

Frail Older Individuals Maintaining a Steady Standing Position: Associations Between Sway Measurements with Frailty Status Across Four Different Frailty Instruments

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Objective: An analysis of the relationships between static equilibrium parameters and frailty status and/or severity across four different frailty measures.

Design: Cross-sectional analysis.

Setting: Geriatric wards of a general hospital.

Participants: One hundred twenty-three geriatric inpatients comprising 70 women (56.5%) and 53 men (42.7%) with an age range of 68–95 years.

Methods: The variation in the center of pressure (CoP), ie, the length of sway, the area of sway, and the mean speed, was assessed for different positions/tasks: 1) wide standing with eyes open (WSEO); 2) wide standing with eyes closed (WSEC); 3) narrow standing with eyes open (NSEO) and 4) narrow standing with eyes closed (NSEC), using a force plate. Frailty status and/or frailty severity were evaluated using the frailty phenotype (FP), the clinical frailty scale (CFS), the 14-item frailty index based on a comprehensive geriatric assessment (FI-CGA), and a 47-item frailty index (FI).

Results: WSEO length of sway (FP, CFS, FI-CGA, FI), WSEO area of sway (FP, CFS, FI-CGA, FI), and WSEO mean speed (FP, CFS, FI-CGA, FI), WSEC length of sway (FP, FI-CGA, FI), WSEC area of sway (FP, FI-CGA, FI) and WSEC mean speed (FI-CGA, FI), NSEO length of sway (FP, FI-CGA, FI), NSEO area of sway (FP, CFS, FI-CGA, FI), and NSEO mean speed (FP, CFS, FI-CGA, FI), NSEC length of sway (FI-CGA, FI), NSEC area of sway (FI-CGA, FI) and NSEC mean speed (FI-CGA, FI) were associated with the frailty status and/or severity across the four different frailty instruments (all $p < 0.05$, respectively).

Conclusion: Greater fluctuations in CoP with increasing frailty status and/or severity were a uniform finding across various major frailty instruments.

Keywords: frailty instruments, balance quality parameters, older people

Introduction

Frailty in older people refers to a clinically identifiable syndrome or condition of reduced reserve capacity, often of multiple organ systems.¹ This leads to frail individuals showing increased vulnerability and is characterized by their impaired ability to regulate homeostasis, in order to adequately compensate for the effects of an intrinsic and/or extrinsic stressor.¹ Consequently, frail individuals are exposed to an increased risk of mortality and other adverse health effects.^{2–7} Several diseases or adverse medical conditions, such as malnutrition, sarcopenia, gait, and visual

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impairments, endocrine alterations, mild inflammations, (chronic) diseases, multimorbidity, polypharmacy, cognitive impairments, affective changes, dependency on help in relation to the activities of daily life, as well as social isolation, amongst others, have been identified as risk factors for the development of frailty.^{8–12} Up until now, no single screening or assessment instrument for the detection of frailty has been established as the gold standard. Nonetheless, the frailty phenotype (FP),³ the clinical frailty scale (CFS),¹³ the frailty index based on a comprehensive geriatric assessment (FI-CGA),^{14,15} and the frailty index (FI)¹⁶ are well-validated instruments for the evaluation of older people in relation to frailty.

Postural stability, also referred to as balance, might best be considered as a multidimensional concept indicating the ability of a person not to fall.^{17–21} Postural stability/postural control is regarded as the ability to control body position in space, in order to achieve or restore a state of equilibrium by maintaining, achieving, or restoring posture or activity.^{17,21–23} The postural system comprises a complex assembly of related and interacting neuronal and musculoskeletal units. Amongst others, these include sensory/perceptual processes (visual acuity, vestibular and proprioceptive sensation), motor processes (organization of all body muscles into neuromuscular synergies), and central processing (slowing and/or reducing signal frequencies to and from effector organs).^{18,24–29} Posture control is commonly quantified by measuring the postural sway resulting from the displacement of the center of pressure (CoP) at the feet.^{17,18,22,23,25,30–32} Changes in such systems may result in impaired posture. Several different conditions have been associated with postural control impairment in older people. This includes, for example, a reduction in visual acuity, polyneuropathy, diabetes mellitus, and peripheral arterial disease.^{33–36} Changes such as a decrease in muscle strength,²³ the development of sarcopenia, and the duration of bed rest during hospitalization,³⁷ increase in muscle volume and size, for example, plantar flexors or trunk musculature, muscle density, lower muscle fat content,^{23,25,38} and increases in body weight. Also of relevance are Parkinson's disease,³⁹ arthrosis of the cervical spine, gonarthrosis and fear of falling,^{22,40} cognitive impairment and moderate Alzheimer's disease,^{41,42} and the presence of orthostatic hypotension.³³

It therefore is of interest to examine older frail people, who often have deficiencies in the functioning of several body/organ systems and/or patients who have risk factors

for frailty, for changes in those systems decisively involved in the body's postural control. However, previous studies investigating this relationship between postural control and/or equilibrium parameters and frailty status produced inconsistent results.^{36,43–45} A limitation of the aforementioned studies was that they categorized patients' frailty exclusively by the frailty phenotype instrument.⁴³ To the best of our knowledge, so far, no data has become available to enable the evaluation of postural control and/or balance in frail individuals whose frailty status has been assessed by frailty assessment tools other than the frailty phenotype instrument. Against this background, our aim was to evaluate postural control and frailty status and/or degree of frailty severity using four significant frailty instruments and risk factors associated with the development of frailty in geriatric inpatients. We investigated whether postural sway measurements are associated with frailty status and/or degree according to the criteria adopted by the four frailty instruments and/or risk factors for frailty.

Methods

Participants and Study Design

This cross-sectional study included 123 geriatric inpatients [70 women (56.5%), 53 men (42.7%)] from the wards of the Geriatrics Centre Erlangen (GCE) of the Malteser Waldkrankenhaus St. Marien, Erlangen, Germany. As recommended by the Medical Association for the Promotion of Geriatrics in Bavaria, Germany (Ärztliche Arbeitsgemeinschaft zur Förderung der Geriatrie in Bayern (AfGiB e.V.)), all patients with signs of balance and mobility disorders undergo a functional mobility assessment. This includes a basic geriatric assessment procedure, in particular, the Timed Up & Go Test (TUG),⁴⁶ a postural stability measurement, and gait analysis. In addition to these functional assessments, visual acuity measured at a distance of 5 m, sensory perception (depth sensitivity) in the feet, and the presence of orthostatic hypotension were examined in the GCE mobility laboratory.^{47,48}

Each patient received detailed information about the study and written informed consent was obtained prior to data collection, in accordance with the Helsinki Declaration. The study was approved by the Clinical Ethics Committee of the Medical Faculty of the Friedrich-Alexander-University Erlangen-Nürnberg (FAU), Germany.

Patients (at least 65 years old) were included if they were able to stand upright, barefoot, with arms held relaxed along the side of the body for at least 60 s without assistance, and

understood and were able to follow verbal instructions. Exclusion criteria were a pronounced Genu valgum, evidence of severe pain, visual impairment ($<0.125/40$ at 5 m), Mini-Mental State Examination (MMSE)⁴⁹ score ≤ 20 , acute injuries and conditions preventing the patient from performing the analysis, such as (sub-)acute limiting diseases, fatigue, vomiting, and dehydration.

Frailty Measures

The Frailty Phenotype (FP)

The FP classifies patients into three categories based on five phenotypic components: “robust” (no deficit in one phenotypic component), “pre-frail” (deficit in one or two phenotypic components), and “frail” (deficit in three or more phenotypic components).³ The operationalization of the five phenotypic components in this study was as follows: 1. unintentional loss of either ≥ 10 lbs or $\geq 5\%$ of body weight within the last 12 months. 2. self-reported feeling of “constant fatigue”, 3. time required for the Timed Up & Go test (>19 s), 4. patient’s inability to stand up and walk at least 50 m (without the wheeled walker), and 5. significant loss of strength within the physical examination as done previously by our group¹⁰ et al.

The Clinical Frailty Scale (CFS)

The clinical frailty scale was adopted from the work of Rockwood et al¹³ by assessing function, morbidity, central nervous system impairment (including severity of dementia), and clinical judgment, as described in detail elsewhere.¹³ The Clinical Frailty Scale discriminates patients across nine categories: Category 1: very fit, category 2: well, category 3: managing well, category 4: vulnerable, category 5: mildly frail, category 6: moderately frail, category 7: severely frail, category 8: very severely frail, category 9: terminally ill.¹³

The Frailty Index Based on a Comprehensive Geriatric Assessment (FI-CGA)

The 14-item frailty index, based on a comprehensive geriatric assessment (FI-CGA), was operationalized on the basis of impairments in 10 functional areas (i.e., cognition, emotion, communication, nutrition, bladder function, bowel function, mobility, balance/history of falls, instrumental, and the basic activities of daily living, social situation) and a comorbidity index (ie, the Cumulative Illness Rating Scale (CIRS)),⁵⁰ based on previous work by Jones et al¹⁵ reported previously by us.⁵¹

The Frailty Index (FI)

The FI consists of 47 items categorized in the following way: 1. requires help with eating, 2. requires help bathing, 3.

requires help dressing, 4. requires help climbing stairs, 5. requires help in/out of the chair, 6. requires help with bathing/showering, grooming nail and oral care, 7. requires help toileting, 8. urinary incontinence, 9. bowel incontinence, 10. lost more than 4.5 kg in the last year, 11. health self-report, 12. history of falls, 13. TUG score, 14. impairment of vision, 15. impaired sense of hearing, 16. insomnia, 17. arterial hypertension, 18. heart failure, 19. peripheral vascular disease, 20. stroke, 21. cancer, 22. diabetes mellitus, 23. chronic lung disease, 24. constipation, 25. other psychogenic disorders, 26–27. other medical diseases, 28. difficulty speaking, 29. cardiac arrhythmia, 30. myocardial infarction, 31. arthritis, 32. kidney disease, 33. anxiety, 34. alcohol addiction, 35. hypo or hyperthyroidism, 36. measured systolic blood pressure, 37. measured diastolic blood pressure, 38. orthostatic hypotension 39. Parkinson’s disease, 40. the feeling of permanent tiredness, 41. reduced muscle strength, 42. depression, 43. MMSE score, 44–47. number of medications.

The FI-CGA and FI were scored by dividing the score for each item by the maximum possible score for the items, resulting in a final score between 0 and 1. Since 0.25 was previously proposed as a cut-off for a frailty index between robust and frail older persons,⁵² we chose the FI-CGA and the FI as categorical variables according to this cut-off criterion. In addition, the FI and the FI-CGA were evaluated as a continuous variable (full scales).

Individual Risk Factors for the Development of Frailty

We selected individual risk factors for the development of frailty based on pathophysiological considerations. These included cognitive decline (MMSE ≤ 23 points), affective alterations (Geriatric Depression Scale (GDS) <5 points), mobility impairment (TUG > 10 s), and difficulties within the activities of daily living (Barthel Index <100 points). In addition, co-morbidity burden (Cumulative Illness Rating Scale (CIRS) $<$ median CIRS of the total study cohort), a history of a fall, a history of diabetes mellitus, a history of a stroke, abnormal muscle strength established in the physical examination, and restricted vision (visus $<$ median visus of the total study cohort) were considered.

Measuring Postural Sway

The Force Plate

The trajectories of the center of pressure (CoP) in the Y-axis (horizontal trace of the anterior-posterior) plane

and the X-axis (horizontal trace of the latero-lateral) plane were measured on the force plate⁵³ (SATEL, 6, rue du Limousin, 31700 Blagnac, France). Three strain gauge force transducers were mounted and positioned as an equilateral triangle of 40 cm per side in this force plate, from whose resistors the computer calculated the instantaneous position of the CoP.²⁶ The dimensions of the platform were 480 mm x 480 mm x 65 mm (LWH) and weighed 12 kg. For a maximum of 100 kg/sensor, the sensitivity was validated at 0.0017%. A force change of 9.81 N on the strain gauge corresponded to a change in power of 50 mV at an output range between 0 and 5 V.³² The displacement of the CoP was recorded in the anterior-posterior and latero-lateral directions, at a sampling frequency of 40 Hz. The system ran using an analogue digital 12-bit converter and a 50 Hz rejection filter. The reliability and validity of the Satel[®] force plate have been published in earlier papers by our research group.^{32,54,55}

Setting

As described by Prieto et al,⁵⁶ evaluations of postural steadiness typically include a separate test, with eyes open and eyes closed.¹⁹ The conditions were standardized before testing. All measurements on the force plate were performed by the same professional physical therapist (S.S.) who was blinded to the clinical characteristics of the subjects and the results were collected using the frailty instruments. The patients stood, without shoes, on the force plate, with laterally relaxed arms hanging down beside the body, for four consecutive measurements, followed by a two-minute break between each measurement (sitting on a chair). The room was constantly indirectly illuminated and a target mark which the participant was required to focus on was fixed, at a height and a distance of 1.5 m, to the wall in front of the participant.

Force-Plate-Derived Parameter

In the mobility laboratory of the Geriatrics Centre of the Malteser Waldkrankenhaus St. Marien, Erlangen, four standardised measurements on the force plate were carried out for all patients. No practice trials and no randomization were performed prior to testing. All force plate parameters were recorded according to the guidelines of the ISPGR Standardization Committee.⁵³ The patients were instructed to stand quietly, without shoes, on the force plate in an upright position with relaxed

arms hanging sideways beside the body. Participants were instructed to maintain balance and look straight ahead with their heads held focusing on a marker point on the wall. They maintained the position (first three recordings) for 30 s and for 60 s within the last trial.³² The data were recorded at a frequency of 40 Hz. The initial positions and examination conditions were: (a) wide standing (30° angle between both feet and 4 cm heel distance) with eyes open (WSEO) and (b) wide standing with eyes closed (WSEC). Tasks three and four were (c) narrow standing with eyes open (NSEO) and narrow standing with eyes closed (NSEC). The position of the feet touching one another during narrow standing was determined by a vertical line in the middle of the force plate. The following three force plate parameters were analyzed: (1) the length of sway (mm), (2) the area of sway (mm²), and (3) mean speed of CoP (mm/s).

Statistics

All statistical analyses were performed with the statistical package for the social sciences software (IBM SPSS Statistics 24). The results are presented as percent (%), mean values, \pm standard deviations and 95% confidence intervals. Correlation analyses were calculated using Spearman's Rho method. Comparisons between the groups were made using the nonparametric Mann–Whitney *U*-Test, the Chi-square Test or the Kruskal–Wallis test, and/or effect size, as appropriate. Effect size of the individual parameter was calculated according to the formula: (mean of experimental group – mean of control group) divided by the standard deviation.⁵⁷ An effect size of 0.2, 0.5 and 0.8 might be described as “small”, “medium” and “large”, respectively.⁵⁷ A two-tailed *p*-value <0.05 was considered statistically significant.

Results

Clinical Characteristics of the Study Participants

The clinical characteristics of the study participants (*n* = 123) are shown in Table 1. The participants were divided into two groups according to the median of the total cohort (median age was 82.98 \pm 6.2 years): (1) Younger group (< median, *n*=61) and (2) Older group (\geq median, *n*= 62). The older individuals had lower GDS points, a lower Barthel score, a higher prevalence of renal/kidney disease, a longer length of sway during NSEO, a higher speed of sway during NSEO, higher CFS, FI-CGA and FI

Table 1 Characteristics of the Patients Stratified into a Younger and an Older Group According to the Median Age of the Patients of 82.98 Years

Characteristics	Age < Median	N	Age ≥ Median	N	P-value
Female (% , n)	52.5, 32	61	61.3, 38	62	0.323 ^b
Age (years)	77.29±3.8	61	87.4±3.3	62	<0.001 ^a
Height (cm)	165.5±9.7	61	162.9±9.7	62	0.108 ^a
Weight (kg)	73.5±15.9	61	67.9±10.7	62	0.106 ^a
BMI (kg/m ²)	26.8±4.9	61	25.7±3.9	62	0.252 ^a
MMSE (points)	27.2±1.9	61	26.0±3.1	62	0.077 ^a
GDS (points)	3.7±2.8	61	2.7±2.0	62	0.029 ^a
Barthel index (points)	88.4±9.2	61	82.3±12.9	62	0.008 ^a
TUG (seconds)	17.8±8.2	61	19.4±9.8	62	0.204 ^a
POMA (points)	20.9±3.8	61	20.3±3.6	62	0.613 ^a
WSEO Length of sway (mm)	444.1±207.1	61	538.7±301.2	62	0.128 ^a
WSEO Area of sway (mm ²)	291.1±209.1	61	386.3±434.7	62	0.183 ^a
WSEO Mean speed (mm/s)	14.8±6.4	61	18.2±9.0	62	0.113 ^a
WSEC Length of sway (mm)	749.8±470.9	60	922.2±637.4	61	0.464 ^a
WSEC Area of sway (mm ²)	774.4±852.1	60	862.4±1095.4	61	0.992 ^a
WSEC Mean speed (mm/s)	26.1±13.7	60	31.3±20.8	61	0.408 ^a
NSEO Length of sway (mm)	660.9±369.5	58	802.4±407.8	59	0.028 ^a
NSEO Area of sway (mm ²)	582.7±761.1	58	620.8±479.7	59	0.190 ^a
NSEO Mean speed (mm/s)	22.3±12.3	58	27.3±14.5	59	0.023 ^a
NSEC Length of sway (mm)	2417.9±1355.4	45	2822.1±1480.3	44	0.127 ^a
NSEC Area of sway (mm ²)	1643.1±1478.3	45	1884.6±1589.8	44	0.264 ^a
NSEC Mean speed (mm/s)	40.7±18.9	45	47.7±22.7	44	0.127 ^a
Frailty phenotype (FP) (% , n)	11.5, 7	61	11.3, 7	62	0.974 ^b
Clinical frailty scale (CFS)	4.2±2.8	61	4.7±1.3	62	0.023 ^a
FI-CGA (-)	0.28±0.09	61	0.34±0.10	62	0.009 ^a
FI (-)	0.33±0.09	61	0.36±0.08	62	0.058 ^a
Cancer (% , n)	17.1, 6	61	9.5, 7	62	0.974 ^b
Stroke (% , n)	11.4, 4	61	16.2, 12	62	0.326 ^b
Heart failure (% , n)	34.3, 12	61	44.6, 33	62	0.636 ^b
Renal/Kidney disease (% , n)	62.3, 38	61	80.6, 50	62	0.025 ^b
Myocardial infarction (% , n)	16.4, 10	61	19.4, 12	62	0.067 ^b
Diabetes mellitus (% , n)	25.7, 9	61	28.4, 21	62	0.395 ^b
Chronic lung disease (% , n)	17.1, 6	61	23.0, 17	62	0.107 ^b
A fall (% , n)	48.6, 17	61	71.6, 53	62	0.235 ^b
Medication > 5 (% , n)	82.9, 29	61	86.5, 64	62	0.412 ^b
Institutionalized (% , n)	2.9, 1	61	10.8, 8	62	0.710 ^b

Notes: Values are: mean, ± SD standard deviation, (% , n) percentage and total number. ^aP-values for Mann-Whitney-U- Test, ^bp-values for Chi-square Test, a two-tailed P value < 0.05 was considered statistically significant. Age, height and weight = on the day of analysis, Barthel index = Hamburger Classification Manual for the Barthel index in geriatrics at hospital discharge (range 0–100), TUG = Timed Up & Go at hospital discharge, POMA = Performance-Oriented Mobility Assessment at hospital discharge (range 2–28), MMSE = Mini-Mental State Examination at hospital discharge (range 0–30), GDS = Geriatric Depression Scale at hospital discharge (range 1–15), FI-CGA = 14-item Frailty Index based on a comprehensive geriatric assessment, FI = 47-item Frailty Index.

Abbreviations: BMI, body mass index; WSEO, wide stand eyes open; WSEC, wide stand eyes closed; NSEO, narrow stand eyes open; NSEC, narrow stand eyes closes.

compared to the younger patients. No differences were found between the aforementioned two groups of patients in anthropometric data, such as gender, height, weight, or body mass index (BMI), in the functional mobility assessments such as TUG and Performance-Oriented Mobility Assessment (POMA),⁵⁸ and in the diagnoses and the history of falls over the past 12 months, amongst other characteristics (Table 1).

Completion Rate for Force Plate Measurements Under the Conditions Normal Standing and Narrow Standing with Eyes Open and Closed

The examination task WSEO was successfully completed by all participating patients. Due to the increased demands and the associated discontinuation rate, the data for three

(2.4%), six (4.9%), and 43 (35%) patients from WSEC, NSEO, and NSEC could not be included in the calculations.

Linkage/Association of Postural Sway (CoP) Parameters and Frailty Status or Frailty Severity Classified According to the Four Major Measures of Frailty for the Study Participants

Associations of CoP parameters and frailty status or frailty severity with respect to the various frailty measuring instruments are shown in [Tables 2–5](#) and [Figures 1–4](#). WSEO – length of sway (FP, CFS and FI-CGA), – area of sway (FI-CGA), – mean speed (FP, CFS and FI-CGA); WSEC – length of sway (FI-CGA and FI); NSEO – length of sway (FP, CFS and FI), – area of sway (FI), – mean speed (CFS and FI); NSEC – length of sway (FI), – area of sway (FI), – mean speed (FI) were associated with the frailty status of the study participants according to the categories used in the four different frailty instruments ([Tables 2–5](#) and [Figures 1–4](#)).

Correlation Analysis Between the Postural Sway (CoP) Parameters and the Frailty Status or Severity of Frailty of the Study Participants in Relation to the Four Different Major Frailty Measures (Full Scales)

The relationships between the CoP parameters and the frailty status of the study participants (full scales) are shown in [Table 6](#). WSEO – length of sway (FP, CFS, FI-CGA and FI), – area of sway (FP, CFS, FI-CGA and FI), – mean speed (FP, CFS, FI-CGA and FI); WSEC – length of sway (FP, FI-CGA and FI), – area of sway (FP, FI-CGA and FI), – mean speed (FI-CGA and FI); NSEO – length of sway (FP, FI-CGA and FI), – area of sway (FP, CFS, FI-CGA and FI), – mean speed (FP, CFS, FI-CGA and FI); NSEC – length of sway (FI-CGA), – area of sway (FI-CGA), – mean speed (FI-CGA) were related to the frailty status of the study participants, in relation to the categories of the four different frailty measurement instruments ([Table 6](#)).

Associations of Postural Sway (CoP) Parameters and Risk Factors for Frailty for the Study Participants

Associations between CoP parameters and risk factors in relation to the frailty status of our participants are shown in [Tables 7](#) and [8](#). WSEO – length of sway (MMSE \leq 23

points, Barthel index $<$ 100 points and TUG $<$ 10 s, abnormal muscle strength and visus), – area of sway (Barthel index $<$ 100 points, abnormal muscle strength and visus), – mean speed (MMSE \leq 23 points, Barthel index $<$ 100 points, and history of a fall, abnormal muscle strength and visus); WSEC – length of sway (MMSE \leq 23 points, Barthel index $<$ 100 points, CIRS $<$ 11 points, history of a fall, a history of diabetes mellitus, and abnormal muscle strength), – area of sway (MMSE \leq 23 points, CIRS $<$ 11 points, history of a fall, a history of diabetes mellitus and abnormal muscle strength), – mean speed (MMSE \leq 23 points, Barthel index $<$ 100 points, CIRS $<$ 11 points, a history of a fall, a history of diabetes mellitus, abnormal muscle strength and visus); NSEO – length of sway (MMSE \leq 23 points, a history of a fall, abnormal muscle strength and visus), – area of sway (a history of a fall, abnormal muscle strength and visus), – mean speed (MMSE \leq 23 points, a history of a fall, abnormal muscle strength and visus); NSEC – length of sway (MMSE \leq 23 points, a history of a fall, a history of diabetes mellitus, abnormal muscle strength and visus), – area of sway (history of diabetes mellitus), – mean speed (MMSE \leq 23 points, a history of a fall, a history of diabetes mellitus, abnormal muscle strength and visus) were associated with individual frailty risk factors for frailty.

Correlation Analysis Between Postural Sway (CoP) and Risk Factors for Frailty (Full Scales) of the Study Participants

The relationships between the CoP parameters and the risk factors for the study participants for Frailty are shown in [Table 9](#). WSEO – length of sway (MMSE, Barthel index, CIRS and visus), – area of sway (Barthel index and visus), – mean speed (MMSE, Barthel index, CIRS and visus); WSEC – length of sway (MMSE and CIRS), – area of sway (CIRS), – mean speed (MMSE and CIRS); NSEO – length of sway (MMSE and visus), – area of sway (TUG and visus), – mean speed (MMSE and visus); NSEC – length of sway (MMSE), – mean speed (MMSE) but not NSEC – area of sway was related with individual risk factors for frailty.

Discussion

The results of our study give an insight into the parameters of postural performance measures and sway characteristics, i.e., the variation in CoP, including length of sway, area of sway, and mean speed of sway during four

Table 2 Force Plate Variables and the Frailty Phenotype (FP)

Force Plate Variables	Robust			Pre-Frail			Frail			P-value	
	Mean ± SD	95% CI	n	Mean ± SD	95% CI	Effect Size (a)	n	Mean ± SD	95% CI		Effect Size (b)
Wide stand, eyes open											
Length of sway (mm)	403.1±214.9	329.3–476.9	35	517.7±269.8	455.1–580.2	0.5	74	567.6±287.2	410.7–742.4	0.8	14
Area of sway (mm ²)	246.8±172.1	187.6–305.9		334.4±231.4	280.8–388.4	0.5		594.6±799.0	133.3–1055.9	2.0	
Mean speed (mm/s)	13.7±7.0	11.3–16.2		17.3±9.6	15.1–19.6	0.5		19.0±9.3	13.6–24.4	0.7	
Wide stand, eyes closed											
Length of sway (mm)	753.3±616.8	541.4–965.2	35	885.9±496.9	770.0–1001.9	0.2	73	863.1± 895.5	322.0–1404.3	0.2	13
Area of sway (mm ²)	669.3±864.3	372.4–966.2		816.6±822.5	624.7–1008.5	0.2		1105.8 ± 1854.7	1499.4–2226.6	0.5	
Mean speed (mm/s)	25.8±18.7	19.3–33.2		29.5±16.2	25.6–33.2	0.2		33.4±0.24.6	17.3–47.5	0.4	
Narrow stand, eyes open											
Length of sway (mm)	619.5±358.3	496.4–742.6	35	764.3±402.7	667.6–861.1	0.4	69	865.5±395.1	626.7–1104.2	0.7	13
Area of sway (mm ²)	576.8±927.8	258.1–895.5		579.8±435.6	475.1–684.4	0		787.0±557.8	450.0–1124.1	0.2	
Mean speed (mm/s)	21.5±12.4	17.2–25.7		25.7±14.1	22.3–29.1	0.3		29.0±13.1	21.0–36.9	0.6	
Narrow stand, eyes closed											
Length of sway (mm)	2463.4±1523.1	1914.3–3012.5	32	2590.2±1187.0	2241.7–2938.7	0.1	47	3241.2±1500.3	2167.9–4314.4	0.5	10
Area of sway (mm ²)	1626.9±1453.3	1103.0–2150.9		1552.9±1028.0	125.1–1854.76	0		3181.2±2774.3	994.1–4771.9	1.1	
Mean speed (mm/s)	41.5±21.5	33.7–49.2		43.8±19.9	38.0–71.2	0.1		54.3±23.7	39.7–48.6	0.6	

Notes: Values are: mean, ± SD = standard deviation and number of patients (n); Effect size (a) = [Mean of Pre-frail]– [Mean of Robust]/[SD of Robust]; Effect size (b) = [Mean of Frail]– [Mean of Robust]/[SD of Robust]; P-values for Kruskal-Wallis-Test, a two-tailed P value <0.05 were considered statistically significant.

Table 3 Force Plate Variables and the Clinical Frailty Scale (CFS)

Force Plate Variables	Not Frail (CFS<5)			Frail (CFS ≥ 5)				P-value
	Mean ± SD	95% CI	n	Mean ± SD	95% CI	Effect Size	n	
Wide stand eyes open			67				56	
Length of sway (mm)	455.2±243.2	395.8–514.5		535.6±279.0	460.4–610.3	0.3		0.046
Area of sway (mm ²)	278.6±188.9	232.6–324.7		411.4±457.9	288.8–534.1	0.7		0.110
Mean speed (mm/s)	15.2±8.3	13.2–17.2		18.1±9.7	15.5–20.6	0.4		0.046
Wide stand, eyes closed			66				55	
Length of sway (mm)	798.4±553.5	662.3–934.5		934.3±570.7	778.5–1090.1	0.3		0.082
Area of sway (mm ²)	741.2±923.9	514.1–968.3		881.3±1064.1	514.1–968.3	0.2		0.148
Mean speed (mm/s)	26.5±17.1	22.3–30.7		31.5±18.5	19.1–48.7	0.3		0.081
Narrow stand, eyes open			64				53	
Length of sway (mm)	675.9±383.8	580.0–771.8		800.3±399.1	690.3–910.3	0.3		0.034
Area of sway (mm ²)	550.7±706.9	374.1–727.7		663.8±529.0	517.9–809.6	0.2		0.083
Mean speed (mm/s)	22.9±13.7	19.5–26.3		27.1±13.2	23.4–30.7	0.3		0.027
Narrow stand, eyes closed			52				37	
Length of sway (mm)	2574.5±1402.2	2184.2–2964.9		2678.0±1303.4	2243.9–3113.0	0.1		0.566
Area of sway (mm ²)	1695.0±1387.3	1308.7–2081.2		1857.4±1727.3	1236.2–2375.5	0.1		0.588
Mean speed (mm/s)	43.0±20.8	37.8–48.7		45.9±21.6	38.6–53.0	0.1		0.479

Notes: Values are: mean, ± SD = standard deviation and number of patients (n); Effect size = [Mean of Frail (CFS ≥5)] – [Mean of not Frail (CFS<5)]/[SD of not frail (CFS <5)]; P-values for Mann–Whitney U-Test, a two-tailed P value <0.05 were considered statistically significant.

Table 4 Force Plate Variables and the 14-Item Frailty Index Based on a Comprehensive Geriatric Assessment (FI-CGA)

Force Plate Variables	FI-CGA < Median			FI-CGA ≥ Median				P-value
	Mean ± SD	95% CI	n	Mean ± SD	95% CI	Effect Size	n	
Wide stand, eyes open			61				62	
Length of sway (mm)	447.2±247.4	401.47 –520.9		535.6±270.6	467.3–618.7	0.4		0.014
Area of sway (mm ²)	305.7±417.3	227.1–403.7		371.9±251.0	304.6–453.0	0.2		0.014
Mean speed (mm/s)	15.0±8.0	13.5–17.5		18.8±9.8	15.5–21.0	0.5		0.025
Wide stand, eyes closed			59				61	
Length of sway (mm)	779.3±523.5	678.6–922.6		937.2±592.8	775.4–1140.2	0.3		0.038
Area of sway (mm ²)	786.7±1085.1	550.5–1010.3		850.5±874.8	596.8–1170.6	0.1		0.074
Mean speed (mm/s)	26.4±17.1	23.0–31.1		31.0±18.3	26.1–37.1	0.3		0.067
Narrow stand, eyes open			59				58	
Length of sway (mm)	695.1±401.1	61.2 –818.9		770.0±386.6	667.7 –850.8	0.2		0.104
Area of sway (mm ²)	602.0±784.8	436.2 –774.3		601.8±432.9	465.9 –726.5	0		0.144
Mean speed (mm/s)	23.5±13.3	20.8–27.9		26.1±13.9	22.6–28.6	0.2		0.143
Narrow stand, eyes closed			47				42	
Length of sway (mm)	2402.8±1275.4	2063.0–2692.8		2858.2±1416.3	2504.8–3628.2	0.4		0.051
Area of sway (mm ²)	1590.7±1297.9	1254.4–2059.9		1954.7±1751.0	1397.1–2522.0	0.3		0.086
Mean speed (mm/s)	41.3±21.4	35.5–46.2		47.4±20.4	42.5–58.2	0.3		0.060

Notes: Median FI-CGA was 0.32143; Values are: mean, ± SD = standard deviation and number of patients (n); Effect size = [Mean of FI-CGA ≥Median] – [Mean of FI-CGA < Median]/[SD of FI-CGA < Median]; P-values for Mann–Whitney U-Test, a two-tailed P value <0.05 were considered statistically significant.

different positions/tasks, i.e., WSEO, WSEC, NSEO, and NSEC, in hospitalized older patients who were classified as “non-frail” and “frail”. We found that several postural

sway characteristics were associated with and/or related to the frailty status and/or severity of individual frailty instruments assessed in this study. It should be emphasized that

Table 5 Force Plate Variables and the Frailty Index (FI)

Force Plate Variables	FI < Median			FI ≥ Median				P-value
	Mean ± SD	95% CI	n	Mean ± SD	95% CI	Effect Size	n	
Wide stand, eyes open			60				63	
Length of sway (mm)	446.7±232.3	386.7 –506.7		534.7±282.8	463.4–605.9	0.4		0.054
Area of sway (mm ²)	283.4±208.7	229.4–333.73		392.2±430.5	283.8–500.6	0.5		0.129
Mean speed (mm/s)	15.2±8.4	13.1–17.4		17.7±9.5	15.3–20.1	0.3		0.069
Wide stand, eyes closed			59				61	
Length of sway (mm)	799.1±587.6	645.9–952.2		918.1±536.5	780.7–1055.5	0.2		0.048
Area of sway (mm ²)	750.3±931.5	507.5–993.0		885.8±1028.4	622.4–1149.2	0.2		0.117
Mean speed (mm/s)	26.8±18.5	22.0–31.6		30.7±17.1	26.3–35.1	0.2		0.056
Narrow stand, eyes open			58				59	
Length of sway (mm)	651.9±373.4	553.8 –750.1		811.2±401.0	706.7 –915.7	0.4		0.007
Area of sway (mm ²)	533.7±746.2	337.5 –729.9		669.0±493.6	540.3 –797.6	0.2		0.005
Mean speed (mm/s)	22.5±13.9	18.9–26.2		27.0±13.1	23.6–30.4	0.3		0.013
Narrow stand, eyes closed			48				41	
Length of sway (mm)	2387.3±1425.9	1973.3–2801.3		2887.5±1230.6	2499.1–3276.0	0.4		0.013
Area of sway (mm ²)	1466.3±1300.8	1088.6–1844.0		2109.0±1713.7	1568.3–2650.1	0.5		0.008
Mean speed (mm/s)	40.9±22.4	34.4–47.4		47.9±19.0	41.9–53.9	0.3		0.021

Notes: Median FI was 0.34574; values are: mean, ± SD = standard deviation and number of patients (n); Effect size = [Mean of FI ≥ Median]– [Mean of FI < Median]/[SD of FI < Median]; P-values for Mann–Whitney U-Test, a two-tailed P value <0.05 were considered statistically significant.

WSEO length of sway, WSEO area of sway, WSEO mean speed, NSEO area of sway, and NSEO mean speed were associated with and/or related to the frailty status and/or frailty severity in all four frailty instruments considered. Moreover, we found that WSEO length of sway, WSEO area of sway, WSEO mean speed, WSEC length of sway, WSEC area of sway, WSEC mean speed, NSEO length of sway, NSEO area of sway, NSEO mean speed, NSEC length of sway, NSEC area of sway, and NSEC mean speed were associated with or related to the quality of

selected individual risk factors for frailty. This also included cognitive decline, affective alterations, mobility impairments, difficulties within activities of daily living, co-morbidity burden, a history of a fall, a history of diabetes mellitus, abnormal muscle strength, and reduced visual acuity. Based on these results, we put forward evidence that changes in postural sway parameters are associated with frailty status and/or severity and individual risk factors for frailty in the patients included in the population under study.

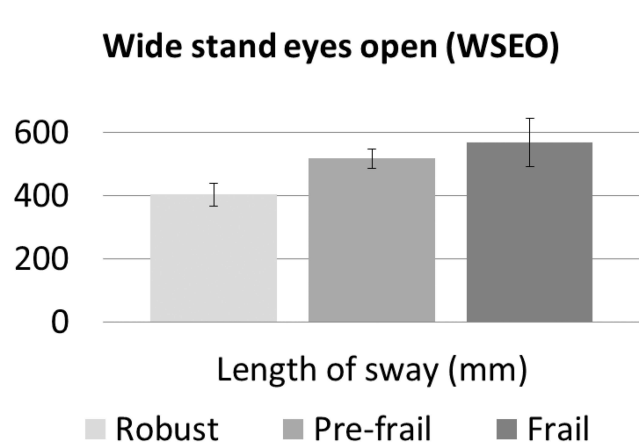


Figure 1 Association between length of sway during the task wide stand eyes open (WSEO) and frailty status according to the frailty phenotype (P = 0.014).

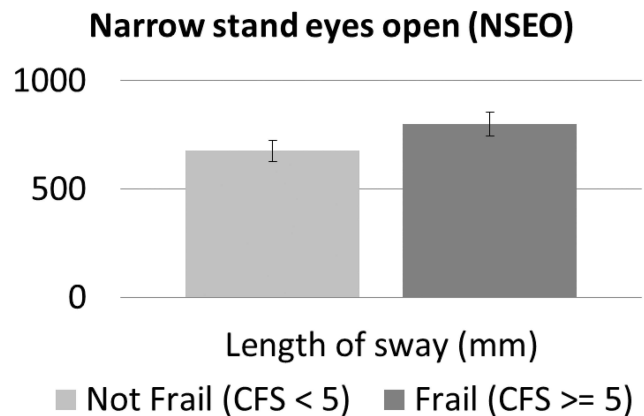


Figure 2 Association between length of sway during the task narrow stand eyes open (NSEO) and frailty status according to the clinical frailty scale (CFS) (P = 0.034).

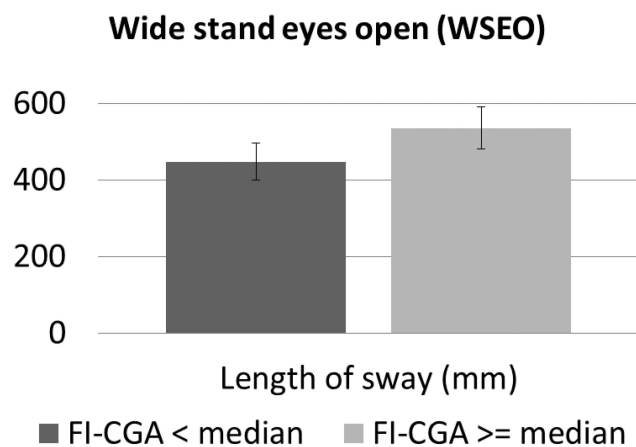


Figure 3 Association between length of sway during the task wide stand, eyes open (NSEO) and frailty status, according to the frailty index based on a comprehensive geriatric assessment (FI-CGA) ($P = 0.014$).

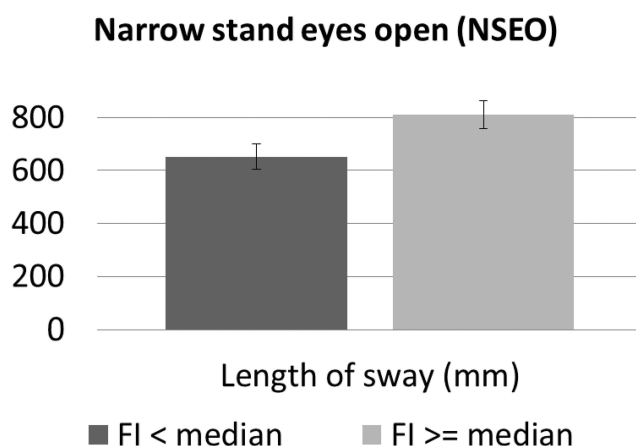


Figure 4 Association between length of sway during the task narrow stand, eyes open (NSEO) and frailty status according to the frailty index (FI) ($P = 0.007$).

It should be noted that, in our study, the pattern of alterations postural sway measured in frail persons was not identical amongst the four major, different frailty measures. Certainly, the four different frailty measures employed potentially identify different individuals as being frail. The frailty phenotype is based on five physical criteria.³ In contrast, the other frailty measures also incorporated dimensions of function and co-morbidity. The Clinical Frailty Scale embodies the criteria of function, central nervous system impairment, co-morbidity, and judgment in terms of residual life expectancy. As it contains multiple items, the frailty index represents an arithmetical model, independent of pre-set items.⁵⁹ Compared to the frailty index, the frailty index based on a comprehensive geriatric assessment approach, as used in our study, was

founded on different domains of a standardized, comprehensive geriatric assessment and comorbidity burden rather than multiple individual items.^{14,15} But, there is no gold standard screening and/or assessment tool for detecting frailty or degrees of frailty.^{8,9} Taking this into account, we evaluated the frailty status and degree of frailty of the patients by applying four different, major frailty instruments.

Other authors have previously reported on postural sway parameters and frailty status in older individuals.^{36,43-45} Kang et al⁴⁴ found that the CoP length of sway was higher in prefrail and frail individuals compared to robust older adults from 550 older volunteers (mean age 77.9 years). Toosizadeh et al⁴³ showed a possible prediction of frail and pre-frail when compared to non-frail, using sensors worn on the body, in a Romberg balance assessment of 15 s with eyes open and eyes shut in 122 older adults with no major mobility disorders (age >65 years). Moreover, the aforementioned study group reported a higher prediction of frail and pre-frail status (Fried's criteria) under eyes closed conditions. In contrast, Marques et al⁴⁵ reported for 60 older adults who were divided into three groups of 20 (non-frail, pre-frail and frail), lower scores for frail in all sections and total score of the Balance Evaluation Systems Test (BESTest). At the same time, force plate measurements showed similar mean oscillation values in all three groups, indicating similar CoP behavior.⁴⁵ While in subjects using sensors attached to the lower back during a 25 m walk to analyze postural sway, Thiede et al³⁶ observed no significant differences in balance parameters based on the frailty phenotype of Fried³ in 17 participants (≥ 55 years) with peripheral artery disease.³⁶ In contrast to the aforementioned studies, the patients in the study presented here were not only evaluated in relation to the frailty phenotype but, in addition, in terms of three other major frailty instruments, utilizing a different concept of frailty.

The association between postural sway changes and frailty status/severity, as well as risk factors for frailty in the study presented here and/or in previous studies by other authors,^{43,44} might be due to the effect of alterations in different bodily/organ systems in frail patients or individual, significant conditions that potentially impact on postural control. This might also explain the relatively low association as shown by a low correlation coefficient between frailty status/severity and CoP parameters in our study cohort. Clearly, our study cohort

Table 6 Correlation Analysis Between Force Plate Variables and the Four Different Frailty Instruments

Force Plate Variables	FP			CFS			FI-CGA			FI		
	r	p-value	n	r	p-value	n	r	p-value	n	r	p-value	n
Wide stand, eyes open			123			123			123			123
Length of sway (mm)	0.26	0.003		0.18	0.043		0.27	0.002		0.25	0.006	
Area of sway (mm ²)	0.21	0.018		0.18	0.049		0.25	0.006		0.24	0.009	
Mean speed (mm/s)	0.25	0.006		0.19	0.034		0.25	0.005		0.22	0.014	
Wide stand, eyes closed			120			120			120			120
Length of sway (mm)	0.19	0.040		0.13	0.157		0.24	0.010		0.20	0.026	
Area of sway (mm ²)	0.18	0.048		0.12	0.210		0.19	0.034		0.21	0.024	
Mean speed (mm/s)	0.16	0.084		0.13	0.148		0.21	0.019		0.18	0.044	
Narrow stand, eyes open			117			117			117			117
Length of sway (mm)	0.26	0.005		0.18	0.058		0.23	0.011		0.23	0.012	
Area of sway (mm ²)	0.21	0.021		0.19	0.037		0.20	0.034		0.25	0.008	
Mean speed (mm/s)	0.23	0.014		0.19	0.044		0.22	0.019		0.20	0.035	
Narrow stand, eyes closed			89			89			89			89
Length of sway (mm)	0.18	0.093		0.09	0.410		0.26	0.013		0.19	0.071	
Area of sway (mm ²)	0.14	0.189		0.12	0.260		0.22	0.040		0.19	0.072	
Mean speed (mm/s)	0.16	0.124		0.10	0.356		0.25	0.017		0.16	0.144	

Notes: FP = Frailty Phenotype (Fried et al 2001), CFS = Clinical Frailty scale (Rockwood et al 2007), FI-CGA = 14-item Frailty Index based on a comprehensive geriatric assessment, FI = 47-item Frailty Index; r = Spearman (bivariate correlation), a two-tailed P value <0.05 was considered statistically significant.

comprised older people with multiple morbidities and conditions that in addition to frailty each per se might impact on CoP parameters. In line with this, previous studies by other authors have found that frailty status or severity to be associated with changes in the neural and musculoskeletal systems, amongst others, that are critically involved in postural control.^{25,37,38,60,61}

To the best of our knowledge, no other study, up until now, has provided evidence comparing postural sway parameters in relation to several different major measures of frailty, in parallel, in older individuals.

A limitation of this study is that we only included geriatric inpatients. Also, patients with an MMSE score of 20 or lower, impaired vision, or an (sub-) acute limiting disease were excluded. This means that several patients suffering from significant multi-morbidity or impairments, frequently treated and cared for at hospital geriatric wards, were excluded. Therefore, our findings may not be transferable to other patient groups or to clinical settings. As was noted, only three common measures of postural sway were analyzed. However, a more comprehensive analysis of postural sway parameters might more accurately represent “balance” which, in nature, is multifactorial. In spite of this, in order to prevent excessive stress being placed on the

frail, older patients participating in the study, we chose a minimum of four trials. As previously reported by our study group^{4,51} and others,⁶² the operationalization of the individual phenotypic components used in our study differed slightly from the original operationalization by Fried et al.³ This was for practical reasons. Our operationalization was not dependent on gender, body size, or other variables. A different operationalization of the phenotypic components might have led to the identification of distinct patients in relation to the frailty status according to the frailty phenotype.⁶² A further limitation of this study is its cross-sectional design. Additional longitudinal studies are needed to evaluate the link between the observed postural sway parameters with frailty – status and degree.

In conclusion, the current study presents evidence that postural sway parameters are associated with frailty status and/or severity and individual risk factors for frailty in patients hospitalized on geriatric wards. We were able to identify several postural sway variables being altered in frail patients across four major, different frailty instruments and in patients showing individual risk factors for frailty. Despite an overlap in postural sway parameters across the various frailty instruments, the individual pattern of frailty-associated changes in postural sway

Table 7 Force Plate Variables and Risk Factors for Frailty Part 1

Force Plate Variables	MMSE			GDS			BARTHEL			TUG			CIRS (Median = 11)		
	> 23	≤ 23	P	< 5	≥ 5	P	100	< 100	P	≥ 10	< 10	P	< 11	≥ 11	P
	Mean ± SD	Mean ± SD		Mean ± SD	Mean ± SD		Mean ± SD	Mean ± SD		Mean ± SD	Mean ± SD		Mean ± SD	Mean ± SD	
n	106	17		59	61		12	111		114	9		61	62	
Wide stand, eyes open															
Length of sway (mm)	469.0±247.5	633.6 ±311.6	0.021	501.3 ±271.2	459.5 ±230.2	0.550	330.0 ±89.6	509.3 ±268.7	0.013	503.1 ±266.6	348.7 ±137.6	0.035	464.6 ±264.2	518.5 ±259.4	0.081
Area of sway (mm ²)	327.2±353.5	409.0 ±275.2	0.124	351.6 ±375.0	296.5 ±205.5	0.662	161.8 ±47.7	358.3 ±356.5	0.010	347.5 ±353.2	232.7 ±166.1	0.212	361.6 ±441.5	317.0 ±209.3	0.854
Mean speed (mm/s)	15.7±8.2	21.7±12.2	0.032	17.1±9.6	14.6±6.6	0.320	11.2±2.6	17.1±9.3	0.011	16.9±9.2	12.0±4.9	0.071	15.9±9.4	17.1±8.7	0.201
n	103	17		59	61		12	108		111	9		59	61	
Wide stand, eyes closed															
Length of sway (mm)	804.4±539.4	1194.1 ±603.6	0.005	873.2 ±574.3	812.7 ±530.0	0.763	517.0 ±218.4	897.6 ±577.1	0.008	860.2 ±523.1	851.3 ±976.3	0.220	737.4 ±518.0	977.7 ±583.5	0.002
Area of sway (mm ²)	790.8 ±1001.0	990.9 ±849.0	0.048	818.6 ±997.8	821.0 ±935.0	0.895	517.0 ±218.4	873.3 ±577.1	0.054	811.4 ±960.7	514.9 ±1260.7	0.976	692.6 ±1031.9	941.6 ±919.4	0.005
Mean speed (mm/s)	26.9±16.5	40.2±21.6	0.006	29.5 ±18.3	26.4 ±16.1	0.536	18.1±7.4	30.0 ±18.3	0.015	28.9 ±17.3	27.0 ±24.7	0.317	25.4 ±17.2	32.4 ±17.8	0.005
n	100	17		58	59		10	105		108	9		58	59	
Narrow stand, eyes open															
Length of sway (mm)	697.0±369.0	939.3 ±479.5	0.011	740.9 ±385.0	698.9 ±434.6	0.353	589.2 ±114.4	748.6 ±411.3	0.483	748.9 ±403.2	532.1 ±170.0	0.102	695.1 ±391.4	768.7 ±396.6	0.151
Area of sway (mm ²)	587.8±642.3	684.9 ±582.4	0.448	573.2 ±444.1	713.1 ±1101.1	0.606	424.9 ±156.0	622.1 ±663.0	0.574	616.7 ±654.2	424.3 ±194.8	0.533	618.4 ±755.4	585.7 ±488.6	0.970
Mean speed (mm/s)	23.5±12.2	32.6±18.6	0.011	25.2 ±13.3	23.2 ±14.8	0.188	20.8±4.6	25.3 ±14.2	0.657	25.3 ±13.9	18.8±7.2	0.133	24.0 ±14.2	25.6 ±13.1	0.340
n	75	14		49	40		10	79		81	8		49	40	
Narrow stand, eyes closed															
Length of sway (mm)	2507.4 ±1377.4	3209.0 ±1090.3	0.022	2696.1 ±1404.5	2260.2 ±1069.2	0.271	2154.3 ±524.8	2676.4 ±1417.7	0.541	2550.7 ±1190.6	3296.9 ±2513.2	0.528	2411.5 ±1183.2	2870.4 ±1571.6	0.123
Area of sway (mm ²)	1719.0 ±1592.1	1995.3 ±1165.8	0.120	1850.3 ±1632.6	1361.9 ±860.1	0.189	1286.9 ±362.8	1822.7 ±1610.9	0.668	1658.7 ±1358.3	2813.4 ±2641.4	0.315	1849.1 ±1473.5	1849.1 ±1473.5	0.339
Mean speed (mm/s)	42.1±21.0	54.9±18.6	0.014	45.7 ±21.7	37.2 ±16.5	0.171	37.6±9.1	45.0 ±22.0	0.541	43.1 ±19.2	54.8 ±35.0	0.482	41.7 ±19.8	47.1 ±22.4	0.205

Notes: Values are: mean, ± SD = standard deviation and number of patients (n); MMSE = Mini-Mental State Examination at hospital discharge (range 0–30); GDS = Geriatric Depression Scale at hospital discharge (range 1–15); Barthel index = Hamburger Classification Manual for the Barthel index in geriatrics at hospital discharge (range 0–100); TUG = Timed Up & Go at hospital discharge; P-values for Mann–Whitney U-Test, a two-tailed P value <0.05 were considered statistically significant.

Abbreviation: CIRS, Cumulative Illness Rating Scale.

Table 8 Force Plate Variables and Risk Factors for Frailty Part 2

Force Plate Variables	History of a Fall			History of Diabetes Mellitus			History of Stroke			Abnormal Muscle Strength			Visus (Median=50%)			
	No	Yes	P	No	Yes	P	No	Yes	P	No	Yes	P	Mean ± SD	≥ 50%	< 50%	P
n	46	77		87	36		105	18		58	65		70	53		
Wide stand, eyes open																
Length of sway (mm)	433.0±223.3	526.8 ±278.2	0.052	485.9 ±278.2	506.0 ±221.4	0.245	499.5 ±271.4	446.9 ±200.0	0.753	411.2 ±208.7	563.6 ±284.7	<0.001	405.5 ±176.6	605.7 ±310.7	<0.001	
Area of sway (mm ²)	269.7±193.9	380.5 ±403.6	0.079	339.1 ±384.5	339.2 ±221.2	0.475	340.6 ±357.7	330.3 ±256.5	0.946	277.0 ±219.5	394.5 ±419.4	0.016	268.7 ±201.9	432.1 ±455.9	0.004	
Mean speed (mm/s)	14.7±8.3	17.6±9.3	0.038	16.5±9.9	16.5±6.7	0.356	16.6±9.2	15.9±8.0	0.971	13.8±6.7	18.9 ±10.2	<0.001	13.5±5.6	20.5±11.0	<0.001	
n	46	74		85	35		102	18		58	62		69	51		
Wide stand, eyes closed																
Length of sway (mm)	707.1±412.5	954.3 ±622.0	0.036	794.2 ±515.4	1018.4 ±645.4	0.034	868.2 ±508.2	810.9 ±464.7	0.994	739.4 ±537.1	972.0 ±567.7	0.004	767.6 ±541.9	984.0 ±572.4	0.011	
Area of sway (mm ²)	532.7±486.8	997.2 ±1155.9	0.013	700.2 ±914.2	1108.1 ±1084.7	0.018	852.7 ±1035.1	629.1 ±561.1	0.564	746.1 ±957.7	887.4 ±1003.7	0.038	741.6 ±910.7	924.1 ±1067.3	0.114	
Mean speed (mm/s)	23.6±13.9	32.0 ±19.3	0.014	27.2±17.9	32.5 ±17.4	0.042	28.8±18.1	28.3 ±16.3	0.857	24.9±16.5	32.4 ±18.4	0.005	25.1±15.4	33.8±19.7	0.008	
n	45	72		83	34		99	18		56	61		68	49		
Narrow stand, eyes open																
Length of sway (mm)	638.4±355.7	790.1 ±407.7	0.018	718.6 ±403.8	765.5 ±372.0	0.265	729.8 ±397.1	745.7 ±387.5	0.850	608.2 ±319.7	846.1 ±423.0	<0.001	619.9 ±262.1	888.1 ±486.5	0.002	
Area of sway (mm ²)	434.9±316.9	706.3 ±750.1	0.004	579.8 ±680.3	655.9 ±501.8	0.101	583.3 ±645.5	704.2 ±561.1	0.231	539.7 ±762.8	659.0 ±482.9	0.013	470.5 ±348.1	784.3 ±859.8	0.013	
Mean speed (mm/s)	21.6±13.5	26.8 ±13.4	0.010	24.5±14.2	25.6 ±12.2	0.325	24.5±13.7	26.4 ±13.1	0.478	20.7±10.7	28.5 ±15.0	<0.001	20.9±8.5	30.2±17.2	0.001	
n	37	52		69	20		75	14		47	42		54	35		
Narrow stand, eyes closed																
Length of sway (mm)	2266.4 ±1000.8	2867.8 ±1519.7	0.049	2441.3 ±1180.4	3226.4 ±1737.6	0.036	2618.1 ±1369.7	2615.9 ±1325.3	0.901	2378.4 ±1400.2	2885.6 ±1266.6	0.016	2456.4 ±1439.1	2866.6 ±1192.2	0.034	
Area of sway (mm ²)	1385.2 ±909.7	2030.9 ±1811.4	0.053	1488.6 ±1069.6	2707.4 ±2354.2	0.014	1746.3 ±1411.1	1849.4 ±2124.3	0.752	1536.1 ±1240.6	2015.8 ±1783.1	0.340	1585.3 ±1303.4	2035.9 ±1813.3	0.118	
Mean speed (mm/s)	39.9±18.2	47.9 ±22.3	0.046	41.7±19.7	52.6 ±23.9	0.037	44.0±21.3	45.2 ±20.6	0.693	39.6±19.5	49.3 ±21.7	0.018	40.7±20.0	49.5±20.3	0.018	

Notes: Values are: mean, ± SD = standard deviation and number of patients (n); P-values for Mann-Whitney U-Test, a two-tailed P value <0.05 were considered statistically significant.

Table 9 Correlation Between Force Plate Variables and Risk Factors for Frailty

Force plate variables	MMSE			GDS			Barthel index			TUG			CIRS			Visus		
	r	P-value	n	r	P-value	n	r	P-value	n	r	P-value	n	r	P-value	n	r	P-value	n
Wide stand, eyes open			123			123			123			123			123			123
Length of sway (mm)	-0.22	0.017		-0.12	0.195		-0.22	0.015		0.15	0.103		0.22	0.014		-0.31	0.001	
Area of sway (mm ²)	-0.16	0.079		-0.03	0.713		-0.19	0.035		0.13	0.139		0.11	0.244		-0.26	0.003	
Mean speed (mm/s)	-0.20	0.029		-0.15	0.101		-0.22	0.016		0.15	0.091		0.19	0.037		-0.30	0.001	
Wide stand, eyes closed			120			120			120			120			120			120
Length of sway (mm)	-0.23	0.013		-0.08	0.364		-0.17	0.065		0.12	0.212		0.27	0.003		-0.13	0.169	
Area of sway (mm ²)	-0.13	0.166		-0.03	0.715		-0.13	0.161		0.10	0.290		0.22	0.017		-0.08	0.361	
Mean speed (mm/s)	-0.21	0.021		-0.10	0.262		-0.16	0.082		0.12	0.202		0.25	0.006		-0.13	0.175	
Narrow stand, eyes open			117			117			117			117			117			117
Length of sway (mm)	-0.28	0.002		-0.09	0.364		-0.13	0.179		0.14	0.131		0.16	0.085		-0.24	0.010	
Area of sway (mm ²)	-0.16	0.077		-0.04	0.663		-0.14	0.122		0.20	0.035		0.08	0.424		-0.25	0.007	
Mean speed (mm/s)	-0.73	0.004		-0.11	0.253		-0.12	0.212		0.16	0.088		0.13	0.175		-0.24	0.010	
Narrow stand, eyes closed			98			89			89			89			89			89
Length of sway (mm)	-0.28	0.009		-0.14	0.191		-0.07	0.524		-0.05	0.625		0.19	0.082		-0.19	0.072	
Area of sway (mm ²)	-0.16	0.129		-0.10	0.368		-0.14	0.200		0.01	0.913		0.10	0.344		-0.18	0.094	
Mean speed (mm/s)	-0.29	0.006		-0.15	0.150		-0.07	0.511		-0.03	0.804		0.16	0.142		-0.21	0.044	

Notes: Values are: number of patients (n); MMSE = Mini-Mental State Examination at hospital discharge (range 0–30); GDS = Geriatric Depression Scale at hospital discharge (range 1–15); Barthel Index = Hamburger Classification Manual for the Barthel Index in geriatrics at hospital discharge (range 0–100); TUG = Timed Up & Go at hospital discharge; CIRS = Cumulative Illness Rating Scale; Visus = visual acuity (Distance 5 m), r = Spearman (bivariate correlation), a two-tailed P value <0.05 was considered statistically significant.

parameters varied across the diverse frailty measures that identified different people as being frail.

Ethics Statement

The study was conducted in accordance with the Declaration of Helsinki and guidelines for Good Clinical Practice. The study was approved by the Clinical Ethics Committee of the Faculty of Medicine, Friedrich-Alexander Universität Erlangen-Nürnberg (FAU), Germany. All data were anonymous and analyzed according to the specifications of the ethics committee. A signed declaration of consent was obtained from each participant prior to measurements being taken.

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Author Contributions

SS, KGG, CCS and MR contributed to data analysis, drafting or revising the article, gave final approval of the version to be published, and agree to be accountable for all aspects of the work.

Disclosure

The authors report no conflicts of interest in this work.

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