.00-4.00]	<.001
Geriatric Depression Scale (GDS) Score	4.00 [2.00-7.00]	4.00 [2.00-7.00]	3.00 [2.00-6.00]	.343
Global Health Score (GHS)	1.62 (1.08)	1.66 (1.07)	1.57 (1.09)	.340
RBANS Total Index Score	91.71 (11.80)	92.20 (12.73)	91.11 (10.54)	.298
RBANS Memory Index Score	95.43 (9.90)	96.68 (10.35)	93.90 (9.12)	.001
Attention/EF Composite	--	--	--	
Letter Fluency z score	0.12 (1.15)	0.22 (1.16)	-0.01 (1.13)	.023
Category Fluency z score	0.20 (1.28)	0.39 (1.27)	-0.04 (1.25)	<.001
Trails A z score	0.32 (1.18)	0.37 (1.05)	0.27 (1.32)	.341
Trails B z score	-0.15 (1.70)	-0.20 (1.66)	-0.10 (1.74)	.514
Digit Symbol Substitution Test z score	-0.09 (1.01)	-0.00 (0.99)	-0.21 (1.02)	.021

Note: Balance Confidence Score is the raw score from the Activities-specific Balance Confidence (ABC) Scale. RBANS memory index score is an average of immediate and delayed memory index scores. Attention/EF Composite = Attention/Executive Functioning Composite. Letter fluency (F, A, S) and category fluency (fruits, vegetables, animals) are from the Controlled Oral Word Association Test (COWAT). All z-scores listed are based on normative data from individual tests for clinical context.

Table 2. Linear Mixed-Effects Model Examining the Effects of Time, Balance Confidence, and Their Interaction on Global, Memory, and Attention/EF Composite Scores Adjusted for Covariates

	Global Cognition (N=519)			Memory (N=519)			Attention/EF (N=519)		
Variable	Estimate	95% CI	p-value	Estimate	95% CI	p-value	Estimate	95% CI	p-value
Intercept	1.24	[0.63, 1.84]	<.001	2.01	[1.25, 2.77]	<.001	0.06	[-0.57, 0.68]	.861
Balance Confidence	<0.01	[-0.00, 0.00]	.250	<0.01	[-0.00, 0.01]	.333	<0.01	[-0.00, 0.01]	.106
Time	0.03	[0.02, 0.04]	<.001	0.06	[0.04, 0.07]	<.001	0.01	[-0.01, 0.02]	.403
Time x Balance Confidence	<0.01	[0.00, 0.00]	.023	<0.01	[0.00, 0.00]	.036	<0.01	[-0.00, 0.00]	.462
Age	-0.03	[-0.04, -0.02]	<.001	-0.04	[-0.05, -0.03]	<.001	-0.02	[-0.02, -0.01]	<.001
Gender	0.12	[0.02, 0.21]	.015	0.27	[0.15, 0.39]	<.001	0.17	[0.07, 0.26]	.001
Education (years)	0.07	[0.06, 0.09]	<.001	0.07	[0.05, 0.09]	<.001	0.07	[0.06, 0.09]	<.001
Falls History	>-0.01	[-0.03, 0.03]	.945	0.01	[-0.04, 0.06]	.720	-0.02	[-0.06, 0.03]	.458
Global Health Status	-0.01	[-0.03, 0.01]	.314	-0.01	[-0.03, 0.01]	.443	<0.01	[-.02, 0.02]	.899
Beck Anxiety Score	>-0.01	[-0.00, 0.00]	.676	<0.01	[-0.00, 0.01]	.711	<0.01	[-0.00, 0.01]	.900
Geriatric Depression Score	<0.01	[-0.01, -0.00]	.004	-0.01	[-0.02, -0.00]	.010	-0.01	[-0.01, 0.00]	.066

Note. Model adjusted for covariates: gender, age, education, falls history, GHS, GDS, and BAI.

Table 3. Linear Mixed-Effects Model Examining the Effects of Time, Balance Confidence, and Their Interaction on Global, Memory, and Attention/EF Composite Scores Adjusted for Covariates Over 5 Years

	Global Cognition (N=519)			Memory (N=519)			Attention/EF (N=519)		
Variable	Estimate	95% CI	p-value	Estimate	95% CI	p-value	Estimate	95% CI	p-value
Intercept	1.21	[0.61, 1.82]	<.001	1.96	[1.20, 2.72]	<.001	-0.03	[-0.64, 0.59]	.930
Balance Confidence	<0.01	[-0.00, 0.00]	.541	<0.01	[-0.00, 0.00]	.609	<0.01	[0.00, 0.00]	.064
Time	0.03	[0.02, 0.04]	<.001	0.06	[0.04, 0.08]	<.001	0.01	[0.00, 0.02]	.029
Time x Balance Confidence	<0.01	[0.00, 0.00]	.007	<0.01	[0.00, 0.00]	.014	<0.01	[-0.00, 0.00]	.139
Age	-0.03	[-0.04, -0.02]	<.001	-0.04	[-0.05, -0.03]	<.001	-0.02	[-0.02, -0.01]	<.001
Gender	0.11	[0.02, 0.21]	.017	0.27	[0.15, 0.39]	<.001	0.16	[0.06, 0.26]	.001
Education (years)	0.07	[0.06, 0.09]	<.001	0.07	[0.05, 0.09]	<.001	0.07	[0.06, 0.09]	<.001
Falls History	-0.01	[-0.04, 0.03]	.657	<0.01	[-0.04, 0.05]	.859	0.01	[-0.02, 0.03]	.691
Global Health Status	-0.01	[-0.03, 0.01]	.218	-0.01	[-0.04, 0.01]	.354	>-0.01	[-0.02, 0.01]	.620
Beck Anxiety Score	<0.01	[-0.00, 0.01]	.547	<0.01	[-0.00, 0.01]	.535	>-0.01	[-0.00, 0.00]	.421
Geriatric Depression Score	-0.01	[-0.02, -0.00]	.003	-0.01	[-0.02, -0.00]	.008	>-0.01	[-0.01, 000]	.141

Note. Model adjusted for covariates: gender, age, education, falls history, GHS, GDS, and BAI.

Table 4. Linear Mixed-Effects Model Examining the Effects of Time, Balance Confidence, and Their Interaction on Global, Memory, and Attention/EF Composite Scores Adjusted for Covariates Over 7 Years, Excluding Incident Dementia Cases

	Global Cognition (N=519)			Memory (N=519)			Attention/EF (N=519)		
Variable	Estimate	95% CI	p-value	Estimate	95% CI	p-value	Estimate	95% CI	p-value
Intercept	1.16	[0.57, 1.75]	<.001	1.89	[1.15, 2.63]	<.001	-0.06	[-0.68, 0.56]	.845
Balance Confidence	<0.01	[-0.00, 0.00]	.052	<0.01	[-0.00, 0.01]	.100	<0.01	[-0.00, 0.01]	.087
Time	0.04	[0.03, 0.05]	<.001	0.07	[0.05, 0.08]	<.001	0.01	[-0.00, 0.03]	.084
Time x Balance Confidence	<0.01	[-0.00, 0.00]	.229	<0.01	[-0.00, 0.00]	.302	<0.01	[-0.00, 0.00]	.912
Age	-0.03	[-0.04, -0.02]	<.001	-0.04	[-0.05, -0.03]	<.001	-0.02	[-0.02, -0.01]	<.001
Gender	0.12	[0.03, 0.21]	.009	0.23	[0.16, 0.39]	.001	0.17	[0.08, 0.27]	<.001
Education (years)	0.07	[0.06, 0.09]	<.001	0.07	[0.05, 0.09]	<.001	0.07	[0.06, 0.09]	<.001
Falls History	>-0.01	[-0.04, 0.03]	.765	<0.01	[-0.04, 0.05]	.853	-0.02	[-0.07, 0.02]	.258
Global Health Status	>-0.01	-0.02, 0.01	.800	>-0.01	[-0.03, 0.03]	.893	0.01	[-0.02, 0.03]	.620
Beck Anxiety Score	>-0.01	[-0.00, 0.00]	.826	>-0.01	[-0.01, 0.01]	.937	>-0.01	[-0.01, 0.00]	.966
Geriatric Depression Score	-0.01	[-0.01, -0.00]	.022	-0.01	[-0.2, 0.00]	.055	-0.01	[-0.01, 0.00]	.174

Note. Model adjusted for covariates: gender, age, education, falls history, GHS, GDS, and BAI.

Table 5. Linear Mixed-Effects Model Examining the Effects of Time, Balance Confidence, and Their Interaction on Global, Memory, and Attention/EF Composite Scores Adjusted for Covariates Over 7 Years, Excluding Participants with ABC scores ≤ 30

	Global Cognition (N=516)			Memory (N=516)			Attention/EF (N=516)		
Variable	Estimate	95% CI	p-value	Estimate	95% CI	p-value	Estimate	95% CI	p-value
Intercept	1.22	[0.62, 1.82]	<.001	1.99	[1.23, 2.75]	<.001	0.06	[-0.57, 0.69]	.859
Balance Confidence	<0.01	[-0.00, 0.00]	.241	<0.01	[-0.00, 0.00]	.390	<0.01	[-0.00, 0.01]	.118
Time	0.03	[0.02, 0.04]	<.001	0.06	[0.04, 0.07]	<.001	0.01	[-0.01, 0.02]	.387
Time x Balance Confidence	<0.01	[0.00, 0.00]	.031	<0.01	[0.00, 0.00]	.038	<0.01	[-0.00, 0.00]	.475
Age	-0.03	[-0.04, -0.02]	<.001	-0.05	[-0.05, -0.03]	<.001	-0.02	[-0.03, -0.01]	<.001
Gender	0.12	[0.03, 0.22]	.009	0.28	[0.16, 0.40]	<.001	0.17	[0.07, 0.26]	.001
Education (years)	0.07	[0.06, 0.09]	<.001	0.07	[0.05, 0.09]	<.001	0.07	[0.06, 0.09]	<.001
Falls History	>-0.01	[-0.04, 0.03]	.861	0.01	[-0.04, 0.05]	.786	-0.02	[-0.06, 0.03]	.454
Global Health Status	-0.01	[-0.03, 0.01]	.327	-0.01	[-0.03, 0.01]	.450	<0.01	[-0.02, 0.02]	.883
Beck Anxiety Score	<0.01	[-0.00, 0.00]	.762	<0.01	[-0.00, 0.01]	.760	<0.01	[-0.00, 0.01]	.915
Geriatric Depression Score	-0.01	[-0.01, -0.00]	.004	-0.01	[-0.02, -0.00]	.390	-0.01	[-0.01, 0.00]	.074

Note. Model adjusted for covariates: gender, age, education, falls history, GHS, GDS, and BAI.

Table 6A. Linear Mixed-Effects Model Examining the Effects of Time, Balance Confidence, and Their Interaction on Global, Memory, and Attention/EF Composite Scores Adjusted for Covariates, in Females Only

	Global Cognition (N=286)			Memory (N=286)			Attention/EF (N=286)		
Variable	Estimate	95% CI	p-value	Estimate	95% CI	p-value	Estimate	95% CI	p-value
Intercept	1.54	[0.68, 2.42]	.001	2.58	[1.49, 3.67]	<.001	0.40	[-0.45, 1.25]	.352
Balance Confidence	>-0.01	[>-0.01, <0.01]	.892	>-0.01	[-0.01, <0.01]	.705	<0.01	[>-0.01, <0.01]	.949
Time	0.05	[0.03, 0.06]	<.001	0.08	[0.05, 0.10]	<.001	0.01	[>-0.01, 0.03]	.051
Time x Balance Confidence	<0.01	[<0.01, <0.01]	.002	<0.01	[<0.01, <0.01]	.027	<0.01	[<0.01, <0.01]	.003
Age	-0.03	[-0.04, -0.00]	<.001	-0.04	[-0.06, -0.03]	<.001	-0.02	[-0.03, -0.01]	<.001
Gender	--	--	--	--	--	--	--	--	--
Education (years)	0.06	[0.04, 0.09]	<.001	0.06	[0.03, 0.09]	<.001	0.06	[0.04, 0.09]	<.001
Falls History	>-0.01	[-0.04, 0.04]	.966	0.01	[-0.05, 0.08]	.696	<0.01	[-0.04, 0.04]	.934
Global Health Status	-0.01	[-0.03, 0.02]	.642	-0.01	[-0.04, 0.02]	.573	>-0.01	[-0.02, 0.02]	.786
Beck Anxiety Score	<0.01	[>-0.01, 0.01]	.500	<0.01	[-0.01, 0.01]	.843	<0.01	[>-0.01, <0.01]	.990
Geriatric Depression Score	-0.01	[-0.02, -0.00]	.039	-0.01	[-0.02, -0.00]	.034	>-0.01	[-0.01, 0.01]	.963

Note: Model adjusted for covariates: age, education, falls history, GHS, GDS, and BAI.

Table 6B. Linear Mixed-Effects Model Examining the Effects of Time, Balance Confidence, and Their Interaction on Global, Memory, and Attention/EF Composite Scores Adjusted for Covariates, in Males Only

	Global Cognition (N=233)			Memory (N=233)			Attention/EF (N=233)		
Variable	Estimate	95% CI	p-value	Estimate	95% CI	p-value	Estimate	95% CI	p-value
Intercept	1.06	[0.23, 1.90]	.013	1.74	[0.66, 2.81]	.002	0.04	[-0.91, 0.98]	.938
Balance Confidence	<0.01	[>-0.01, 0.01]	.192	<0.01	[>-0.01, 0.01]	.227	<0.01	[>-0.01, 0.01]	.336
Time	0.01	[>-0.01, <0.01]	.108	0.04	[0.02, 0.06]	.001	>-0.01	[-0.03, 0.02]	.952
Time x Balance Confidence	<0.01	[>-0.01, <0.01]	.421	<0.01	[>-0.01, <0.01]	.122	>-0.01	[>-0.01, <0.01]	.865
Age	-0.03	[-0.04, -0.02]	<.001	-0.04	[-0.05, -0.03]	<.001	-0.02	[-0.03, -0.01]	.002
Gender	--	--	--	--	--	--	--	--	--
Education (years)	0.08	[0.06, 0.10]	<.001	0.08	[0.05, 0.10]	<.001	0.08	[0.06, 0.10]	<.001
Falls History	>-0.01	[-0.05, 0.04]	.919	0.01	[-0.06, 0.08]	.847	-0.02	[-0.10, 0.06]	.634
Global Health Status	-0.01	[-0.04, 0.01]	.391	-0.01	[-0.05, 0.03]	.657	0.01	[-0.03, 0.05]	.727
Beck Anxiety Score	>-0.01	[-0.01, 0.01]	.798	<0.01	[-0.01, 0.01]	.878	>-0.01	[-0.01, 0.01]	.751
Geriatric Depression Score	-0.01	[-0.02, <0.01]	.064	-0.01	[-0.02, <0.01]	.153	-0.01	[-0.03, <0.01]	.102

Note: Model adjusted for covariates: age, education, falls history, GHS, GDS, and BAI.

Table 7A. Linear Mixed-Effects Model Examining the Effects of Time, Balance Confidence, and Their Interaction on Global, Memory, and Attention/EF Composite Scores Adjusted for Covariates Over 5 Years, in Females Only

	Global Cognition (N=286)			Memory (N=286)			Attention/EF (N=286)		
Variable	Estimate	95% CI	p-value	Estimate	95% CI	p-value	Estimate	95% CI	p-value
Intercept	1.54	[0.66, 2.41]	.001	2.53	[1.45, 3.63]	<.001	0.38	[-0.47, 1.23]	.347
Balance Confidence	>-0.01	[>-0.01, <0.01]	.867	>-0.01	[-0.01, <0.01]	.728	<0.01	[>-0.01, <0.01]	.705
Time	0.05	[>-0.01, 0.01]	<.001	0.08	[0.06, 0.11]	<.001	0.02	[<0.01, 0.04]	.017
Time x Balance Confidence	<0.01	[<0.01, <0.01]	.013	<0.01	[>-0.01, <0.01]	.066	<0.01	[<0.01, <0.01]	.047
Age	-0.03	[-0.04, -0.02]	<.001	-0.04	[-0.06, -0.03]	<.001	-0.02	[-0.03, 0.01]	<.001
Gender	--	--	--	--	--	--	--	--	--
Education (years)	0.06	[0.04, 0.09]	<.001	0.06	[0.03, 0.10]	<.001	0.06	[0.04, 0.09]	<.001
Falls History	>-0.01	[-0.05, 0.04]	.866	0.01	[-0.06, 0.07]	.825	<0.01	[-0.04, 0.04]	.960
Global Health Status	-0.01	[-0.03, 0.01]	.423	-0.01	[-0.05, 0.02]	.480	>-0.01	[-0.02, 0.02]	.811
Beck Anxiety Score	<0.01	[>-0.01, 0.01]	.367	<0.01	[-0.01, 0.01]	.624	<0.01	[>-0.01, <0.01]	.777
Geriatric Depression Score	-0.01	[-0.02, <0.01]	.064	-0.01	[-0.02, <0.01]	.058	>-0.01	[-0.01, 0.01]	.820

Note: Model adjusted for covariates: age, education, falls history, GHS, GDS, and BAI.

Table 7B. Linear Mixed-Effects Model Examining the Effects of Time, Balance Confidence, and Their Interaction on Global, Memory, and Attention/EF Composite Scores Adjusted for Covariates Over 5 Years, in Males Only

	Global Cognition (N=233)			Memory (N=233)			Attention/EF (N=233)		
Variable	Estimate	95% CI	p-value	Estimate	95% CI	p-value	Estimate	95% CI	p-value
Intercept	1.06	[0.23, 1.89]	.013	1.71	[0.65, 2.78]	.002	-0.19	[-1.09, 0.70]	.671
Balance Confidence	<0.01	[>-0.01, 0.00]	.698	<0.01	[-0.01, 0.01]	.815	<0.01	[<0.01, 0.01]	.046
Time	0.01	[>-0.01, 0.03]	.114	0.04	[0.01, 0.06]	.006	0.01	[-0.01, 0.03]	.317
Time x Balance Confidence	<0.01	[0.00, 0.00]	.026	<0.01	[<0.01, <0.01]	.005	<0.01	[>-0.01, <0.01]	.655
Age	-0.03	[-0.04, -0.02]	<.001	-0.04	[-0.05, -0.03]	<.001	-0.02	[-0.03, >-0.01]	.005
Gender	--	--	--	--	--	--	--	--	--
Education (years)	0.08	[0.06, 0.10]	<.001	0.08	[0.05, 0.10]	<.001	0.08	[0.06, 0.10]	<.001
Falls History	-0.01	[-0.06, 0.04]	.685	0.01	[-0.06, 0.08]	.818	0.01	[-0.04, 0.06]	.668
Global Health Status	-0.01	[-0.04, 0.02]	<.001	-0.01	[-0.05, 0.03]	.637	>-0.01	[-0.03, 0.02]	.717
Beck Anxiety Score	>-0.01	[-0.01, 0.01]	.795	<0.01	[-0.01, 0.01]	.823	-0.01	[-0.01, <0.01]	.106
Geriatric Depression Score	-0.01	[-0.01, >-0.01]	.030	-0.01	[-0.03, <0.01]	.106	-0.01	[-0.02, <0.01]	.069

Note: Model adjusted for covariates: age, education, falls history, GHS, GDS, and BAI.

Table 8A. Linear Mixed-Effects Model Examining the Effects of Time, Balance Confidence, and Their Interaction on Global, Memory, and Attention/EF Composite Scores Adjusted for Covariates Over 7 Years, in Females Only, Excluding Incident Dementia Cases

	Global Cognition (N=286)			Memory (N=286)			Attention/EF (N=286)		
Variable	Estimate	95% CI	p-value	Estimate	95% CI	p-value	Estimate	95% CI	p-value
Intercept	1.52	[0.67, 2.37]	.001	2.52	[1.46, 3.57]	<.001	0.36	[-0.48, 1.20]	.395
Balance Confidence	<0.01	[>-0.01, <0.01]	.844	>-0.01	[>-0.01, <0.01]	.979	>-0.01	[>-0.01, <0.01]	.917
Time	0.05	[0.04, 0.07]	<.001	0.08	[0.06, 0.10]	<.001	0.02	[<0.01, 0.03]	.010
Time x Balance Confidence	<0.01	[<0.01, <0.01]	.031	<0.01	[>-0.01, <0.01]	.275	<0.01	[<0.01, <0.01]	.035
Age	-0.03	[-0.04, -0.02]	<.001	-0.04	[-0.06, -0.03]	<.001	-0.02	[-0.03, -0.01]	<.001
Gender	--	--	--	--	--	--	--	--	--
Education (years)	0.06	[0.04, 0.09]	<.001	0.06	[0.03, 0.09]	<.001	0.06	[0.04, 0.09]	<.001
Falls History	>-0.01	[-0.05, 0.04]	.948	0.01	[-0.05, 0.08]	.687	>-0.01	[-0.04, 0.03]	.853
Global Health Status	<0.01	[-0.02, 0.03]	.841	>-0.01	[-0.04, 0.03]	.867	<0.01	[-0.02, 0.02]	.772
Beck Anxiety Score	<0.01	[>-0.01, 0.01]	.785	>-0.01	[-0.01, 0.01]	.902	>-0.01	[>-0.01, <0.01]	.692
Geriatric Depression Score	-0.01	[-0.02, <0.01]	.059	-0.01	[-0.02, <0.01]	.055	<0.01	[-0.01, 0.01]	.914

Note. Model adjusted for covariates: age, education, falls history, GHS, GDS, and BAI.

Table 8B. Linear Mixed-Effects Model Examining the Effects of Time, Balance Confidence, and Their Interaction on Global, Memory, and Attention/EF Composite Scores Adjusted for Covariates Over 7 Years, in Males Only, Excluding Incident Dementia Cases

	Global Cognition (N=233)			Memory (N=233)			Attention/EF (N=233)		
Variable	Estimate	95% CI	p-value	Estimate	95% CI	p-value	Estimate	95% CI	p-value
Intercept	0.94	[0.12, 1.75]	.025	1.54	[0.50, 2.59]	.004	-0.11	[-1.03, 0.80]	.806
Balance Confidence	<0.01	[<0.01, 001]	.035	0.01	[>-0.01, 0.01]	.055	<0.01	[>-0.01, 0.01]	.268
Time	0.02	[0.01, 0.04]	.009	0.05	[0.03, 0.08]	<.001	0.01	[-0.02, 0.03]	.494
Time x Balance Confidence	<0.01	[>-0.01, <0.01]	.903	<0.01	[>-0.01, <0.01]	.350	>-0.01	[>-0.01, <0.01]	.748
Age	-0.03	[-0.04, -0.02]	<.001	-0.04	[-0.05, -0.02]	<.001	-0.02	[-0.03, -0.01]	.002
Gender	--	--	--	--	--	--	--	--	--
Education (years)	0.08	[0.06, 0.10]	<.001	0.08	[0.05, 0.10]	<.001	0.08	[0.06, 0.11]	<.001
Falls History	-0.01	[-0.06, 0.04]	.673	>-0.01	[-0.07, 0.07]	.929	-0.03	[-0.11, 0.05]	.478
Global Health Status	-0.01	[-0.03, 0.02]	.651	<0.01	[-0.03, 0.04]	.926	0.01	[-0.03, 0.05]	.607
Beck Anxiety Score	>-0.01	[-0.01, <0.01]	.387	>-0.01	[-0.01, 0.01]	.830	>-0.01	[-0.01, 0.01]	.711
Geriatric Depression Score	-0.01	[-0.01, <0.01]	.289	>-0.01	[-0.02, 0.01]	.508	-0.01	[-0.02, 0.01]	.323

Note. Model adjusted for covariates: age, education, falls history, GHS, GDS, and BAI.

Table 9A. Linear Mixed-Effects Model Examining the Effects of Time, Balance Confidence, and Their Interaction on Global, Memory, and Attention/EF Composite Scores Adjusted for Covariates Over 7 Years, in Females Only, Excluding Outliers

	Global Cognition (N=283)			Memory (N=283)			Attention/EF (N=283)		
Variable	Estimate	95% CI	p-value	Estimate	95% CI	p-value	Estimate	95% CI	p-value
Intercept	1.51	[0.65, 2.38]	.001	2.54	[1.47, 3.62]	<.001	0.40	[-0.45, 1.26]	.352
Balance Confidence	>-0.01	[>-0.01, <0.01]	.927	>-0.01	[-0.01, <0.01]	.608	<0.01	[>-0.01, <0.01]	.974
Time	0.05	[0.03, 0.06]	<.001	0.08	[0.05, 0.10]	<.001	0.02	[<0.01, 0.03]	.045
Time x Balance Confidence	<0.01	[<0.01, <0.01]	.004	<0.01	[<0.01, <0.01]	.027	<0.01	[<0.01, <0.01]	.004
Age	-0.03	[-0.04, -0.02]	<.001	-0.04	[-0.06, -0.03]	<.001	-0.02	[-0.03, -0.01]	<.001
Gender	--	--	--	--	--	--	--	--	--
Education (years)	0.07	[0.04, 0.09]	<.001	0.07	[0.04, 0.02]	<.001	0.06	[0.04, 0.09]	<.001
Falls History	>-0.01	[-0.05, 0.04]	.860	0.01	[-0.05, 0.07]	.786	<0.01	[-0.04, 0.04]	.919
Global Health Status	>-0.01	[-0.03, 0.02]	.676	-0.01	[-0.04, 0.02]	.595	>-0.01	[-0.02, 0.02]	.822
Beck Anxiety Score	<0.01	[>-0.01, 0.01]	.585	<0.01	[-0.01, 0.01]	.890	>-0.01	[>-0.01, <0.01]	.972
Geriatric Depression Score	-0.01	[-0.02, -0.00]	.042	-0.01	[-0.02, >-0.01]	.034	<0.01	[-0.01, 0.01]	.976

Note: Model adjusted for covariates: age, education, falls history, GHS, GDS, and BAI.

Table 9B. Linear Mixed-Effects Model Examining the Effects of Time, Balance Confidence, and Their Interaction on Global, Memory, and Attention/EF Composite Scores Adjusted for Covariates Over 7 Years, in Males Only, Excluding Outliers

	Global Cognition (N=233)			Memory (N=233)			Attention/EF (N=233)		
Variable	Estimate	95% CI	p-value	Estimate	95% CI	p-value	Estimate	95% CI	p-value
Intercept	1.06	[0.23, 1.90]	.013	1.74	[0.66, 2.81]	.002	0.04	[-0.91, 0.98]	.938
Balance Confidence	<0.01	[>-0.01, 0.01]	.192	<0.01	[>-0.01, 0.01]	.227	<0.01	[>-0.01, 0.01]	.336
Time	0.01	[>-0.01, 0.03]	.108	0.04	[0.02, 0.06]	.001	>-0.01	[-0.03, 0.02]	.952
Time x Balance Confidence	<0.01	[>-0.01, 0.00]	.421	<0.01	[>-0.01, <0.01]	.122	>-0.01	[>-0.01, <0.01]	.865
Age	-0.03	[-0.04, -0.02]	<.001	-0.04	[-0.05, -0.03]	<.001	-0.02	[-0.03, -0.01]	.002
Gender	--	--	--	--	--	--	--	--	--
Education (years)	0.08	[0.06, 0.10]	<.001	0.08	[0.05, 0.10]	<.001	0.08	[0.06, 0.10]	<.001
Falls History	>-0.01	[-0.05, 0.04]	.919	0.01	[-0.06, 0.08]	.847	-0.02	[-0.10, 0.06]	.634
Global Health Status	-0.01	[-0.04, 0.01]	.391	-0.01	[-0.05, 0.02]	.657	0.01	[-0.03, 0.05]	.727
Beck Anxiety Score	>-0.01	[-0.01, 0.01]	.798	<0.01	[-0.01, 0.01]	.878	>-0.01	[-0.01, 0.01]	.751
Geriatric Depression Score	-0.01	[-0.02, 0.00]	.064	-0.01	[-0.02, <0.01]	.153	-0.01	[-0.03, <0.01]	.102

Note: Model adjusted for covariates: age, education, falls history, GHS, GDS, and BAI.

Appendix

Supplemental Figures and Tables

Figure 1. Sample Distribution of Raw ABC-scale Scores

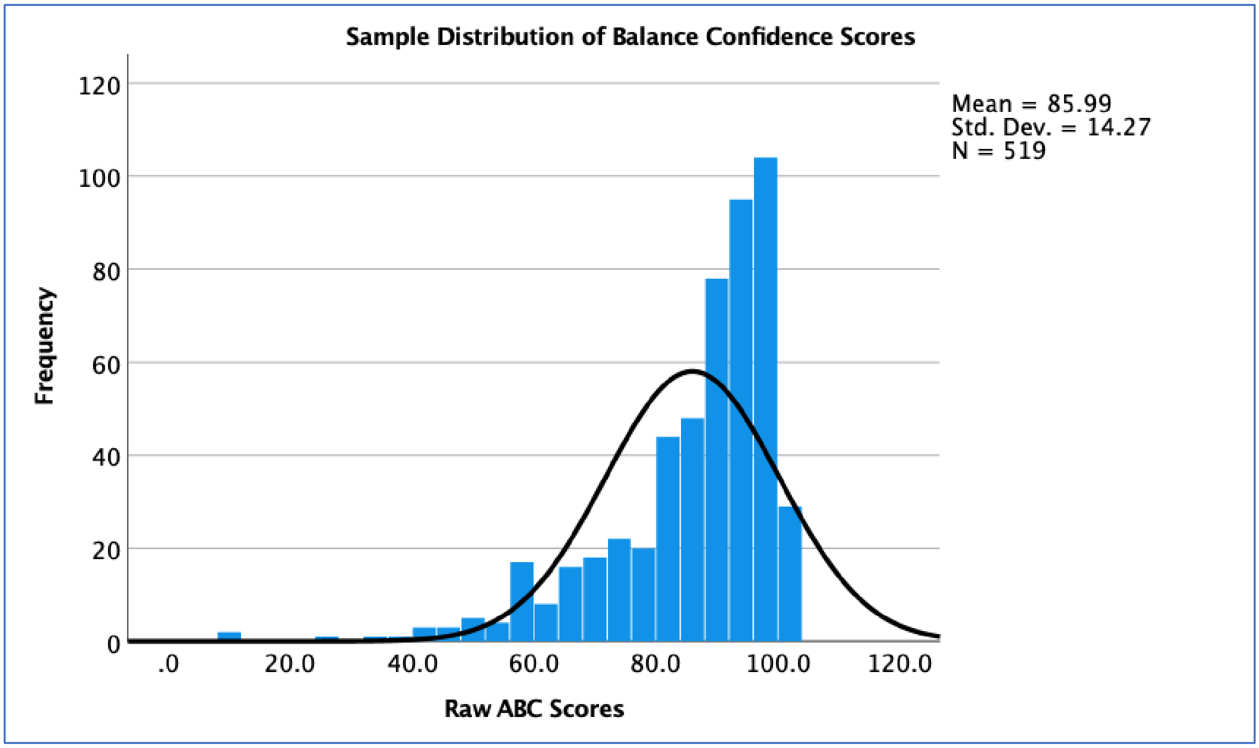

Figure 2. Sample Distribution of Log Transformed ABC-scale Scores

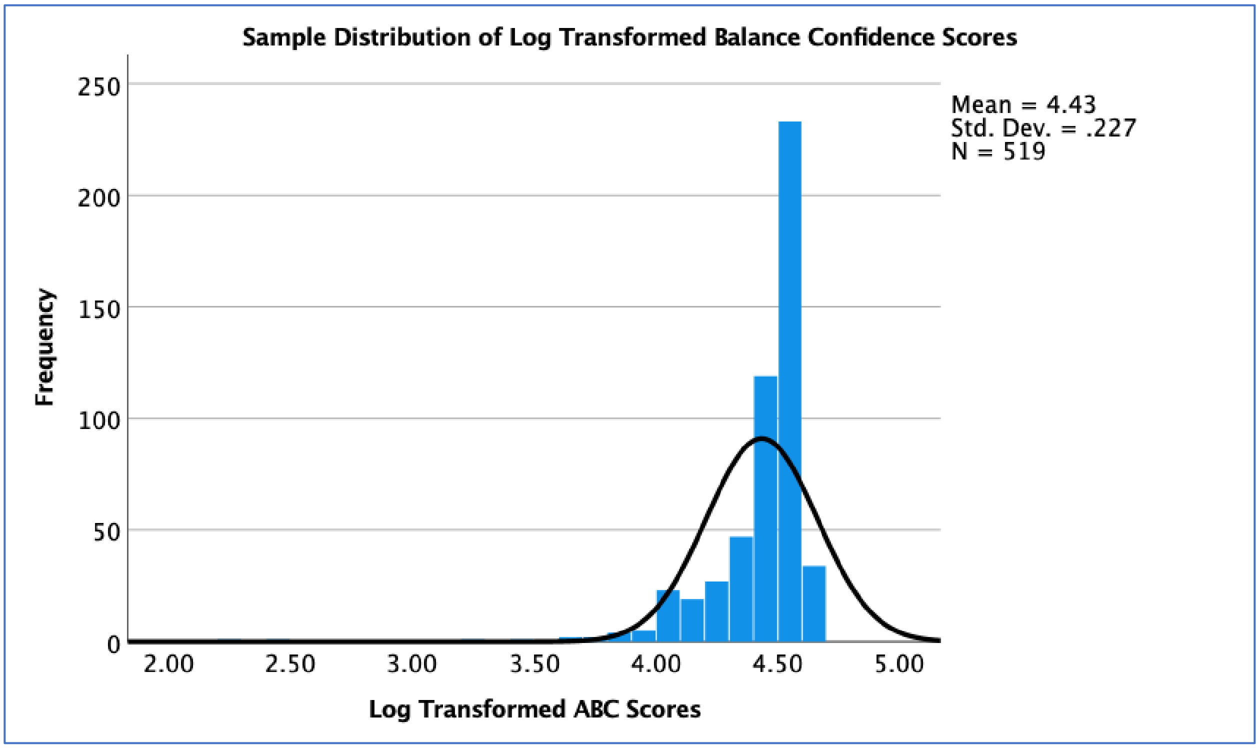

Figure 3. Sample Distribution of ABC-scale Scores After Excluding Outliers

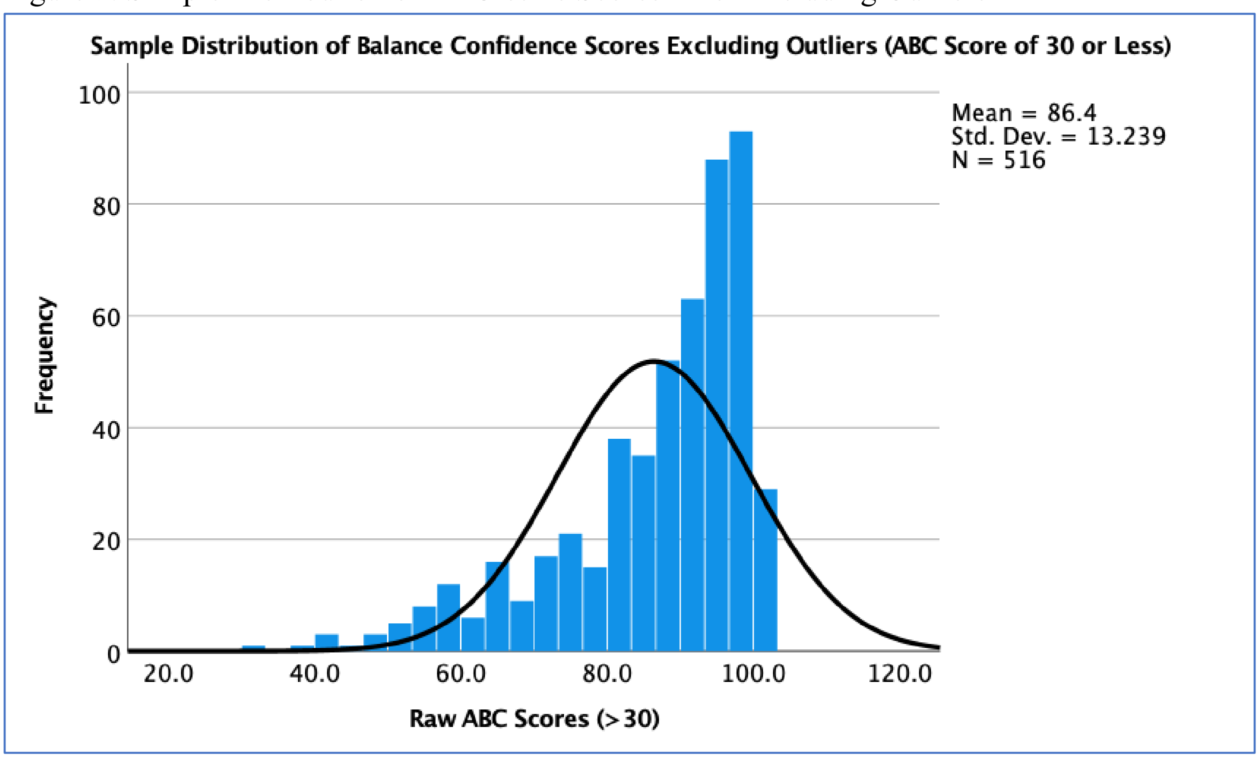

Table 1. Multivariate Linear Mixed-Effects Model Examining the Covariance of Balance Confidence and Cognitive Outcomes Over 7 Years (N=519).

Variable	Covariance Slopes Estimate	r	p-value
Global Cognition	0.29	0.36	<.001
Memory	0.28	0.29	<.001
Attention/EF	0.26	0.31	<.001

Note. Model adjusted for covariates: gender, age, education, falls history, GHS, GDS, and BAI.

Table 2. Multivariate Linear Mixed-Effects Model Examining the Covariance of Balance Confidence and Cognitive Outcomes Over 5 Years (N=519).

Variable	Covariance Slopes Estimate	r	p-value
Global Cognition	0.34	0.35	<.001
Memory	0.33	0.29	<.001
Attention/EF	0.29	0.32	<.001

Note: Model adjusted for covariates: gender, age, education, falls history, GHS, GDS, and BAI.

Table 3. Multivariate Linear Mixed-Effects Model Examining the Covariance of Balance Confidence and Cognitive Outcomes Over 7 Years, Excluding Incident Dementia Cases (N=519).

Variable	Covariance Slopes Estimate	r	p-value
Global Cognition	0.22	0.31	<.001
Memory	0.21	0.24	.004
Attention/EF	0.18	0.24	.003

Note: Model adjusted for covariates: gender, age, education, falls history, GHS, GDS, and BAI.

Table 4. Multivariate Linear Mixed-Effects Model Examining the Covariance of Balance Confidence and Cognitive Outcomes Over 7 Years, Excluding Outliers (N=516).

Variable	Covariance Slopes Estimate	r	p-value
Global Cognition	0.29	0.36	<.001
Memory	0.28	0.29	<.001
Attention/EF	0.26	0.31	<.001