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Original Study

Physical Resilience in Daily Functioning Among Acutely Ill Hospitalized Older Adults: The Hospital-ADL Study

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A B S T R A C T

Objectives: Insight into older adults' physical resilience is needed to predict functional recovery after hospitalization. We assessed functional trajectories in response to acute illness and subsequent hospitalization and investigated baseline variables and dynamic variables associated with these trajectories.
Design: Prospective observational cohort study (Hospitalization-Associated Disability and impact on daily Life Study).
Setting and Participants: This study included 207 older adults (aged 79.8 ± 6.9 years, 49% female, 57% frail) acutely hospitalized in 6 Dutch hospitals.
Methods: Functional disability was assessed using the 15-item modified activities of daily living index retrospectively 2 weeks before admission, and prospectively from admission up to 3 months after discharge. Baseline variables including frailty, somatic, physical, and psychosocial factors were assessed at admission. Dynamic variables (step count, pain, fatigue, and fear of falling) were continuously or repeatedly assessed during hospitalization. We performed individual spline modeling using random effects. Baseline variables and within-person mean levels and variability in the dynamic variables were assessed as predictors of functional trajectories.
Results: Functional disability significantly increased before admission and decreased from admission to 3 months post discharge. Frail participants had a significantly higher increase in functional disability before admission compared with nonfrail participants. Lower step count, higher pain scores, and higher within-person variability in fear of falling were significantly associated with higher increase in functional disability before admission. Higher within-person variability in fear of falling was associated with more recovery.
Conclusions and Implications: Older adults increase in functional disability before hospitalization and start to recover from admission onward. Frailty and dynamic variables are associated with a higher increase in functional disability after acute illness. Our findings give more insight into older adults' physical resilience, which may improve the prediction of functional recovery and may improve therapeutic decision-making and rehabilitation strategies to improve functional recovery after acute hospitalization.

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Acute illness and subsequent hospitalization including medical treatment are large health stressors for older adults, and their functional recovery is often unpredictable.[1] After acute hospitalization, older adults are at high risk of functional decline in activities of daily living (ADL) like bathing and dressing, or instrumental ADLs (IADLs) such as handling finances.[2–5] Frail older adults are at increased risk of functional decline after acute hospitalization,[6,7] as they are less resistant to stressors.[8] After discharge, the prognosis for functional recovery is poor because there is a high risk that this functional loss will become permanent.[2] However, in clinical practice, it is often hard to predict which individuals will maintain or regain function after a stressor and who will not.

Using the concept of physical resilience, we may get a deeper understanding of the individual's ability to bounce back following an acute illness and hospitalization.[9,10] Whitson et al.[10] defined physical resilience as a characteristic at the whole-person level that determines an individual's capacity to resist decline and to recover function in response to a health stressor.[10] The actual response to the health stressor is proposed to be a complex, dynamic process.[1,11–13] Whitson et al.[10] suggested measuring the individual's resistance and resilience by direct observation of functional trajectories following a health stressor. In their conceptual model, they propose that physical resilience is influenced by the pre-stressor reserve in the cognitive, psychological, and physical domains ranging from robust to frail. However, physical resilience is a dynamic process rather than a static state. This implies that besides the more static factors, such as cognition and frailty, variability markers can reflect the quality of an individual's dynamic regulatory processes involved in the response to stressors.[14] Previous research using the dynamic systems theory showed that the within-person variability and dynamic behavior of variables may indicate an individual's physical resilience.[15–18] To detect the within-person variability, time series data of variables such as physical performance measures,[12,19,20] physical activity,[21,22] and self-rated health factors[15] can be used.

A previous study[22] showed that among hospitalized older adults, the dynamics in physical and mental factors improved the prediction of recovery in addition to frailty status. However, in this earlier study, recovery was assessed at one time point and did not provide detailed information on the individual's functional trajectories in response to the stressor. To get more insight into hospitalized older adults' physical resilience, the next step is to directly observe the functional trajectories in in the presence of a stressor according to the model of Whitson et al.[10] and to identify indicators of physical resilience. We hypothesized that besides single baseline characteristics that represent the pre-stressor reserve, also dynamic variables are indicators of physical resilience. The aims of this study were (1) to assess functional trajectories in response to acute illness and subsequent hospitalization in older adults, and (2) to investigate the association of single baseline variables and dynamic variables assessed during hospitalization with resistance and resilience trajectories in ADL functioning.

Methods

Setting and Participants

Participants were included from the Hospital-Associated Disability and impact on daily Life (Hospital-ADL) study, a multicenter observational prospective cohort study.[23] Acutely hospitalized older adults who were admitted to internal medicine, cardiology, and geriatric wards in 6 Dutch hospitals for ≥48 hours between October 2015 and June 2017 were included. Inclusion criteria were as follows: (1) age ≥70 years; (2) approval of the medical doctor; (3) sufficient understanding of the Dutch language to answer questionnaires; and (4) a Mini-Mental State Examination (MMSE) score of ≥15.[24] Older adults were excluded if they (1) had a life expectancy ≤3 months, or (2) needed help with all 6 basic Katz-ADLs[25] at the time of inclusion.

This study was approved by the institutional review board of the Academic Medical Center. All participating hospitals provided local approval. The study was performed according to the Dutch Medical Research Involving Human Subjects Act[26] and principles of the Declaration of Helsinki (1964).[27] Before study inclusion, written informed consent was given by all participants or a legal representative of the participant if cognitively impaired.

Data Collection

All assessments were performed by trained researchers following a standardized study protocol.[23]

Single Baseline Measurements

Single baseline characteristics included severity of acute illness, education, comorbidities, cognitive functioning, depressive symptoms, and frailty, and were measured at study inclusion. Severity of acute illness was measured with the Modified Early Warning Score (MEWS).[28] Comorbidities were assessed with the Charlson Comorbidity Index (CCI).[29] Cognitive functioning was assessed with the MMSE, with a score of ≤23 indicating cognitive impairment.[30] Depressive symptoms were measured with the Geriatric Depression Scale-15, whereby a score of ≥6 indicates depressive symptoms.[31] Frailty was assessed according to Fried's criteria,[8] including weight loss (having lost ≥6 kg in the past 6 months, or ≥3 kg in the past month), fatigue [score of ≥4 assessed with numeric rating scale (NRS) ranging from 0 to 10],[32] slowness (walking 4 m in <6.42 seconds), low physical activity (<30 minutes of moderate/vigorous physical activity, like brisk walking or cycling, per month in the past 6 months), and muscle weakness (maximum handgrip strength of <18 kg for women and <30 kg for men).[33,34] When 3 or more criteria were present, a person was considered frail.

Dynamic Variables

Dynamic variables were step count and self-rated levels of pain, fatigue, and fear of falling. Step count was continuously assessed from study inclusion until discharge using the Fitbit Flex activity tracker.[35–37] For the analysis, step numbers were counted per day and divided by 100. We asked participants to repeatedly rate their level of pain, fatigue, and fear of falling using the NRS[32,38] from inclusion until discharge. For each variable, we calculated 2 predictors per participant: (1) the within-person mean during the whole admission period; and (2) the within-person variability (Supplementary Table 1). The within-person variability was calculated as a coefficient of variation instead of a standard deviation (SD), as a higher SD can reflect a higher mean. Thirty-three participants with less than 3 days of data were omitted from the analysis.

Primary Outcome

The primary outcome was the functional disability score assessed using the 15-item modified ADL index including basic and instrumental ADLs[39] at 6 time points: 2 weeks before admission (retrospectively assessed), admission, discharge, and 1 month, 2 months, and 3 months post discharge. We asked participants to rate whether they can independently perform the ADLs. A score of 1 was given for every ADL that could not be performed independently, and a total score was calculated ranging from 0 (independent on all ADLs) to 15 (dependent on all ADLs). The researcher collected the data in person during hospitalization, and at 1 and 3 months, and by telephone at 2 months after discharge.

Statistical Analyses

Continuous variables were described with a mean and SD or median and interquartile range (IQR), depending on whether data were normally distributed. Categorical variables were reported as a number (n) and percentage (%).

The main analysis comprised 3 steps: (1) modeling the individual change (ie, decline and recovery) in functional disability over time; (2) examining which baseline characteristics are associated with these changes in functional disability; and (3) examining the association of the within-person mean and variability of each dynamic variable with the change in functional disability. For this, we performed individual growth modeling using multilevel regression analysis with repeated measurements of functional disability.[40] Time was structured as time points: preadmission, admission, discharge, and 1-month, 2-months, and 3-months post discharge. As the first step, we aimed to identify the individual growth model that best explained how functional disability changed over time within the individuals, for example, linear growth, quadratic growth, or whether we needed to model the trajectories using multiple splines representing different periods in which the trajectory developed in a different direction. After we identified the best fitting model, we added each single baseline variable one-by-one to the model to assess which variables are associated with the changes in functional disability over time, corrected for age and gender. Variables with a P value $<.10$ were retained for further analysis. Each variable was added to the multivariable model and were retained only if it statistically improved the fit of the model. As the last step, we aimed to examine which dynamical variables are associated with changes in functional disability in addition to the baseline variables. Therefore, we added the calculated individual mean and variability of the dynamic variables to the model, which was done separately for each dynamic variable. In the Supplementary Information we elaborate in detail on how we performed these individual growth models.

To identify any influence of participants who died or dropped out to the results, all analyses were repeated with only complete cases. To check for selection bias, we compared baseline variables between participants included in this analytic sample with excluded Hospital-ADL participants. All statistical analyses were performed in RStudio/1.2.1335 (RStudio Team (2018), RStudio: Integrated Development for R. RStudio, Inc., Boston, MA, URL http://www.rstudio.com/). The individual growth models were fitted in "nlme".

Results

Of the 401 participants in the Hospital-ADL study, 207 older adults were included in the analytic sample (Figure 1). Participants had a mean (SD) age of 79.8 (6.9) years, 101 (49%) were women, and 118 (57%) were frail at admission. The median (IQR) length of hospital stay was 6.8 (4.9–9.5) days (Table 1). Hospital-ADL study participants who were not included in this analytic sample (n = 194) had a lower education and were less frail compared with the participants included in this analytic sample (n = 207).

Functional Disability Over Time

When modeling within-person changes in functional disability over time, we found that the best fitting model contained 2 splines. The first spline described the individual difference between preadmission to admission (called "spline 1" in Supplementary Tables 2–4). The second spline described the changes between time points from admission to 3 months after discharge and contained both a linear ("spline 2") and a quadratic ("spline 2^2") individual growth factor. This model contained a random intercept and a random slope for the linear growth factor of spline 2. A random slope for spline 2^2 was tested but did not improve the fit of the model.

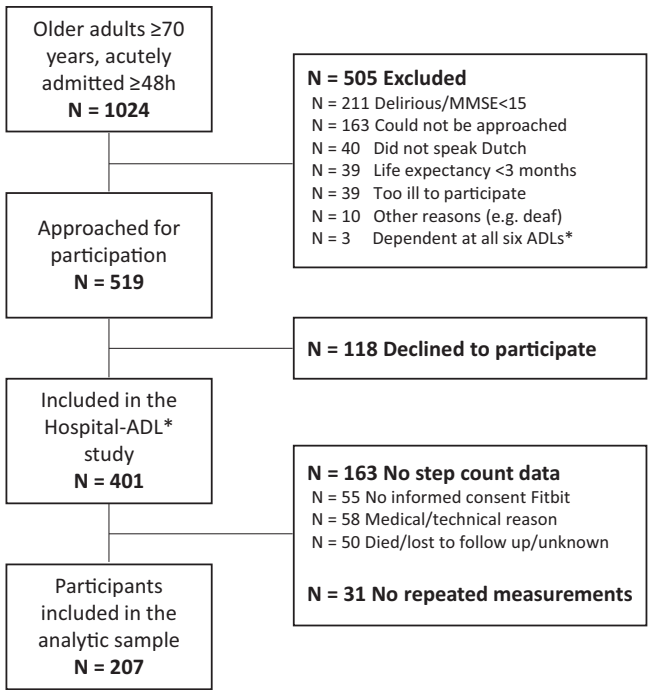

Fig. 1. Derivation of the study sample. *Activities of daily living.

Figure 2 shows the mean growth curves of functional disability over time for all participants predicted by model 1 (Supplementary Table 2). Participants increased in functional disability with a point estimate of 1.5 [95% confidence interval (CI) 1.2–1.7] from preadmission to admission and scored 4.6 (95% CI 4.2–5.0) at admission. From admission, participants started to recover with the point estimate decreasing by 0.5 (95% CI −0.7 to −0.3) at each time point. The estimated quadratic rate of change was 0.1 (95% CI 0.0–0.1), showing that recovery rates slowed down at each time point. At 3 months post-discharge, the functional disability score was not significantly different from the score at preadmission (b = 0.3; 95% CI −0.1 to 0.7).

Association With Single Baseline Characteristics

Based on the univariable analysis, only frailty was found to be significantly associated with changes in functional disability (Supplementary Table 3). Also, the MEWS and CCI score were retained for further analysis ($P < .10$). We added frailty to model 1 (model 2) and added the MEWS (model 2A, Supplementary Table 3) and the CCI (model 2B, Supplementary Table 3) to model 2. We found that adding the MEWS or the CCI to model 2 did not significantly improve the fit of the model ($P > .05$) and continued with model 2.

Figure 2 shows the mean growth curves predicted by model 2 (Supplementary Table 2) per frailty group. At every time point, functional disability scores were significantly higher in the frailty group than in the nonfrailty group. Frail participants showed a significantly higher increase in functional disability than nonfrail participants did before admission (b = 0.8; 95% CI 0.3–1.2). From admission, there was no difference in recovery rates between frail and nonfrail participants, estimated as −0.2 (95% CI −0.6 to 0.3). Compared with their preadmission levels, frail participants did not show significantly more functional loss at 3 months than nonfrail participants did (b = 0.1; 95% CI −0.7 to 0.9).

Table 1
Characteristics of the Study Sample

Characteristics	N = 207
Age (y), mean (SD)	79.8 (6.9)
Female, n (%)	101 (49)
Education, n (%)	
Primary school	54 (26)
Elementary technical/domestic science school	43 (21)
Secondary vocational education	73 (35)
Higher-level high school/third-level education	37 (18)
Born in the Netherlands, n (%)	184 (89)
Living situation before admission, n (%)	
Living independent	177 (86)
Senior residence	25 (12)
Nursing home	5 (2)
Primary admission diagnosis, n (%)	
Cardiac	66 (32)
Respiratory	40 (19)
Other	31 (15)
Infection	28 (13)
Gastrointestinal	20 (10)
Renal	8 (4)
Electrolyte disturbance	8 (4)
Cancer (including hematology)	6 (3)
MEWS,* median (IQR)	1 (0–1)
Frail,† n (%)	118 (57)
Charlson Comorbidity Index,‡ median (IQR)	2 (1–3)
Cognitive impairment,§ n (%)	39 (19)
Depressive symptoms,‖ n (%)	48 (23)
Length of hospital stay (d), median (IQR)	6.8 (4.9–9.5)
Discharge destination, n (%)	
Home, living independently	157 (76)
Rehabilitation center	22 (11)
Senior residence	15 (7)
Nursing home	8 (4)
Other (eg, other hospital)	5 (2)
Health care utilization after discharge, n (%)	
Physical/occupational therapy	148 (71)
Number of consultations, median (IQR)	8 (4–12)
General practitioner	134 (65)
Number of consultations, median (IQR)	2 (1–4)
Home care	65 (31)
Hours per week, median (IQR)	1.6 (0.7–3.4)
Unknown	14 (7)

*Modified Early Warning Score ranging from 0–14, higher scores indicate more severe illness.
†Assessed using the 5 Fried criteria. A participant is defined frail if >2 components are present.
‡Range of 0–31, with a higher score indicating more or severe comorbidity.
§If a score is <24 on the Mini-Mental State Examination (range 0–30).
‖If a score is >5 on the Geriatric Depression Scale (range 0–15).

Associations With Dynamic Variables

Corrected for age, sex, and frailty, a higher mean step count was significantly associated with a lower increase in functional disability before admission, estimated as −0.03 (95% CI −0.06 to −0.01) per 100 additional steps (model 3, Supplementary Table 4). Figure 3A shows the predicted mean growth curves for different mean step levels. As shown in Figure 3A, a higher mean step count was associated with lower recovery rates up to 1 month postdischarge (b = 0.04; 95% CI 0.02–0.06), but also with higher recovery rates in the second and third month compared with those with lower step count. In the complete case analysis, we found that a higher within-person variability in step count was associated with a higher increase in functional disability before admission.

As shown in Figure 3B, a higher within-person mean pain score was associated with a significantly higher increase in functional disability before admission, estimated as 0.1 (95% CI 0.0–0.2). A higher mean pain score was not statistically significantly associated with more recovery from admission (model 4, Supplementary Table 4). The within-person variability in pain scores was not associated with functional trajectories.

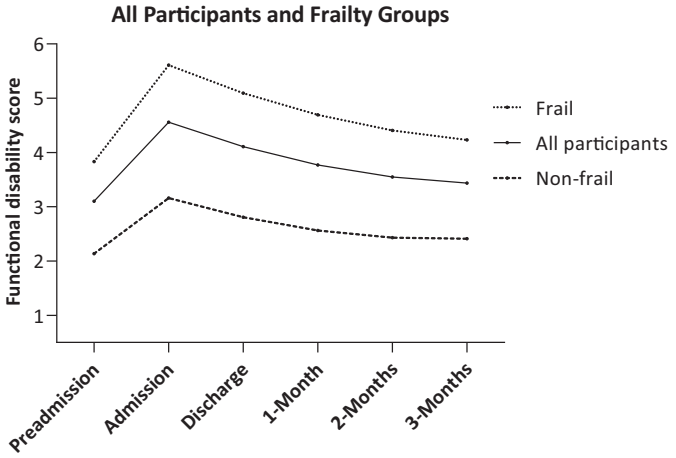

Fig. 2. Mean growth curves for functional disability* in all participants and frailty† groups. Black solid line shows mean growth curve for all participants as predicted by model 1 in Supplementary Table 2. Black dotted line shows mean growth curve for frail participants and black dashed line for nonfrail participants as predicted by model 2 in Supplementary Table 2. *Assessed with the 15-item modified ADL index, which rates 6 basic activities and 9 instrumental activities based on whether they can be performed dependently (score = 1) or independently (score = 0). Scores range from 0 to 15 with higher scores indicating more dependency. Assessed at 6 time points: 2 weeks before admission (assessed retrospectively), admission, discharge, and at 1, 2, and 3 months post discharge. †Assessed using the 5 Fried criteria. A participant is defined frail if >2 components are present.

Neither the within-person mean and variability in fatigue scores were significantly associated with individual changes in functional disability (Supplementary Table 5, model 5). As shown in Figure 3C, a higher variability in fear of falling was significantly associated with a higher increase in functional disability before admission, estimated as 0.7 (95% CI 0.2–1.2). After admission, a higher within-person variability was also associated with significantly more recovery after admission up to 1 month after discharge, which made up for the loss of function before admission (Supplementary Table 5, model 6).

Discussion

In older adults hospitalized with acute illness, we found that functional disability significantly increased before hospital admission and improved from admission to 3 months post discharge. We found that frailty was the only single baseline variable that was significantly associated with changes in functional disability over time. Frail older adults showed significantly a higher increase in functional disability in the 2 weeks before admission than nonfrail older adults did. In addition to frailty, we found that the dynamic variables of lower step count, higher pain score, and higher within-person variability in fear of falling during hospitalization were associated with a higher increase in functional disability before hospitalization. We also found that higher within-person variability in fear of falling was associated with better recovery after admission, which made up for the functional loss before admission.

Our findings provide clinically relevant information about the ability of older adults to resist and recover from functional decline following acute illness. In agreement with previous findings,[41,42] our study shows that older adults decline in function in the 2 weeks before hospitalization and are most dependent on help for ADL functioning at hospital admission, especially if they are frail. We observed that most recovery in ADL functioning occurred during hospitalization and in

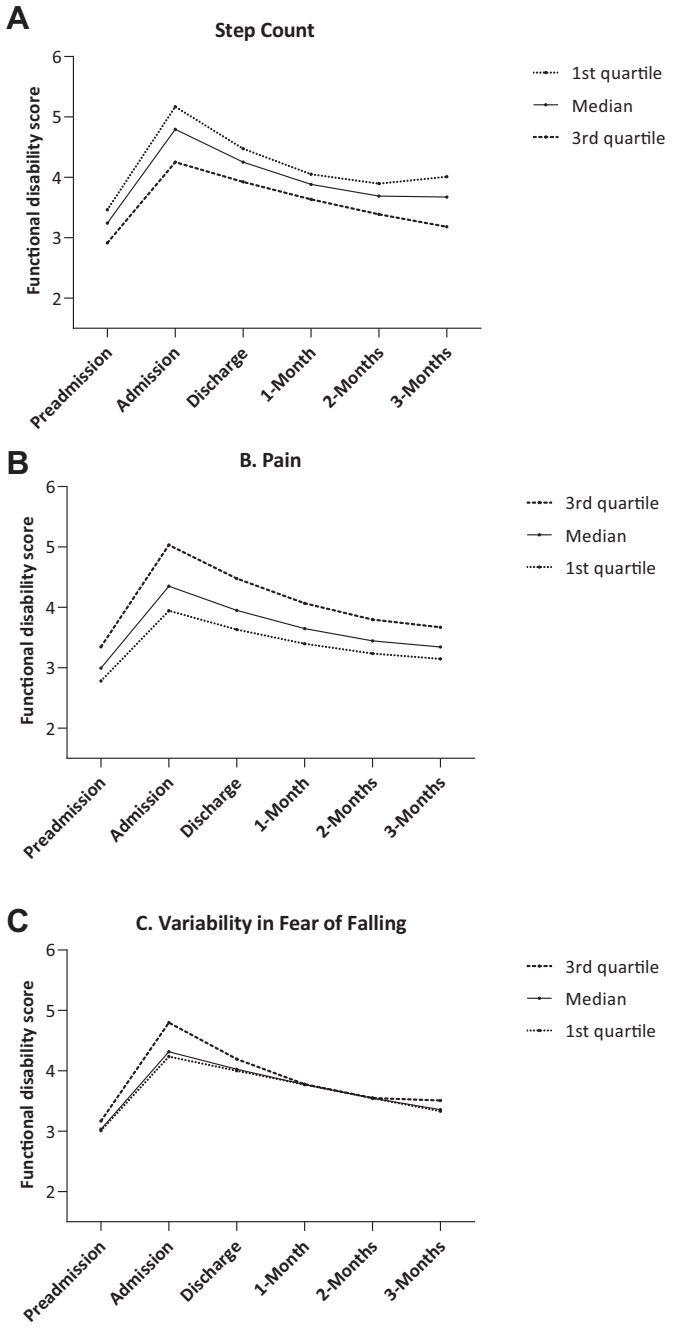

Fig. 3. Mean growth curves for functional disability* for different levels of (A) step count, (B) pain, and (C) variability in fear of falling. The mean growth curve for functional disability is presented as the median value (black solid line), the highest value of the first quartile (black dotted line), and the highest value of the third quartile (black dashed line) for each variable. *Assessed with the 15-item modified ADL index, which rates 6 basic activities and 9 instrumental activities based on whether they can be performed dependently (score = 1) or independently (score = 0). Scores range from 0 to 15, with higher scores indicating more dependency. Assessed at 6 time points: 2 weeks before admission (assessed retrospectively), admission, discharge, and at 1, 2, and 3 months post discharge.

the first month after discharge, which supports the findings of Boyd et al.,[2] who indicated that the first month after discharge is the most critical for recovery of ADL functioning after discharge. Our findings highlight the importance of assessing the prehospitalization functional status of older adults and setting personalized rehabilitation goals at hospital admission to optimize functional recovery after acute hospitalization.

Our study also provides new evidence that frail older adults show a higher increase in functional disability before hospitalization than nonfrail older adults.[1,3,8,11,43,44] In terms of physical resilience, our findings may suggest that older adults are not resistant to functional decline in response to acute health stressors, especially if frail.[1,10,11] In agreement with the conceptual model of Whitson et al.,[10] our findings show that frailty is a state of physiological vulnerability to stressors among acutely hospitalized older adults. This underlines the importance of identifying frailty both in the community and at the time of hospital admission.[7] In the model of Whitson et al.,[10] they also proposed that physical resilience is constrained by the pre-stressor reserve including physical, psychological, and cognitive factors, and that health outcomes are also affected by the severity of the stressor.[10] However, in our study, neither the severity of acute illness, which may indicate the severity of the stressor, and other factors that may represent the pre-stressor reserve, including education, comorbidities, cognitive functioning, and depressive symptoms, were significantly associated with resistant and resilience trajectories.

Several researchers have suggested that besides frailty status, it is important to identify dynamic indicators of resilience to measure physical resilience in clinical practice.[10–12,44] Our study shows that measuring dynamic variables that vary within a person over time may improve the prediction of recovery.[15,22] We found that, in addition to frailty status, the dynamic variables of step count, and self-rated factors of pain and fear of falling may act as indicators of physical resilience.[22] Previous studies showed that especially the variability in factors might be good indicators of resilience[15,16,18,22]; however, we found that only the variability in fear of falling was associated with recovery. This contrasts with the study of Gijzel et al.,[22] who also found that high variability in physical activity measured using accelerometers indicates high resilience. However, Gijzel et al.[22] measured within-person variabilities within 1 day whereas we studied day-to-day variabilities in the dynamic variables measured over several days instead of several times per day, which might explain this discrepancy.

This study provides clinically relevant information on older adults' functional recovery and also on how indicators of physical resilience can be explored in future studies. This approach might be used to identify more robust indicators of resilience and improve the prediction of functional recovery among acutely hospitalized older adults. A better prediction of recovery may help clinicians in therapeutic decision making, discharge planning, and the identification of older adults in need of rehabilitation resources, but may also help older adults and their caregivers to set realistic rehabilitation goals.[45] Based on our findings and previous studies,[15,16,18,22] we may suggest measuring dynamic variables continuously during the day and during the whole recovery period to provide more information on the variability (eg, variability within the day and day-to day variability over longer periods of time). We may also suggest assessing dynamic variables both during hospital admission as after discharge, preferable via wearable sensors, as this may be less burdensome and easier to implement in clinical practice than collecting self-rated measures from older adults.

Strengths and Limitations

A strength of this study is that functional disability was measured as an outcome of physical resilience over time, from 2 weeks before hospitalization to 3 months post discharge. The use of discontinuous growth models[40] enabled us to model the increase in functional disability before admission and the recovery after admission. This gave more insight into physical resilience in older adults and showed

their resistance to functional decline and their ability to recover.[46] Using this statistical technique, we also investigated the associations between variables and resistance and recovery trajectories to identify potential indicators of resilience. We investigated single baseline variables at admission and dynamic variables repeatedly from study inclusion to discharge. For some participants, the within-person variability in the dynamic variables could not be assessed, as the amount of data collected was limited by a short hospital stay, so these participants had to be excluded, which may lower the generalizability of our results. Another limitation is that we could not measure functional disability before admission prospectively because acute hospital admissions are unpredictable. The functional disability score at 2 weeks before admission was therefore assessed retrospectively. This might have introduced recall bias in our outcome measure; however, a previous study showed that this should give valid results.[47] In addition, we were not able to fully capture the variables to quantify the stressor that may modify physical resilience. This is an important implication for future research to investigate how the severity of the stressor can be measured.[10] Another limitation of our analysis was missing data in the outcome of interest due to death or loss to follow-up after hospital discharge. To prevent selection bias, we did not omit any participants from the analyses and used individual growth models in a mixed-effects framework to deal with missing values in the outcome variable. Sensitivity analysis suggested that the results were not sensitive to missing values due to death and dropouts; however, we observed a larger dropout rate in frail participants after discharge, so the recovery rates in frail participants may have been overestimated. Moreover, in our heterogeneous sample of participants, we observed a large variety in discharge destinations and health care resources used after discharge, which probably also influenced older adults' recovery. Even though we have measured these variables, the use of such resources may either be an indication of more need for such resource (and thus be related to a risk for impaired recovery) or be a factor promoting recovery. In the analysis, this cannot be distinguished. Therefore, we refrained from additionally adjusting for this.

Conclusions and Implications

We showed that older adults increase in functional disability in response to acute illness before hospitalization but that they start to recover during hospitalization. Frail older adults are especially vulnerable to functional decline, highlighting the importance of identifying frailty in older adults on hospital admission to determine their physical resilience. Measuring both frailty and dynamic variables may improve the prediction of an individual's ability to recover from acute illness. A better prediction may help to improve therapeutic decision-making during hospitalization, discharge planning, and rehabilitation strategies to improve functional recovery after acute hospitalization. Future cohort studies are recommended to collect intensive longitudinal data, including sensor technology measurements, to further explore indicators of physical resilience.

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References

1. Varadhan R, Walston JD, Bandeen-Roche K. Can a link be found between physical resilience and frailty in older adults by studying dynamical systems? J Am Geriatr Soc 2018;66:1455–1458.
2. Boyd CM, Landefeld CS, Counsell SR, et al. Recovery of activities of daily living in older adults after hospitalization for acute medical illness. J Am Geriatr Soc 2008;56:2171–2179.
3. Gill TM, Allore HG, Gahbauer EA, Murphy TE. Change in disability after hospitalization or restricted activity in older persons. JAMA 2010;304:1919–1928.
4. Zisberg A, Shadmi E, Gur-Yaish N, et al. Hospital-associated functional decline: The role of hospitalization processes beyond individual risk factors. J Am Geriatr Soc 2015;63:55–62.
5. World Health Organization. ICF international classification of functioning, disability and health. Geneva: WHO; 2001.
6. de Saint-Hubert M, Schoevaerdts D, Poulain G, et al. Risk factors predicting later functional decline in older hospitalized patients. Acta Clin Belg 2009;64:187–194.
7. Cunha AIL, Veronese N, de Melo Borges S, Ricci NA. Frailty as a predictor of adverse outcomes in hospitalized older adults: A systematic review and meta-analysis. Ageing Res Rev 2019;56:100960.
8. Fried LP, Tangen CM, Walston J, et al. Frailty in older adults: Evidence for a phenotype. J Gerontol A Biol Sci Med Sci 2001;56:M146–M156.
9. Kuchel GA. Function begets function and resilience in old age: Is precision gerontology possible? J Am Geriatr Soc 2017;65:1141–1144.
10. Whitson HE, Duan-Porter W, Schmader KE, et al. Physical resilience in older adults: Systematic review and development of an emerging construct. J Gerontol A Biol Sci Med Sci 2016;71:489–495.
11. Whitson HE, Cohen HJ, Schmader KE, et al. Physical resilience: Not simply the opposite of frailty. J Am Geriatr Soc 2018;66:1459–1461.
12. Hadley EC, Kuchel GA, Newman AB. Workshop Speakers and Participants. Report: NIA workshop on measures of physiologic resiliencies in human aging. J Gerontol A Biol Sci Med Sci 2017;72:980–990.
13. Gijzel SMW, Whitson HE, van de Leemput IA, et al. Resilience in clinical care: Getting a grip on the recovery potential of older adults. J Am Geriatr Soc 2019;67:2650–2657.
14. Scheffer M, Bolhuis JE, Borsboom D, et al. Quantifying resilience of humans and other animals. Proc Natl Acad Sci U S A 2018;115:11883–11890.
15. Gijzel SMW, van de Leemput IA, Scheffer M, et al. Dynamical resilience indicators in time series of self-rated health correspond to frailty levels in older adults. J Gerontol A Biol Sci Med Sci 2017;72:991–996.
16. Gijzel SMW, van de Leemput IA, Scheffer M, et al. Dynamical indicators of resilience in postural balance time series are related to successful aging in high-functioning older adults. J Gerontol A Biol Sci Med Sci 2019;74:1119–1126.
17. Olde Rikkert MG, Dakos V, Buchman TG, et al. Slowing down of recovery as generic risk marker for acute severity transitions in chronic diseases. Crit Care Med 2016;44:601–606.
18. van de Leemput IA, Wichers M, Cramer AO, et al. Critical slowing down as early warning for the onset and termination of depression. Proc Natl Acad Sci U S A 2014;111:87–92.
19. Kuchel GA. Frailty and resilience as outcome measures in clinical trials and geriatric care: Are we getting any closer? J Am Geriatr Soc 2018;66:1451–1454.
20. LeBrasseur NK. Physical resilience: Opportunities and challenges in translation. J Gerontol A Biol Sci Med Sci 2017;72:978–979.
21. Dunton GF. Ecological momentary assessment in physical activity research. Exerc Sport Sci Rev 2017;45:48–54.
22. Gijzel SMW, Rector J, van Meulen FB, et al. Measurement of dynamical resilience indicators improves the prediction of recovery following hospitalization in older adults. J Am Med Dir Assoc 2020;21:521–530.e4.
23. Reichardt LA, Aarden JJ, van Seben R, et al. Unravelling the potential mechanisms behind hospitalization-associated disability in older patients; the Hospital-Associated Disability and impact on daily Life (Hospital-ADL) cohort study protocol. BMC Geriatr 2016;16:59.
24. McGivney SA, Mulvihill M, Taylor B. Validating the GDS depression screen in the nursing home. J Am Geriatr Soc 1994;42:490–492.
25. Katz S, Downs TD, Cash HR, Grotz RC. Progress in development of the index of ADL. Gerontologist 1970;10:20–30.
26. Medical Research Involving Human Subjects Act (WMO). Available at: https://english.ccmo.nl/investigators/legal-framework-for-medical-scientific-research/laws/medical-research-involving-human-subjects-act-wmo. Accessed July 29, 2021.
27. World Medical Association. Declaration of Helsinki: Ethical principles for medical research involving human subjects. JAMA 2013;310:2191–2194.
28. Subbe CP, Kruger M, Rutherford P, Gemmel L. Validation of a modified early warning Score in medical admissions. QJM 2001;94:521–526.
29. Charlson ME, Pompei P, Ales KL, MacKenzie CR. A new method of classifying prognostic comorbidity in longitudinal studies: Development and validation. J Chronic Dis 1987;40:373–383.

30. Folstein MF, Folstein SE, McHugh PR. "Mini-mental state". A practical method for grading the cognitive state of patients for the clinician. J Psychiatr Res 1975; 12:189–198.
31. Dennis M, Kadri A, Coffey J. Depression in older people in the general hospital: A systematic review of screening instruments. Age Ageing 2012;41: 148–154.
32. Hwang SS, Chang VT, Cogswell J, Kasimis BS. Clinical relevance of fatigue levels in cancer patients at a Veterans Administration Medical Center. Cancer 2002; 94:2481–2489.
33. Roberts HC, Denison HJ, Martin HJ, et al. A review of the measurement of grip strength in clinical and epidemiological studies: Towards a standardised approach. Age Ageing 2011;40:423–429.
34. Trutschnigg B, Kilgour RD, Reinglas J, et al. Precision and reliability of strength (Jamar vs. Biodex handgrip) and body composition (dual-energy X-ray absorptiometry vs. bioimpedance analysis) measurements in advanced cancer patients. Appl Physiol Nutr Metab 2008;33:1232–1239.
35. Alharbi M, Bauman A, Neubeck L, Gallagher R. Validation of Fitbit-Flex as a measure of free-living physical activity in a community-based phase III cardiac rehabilitation population. Eur J Prev Cardiol 2016;23:1476–1485.
36. Bai Y, Welk GJ, Nam YH, et al. Comparison of consumer and research monitors under semistructured settings. Med Sci Sports Exerc 2016;48: 151–158.
37. O'Brien T, Troutman-Jordan M, Hathaway D, et al. Acceptability of wristband activity trackers among community dwelling older adults. Geriatr Nurs 2015; 36(2 Suppl):S21–S25.
38. MacCaffery M, Beebe A. Pain: Clinical Manual for Nursing Practice. St. Louis, Missouri: Mosby; 1989.
39. Laan W, Zuithoff NP, Drubbel I, et al. Validity and reliability of the Katz-15 scale to measure unfavorable health outcomes in community-dwelling older people. J Nutr Health Aging 2014;18:848–854.
40. Singer JD, Willet JB. Applied Longitudinal Data Analysis: Modeling Change and Event Occurrence. New York: Oxford University Press; 2003.
41. Huang HT, Chang CM, Liu LF, et al. Trajectories and predictors of functional decline of hospitalised older patients. J Clin Nurs 2013;22:1322–1331.
42. Wakefield BJ, Holman JE. Functional trajectories associated with hospitalization in older adults. West J Nurs Res 2007;29:161–177. discussion: 178–182.
43. Xue QL. The frailty syndrome: Definition and natural history. Clin Geriatr Med 2011;27:1–15.
44. Varadhan R, Seplaki CL, Xue QL, et al. Stimulus-response paradigm for characterizing the loss of resilience in homeostatic regulation associated with frailty. Mech Ageing Dev 2008;129:666–670.
45. van Seben R, Smorenburg SM, Buurman BM. A qualitative study of patient-centered goal-setting in geriatric rehabilitation: Patient and professional perspectives. Clin Rehabil 2019;33:128–140.
46. Colón-Emeric C, Pieper CF, Schmader KE, et al. Two approaches to classifying and quantifying physical resilience in longitudinal data. J Gerontol A Biol Sci Med Sci 2020;75:731–738.
47. Covinsky KE, Palmer RM, Counsell SR, et al. Functional status before hospitalization in acutely ill older adults: Validity and clinical importance of retrospective reports. J Am Geriatr Soc 2000;48:164–169.

Supplementary Information
Unconditional Individual Growth Modeling

The main analysis comprised 3 steps: (1) modeling the individual change (ie, decline and recovery) in functional disability scores over time, (2) examining which single baseline characteristics are associated with these changes in functional disability, and (3) examining the association of the within-person mean and variability of each dynamic variable with the change in functional disability. For each step, we performed individual growth modeling using multilevel regression analysis.[40] Individual growth models include a level-1 sub model describing the individual changes over time and a level-2 model that describes how these changes vary across individuals. Time was treated as structured time points rather than an exact time. First, we generated graphs for each participant's functional trajectory and explored which unconditional individual growth model best explained the changes in functioning over time using the deviance statistic (comparing the −2-log likelihood of models). Starting with an unconditional means or empty model, we fitted increasingly complex models to model the individual trajectories in functioning before and after admission. We tested unconditional (ie, no level-2 predictors included), linear, and quadratic growth and modeled separate splines for the pre- and postadmission time periods.[40] Second, we added each single baseline variable separately to model 1 as a level-2 (between-participant) predictor. Variables with a P value $< .10$ were retained for further analysis. We built a multivariable model by adding variables whose inclusion gives a statistically significant improvement of the fit of the model (model 2). Thirdly, we added the individual means and variability of dynamic variables over time to model 2 to assess whether these between-person differences explained the heterogeneity in changes in functional disability in the unconditional models modeled with (uninformative) random terms. This last step was done separately for each dynamic variable.

Supplementary Table 1
Calculation of the Within-Person Mean and Variability of the Dynamic Variables

Parameters	Calculation of Mean	Calculation of Coefficient of Variation
Step count	Available within-person step numbers per day in the past 7 days of hospitalization were summed and divided by the number of days with data	SD of all available within-person step numbers per day in the past 7 days of hospitalization divided by the calculated mean
Pain	Mean of all available within-person NRS scores during hospitalization	SD of all available within-person NRS scores during hospitalization divided by the mean
Fatigue	Mean of all available within-person NRS scores during hospitalization	SD of all available within-person NRS scores during hospitalization divided by the mean
Fear of falling	Mean of all available within-person NRS scores during hospitalization	SD of all available within-person NRS scores during hospitalization divided by the mean

Supplementary Table 2
Changes in Functional Disability* Over Time (Model 1) and the Differences in Changes Between Frailty Groups (Model 2)

Parameter	Model 1: Changes in ADL Functioning Over Time			Model 2†: Associations With Frailty		
	Estimate	95% CI		Estimate	95% CI	
ADL functioning* score at admission‡	4.6	4.2	5.0	3.2	2.7	3.6
Change in ADL functioning preadmission to admission§	1.5	1.2	1.7	1.0	0.7	1.4
Time (linear) after admission‖	−0.5	−0.7	−0.3	−0.4	−0.7	−0.1
Time (quadratic) after admission**	0.1	0.0	0.1	0.1	−0.0	0.1
Difference in ADL functioning at admission frail vs nonfrail††				2.5	1.8	3.1
Change in ADL functioning preadmission to admission frail vs nonfrail				0.8	0.3	1.2
Time (linear) after admission frail vs nonfrail				−0.2	−0.6	0.3
Time (quadratic) after admission frail vs nonfrail				0.0	−0.1	0.1

*Assessed with the 15-item modified ADL index, which rates 6 basic activities and 9 instrumental activities based on whether they can be performed dependently (score = 1) or independently (score = 0). Scores range from 0 to 15 with higher scores indicating more dependency. Assessed at 6 time points: 2 weeks before admission (assessed retrospectively), admission, discharge, and at 1, 2, and 3 months post discharge.

†Adjusted for age and sex.

‡In model 2, this row indicates the Katz-15 score at time of admission for participants without frailty.

§Rate of change in Katz-15 scores from admission to preadmission. In model 2 this only holds for participants without frailty.

‖Linear rate of change in Katz-15 scores per time point from admission. Time points after admission are (1) discharge, (2) 1 month, (3) 2 months, and (4) 3 months post discharge. In model 2, this only holds for participants without frailty.

**Quadratic rate of change in Katz-15 scores per time point from admission. Time points after admission are (1) discharge, (2) 1 month, (3) 2 months, and (4) 3 months post discharge. In model 2 this only holds for participants without frailty.

††Assessed using the 5 Fried criteria. A participant is defined frail if >2 components are present. This row indicates the difference in Katz-15 scores in the frail group compared with the nonfrail group at time of admission.

Supplementary Table 3
Single Baseline Characteristics Associated With Changes in Functional Disability* Before Admission (Spline 1), Changes Per Time Point From Admission (Spline 2) and the Quadratic Rate of Spline 2 (Spline 2^2)

Parameter	Reference	Univariable Analysis†		Multivariable Analysis			
		Estimate	*P* Value‡	Model 2A: MEWS and Frailty		Model 2B: CCI and Frailty	
				Estimate	*P* Value	Estimate	*P* Value
MEWS§ *spline1	Score	0.2	**.09**	0.2	.10		
MEWS§ *spline2	Score	−0.1	.26	−0.1	.27		
MEWS§ *spline2^2	Score	0.0	.80	0.0	.81		
Education*spline1	Primary school						
Elementary technical/domestic science school		−0.3	.44				
Secondary vocational education		−0.3	.42				
Higher level high school/third-level education		−0.3	.38				
Education*spline2	Primary school						
Elementary technical/domestic science school		0.1	.72				
Secondary vocational education		−0.1	.70				
Higher level high school/third-level education		−0.1	.86				
Education*spline2^2	Primary school						
Elementary technical/domestic science school		0.0	.70				
Secondary vocational education		0.1	.42				
Higher level high school/third-level education		0.1	.24				
CCI‖ *spline1	Score	0.1	**.08**			0.1	.33
CCI‖ *spline2	Score	−0.1	.17			−0.1	.24
CCI‖ *spline2^2	Score	0.0	.46			0.0	.48
MMSE** *spline1	Score	−0.1	.12				
MMSE** *spline2	Score	−0.0	.91				
MMSE** *spline2^2	Score	0.0	.91				
Depressive symptoms†† *spline1	No	0.3	.28				
Depressive symptoms†† *spline2	No	−0.2	.54				
Depressive symptoms†† *spline2^2	No	0.0	.61				
Frailty‡‡ *spline1	Nonfrail	0.7	**.00**	0.8	.00	0.7	.01
Frailty‡‡ *spline2	Nonfrail	−0.2	.47	−0.2	.48	−0.1	.24
Frailty‡‡ *spline2^2	Nonfrail	0.0	.98	−0.0	.99	−0.0	.86

CV, coefficient of variation.

*Assessed with the 15-item modified ADL index, which rates 6 basic activities and 9 instrumental activities based on whether they can be performed dependently (score = 1) or independently (score = 0). Scores range from 0 to 15, with higher scores indicating more dependency. Assessed at 6 time points: 2 weeks before admission (assessed retrospectively), admission, discharge, and at 1, 2, and 3 months post discharge.

†Adjusted for age and sex.

‡Variables with a *P* value <.10 were retained for further analysis.

§Modified Early Warning Score ranging from 0–14, higher scores indicate more severe illness.

‖Charlson Comorbidity Index ranging from 0–31, higher scores indicate more or severe comorbidity.

**Mini-Mental State Examination ranging from 0–30, higher scores indicate better cognitive functioning.

††If a score of ≥6 on the Geriatric Depression Scale.

‡‡Assessed using the 5 Fried criteria. A participant is defined frail if >2 components are present.

Supplementary Table 4
Results of Individual Growth Model 3 and 4 of Functional Disability Over Time*

Parameter	Model 3: Step Count†			Model 4: Pain†		
	Estimate	95% CI		Estimate	95% CI	
Fixed effects						
Intercept‡	4.6	4.2	4.9	3.3	2.8	3.8
Frailty§	1.8	1.1	2.5	2.2	1.6	2.8
Step count, mean‖	−0.1	−0.1	−0.0			
Step count, CV	0.0	−1.1	1.1			
Pain, mean				0.27	0.14	0.40
Pain, CV				0.11	−0.45	0.68
Difference between preadmission and admission (spline 1)**	1.5	1.2	1.7	1.1	0.7	1.5
Frailty*spline1	0.5	−0.1	1.0	0.6	0.1	1.1
Step count, mean*spline1	−0.03	−0.06	−0.01			
Step count, CV*spline1	0.6	−0.3	1.5			
Pain, mean*spline1				0.1	0.0	0.2
Pain, CV*spline1				−0.1	−0.6	0.3
Linear rate of change per time point from admission (spline 2)††	−0.5	−0.7	−0.3	−0.5	−0.8	−0.1
Frailty*spline2	0.2	−0.3	0.7	−0.1	−0.5	0.3
Step count, mean*spline2	0.04	0.02	0.06			
Step count, CV*spline2	−0.4	−1.3	0.4			
Pain, mean*spline2				−0.1	−0.2	0.0
Pain, CV*spline2				0.1	−0.3	0.5
Quadratic rate of change spline 2^2‡‡	0.1	0.0	0.1	0.1	−0.0	0.1
Frailty*spline2^2	−0.1	−0.2	0.0	−0.0	−0.1	0.1
Step count, mean*spline2^2	−0.01	−0.01	−0.00			
Step count, CV*spline2^2	0.1	−0.1	0.3			
Pain, mean*spline2^2				0.0	−0.0	0.0
Pain, CV*spline2^2				−0.0	−0.1	0.1
Random effects: variance components						
Intercept, SD	1.8	1.6	2.0	1.8	1.6	2.0
Linear rate of change spline 2, SD	0.5	0.4	0.6	0.5	0.4	0.6
Correlation	−0.2	−0.4	−0.0	−0.2	−0.4	0.0
Residual	1.2	1.2	1.3	1.3	1.2	1.3

CV, coefficient of variation.

*Assessed with the 15-item modified ADL index, which rates 6 basic activities and 9 instrumental activities based on whether they can be performed dependently (score = 1) or independently (score = 0). Scores range from 0 to 15, with higher scores indicating more dependency. Assessed at 6 time points: 2 weeks before admission (assessed retrospectively), admission, discharge, and at 1, 2, and 3 months post discharge.

†Adjusted for age and sex.

‡This row indicates the status at time of admission for participants without frailty, and with average step numbers (model 3) or pain scores (model 4).

§Assessed using the 5 Fried criteria. A participant is defined frail if >2 components are present.

‖One-unit stands for 100 steps.

**This row indicates the rate of change from preadmission to admission for participants without frailty and with average steps numbers (model 3) or pain scores (model 4).

††This row indicates the linear rate of change for every time point from admission to discharge, and 1 month, 2 months, and 3 months post discharge for participants without frailty and with average steps numbers (model 3) or pain scores (model 4).

‡‡This row indicates the quadratic rate of change for every time point from admission to discharge, and 1 month, 2 months, and 3 months post discharge for participants without frailty and with average step numbers (model 3) or pain scores (model 4).

Supplementary Table 5
Results of Individual Growth Model 5 and 6 of Functional Disability* Over Time

Parameter	Model 5: Fatigue†			Model 6: Fear of falling†		
	Estimate	95% CI		Estimate	95% CI	
Fixed effects						
Intercept‡	3.3	2.8	3.7	3.3	2.9	3.7
Frailty§	2.3	1.6	3.0	2.2	1.6	2.8
Fatigue, mean	0.1	−0.1	0.3			
Fatigue, CV	−0.5	−1.4	0.4			
Fear of falling, mean				0.3	0.2	0.4
Fear of falling, CV				0.9	0.3	1.5
Difference between preadmission and admission (spline 1)‖	1.1	0.7	1.5	1.1	0.7	1.4
Frailty*spline1	0.7	0.2	1.2	0.7	0.2	1.1
Fatigue, mean*spline 1	0.1	−0.1	0.2			
Fatigue, CV*spline 1	−0.3	−1.0	0.4			
Fear of falling, mean*spline 1				0.1	−0.0	0.1
Fear of falling, CV*spline 1				0.7	0.2	1.2
Linear rate of change per time point from admission (spline 2)**	−0.4	−0.8	−0.1	−0.5	−0.8	−0.1
Frailty*spline2	−0.2	−0.6	0.3	−0.1	−0.5	0.3
Fatigue, mean*spline 2	−0.0	−0.1	0.1			
Fatigue, CV*spline 2	0.1	−0.6	0.7			
Fear of falling, mean*spline 2				−0.0	−0.1	0.1
Fear of falling, CV*spline 2				−0.8	−1.2	−0.3
Quadratic rate of change spline 2^2††	0.1	−0.0	0.1	0.1	−0.0	0.1
Frailty*spline2^2	0.0	−0.1	0.1	−0.0	−0.1	0.1
Fatigue, mean*spline2^2	−0.0	−0.0	0.0			
Fatigue, CV*spline2^2	0.1	−0.1	0.2			
Fear of falling, mean*spline2^2				0.0	−0.0	0.0
Fear of falling, CV*spline2^2				0.2	0.0	0.3
Random effects: variance components						
Intercept, SD	1.9	1.7	2.1	1.8	1.6	2.0
Linear rate of change spline 2, SD	0.5	0.4	0.6	0.5	0.4	0.6
Correlation	−0.2	−0.4	0.0	−0.2	−0.4	0.0
Residual	1.3	1.2	1.3	1.2	1.3	1.3

CV, coefficient of variation.

*Assessed with the 15-item modified ADL index, which rates 6 basic activities and 9 instrumental activities based on whether they can be performed dependently (score = 1) or independently (score = 0). Scores range from 0 to 15 with higher scores indicating more dependency. Assessed at 6 time points: 2 weeks before admission (assessed retrospectively), admission, discharge, and at 1, 2, and 3 months post discharge.

†Adjusted for age and sex.

‡This row indicates the status at time of admission for participants without frailty, and with an average level of fatigue (model 5) or fear of falling (model 6).

§Assessed using the 5 Fried criteria. A participant is defined frail if >2 components are present.

‖This row indicates the linear rate of change from preadmission to admission for participants without frailty and with an average level of fatigue (model 5) or fear of falling (model 6).

**This row indicates the linear rate of change for every time point from admission to discharge, and 1 month, 2 months, and 3 months post discharge for participants without frailty and with an average level of fatigue (model 5) or fear of falling (model 6).

††This row indicates the quadratic rate of change for every time point from admission to discharge, and 1 month, 2 months, and 3 months post discharge for participants without frailty and with an average level of fatigue (model 5) or fear of falling (model 6).