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ORIGINAL RESEARCH

Multimodal Factors Affect Longitudinal Changes in Dynamic Balance in Community-Dwelling Older Adults

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Purpose: Dynamic balance, an important contributor to fall risk in older adults, involves maintaining the center of pressure while in locomotive states and is. Fall risk appraisal (FRA) is defined as assessing an older adult's awareness of their physiological and perceived fall risk. This longitudinal study aimed to evaluate how multimodal factors predict fluctuations in dynamic balance in community-dwelling low-income older adults, utilizing fear of falling (FoF), static balance, fall history, and moderate-to-vigorous physical activity (MVPA).

Patients and Methods: The longitudinal study included 140 community-dwelling, low-income older adults, with 124 women and 16 men. FoF was assessed using the Short Falls Efficacy Scale International (Short FES-I) and static balance using BTracks Balance Test (BBT). Both were utilized to define FRA Distance, an integrated quantification of physiological and perceived balance deficits. MVPA was assessed using accelerometers, fall history using self-report, and dynamic balance using the Timed Up and Go (TUG) test. The study was conducted at 4 timepoints at T1 (baseline), T2 (2 months), T3 (4 months), and T4 (6 months).

Results: Using mixed effects multilevel models, TUG scores were predicted by time, %MVPA, and FRA distance ratio. The effect of FRA distance ratio was primarily driven by FoF, and the effect of %MVPA varied by age. Additionally, while fall history did not show a predictive relationship with TUG scores, it did predict FRA distance.

Conclusion: Dynamic balance fluctuated over time and was influenced by multimodal factors, namely MVPA and FRA, which captured the interplay between static balance and FoF. Fall history did not directly predict dynamic balance but played a role in FRA, implicating the subjective effects of fall history. These findings demonstrate how physical activity, FRA, and their interactions can predict changes in dynamic balance. Future work can utilize the results to evaluate low-cost interventions for community-dwelling older adults.

Plain Language Summary: Evaluating changes in dynamic balance is critical for evaluating fall risk in older adults. This study aimed to determine what drives these fluctuations, including fear of falling, static balance, physical activity, and fall history using assessments at four timepoints across 6 months. The authors found that each of these variables except fall history directly influenced dynamic balance, with fall history influencing how older adults perceive their fall risk compared to their actual fall risk. These results confirm that changes in dynamic balance are influenced by modifiable factors, an important point for designing future interventions.

Keywords: balance, older adults, physical activity, fear of falling

Introduction

Falls are the leading cause of injury-related death for older adults, aged 60 years and older.[1] The increasing prevalence of falls is becoming a critical issue in healthcare as older adults are one of the fastest growing demographics in the United States with

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Graphical Abstract

limited care systems to address their many health concerns.[2] Despite the prevalence of falls in older adults, there are non-pharmacological interventions geared toward preventing and decreasing the severity of falls. Increased social awareness of individuals' risk of falling and methods of decreasing this risk are important in implementing preventative programs.[3] Low-income older adults face limited access to fall risk assessments and 84.1% have discrepancies of perceived and physiological fall risks or maladaptive fall risk appraisal (FRA) that reduced their physical activity (PA) and increased multiple falls.[4] Falls have resulted in decreased quality of life, increased risk of chronic diseases, and limited physical and psychosocial functioning, adding to the burden of care in the United States healthcare system.[5,6] Because falls often occur during movement,[7] it is crucial to understand the longitudinal decline of dynamic balance in older adults. In this study, we aim to characterize multimodal determinants of longitudinal shifts in dynamic balance to improve the efficacy of fall risk screening and maximize early intervention implementation in low-income older adults.

Both dynamic and static balance play vital roles in maintaining postural control during different activities. Dynamic balance plays a role in unstable environments or locomotive states, such as walking, standing, climbing stairs, while static balance involves maintaining upright posture and stable center of mass while fully supported on a fixed, level ground. Both dynamic and static elements of balance affect fall risk and activities of daily living.[8,9] The majority of falls occur during dynamic movements, including standing up from sitting, tripping, slipping, or changes in height such as climbing or descending stairs.[10] As individuals age, dynamic and static balance are unstable variables that decline at distinct rates over time, driven by physiological aging, hormonal changes, and sarcopenic decline in muscle mass.[7] As such, determining driving factors of changes in dynamic balance can inform appropriate interventions.

While it is well known that balance deteriorates with age,[11] this decline is not well characterized. Similarly, gender is also known to affect performance on dynamic balance assessments such as the TUG, with female outperforming male individuals. In addition to age and gender, other factors that influence dynamic balance include physical activity engagement, previous history of falls, and cognitive impairment.[12,13] In addition to the aforementioned contributors, static balance and fear of falling (FoF) also affect performance on the TUG.[14–16] Physical activity, static balance, and FoF are modifiable and dynamic factors that can be targeted in interventional models to improve dynamic balance. Recent studies have explored the effects of varying intensities of physical activity, including moderate-vigorous physical activity (MVPA), light physical activity (LPA), and sedentary time (ST), on fall risk and dynamic balance.[17–20] Static balance has been shown to decrease over time,[21] driven by closely related physiological changes in muscle strength and bone density.[22,23] However, because the rate of changes in static balance differ by age, sex, and activity,[11,24] evaluating short-term fluctuations in balance over time is crucial for understanding the effect on dynamic balance. Similarly, FoF is a dynamic measure that varies over the lifespan.[25]

Current work assessing longitudinal changes in dynamic balance focuses on separate investigation of the effects of objective measures, such as physical activity and static balance, and subjective measures, such as FoF. As a result, previous work leaves a significant gap in the integration of physiological and perceived fall risk and how they affect dynamic balance. Our team has developed the FRA matrix, a tool that integrates physiological ability and subjective perception to evaluate older adults holistically when screening for fall risk.[26] This tool evaluates physiological fall risk using static balance from the BTrackS Balance System and perceived fall risk using fear of falling (FoF) from the Short Falls Efficacy Scale International (Short FES-I). The BTrackS System is a portable and affordable balance system that utilizes a force plate to quantify static balance by evaluating postural sway distance, or variability in center of pressure.[27]

The FRA matrix can identify individuals with maladaptive FRA, where their physiological fall risk differs from perceived fall risk.[4,28] Previous studies have shown that one-third to two-thirds of community-dwelling older adults have maladaptive FRA, which is associated with fall history.[28–30] Determining how maladaptive FRA affects dynamic balance may illuminate how the integrated measure is correlated with an important factor associated with fall risk.[31,32] While previous work by our group introduces protocols for examining longitudinal shifts in FRA,[33] this preliminary study develops a new measure, FRA Distance, which quantifies such shifts to detect granular changes over time. The relationship between FRA and dynamic balance can additionally inform effective activity-based and psychosocial interventions.[34]

The present study evaluates the integration of FoF, static balance, and PA to understand longitudinal changes in dynamic balance of older adults. To do this, we utilize subjective questionnaires and objective measures in a longitudinal framework. In doing so, the synergistic effects of multiple components on dynamic balance can inform the interventional components to reduce fall risk in older adults. This study aims to expand understanding of accessible measures such as FRA and PA to inform older adults about their fall risk and dynamic balance, both of which play critical roles in their functional abilities.

Methods

Participants

This longitudinal study was conducted as part of a larger study that is federally funded by the National Institute on Minority Health and Health Disparities (R01MD018025).[33] The sample consisted of 140 community-dwelling older adults aged 60 to 90 years. Participants were recruited from community centers who are in low-income households

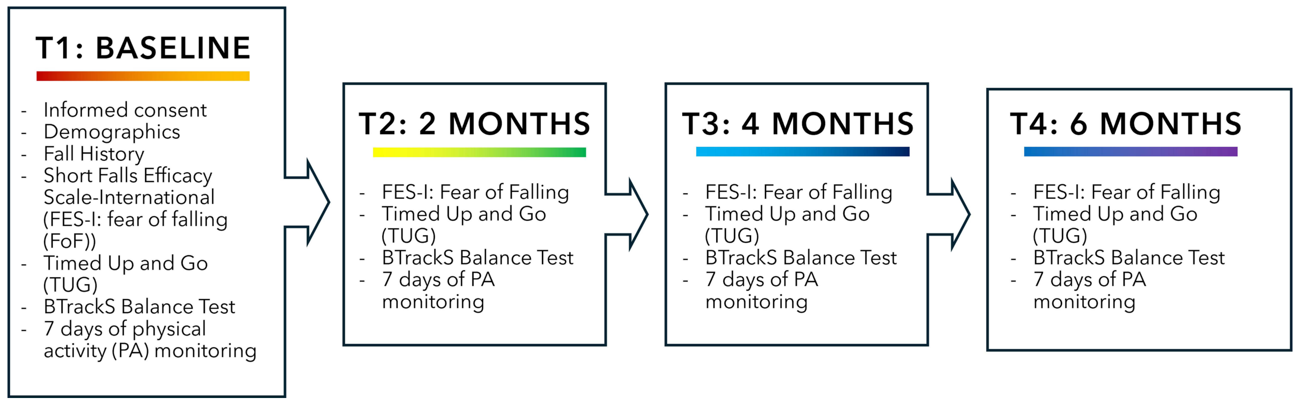

Figure 1 Schematic figure of data collection timeline and collected measures.

(determined by their eligibility for Section 202 Supportive Housing for the Elderly program) within Orlando, Florida using various strategies, including flyers, word-of-mouth, and collaboration with community partners. The inclusion criteria were that participants must be aged ≥60 years, be able to walk (with or without assistive devices but not requiring assistance from another person), live in their own homes or apartments, and be fluent in English or Spanish. The exclusion criteria were (1) having a medical condition that may preclude engagement in PA (including shortness of breath, dizziness, tightness or pain in the chest, and unusual fatigue at rest or with light exertion) and (2) currently receiving treatment from a rehabilitation facility. Upon enrollment in the study, participants completed a demographics survey including fall history within the past year. Then, participants completed several visits at baseline (T1), 2 months (T2), 4 months (T3), and 6 months (T4), where they arrived at a local community center to complete FRA assessments and questionnaires (Figure 1). Following each visit, each participant was fitted with an accelerometer worn on the non-dominant wrist and given instructions on how to wear it during the PA-monitoring period of 7 days. Given the higher proportion of women in the older adult population frequenting community centers, our study sample exhibited a sex-based bias, as shown in Table 1.

Ethics Approval and Informed Consent

The study was carried out in accordance with the Declaration of Helsinki and was pre-registered on ClinicalTrials.gov (NCT06063187). All study procedures were approved by the University of Central Florida Institutional Review Board (IRB# STUDY00002473) and all participants provided written informed consent prior to participation.

Table 1 Sample Characteristics

Variable	N (%)
Sex	
Female	124 (88.57%)
Male	16 (11.03%)
Age (years)	
60–69	44 (30.34%)
70–79	64 (44.14%)
≥80	32 (22.07%)
Total	140

Measures

Dynamic Balance

Dynamic balance was assessed using the Timed Up and Go (TUG) test.[35] Before participants completed the TUG test, experimenters instructed and demonstrated the assessment. Participants were instructed to stand up from a chair, walk 3 meters, turn around, walk back to the chair, and sit down again. The measure of dynamic balance was recorded as the time in seconds that the participants take to complete the assessment.

Fall Risk Appraisal

FRA was assessed, as described in previous work,[4,26,33] using objective and subjective measures to assess physiological fall risk using the BTrackS balance test and perceived fall risk using the Short Falls Efficacy Scale-International (Short FES-I).

Static Balance

Static balance (postural sway) was used to quantify physiological fall risk using the previously validated BTrackS System (Balance Tracking Systems, Inc. San Diego, CA), consisting of a balance plate, software, and a computer with Windows 7 or higher. Postural sway was quantified as the BTrackS Balance Test (BBT) by evaluating the path length of center of pressure while in a static posture. Participants completed one 20-second trial for familiarization, in which they were instructed to stand on the balance plate with their feet 30cm apart, hands on hips, and eyes closed. After this practice trial, 3 additional 20-second trials were conducted and averaged to determine the final score of static balance.[36] The BTrackS System has been validated for reliability and validity using intraclass correlation coefficients and Pearson correlations.[27]

Fear of Falling

Fear of falling (FoF) was evaluated using the Short-FES-I, a 7-item self-administered tool measuring concern about falling while performing daily activities on a 4-point Likert scale (1=not at all concerned to 4=very concerned) with total scores ranging from 7 to 28. The Short FES-I questionnaire has been validated in older adults for reliability and predictive validity in psychological fall risk and balance ability.[37]

Longitudinal Shift in FRA

Longitudinal shifts in FRA were quantified using a modified distance calculation. First, target FRA was defined as minimizing FoF (low FES-I score) and maximizing static balance (low BBT score). To quantify the shifts in FRA, we developed the following measure: FRA distance at each timepoint *t* defined as:

$$\text{FRA Distance}_t = \sqrt{{\text{BBT}_t}^2 + {\text{FoF}_t}^2}.$$

Accelerometer-Based Physical Activity

ActiGraph GT9X Link and LEAP (ActiGraph LLC, Pensacola, FL, USA) were used to measure PA levels in participants at each timepoint. The wrist-worn devices are lightweight and small and contain a triaxial accelerometer. The devices were initialized to record data at a sampling rate of 30 hz (GT9X) and 32 hz (LEAP) at 1-minute intervals with a dynamic range of ±8 gravitational units (g), as per prior studies.[38] The ActiGraph LEAP device is a newer model of the GT9X, which expands upon the framework of the GT9X to minimize participant burden and maximize adherence. The ActiGraph LEAP, like the GT9X, has been approved by the Food and Drug Administration for measurement of activity.[39] Participants were instructed to wear it on their nondominant wrist and only remove it near water or undergoing medical imaging for 7 consecutive days, after which the devices were collected from the participants. The ActiGraph GT9X devices have demonstrated high accuracy at distinguishing types of PA based on established cutpoints.[40]

For data analysis, only participants who had at least 6 days for 10 hours were included. Raw acceleration data was downloaded using ActiLife (GT9X) and CentrePointe (LEAP) and analyzed using R statistical software (R Core Team, Vienna, Austria) to process the ".csv" files. Raw Accelerometer Data Analysis (GGIR), an open-source R-package, was used to process the data to include autocalibration of acceleration signals, non-wear time detection, and calculation of the Euclidean norm of acceleration minus 1 g (ENMO), as previously described.[41,42] Out of total wear time, the percentage of time spent in ST, LPA, and MVPA was calculated based on the following cut-off points: (i) SB < 30 milligravitational

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units (mg); (ii) 30 mg ≤ LPA < 100 mg; (iii) MVPA ≥ 100 mg.[43,44] This percentage was then averaged across the seven-day period that the accelerometer was worn at each timepoint.

Statistical Analysis

All data were stored in a REDCap database managed by the University of Central Florida.[45,46] Mixed-effects (multilevel) modeling was conducted in R statistical software (version 4.1.2, R Core Team, Vienna, Austria) with statistical significance level set at 0.05. The Shapiro–Wilk test was utilized to determine if continuous variables followed normal distributions.[47] Linear mixed effects regression models were fitted using the lmer function in the "lme4" package.[48] The models were optimized using the "bobyqa" optimizer.[49] Models employed restricted maximum likelihood (REML) estimation method for parameterization, and for model comparison, Akaike information criterion and Bayesian information criterion (AIC and BIC) was utilized to determine the optimal model.[49,50] Using model comparison as specified, we removed uninformative interactions. The final model utilized TUG score as the response variable. Fixed effects included timepoint (T1-T4), centered FRA distance ratio, and % MVPA, while controlling for demographic variables (centered age, and sex), with a random effect at the individual level to account for inter-subject variance. Scatterplots, boxplots, and violin plots were utilized to visualize and present the data.

Power Analysis

A post-hoc power analysis was conducted for the mixed-effects model using the simr package in R to assess the power of the fixed effect in validating the variable of FRA distance.[51] The analysis was based on 100 simulations of the dataset with a sample size of n=438. The power was calculated at a significance level of $\alpha=0.05$ using the likelihood ratio test. The estimated power of the model for detecting the fixed effect was 98%, with a 95% confidence interval of [92.96, 99.76]. This high level of power indicates strong evidence of the model's ability to reliably detect the fixed effect.

Results

Participants

140 participants were included in the analysis at baseline (T1), and after retaining only timepoints with at least 6 valid days with 10 hours of data, participants had a total of 438 timepoints ($M_{visits} = 3.13 \pm 0.86$) with 298 subsequent visits at T2 (126), T3 (96), and T4 (76) after baseline (T1).

Longitudinal Predictors of Dynamic Balance

TUG scores were predicted by time, %MVPA, and FRA distance ratio (Table 2, Model 1). For time, one of the time comparisons (T3 compared to T1) was significant (p < 0.001), indicating worse performance at T3 compared to T1, but

Table 2 Longitudinal Effects of Time, Physical Activity, and FRA Distance on Dynamic Balance

Predictors	**Outcome: Timed Up and Go (TUG) Scores**					
	Model 1		**Model 2**		**Model 3**	
	β	***p-value***	***β***	***p-value***	***β***	***p-value***
(Intercept)	5.26	0.232	1.13	0.780	−8.81	0.158
T2-T1	0.18	0.769	0.20	0.750	0.04	0.948
T3-T1	1.53	**0.024**	1.56	**0.021**	1.33	**0.048**
T4-T1	0.03	0.973	0.12	0.865	−0.14	0.845
%MVPA	−0.29	**0.023**	–	–	4.37	**0.003**
FRA Distance	0.05	**0.009**	0.05	**0.006**	–	–
Age	0.06	0.329	0.10	0.084	0.27	**0.001**
Sex	−2.19	0.065	−2.36	**0.049**	−1.53	0.189
%MVPA x Age	–	–	–	–	−0.07	**0.002**

(*Continued*)

Table 2 (Continued).

Predictors	Outcome: Timed Up and Go (TUG) Scores					
	Model 1		Model 2		Model 3	
	β	*p-value*	*β*	*p-value*	*β*	*p-value*
σ^2	24.74		24.75		76.17	
$\tau_{00\ study\_id}$	10.65		11.22		223.07	
ICC	0.30		0.31		0.75	
Marginal / Conditional R^2	0.076 / 0.354		0.060 / 0.353		0.137 / 0.780	
AIC / BIC	2785.79 / 2826.61		2786.62 / 2823.36		2782.38 / 2823.20	

Notes: Bolded p-values represent significance as defined as p-value < 0.05. For each model below, the response variable, Timed Up and Go score, is representative of dynamic balance such that increased values indicate worse performance and decreased values indicate improved performance. Model 1 represents the full model, with positive coefficients revealing that at Time 3 and with increased FRA distance, TUG scores increased, and negative coefficients revealing that increases in %MVPA decreased TUG scores. Model 2 and Model 3 describe the isolated effects of FRA Distance and %MVPA, respectively, along with their significant interactions.
Abbreviations: σ2, residual variance at level 1 (observation); ICC, intraclass correlation; AIC, Akaike information criterion; BIC, Bayesian information criterion.

not at other time comparisons (T2-T1, T4-T1). Additional models exploring interactions between the three fixed effects of interest were evaluated (Supplementary Tables S1–S3), but the model with the minimum AIC (1460.08) was utilized to use the final model described here. Increased %MVPA showed decreased TUG scores, indicating an improvement in performance. Increased FRA Distance, on the other hand, showed increased TUG scores, indicating a worse performance (Figure 2). In Figure 3, we observed a significant increase (worsening) of TUG scores at T3 compared to T1, but not at other timepoints.

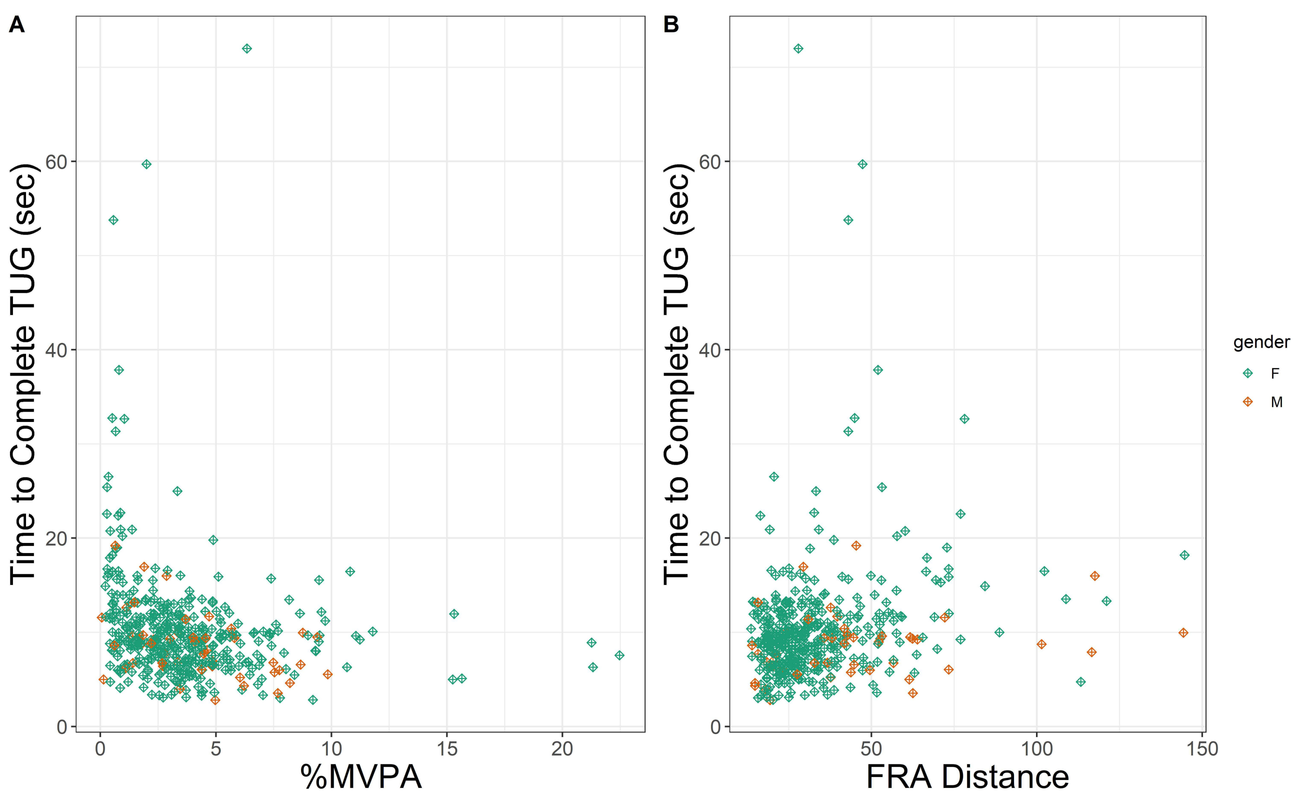

Figure 2 Effects of %MVPA and FRA Distance on TUG Scores. %MVPA (Moderate-to-Vigorous Physical Activity, (**A**)) and FRA (Fall Risk Appraisal) Distance (**B**) both showed significant (p<0.05) effects on TUG (Timed Up and Go) scores, such that increased MVPA improved TUG performance and increased FRA Distance decreased TUG performance.

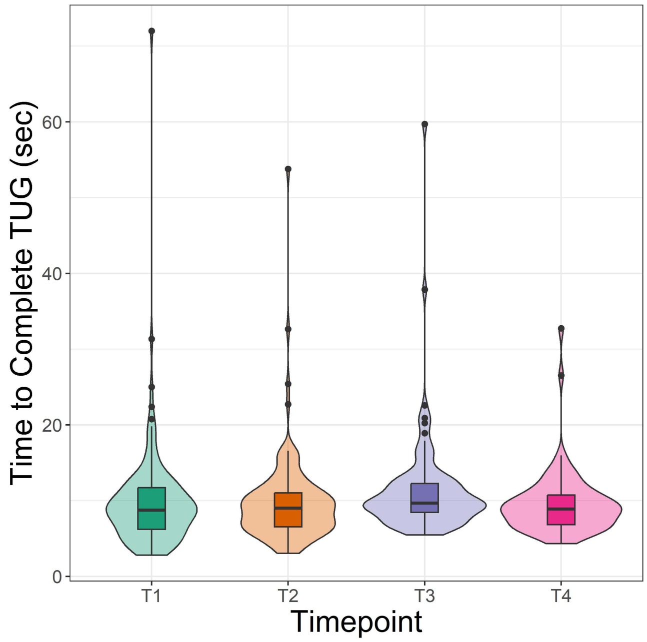

Figure 3 Longitudinal Changes in Timed Up and Go (TUG) Scores. While T2 and T4 did not show significant differences between the baseline timepoint (T1), T3 showed a significant increase (worse performance) in TUG scores than the baseline. Here, T1 is baseline, T2 is 2 months, T3 is 4 months, and T4 is 6 months from baseline.

Components of FRA Distance on TUG Score

The value of FRA Distance is based on the integration of FoF and static balance, as measured by the BTrackS Balance Test (BBT). To investigate the value of FRA Distance as an integrated measure, we developed models investigating the independent effects of FoF and static balance over time, and FRA distance over time. In Table 3, FoF, but not BBT,

Table 3 Longitudinal Effects of Time, Fear of Falling, and Static Balance on Dynamic Balance

Predictors	**Outcome: TUG Score**			
	β	***Confidence Interval***	***t-statistic***	***p-value***
(Intercept)	−1.03	−8.76–6.69	−0.26	0.793
T2-T1	0.19	−1.02–1.41	0.31	0.753
T3-T1	1.69	0.36–3.01	2.49	**0.013**
T4-T1	0.10	−1.34–1.54	0.14	0.891
FoF	0.30	0.14–0.45	3.73	**<0.001**
BBT	0.03	−0.01–0.07	1.60	0.110
Age	0.10	−0.01–0.20	1.81	0.070
Sex	−2.16	−4.41–0.10	−1.88	0.061
σ^2	24.93			
$\tau_{00\ study\_id}$	9.44			
ICC	0.27			
N_{study_id}	140			
Observations	438			
Marginal R^2 / Conditional R^2	0.096 / 0.344			
AIC / BIC	2780.38 / 2821.20			

Notes: Bolded p-values represent significance as defined as p-value < 0.05. Timed Up and Go score is representative of dynamic balance such that increased values indicate worse performance and decreased values indicate improved performance. Positive coefficients reveal that at Time 3 and with increased fear of falling, TUG scores increase, but static balance (BTrackS Balance Test – BBT) did not significantly predict TUG scores.

Abbreviations: σ2, residual variance at level 1 (observation); FoF, fear of falling; BBT, BtrackS Balance Test; ICC, intraclass correlation; AIC, Akaike information criterion; BIC, Bayesian information criterion.

significantly predicted TUG scores, such that increased FoF resulted in increased TUG scores. Similar to FoF, increased FRA distance predicted worsened TUG scores in Table 2, Model 2.

Age Dependence of %MVPA on TUG Score

Other models investigated how age and sex may influence the effect of %MVPA and FRA Distance on TUG scores. The model revealed significant fixed effects of time, %MVPA, and age. A significant interaction between %MVPA and age showed the age-dependent effects of %MVPA on TUG scores, specifically that the positive effects of %MVPA increase as older adults age (Table 2, Model 3). A similar model investigating how age moderates the effect of FRA distance showed no significant interactions (Supplementary Table S4).

Longitudinal Effects of Fall History

Additional multilevel models evaluated the longitudinal effects of fall history on changes in TUG, %MVPA, and FRA Distance. While TUG scores and %MVPA both did not show any significance, FRA Distance increased with fall history, age, and female sex. Additionally, the model revealed a significant interaction between timepoints T3 and T4 and fall history.

Discussion

This longitudinal study aimed to investigate and describe the factors that are associated with improved or worsened dynamic balance scores, a common predictor of falls in community-dwelling older adults.[8,52] Using mixed effect multilevel models, the findings revealed the significance of time, fall risk appraisal (FRA), and moderate-to-vigorous physical activity in the evaluation of dynamic balance in older adults. Additionally, characterizing changes in each of these factors in this longitudinal study revealed the moderating effect of fall history on FRA, through the introduction of the quantitative variable of FRA Distance.

In the interpretation of changes in TUG scores, a critical component to consider is the effect of time. It has been shown in other studies that dynamic balance varies over time;[11] however, most studies investigate these changes over long periods of time. In this study, we aimed to investigate how multiple variables influence these time dependent changes in TUG performance. While T2 and T4 showed insignificant increases in TUG scores compared to baseline at 2 and 6 months, T3 showed an increase in scores, indicating a significant worsening in dynamic balance at 4 months. The findings at T3 may indicate that dynamic balance varies in a more volatile fashion than previously thought, suggesting potential need for more frequent monitoring. However, many external factors including recent activities, seasonal variations, and mood could have influenced these results.[53,54] Additionally, participant withdrawal over the course of T2-T4 could have shifted mean performance, although within-subject variance was controlled using the random effect in the mixed effects model.

The influence of physical activity on the physical performance of older adults is mixed, with some studies showing improved physical function,[55–57] and others showing no significant associations.[58] Our study aligns with previous research showing improved performance on physical function tests such as the TUG that focus on maintenance of mobility, based on the significance of %MVPA as a fixed effect in the MLM. Surprisingly, there were no significant interactions between time and %MVPA in other, less optimized models (Supplementary Table S2). However, a deeper investigation into the age-dependent effects of %MVPA revealed that as adults age (Table 2, Model 3), the benefits of % MVPA in improving dynamic balance increase. This shows that while there is not a short-term impact of %MVPA on TUG scores, over time there is increased efficacy of %MVPA as a non-pharmacological intervention and recommendation for improving and maintaining mobility in older adults.

Previous work by our team has used the metric of FRA to stratify older adults with different attitudes and risk levels toward their perceived and physiological fall risk.[34] This work introduces the quantification of FRA using the variable FRA Distance, a modification of the Euclidean distance formula to quantify the older adult's distance from the target FRA of no perceived or physiological fall risk. Previous work has investigated the independent association of fear of falling (FoF) on dynamic balance (TUG score);[14,59,60] however, the same association does not exist between static and dynamic balance, which are two very different measures. To validate FRA Distance, we investigated the significance of the separate components of this measure. Indeed, in Table 3, we find that FoF but not static balance (BBT) significantly

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predicts TUG scores, such that increased FoF shows worsened TUG performance. This finding reveals that under-confident older adults are more likely to show poorer TUG performance. However, the added value of FRA Distance is the integration of static balance performance into the measure and is still a significant predictor of TUG scores, in a similar direction as FoF (Table 3). The contribution of FoF to FRA distance validates the inclusion of perceived fall risk in the measure. The non-significance of BBT indicates an indirect role that requires contextualization alongside subjective perceptions.

Various theoretical frameworks have been developed to identify the pathway of this relationship. For example, fearful older adults are more likely to undergo anxiety-driven stiffening of their posture, which ultimately decreases dynamic functioning.[61] Other theoretical models consider how perceived control of balance challenges influences the effect of FoF.[62] By including static balance, FRA Distance accounts for the effect of postural stiffening and may be indicative of perceived control by integrating objectively measured balance with fearful perceptions. The significance of FoF demonstrates that it primarily drives worsened TUG performance. However, the significance of FRA distance suggests that both psychological and physical domains interact to influence functional mobility and validates the measure as relevant in the domain of fall risk. By integrating these domains, this measure might better reflect perceived control and real-world fall risk compared to assessing these domains separately.

Additional models evaluated the effect of previous falls in the last year as measured by self-report. While fall history did not significantly affect dynamic balance or %MVPA, Table 4 shows that FRA Distance tells a different story. Previous research has shown that previous falls within the past year is a predictor of FoF.[63] Similarly, older adults with recurrent falls show greater postural sway, a measure directly related to static balance (BBT).[64] In this way, the results showing that FRA Distance is related to fall history are corroborated by existing literature, further validating the measure. The negative coefficients of the significant interactions between fall history and timepoint suggest that over time, the poor consequences of fall history are ameliorated. Finally, age and sex are both significant in this model, unlike many of

Table 4 Longitudinal Effects of Fall History, Time, and Demographics on FRA Distance

Predictors	**Outcome: FRA Distance**			
	β	***Confidence Interval***	***t-statistic***	***p-value***
(Intercept)	−4.42	−32.99–24.15	−0.30	0.761
Fall History	14.44	8.08–20.79	4.47	**<0.001**
T2-T1	−0.81	−3.35–1.74	−0.62	0.534
T3-T1	0.08	−2.76–2.92	0.06	0.954
T4-T1	−0.42	−3.48–2.64	−0.27	0.789
Age	0.46	0.07–0.84	2.34	**0.020**
Sex	8.99	0.71–17.27	2.13	**0.033**
Fall History x T2-T1	−3.39	−8.10–1.33	−1.41	0.159
Fall History x T3-T1	−8.51	−13.72 – −3.29	−3.21	**0.001**
Fall History x T4-T1	−6.05	−11.80 – −0.30	−2.07	**0.039**
σ^2	76.17			
$\tau_{00study\_id}$	223.07			
ICC	0.75			
N_{study_id}	138			
Observations	431			
Marginal R^2 / Conditional R^2	0.137 / 0.780			
AIC / BIC	3392.95 / 3441.74			

Notes: Bolded p-values represent significance as defined as p-value < 0.05. FRA Distance is the quantified measure of fall risk appraisal, integrating subjective fear of falling and objective static balance. This model shows that fall history, age, and male sex results in increased FRA distances, and interactions between fall history and timepoints T3 and T4 reveal mitigating factors over time.

Abbreviations: σ2, residual variance at level 1 (observation); ICC, intraclass correlation; AIC, Akaike information criterion; BIC, Bayesian information criterion.

the previous models with older age and male sex showing worsened TUG performance. While the deterioration of TUG performance with age is expected, the effect of sex does not have enough statistical power to reach a concrete conclusion due to the low number of male older adults in the study. In these comparisons, TUG scores and %MVPA were not significantly affected by fall history, suggesting that psychological resilience or prior history of falls may encourage older adults to perform at similar levels to their non-falling peers.

The limitations of the study include the predominantly female sample, limiting exploration of sex differences, an important facet given that women are likely to have both higher FoF and fall risk.[1,65,66] The use of TUG scores to represent dynamic balance presents some limitations, namely the effects of impaired lower limb strength or mobility that may delay sit-to-stand or stand-to-sit transitions despite intact gait. However, in using time to complete the TUG, we are utilizing a comprehensive measure that reflects both gait and lower limb abilities and has been used to reflect dynamic balance in a number of previous studies.[8,67] However, as various tests exist to assess dynamic balance, further research is needed to see if the present results hold up when a different assessment of dynamic balance is used. Additionally, sample size was affected by participant drop out at each timepoint, a limitation of most community-based longitudinal studies. However, the 7-days of PA monitoring as well as subjective and objective measures of dynamic balance, static balance, and FoF maximized participant data collection at each timepoint. A significant limitation of the study is the lack of validation for the novel measure of FRA Distance. However, given the predictive validity of each component involved in the calculation of FRA distance, we propose that the results in Table 3 and the conceptual definition of FRA distance provide sufficient construct validity. However, future research should involve a prospective study analyzing the relationship between FRA Distance and future falls, to understand how the addition of static balance increases the predictive validity of FRA distance, as compared to FoF. Finally, the longitudinal aspect of the study introduces the limitation of participant drop-out at each of the timepoints: T2 (10.0%), T3 (34.9%), and T4 (20.8%). However, the use of mixed-effect models included all available data to mitigate the effects of drop-out.

The presented study examines the longitudinal trajectory and factors associated with dynamic balance in community-dwelling older adults. Additionally, the study introduces the quantification of fall risk appraisal through the variable of FRA Distance, integrating perceived and physiological fall risk. Findings indicate that dynamic balance fluctuates over time and is associated with physical activity and FRA distance. Age-related differences are found in the effects of MVPA on dynamic balance, and fall history plays a role in fall risk appraisal. The results additionally expand the utility of affordable interventions targeting PA and FoF for improving dynamic balance in low-income communities.

Conclusions

Exploring the factors associated with changes in dynamic balance revealed the significance of physical activity, FRA distance, and time. The findings in this study can be utilized to identify those at increased risk and optimize fall prevention. In a rapidly aging population, understanding the longitudinal factors of age-related changes in dynamic balance provides avenues to improve quality of life.

Abbreviations

FRA, Fall Risk Appraisal; FoF, Fear of Falling; MVPA, Moderate-to-Vigorous Physical Activity; FES-I, Falls Efficacy Scale International; BBT, BTrackS Balance Test; TUG, Timed Up and Go; PA, Physical Activity; STEADI, Stopping Elderly Accidents, Deaths, and Injuries; LPA, Light Physical Activity; ST, Sedentary Time.

Data Sharing Statement

The deidentified data and R code that support the findings of this study are available on the Open Science Framework: https://osf.io/nf3ps/?view_only=5bae8d840ad6412fb781e6b8defa1f9a.

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Author Contribution

All authors made a significant contribution to the work reported, whether that is in the conception, study design, execution, acquisition of data, analysis and interpretation, or in all these areas; took part in drafting, revising or critically reviewing the article; gave final approval of the version to be published; have agreed on the journal to which the article has been submitted; and agree to be accountable for all aspects of the work.

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Disclosure

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