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Determinants of instrumented sedentary and physical activity behavior in geriatric rehabilitation inpatients: RESORT

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ABSTRACT

Background: Physical inactivity in hospitalized older adults is highly prevalent and associated with detrimental health outcomes. Understanding its determinants is important for prognosis and tailoring interventions in geriatric rehabilitation inpatients.

Methods: Within the REStORing health of acutely unwell adulTs (RESORT) observational, longitudinal cohort, geriatric rehabilitation inpatients wore an inertial sensor (ActivPAL4) for one week to objectively assess instrumented sedentary behavior (i-SB) and physical activity (i-PA). Determinants were grouped in five geriatric domains: morbidity, cognition/psychology, physical performance, functional performance, and nutritional status. Their association with i-SB (mean sitting, lying, non-upright time) and i-PA (mean number of steps, sit-to-stand transitions and upright time) quintiles were examined using multivariate ordinal logistic regression analyses with Bonferroni correction ($p < 0.006$).

Results: A total of 145 inpatients were included (mean age 83.0, SD 7.7 years; 55.9% females). More comorbidities were associated with a lower daily number of steps (OR:0.91, 95%CI: 0.86–0.96) and lower upright time (OR:0.93, 95%CI: 0.88–0.98). Depressive symptoms (higher Hospital Anxiety and Depression Scale score) were associated with higher non-upright time (OR: 1.12, 95%CI: 1.03–1.21) and lower upright time (OR: 0.89, 95%CI: 0.83–0.96). Better physical performance (higher Functional Ambulation Classification, gait speed, and Short Physical Performance Battery score) was associated with lower i-SB measures (OR range: 0.07–0.78, $p < 0.0005$) and higher i-PA measures (OR range: 1.35–19.50, $p < 0.0005$). Higher functional performance (Katz index of Activities of Daily Living score) was associated with lower i-SB measures (OR range: 0.61–0.69, $p \leq 0.003$) and higher i-PA measures (OR range: 1.60–3.64, $p < 0.0005$). Being malnourished was associated with lower i-PA measures (OR range: 0.29–0.32, $p \leq 0.004$).

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Conclusions: Worse morbidity, depressive symptoms, worse physical and functional performance, and worse nutritional status were associated with higher i-SB and lower i-PA. These determinants should be taken into account while designing and promoting multidisciplinary physical activity interventions.

1. Introduction

Physical inactivity is highly prevalent in hospitalized older adults (Jasper et al., 2020) and contributes to lower physical function (Tasheva et al., 2020) and higher mortality rates (Ostir et al., 2013) after hospital discharge. In addition, physical inactivity is also high in geriatric rehabilitation inpatients (Klenk et al., 2019). Understanding the determinants of sedentary behavior (SB) and physical activity (PA) enables identifying inpatients at risk for physical inactivity during in-hospital geriatric rehabilitation, and allows for tailored intervention strategies after hospital discharge and/or during geriatric rehabilitation to limit the accelerated decline in physical function.

Age, ambulatory status, functional performance, history of falls, and cognitive function determine objectively assessed (instrumented) PA (i-PA) in acutely hospitalized older adults (Fisher et al., 2011; Evensen et al., 2017; Pedersen et al., 2013). During geriatric rehabilitation, i-PA measures were not associated with age, admission diagnosis, physical or cognitive function at admission, but were associated with ambulatory status and functional performance (Klenk et al., 2019). The above studies did not comprehensively address geriatric domains (i.e., morbidity, cognition/psychology, physical performance, functional performance, and nutritional status) within the same individuals, which is highly warranted to identify multifactorial determinants of instrumented SB (i-SB) and i-PA, to identify individuals likely to have high i-SB and low i-PA, and to guide interventions improving i-PA.

This study aimed to identify determinants of i-SB and i-PA in geriatric rehabilitation inpatients considering five major geriatric domains, namely morbidity, cognition/psychology, physical performance, functional performance, and nutritional domains.

2. Methods

2.1. Study design

REStORing health of acutely unwell adulTs (RESORT) is an observational, longitudinal cohort of geriatric rehabilitation inpatients admitted at the Royal Park Campus of the Royal Melbourne Hospital (Melbourne, Victoria, Australia). Patients were selected during their acute hospital stay to continue care in geriatric rehabilitation wards to regain function before discharge. As soon as patients were medically stable and their principal diagnoses were treated, patients were transferred to geriatric rehabilitation wards. Morbidity, cognition/psychology, physical performance, functional performance, and nutritional domains were assessed by a Comprehensive Geriatric Assessment (CGA) within 48 h of admission. Inpatients were excluded if they were unable to provide informed consent, without a legal proxy to consent or undergoing palliative care at hospital admission. Inpatients within the RESORT cohort were considered for inclusion in the Ending PyJama (PJ) Paralysis campaign adopted on two out of four geriatric rehabilitation wards from June 3, 2019 to March 29, 2020. The aims of the campaign were to 1) get 80% of inpatients dressed in their day-clothes by 11 o'clock; 2) have 80% of inpatients wearing appropriate footwear when out of bed; 3) have 80% of inpatients eat lunch sitting out of bed; 4) achieve a 50% increase in inpatients' participation in daily PA. Details on the Ending PJ Paralysis campaign in this hospital are presented elsewhere (Goonan, 2020). As part of the Ending PJ Paralysis campaign, a random sample of geriatric rehabilitation inpatients on all four wards wore an inertial sensor to measure i-SB and i-PA, from October 22, 2019 to March 29, 2020. All inpatients without bilateral lower extremity paralysis were considered eligible, and no further restrictions to ambulation status were present. This study was approved by the Melbourne Health Human Research Ethics Committee (HREC/17/MH/103) with all ethical guidelines followed in full accordance with the Declaration of Helsinki (World Medical A, 2013). Written informed consent was obtained from inpatients or nominated proxies.

2.2. Inpatient characteristics

Inpatients' medical records were used to extract age, sex, and the length of stay (in days) in geriatric rehabilitation and their principal diagnoses. The use of a walking aid was self-reported by patients and/or carers or extracted from medical records. A stadiometer assessed standing height for inpatients able to stand. Otherwise, knee height was assessed, and height was calculated using the Chumlea equation for Caucasians (Chumlea and Guo, 1992). Weight was assessed by a standing scale, seated scale, or a weighted hoist depending on ambulation status. Body mass index (BMI) was calculated by body mass (kg) divided by height squared (m) and expressed in kg/m^2.

2.3. Morbidity domain

The primary reason for hospital admission was categorized into musculoskeletal, cardiovascular and respiratory, neurological, infectious, and other reasons. Comorbidity was assessed by the Cumulative Illness Rating Scale (CIRS) (Hudon et al., 2005) with total scores from 0 to 56, based on the scoring from 0 (no problem) to 4 (extremely severe problem). Higher scores indicating higher severity.

2.4. Cognition/psychology domain

Cognitive status was assessed by the standardized Mini-Mental State Examination (MMSE) (Folstein et al., 1975), the Montreal Cognitive Assessment (MoCA) (Nasreddine et al., 2005) or the Rowland Universal Dementia Scale (RUDAS) (Storey et al., 2004). Cognitive impairment was defined as either a dementia diagnosis reported in medical records, an MMSE score $< 24/30$, a MoCA score $< 26/30$, or a RUDAS score $< 23/30$. Delirium was defined as either a clinical diagnosis or indicated by the Short Confusion Assessment Method (short CAM) (Inouye et al., 2014). The Hospital Anxiety and Depression Scale (HADS) (Zigmond and Snaith, 1983) was used to assess symptoms of anxiety and depression. The score ranged from zero to 21 points, and a cut-off score of ≥ 8 points on each subscale indicated borderline/abnormal symptoms.

2.5. Physical performance domain

The Functional Ambulation Classification (FAC) was used to assess ambulation status (Viosca et al., 2005). A score ranged from 0 (completely bed-bound) to 5 (full independence). Handgrip strength was assessed three times on both hands alternating using a handheld dynamometer (JAMAR hand dynamometer; Sammons Preston, Inc. Bolingbrook, IL, USA) (Reijnierse et al., 2017). The maximum score in kilograms was used. The Short Physical Performance Battery (SPPB) included balance tests, a timed four-meter walk to assess gait speed (m/s), and the timed chair stand test (Guralnik et al., 1994). A score ranged from 0 to 12 points, and higher scores represented better physical performance.

Muscle mass was measured by a direct-segmental Bio-electrical Impedance Analyser (BIA) (DSM-BIA, InBody S10, Biospace Co., Ltd., Seoul, South Korea). BIA measured appendicular skeletal muscle mass (ASMM) in kilograms and this measure was adjusted for body size using

height squared (m^2) (ASMM/height^2). Sarcopenia was diagnosed by the revised European Working Group on Sarcopenia in Older People (EWGSOP2) definition using a combination of poor muscle strength and muscle mass (Cruz-Jentoft et al., 2019).

2.6. Functional performance domain

Falls were defined as a history of at least one self-reported fall in the past year. Functional performance at admission into geriatric rehabilitation was assessed by the Katz Index of Activities of Daily Living (ADL) (Katz et al., 1963) and the Lawton and Brody scale of Instrumental ADL (IADL) (Lawton and Brody, 1969). The ADL and IADL scores ranged from 0 to 6 and 0 to 8 points, respectively, with a higher score indicating higher functional performance.

2.7. Nutritional domain

The Malnutrition Screening Tool (MST) was used to classify whether or not all inpatients were at risk of malnutrition using a score of 2 or above (Ferguson et al., 1999). Malnutrition was diagnosed by the Global Leadership Initiative on Malnutrition (GLIM) criteria by the presence of at least one phenotypic criterion (i.e., low BMI, weight loss, or low fat-free mass index (FFMI)) and one etiologic criterion (Cederholm et al., 2019).

2.8. Assessment of i-SB and i-PA

The ActivPAL4 (PAL Technologies Ltd., Glasgow, United Kingdom) was used to assess daily SB and PA patterns (i-SB and i-PA) and consisted of a tri-axial accelerometer with a range of ±4 g that collected data at a sampling frequency of 20 Hz. On day five (range: three to seven) of hospital admission, the ActivPAL4 sensor was attached to the right thigh for one week, or until hospital discharge. Inpatients with at least one day of valid wear, defined as a minimum of 20/24 h of wear, were included. The ActivPAL software package (Generation 8) was used to generate three i-SB measures, including sitting, lying and non-upright (sum of sitting and lying) time (hours/day) and three i-PA measures, including upright (the sum of standing and stepping) time (hours/day), number of steps (#/day) and number of sit-to-stand transitions (#/day). As our previous study did not indicate a change of i-SB and i-PA measures over measurement days (Rojer et al., n.d.), i-SB and i-PA measures were averaged over valid days, after which quintiles of i-SB and i-PA measures were conducted.

2.9. Statistical analyses

Descriptive statistics for continuous variables with a Gaussian (normal) distribution are presented as means with standard deviations (SD) and a non-Gaussian (skewed) distribution as medians with interquartile ranges [IQR]. Categorical variables were presented as numbers with percentages, n (%). Handgrip strength was expressed as sex-specific z-scores.

The association between the determinants and quintiles of i-SB and i-PA measures were analyzed using ordinal logistic regression analyses. A multinomial logistic regression analysis was performed if proportional odds were not met (full likelihood ratio test comparing the fitted model to a model with varying location parameters). Analyses were adjusted for age and sex (model 1) and additionally for comorbidity (CIRS score) (model 2). The associations between comorbidity (CIRS score) and i-SB and i-PA measures were additionally adjusted for BMI after model 1, as BMI is associated with both comorbidity (Khan et al., 2018) and PA (Gennuso et al., 2013). Gait speed was additionally adjusted for height from model 1 onwards, as height is positively correlated with gait speed (Tolea et al., 2010). Functional performance was additionally adjusted for cognitive function (model 3) as cognitive dysfunction predicts impaired functional performance (Ruchinskas et al., 2000). Allocation into the Ending PJ Paralysis campaign was tested as a potential effect-modifier in all association models.

Considering the number of geriatric domains ($n = 5$) and outcome measures ($n = 6$) a Bonferroni correction was applied to avoid type 1 errors. As determinants within geriatric domains, the domains themselves and i-SB/i-PA outcomes are highly correlated, a Bonferroni correction for 8 associations was applied (for 4 domains (the functional performance domain was considered as a result of the other domains) and two i-SB/i-PA outcomes) to avoid an increase in type 2 errors, resulting in p values <0.006 to be statistically significant. Analyses were performed using the Statistical Package for the Social Sciences (IBM SPSS Statistics for Windows, version 27.0; Armonk, NY, IBM Corp.).

3. Results

Table 1 shows the characteristics of 145 geriatric rehabilitation inpatients with a mean age of 83.0 (SD 7.7) years and 81 (55.9%) females. The median SPPB score at admission was 1 point [IQR 0–4]. The median wearing time of the ActivPAL4 was 6 days [IQR 5–6], and inpatients spent most of their day in non-upright time with a median of 23.0 [22.0–23.6] hours/day. The median number of steps and sit-to-stand transitions per day were 402 [IQR 65–899] and 20 [IQR 10–30], respectively.

Tables 2a and 2b show the associations between determinants and i-SB and i-PA measures using ordinal logistic regression analyses. Tables 3a and 3b reports the associations between determinants and i-SB and i-PA measures if proportional odds were not present, in which case multinomial logistic regression analyses were performed. Fig. 1 shows an overview of the determinants of i-SB and i-PA measures.

Model 1: age and sex adjusted. Model 2: model 1 + comorbidity.

For comorbidity: model 2: model 1 + BMI. For gait speed: model 1: age, sex and height adjusted. For ADL: model 3: model 2 + cognitive function.

Interpretation: One unit increase in the determinant is associated with a higher/lower odds of allocation in the specific quintile when compared to the reference quintile. *Note:* Bonferroni correction: $\alpha = 0.05/8 = 0.006$.

3.1. Morbidity domain

A higher CIRS score was associated with lower daily number of steps ($p = 0.001$) in all adjusted models, and with lower upright time in the final adjusted model ($p = 0.005$).

3.2. Cognition/psychology domain

A higher HADS depression score was associated with lower sitting time in the final adjusted model ($p = 0.005$), and with lower upright time ($p \leq 0.004$), and higher non-upright time in all adjusted models ($p \leq 0.005$). None of the other determinants of the cognition/psychology domain were associated with i-SB or i-PA measures.

3.3. Physical performance domain

A higher FAC score was associated with higher sitting time ($p = 0.003$), higher daily number of steps ($p < 0.0005$), higher daily number of sit-to-stand transitions ($p < 0.0005$), and lower lying time ($p < 0.0005$) and lower non-upright time ($p < 0.0005$) in all adjusted models. Multinomial logistic regression analyses showed that one unit higher FAC score was associated with a higher odds of allocation in the active quintiles based on upright time compared to the very inactive quintile in all adjusted models ($p \leq 0.001$). Higher gait speed and SPPB score were associated with lower non-upright time ($p < 0.0005$) and with higher number of sit-to-stand transitions ($p < 0.0005$) in all adjusted models. Multinomial logistic regression analyses showed that one unit higher gait speed was associated with a higher odds of allocation in the

Table 1
Geriatric rehabilitation inpatient characteristics.

	n	Total ($N = 145$)
Age (years), mean (SD)	145	83.0 (7.7)
Female, n (%)	145	81 (55.9)
Walking aid, n (%)	141	96 (68.1)
Walking stick, n (%)		33 (23.4)
Walker, n (%)		63 (44.7)
Length of stay (days)	145	17 [12–30]
Anthropometry		
Height (cm)	141	163.23 (10.17)
Weight (kg)	145	70.90 [59.40–84.55]
BMI (kg/m^2)	141	27.22 [23.17–31.52]
Morbidity domain		
Primary reason hospital admission, n (%)	145	
Musculoskeletal		71 (49.0)
Cardiovascular and respiratory		21 (14.5)
Neurological		20 (13.8)
Infectious		4 (2.8)
Other		29 (20.0)
Principle diagnoses, n (%)	145	
Fall		38 (26.2)
Fracture		32 (22.1)
Functional decline		26 (17.9)
Pneumonia/urinary tract infection/sepsis		26 (17.9)
Stroke		11 (7.6)
Ischaemic heart disease/heart failure		8 (5.5)
Comorbidity:		
CIRS [0–56] (points), median [IQR]	145	12 [8–16]
Cognition/Psychology domain		
Cognitively impaired, n (%)	145	89 (61.4)
Delirium, n (%)	145	27 (18.6%)
HADS, score 0–21(points)		
Anxiety	109	7 [4–10]
Depression	105	8 [5–11]
Physical performance domain		
FAC score [0–5] (points)	140	3 [1–3]
Handgrip strength (kg)	131	
Female	72	13.05 (6.90)
Male	59	20.53 (8.89)
Gait speed (m/s)	140	0.18 [0.00–0.49]
SPPB score [0−12] (points)	136	1 [0–4]
Sarcopenic, EWGSOP2, n (%)	114	19 (16.7)
Functional performance domain		
Fall in the past year, n (%)	143	108 (75.5)
ADL score [0–6] (points)	145	2 [1–3]
IADL score [0–8] (points)	145	1 [0–2]
Nutritional domain		
At risk of malnutrition, MST, n (%)	141	50 (35.5)
Malnourished, GLIM criteria, n (%)	119	65 (54.6)
Instrumented physical activity[a]		
Wearing time (days)	145	6 [5–6]
Non-upright time (hours/day)	145	23.0 [22.0–23.6]
Sitting time (hours/day)	145	9.2 [2.5–11.6]
Lying time (hours/day)	145	12.9 [10.0–20.5]
Upright time (hours/day)	145	1.0 [0.4–2.0]
Steps (number/day)	145	402 [65–899]
Sit-to-Stand transitions (number/day)	145	20 [10−30]

Note: SD = standard deviation; cm = centimeter, kg = kilogram, BMI=Body Mass Index; CIRS=Cumulative Illness Rating Scale; IQR = interquartile ranges; MMSE = standardized Mini-Mental State Examination; HADS=Hospital Anxiety and Depression Scale; FAC=Functional Ambulation Classification; SPPB=Short Physical Performance Battery; EWGSOP2 = European Working Group on Sarcopenia in Older People; ADL = Katz index of Activities of Daily Living; IADL = Lawton and Brody Instrumental Activities of Daily Living; MST = Malnutrition Screening Tool; GLIM = Global Leadership Initiative on Malnutrition criteria.

[a] Mean of i-SB or i-PA measure over valid measurement days.

sedentary quintile based on sitting time compared to the very low sedentary quintile in the all adjusted models ($p \leq 0.002$). One unit higher gait speed and SPPB score were associated with a higher odds of allocation in the active quintiles compared to the very inactive quintile for both the number of steps and upright time in all adjusted models ($p \leq 0.005$). Handgrip strength and sarcopenia were not associated with either i-SB or i-PA measures.

3.4. Functional performance domain

A higher ADL score was associated with lower lying time, lower non-upright time ($p \leq 0.003$), and higher daily number of steps and sit-to-stand transitions in all adjusted models ($p < 0.0005$). One unit higher ADL score showed a higher odds of allocation in more active quintiles based on upright time compared to the very inactive quintile in all adjusted models ($p \leq 0.001$). Higher IADL score was not associated with any of the i-SB measures, but was associated with higher daily number of steps, although associations disappeared in the final adjusted model ($p = 0.013$). A history of falls was not associated with i-SB or i-PA measures.

3.5. Nutritional domain

Being malnourished was associated with higher non-upright time, although associations were less significant in the final adjusted model ($p = 0.009$). Being malnourished was also associated with lower daily number of steps in the crude model ($p = 0.004$), and lower daily number of sit-to-stand transitions ($p \leq 0.002$), and lower upright time ($p \leq 0.004$) in all adjusted models. Multinomial logistic regression analyses showed that being malnourished was associated with a lower odds of allocation in the sedentary quintile for sitting time compared to the very low sedentary quintile ($p \leq 0.004$).

4. Discussion

Using a comprehensive approach, addressing all major geriatric domains, determinants of i-SB and i-PA in geriatric rehabilitation inpatients were found within domains of morbidity, cognition/psychology, physical and functional performance, and nutritional status. Worse comorbidity was associated with lower daily number of steps, and depressive symptoms were associated with higher non-upright time and lower upright time. Higher physical and functional performance were associated with lower i-SB measures and higher i-PA measures. Being malnourished was associated with lower daily number of sit-to-stand transitions and lower upright time. Cognitive function, muscle mass and muscle strength measures were not associated with i-SB and i-PA measures.

Our findings are in line with previously described significant associations in acutely hospitalized inpatients between physical performance, ambulatory status, and functional performance and i-PA measures (Fisher et al., 2011; Evensen et al., 2017), and confirmed non-significant association with cognitive function (Evensen et al., 2017). Previously found significant associations between delirium (Fisher et al., 2011), a history of falls (Fisher et al., 2011), and cognitive function (Pedersen et al., 2013) and i-SB and i-PA were not confirmed in the present study. In geriatric rehabilitation inpatients, our findings confirm previously described significant associations between ambulation status and functional performance and i-PA measures, and insignificant associations with orientation disorders (delirium) and cognition (Klenk et al., 2019). Newly identified determinants of i-SB and i-PA measures in geriatric rehabilitation inpatients were comorbidity, depressive symptoms, and malnutrition diagnosis. However, a direct comparison between the previously described studies examining determinants of in-hospital i-SB and i-PA and our study remains difficult for two reasons. First, acute illness could contribute to physical inactivity in the studies in acutely hospitalized older adults (Fisher et al., 2011; Evensen et al., 2017; Pedersen et al., 2013). During acute illness, inflammation can lead to impaired muscle function, as inpatients with inflammation showed lower muscle strength and fatigue resistance compared to inpatients without inflammation, despite adequate treatment (Bautmans et al., 2005). Second, a direct comparison between studies is also complicated because of the use of different inertial sensors and the different i-SB and i-PA measures included in analyses. Only one other study focused on using both i-SB and i-PA measures (Pedersen et al., 2013). Fortunately,

Table 2a
The association between determinants and quintiles of instrumented sedentary behavior measures in geriatric rehabilitation inpatients using ordinal logistic regression analyses.

	n	Sitting time per day (quintiles)			Lying time per day (quintiles)			Non-upright time per day (quintiles)		
		OR	95% CI	*p*	OR	95% CI	*p*	OR	95% CI	*p*
Morbidity domain										
Comorbidity (CIRS), 0–56 points										
Crude	145	1.03	0.98–1.08	0.325	0.99	0.95–1.05	0.830	1.06	1.00–1.11	0.038
Model 1	145	1.03	0.97–1.08	0.331	0.99	0.94–1.05	0.807	1.06	1.01–1.12	0.031
Model 2	141	1.03	0.98–1.09	0.282	1.00	0.95–1.05	0.892	1.08	1.02–1.14	0.006
Cognition/psychology domain										
Cognitively impaired (yes/no)										
Crude	145	0.96	0.53–1.74	0.901	1.00	0.55–1.81	1.000	0.90	0.50–1.62	0.720
Model 1	145	0.97	0.64–1.76	0.917	0.96	0.53–1.74	0.892	0.90	0.49–1.62	0.716
Model 2	145	0.95	0.53–1.73	0.874	0.96	0.53–1.75	0.904	0.89	0.49–1.61	0.697
Delirium (yes/no)										
Crude	145	0.51	0.24–1.07	0.074	1.78	0.85–3.76	0.129	0.88	0.42–1.84	0.727
Model 1	145	0.48	0.22–1.04	0.062	1.74	0.81–3.74	0.158	0.87	0.41–1.87	0.724
Model 2	145	0.46	0.21–1.00	0.049	1.76	0.81–3.80	0.152	0.81	0.38–1.75	0.597
Anxiety (HADS), 0–21 points										
Crude	109	0.98	0.91–1.06	0.629	1.02	0.95–1.10	0.537	1.01	0.94–1.09	0.700
Model 1	109	0.98	0.92–1.06	0.661	1.02	0.95–1.10	0.535	1.01	0.94–1.09	0.777
Model 2	109	0.98	0.91–1.05	0.515	1.03	0.95–1.10	0.501	1.01	0.94–1.09	0.755
Depression (HADS), 0–21 points										
Crude	105	0.90	0.84–0.97	0.008	1.10	1.02–1.19	0.010	1.13	1.01–1.22	**0.002**
Model 1	105	0.91	0.84–0.98	0.010	1.10	1.02–1.19	0.012	1.12	1.04–1.21	**0.004**
Model 2	105	0.90	0.83–0.97	0.005	1.10	1.02–1.19	0.010	1.12	1.03–1.21	**0.005**
Physical performance domain										
Ambulation status (FAC), 0–5 points										
Crude	140	1.38	1.11–1.70	**0.003**	0.68	0.55–0.84	**<0.0005**	0.48	0.38–0.61	**<0.0005**
Model 1	140	1.37	1.11–1.70	**0.003**	0.68	0.55–0.84	**<0.0005**	0.48	0.37–0.60	**<0.0005**
Model 2	140	1.39	1.12–1.72	**0.003**	0.68	0.55–0.84	**<0.0005**	0.48	0.37–0.61	**<0.0005**
Handgrip strength, z-score										
Crude	131	1.00	0.74–1.35	0.987	0.93	0.68–1.26	0.636	0.82	0.61–1.12	0.212
Model 1	131	0.99	0.73–1.35	0.957	0.97	0.71–1.31	0.820	0.83	0.61–1.13	0.225
Model 2	131	1.01	0.74–1.38	0.957	0.96	0.70–1.32	0.813	0.86	0.63–1.18	0.357
Gait speed, m/s										
Crude	140	Proportional odds not met. See results			0.27	0.10–0.75	0.012	0.08	0.03–0.24	**<0.0005**
Model 1	136	Table 3a.			0.24	0.08–0.68	0.007	0.07	0.02–0.20	**<0.0005**
Model 2	136				0.23	0.08–0.67	0.007	0.07	0.02–0.22	**<0.0005**
Physical performance (SPPB), 0–12 points										
Crude	136	1.10	0.99–1.22	0.080	0.89	0.80–0.99	0.031	0.78	0.70–0.87	**<0.0005**
Model 1	136	1.10	0.99–1.22	0.077	0.89	0.80–0.99	0.033	0.78	0.69–0.87	**<0.0005**
Model 2	136	1.11	1.00–1.23	0.061	0.89	0.80–0.99	0.033	0.78	0.70–0.88	**<0.0005**
Sarcopenia, EWGSOP2 (yes/no)		Proportional odds not met. See results Table 3a.			Proportional odds not met. See results Table 3a.			Proportional odds not met. See results Table 3a.		
Functional performance domain										
History of falls (yes/no)		Proportional odds not met. ee results Table 3a.			Proportional odds not met. See results Table 3a.			Proportional odds not met. See results Table 3a.		
ADL, 0–6 points										
Crude	145	1.32	1.07–1.62	0.009	0.68	0.55–0.85	**<0.005**	0.65	0.52–0.80	**<0.0005**
Model 1	145	1.32	1.07–1.63	0.009	0.69	0.56–0.86	**0.001**	0.65	0.52–0.81	**<0.0005**
Model 2	145	1.32	1.08–1.63	0.008	0.69	0.56–0.85	**0.001**	0.65	0.52–0.81	**<0.0005**
Model 3	127	1.33	1.05–1.67	0.016	0.69	0.55–0.88	**0.003**	0.61	0.48–0.78	**<0.0005**
IADL, 0–8 points										
Crude	145	1.14	0.91–1.44	0.259	0.87	0.69–1.09	0.233	0.89	0.71–1.12	0.328
Model 1	145	1.14	0.90–1.44	0.281	0.89	0.71–1.13	0.351	0.90	0.71–1.13	0.361
Model 2	145	1.14	0.90–1.44	0.281	0.89	0.71–1.13	0.348	0.90	0.71–1.14	0.396
IADL, 0–8 points										
Model 3	127	1.14	0.88–1.48	0.327	0.90	0.69–1.17	0.423	0.89	0.68–1.15	0.359
Nutritional domain										
Malnutrition, GLIM (yes/no)										
Crude	119	Proportional odds not met.			Proportional odds not met.			3.11	1.60–6.06	**0.001**
Model 1	119	See results Table 3a.			See results Table 3a.			3.00	1.39–6.51	**0.005**
Model 2	119							2.83	1.30–6.16	0.009

Note: CIRS=Cumulative Illness Rating Scale; BMI = Body Mass Index; HADS=Hospital Anxiety and Depression Scale; FAC=Functional Ambulation Classification; SPPB=Short Physical Performance Battery; EWGSOP2 = European Working Group on Sarcopenia in Older People; ADL = Katz index of Activities of Daily Living; IADL = Lawton and Brody Instrumental Activities of Daily Living; GLIM = Global Leadership Initiative on Malnutrition.
Model 1: age and sex adjusted. Model 2: model 1 + comorbidity.
For comorbidity: model 2: model 1 + BMI. For gait speed: model 1: age, sex and height adjusted. For ADL: model 3: model 2 + cognitive function.
Interpretation: One unit increase in the determinant is associated with a higher/lower odds of falling in the next quintile of the specific i-SB or i-PA measure. Bonferroni correction: $\alpha = 0.05/8 = 0.006$.

Table 2b
The associations between determinants and quintiles of instrumented physical activity measures in geriatric rehabilitation inpatients.

	n	Number of steps per day (quintiles)			Number of sit-to-stand transitions per day (quintiles)			Upright time per day (quintiles)		
		OR	95% CI	*p*	OR	95% CI	*p*	OR	95% CI	*p*
Morbidity domain										
Comorbidity (CIRS), 0–56 points										
Crude	145	0.91	0.86–0.96	**0.001**	0.96	0.92–1.02	0.163	0.95	0.90–1.00	0.033
Model 1	145	0.91	0.86–0.96	**0.001**	0.96	0.91–1.01	0.142	0.94	0.90–0.99	0.028
Model 2	141	0.91	0.86–0.96	**0.001**	0.95	0.90–1.00	0.071	0.93	0.88–0.98	**0.005**
Cognition/psychology domain										
Cognitively impaired (yes/no)										
Crude	145	0.78	0.43–1.41	0.411	0.85	0.47–1.53	0.586	1.04	0.57–1.87	0.905
Model 1	145	0.81	0.44–1.46	0.477	0.83	0.46–1.51	0.540	1.04	0.57–1.88	0.898
Model 2	145	0.88	0.48–1.60	0.677	0.84	0.46–1.53	0.573	1.05	0.58–1.90	0.880
Delirium (yes/no)										
Crude	145	0.53	0.25–1.11	0.094	0.74	0.35–1.55	0.419	1.14	0.55–2.39	0.727
Model 1	145	0.56	0.26–1.21	0.142	0.65	0.30–1.40	0.273	1.16	0.54–2.47	0.708
Model 2	145	0.62	0.29–1.35	0.230	0.68	0.31–1.46	0.322	1.24	0.58–2.68	0.579
Anxiety (HADS), 0–21 points										
Crude	109	0.99	0.92–1.06	0.690	0.98	0.92–1.06	0.658	0.98	0.92–1.06	0.641
Model 1	109	0.98	0.91–1.06	0.602	0.99	0.92–1.06	0.705	0.99	0.92–1.06	0.704
Model 2	109	0.98	0.91–1.06	0.617	0.99	0.92–1.06	0.701	0.99	0.92–1.06	0.678
Depression (HADS), 0–21 points										
Crude	105	0.91	0.84–0.98	0.011	0.90	0.84–0.97	0.007	0.89	0.82–0.96	**0.002**
Model 1	105	0.90	0.84–0.98	0.008	0.91	0.84–0.98	0.010	0.89	0.82–0.96	**0.003**
Model 2	105	0.91	0.84–0.98	0.016	0.91	0.84–0.98	0.012	0.89	0.83–0.96	**0.004**
Physical performance domain										
Ambulation status (FAC), 0–5 points										
Crude	140	2.88	2.20–3.77	**<0.0005**	2.28	1.78–2.92	**<0.0005**	Proportional odds not met.		
Model 1	140	2.88	2.20–3.78	**<0.0005**	2.29	1.79–2.93	**<0.0005**	See results Table 3b.		
Model 2	140	3.02	2.28–4.00	**<0.0005**	2.29	1.78–2.93	**<0.0005**			
Handgrip strength, z-scores										
Crude	131	1.58	1.15–2.17	**0.004**	1.45	1.06–1.98	0.020	1.24	0.91–1.69	0.171
Model 1	131	1.56	1.14–2.15	0.006	1.47	1.07–2.02	0.017	1.23	0.90–1.68	0.185
Model 2	131	1.48	1.07–2.05	0.019	1.48	1.07–2.05	0.019	1.18	0.86–1.62	0.304
Gait speed, m/s										
Crude	140	Proportional odds not met.			18.68	6.08–57.40	**<0.0005**	Proportional odds not met.		
Model 1	136	See results Table 3b.			20.69	6.52–65.64	**<0.0005**	See results Table 3b.		
Model 2	136				19.50	6.12–62.18	**<0.0005**			
Physical performance (SPPB), 0–12 points										
Crude	136	Proportional odds not met.			1.36	1.21–1.53	**<0.0005**	Proportional odds not met.		
Model 1	136	See results Table 3b.			1.36	1.21–1.53	**<0.0005**	See results Table 3b.		
Model 2	136				1.35	1.20–1.52	**<0.0005**			
Sarcopenia, EWGSOP 2 (yes/no)										
Crude	114	Proportional odds not met.			0.48	0.20–1.17	0.107	0.49	0.20–1.17	0.108
Model 1	114	See results Table 3b.			0.58	0.23–1.46	0.246	0.61	0.24–1.54	0.292
Model 2	114				0.59	0.23–1.49	0.261	0.63	0.25–1.60	0.327
Functional performance domain										
History of falls (yes/no)										
Crude	143	0.77	0.39–1.51	0.442	0.66	0.34–1.30	0.232	0.68	0.34–1.33	0.259
Model 1	143	0.77	0.39–1.51	0.443	0.67	0.34–1.33	0.255	0.68	0.34–1.33	0.260
Model 2	143	1.51	0.77–2.98	0.236	0.65	0.33–1.27	0.207	0.63	0.32–1.24	0.179
ADL, 0–6 points										
Crude	145	1.99	1.57–2.52	**<0.0005**	1.60	1.29–1.99	**<0.0005**	Proportional odds not met.		
Model 1	145	1.99	1.57–2.52	**<0.0005**	1.59	1.28–1.98	**<0.0005**	See results Table 3b.		
Model 2	145	2.04	1.60–2.59	**<0.0005**	1.59	1.27–1.97	**<0.0005**			
Model 3	127	1.96	1.51–2.55	**<0.0005**	1.60	1.26–2.05	**<0.0005**			
IADL, 0–8 points										
Crude	145	1.51	1.18–1.94	**0.001**	1.15	0.92–1.45	0.220	1.13	0.90–1.42	0.306
Model 1	145	1.50	1.16–1.94	**0.002**	1.15	0.91–1.45	0.254	1.12	0.89–1.42	0.344
Model 2	145	1.48	1.14–1.93	**0.003**	1.14	0.90–1.45	0.276	1.11	0.88–1.41	0.378
Model 3	127	1.44	1.08–1.91	0.013	1.15	0.89–1.50	0.295	1.13	0.87–1.47	0.359
Nutritional domain										
Malnutrition, GLIM (yes/no)										
Crude	119	0.38	0.20–0.74	0.004	0.30	0.15–0.59	**<0.0005**	0.31	0.16–0.60	**<0.0005**
Model 1	119	0.37	0.17–0.81	0.012	0.28	0.13–0.62	**0.002**	0.30	0.14–0.66	**0.003**
Model 2	119	0.40	0.18–0.86	0.020	0.29	0.13–0.64	**0.002**	0.32	0.15–0.70	**0.004**

Note: CIRS=Cumulative Illness Rating Scale; BMI = Body Mass Index; HADS=Hospital Anxiety and Depression Scale; FAC=Functional Ambulation Classification; SPPB=Short Physical Performance Battery; EWGSOP2 = European Working Group on Sarcopenia in Older People; ADL = Katz index of Activities of Daily Living; IADL = Lawton and Brody Instrumental Activities of Daily Living; GLIM = Global Leadership Initiative on Malnutrition; OR = odds ratio; CI = Confidence Interval; *p* = *p*-value.
Model 1: age and sex adjusted. Model 2: model 1 + comorbidity.
For comorbidity: model 2: model 1 + BMI. For gait speed: model 1: age, sex and height adjusted. For ADL: model 3: model 2 + cognitive function.
Interpretation: One unit increase in the determinant is associated with a higher/lower odds of falling in the next quintile of the specific i-SB or i-PA measure. Bonferroni correction: $\alpha = 0.05/8 = 0.006$.

Table 3a
The association between determinants and quintiles of instrumented sedentary behavior measures in geriatric rehabilitation inpatients using multinomial logistic regression analysis.

	Quintiles of i-SB measures																	
	Very highly sedentary				Highly sedentary				Sedentary				Low sedentary				Very low sedentary	
	n	OR	95% CI	*p*	n	OR	95% CI	*p*	n	OR	95% CI	*p*	n	OR	95% CI	*p*	n	OR
Gait speed, m/s									Sitting time									
Crude	28	11.15	1.22-101.73	0.033	28	10.03	1.09-92.01	0.041	27	41.10	1.49-376.28	**0.001**	29	7.77	0.85-71.37	0.070	28	1.00 (ref)
Model 1	26	15.18	1.57-146.56	0.019	28	10.20	1.09-101.28	0.042	26	42.05	4.29-712.32	**0.001**	29	8.65	0.90-83.37	0.062	27	1.00 (ref)
Model 2	29	17.10	1.73-168.71	0.015	28	10.89	1.12-106.11	0.040	26	39.33	3.97-389.43	**0.002**	29	7.97	0.82-77.76	0.074	27	1.00 (ref)
Sarcopenia (yes/no)									Sitting time									
Crude	20	0.12	0.01-1.14	0.065	26	0.70	0.19-2.63	0.597	24	0.21	0.04-1.20	0.080	24	0.47	0.11-1.97	0.299	20	1.00 (ref)
Model 1	20	0.10	0.01-0.99	0.049	26	0.71	0.17-3.03	0.642	24	0.23	0.04-1.44	0.117	24	0.47	0.10-2.22	0.341	20	1.00 (ref)
Model 2	20	0.10	0.01-0.99	0.049	26	0.71	0.17-3.07	0.649	24	0.23	0.04-1.43	0.114	24	0.47	0.10-2.22	0.340	20	1.00 (ref)
									Lying time									
Crude	20	4.07	0.71-23.26	0.114	24	1.90	0.31-11.61	0.487	25	3.00	0.54-16.79	0.211	24	0.41	0.04-4.91	0.484	21	1.00 (ref)
Model 1	20	4.25	0.97-27.00	0.125	24	1.47	0.22-9.76	0.689	25	3.55	0.55-22.69	0.181	24	0.43	0.03-5.54	0.519	21	1.00 (ref)
Model 2	20	4.27	0.67-27.05	0.124	24	1.47	0.22-9.75	0.689	25	3.60	0.56-23.05	0.177	24	0.43	0.03-5.47	0.515	21	1.00 (ref)
									Non-upright time									
Crude	21	1.98	0.41-9.59	0.397	23	3.38	0.76-14.98	0.109	23	0.00	0.00-0.00	n/a	25	0.86	0.16-4.79	0.867	22	1.00 (ref)
Model 1	21	1.07	0.19-5.99	0.938	23	2.09	0.41-10.71	0.379	23	0.00	0.00-0.00	n/a	25	0.52	0.08-3.37	0.492	22	1.00 (ref)
Model 2	21	1.09	0.18-6.52	0.924	23	2.18	0.40-11.91	0.368	23	0.00	0.00-0.00	n/a	25	0.54	0.08-3.53	0.521	22	1.00 (ref)
History of falls (yes/no)									Sitting time									
Crude	29	0.80	0.19-3.35	0.760	29	0.21	0.06-0.74	0.016	28	0.42	0.11-1.59	0.200	29	0.80	0.19-3.35	0.760	28	1.00 (ref)
Model 1	29	0.79	0.19-3.33	0.747	29	0.20	0.05-0.72	0.014	28	0.41	0.11-1.58	0.194	29	0.79	0.19-3.33	0.747	28	1.00 (ref)
Model 2	29	0.79	0.19-3.35	0.753	29	0.20	0.06-0.73	0.015	28	0.41	0.11-0.57	0.191	29	0.79	0.19-3.35	0.752	28	1.00 (ref)
									Lying time									
Crude	26	1.91	0.49-7.42	0.351	27	1.00	0.30-3.33	1.000	24	0.80	0.24-2.59	0.704	26	0.71	0.22-2.25	0.558	26	1.00 (ref)
Model 1	26	1.97	0.50-7.78	0.335	27	1.02	0.30-3.43	0.976	24	0.78	0.23-2.66	0.696	26	0.71	0.22-2.30	0.567	26	1.00 (ref)
Model 2	26	1.95	0.49-7.74	0.340	27	1.02	0.30-3.44	0.974	24	0.79	0.23-2.66	0.699	26	0.71	0.22-2.30	0.562	26	1.00 (ref)
									Non-upright time									
Crude	28	2.04	0.62-6.69	0.241	29	1.75	0.55-5.51	0.342	29	2.13	0.65-6.97	0.211	29	2.13	0.65-6.97	0.211	28	1.00 (ref)
Model 1	28	2.09	0.63-6.97	0.232	29	1.84	0.57-5.94	0.306	29	2.24	0.67-7.50	0.190	29	2.23	0.66-7.53	0.199	28	1.00 (ref)
Model 2	28	2.15	0.63-7.31	0.219	29	1.96	0.59-6.46	0.270	29	2.38	0.70-8.11	0.165	29	2.25	0.66-7.68	0.194	28	1.00 (ref)
Malnutrition, GLIM (yes/no)									Sitting time									
Crude	22	0.26	0.07-0.96	0.043	24	0.44	0.12-1.59	0.209	24	0.13	0.04-0.48	**0.002**	25	0.24	0.07-0.86	0.028	24	1.00 (ref)
Model 1	22	0.27	0.06-1.14	0.075	24	0.30	0.07-1.35	0.116	24	0.11	0.03-0.50	0.004	25	0.19	0.04-0.81	0.025	24	1.00 (ref)
Model 2	22	0.26	0.06-1.13	0.073	24	0.29	0.06-1.30	0.106	24	0.11	0.02-0.50	0.004	25	0.19	0.04-0.83	0.028	24	1.00 (ref)
									Lying time									
Crude	24	4.33	1.24-15.21	0.022	24	1.71	0.53-5.50	0.370	24	1.22	0.38-3.94	0.737	25	1.84	0.58-5.87	0.304	22	1.00 (ref)
Model 1	24	3.60	0.86-15.08	0.080	24	0.85	0.20-3.54	0.848	24	0.60	0.14-2.62	0.501	25	1.36	0.34-5.46	0.662	22	1.00 (ref)
Model 2	24	3.55	0.84-15.04	0.086	24	0.85	0.20-3.58	0.821	24	0.57	0.13-2.52	0.461	25	1.32	0.33-5.32	0.702	22	1.00 (ref)

Note: FAC=Functional Ambulation Classification; SPPB=Short Physical Performance Battery; EWGSOP 2 = European Working Group on Sarcopenia in Older People; ADL = Katz Activities of Daily Living; GLIM = Global Leadership Initiative on Malnutrition, ref. = reference quintile; OR = odds ratio; CI = Confidence Interval; *p* = *p*-value.

Table 3b
The association between determinants and quintiles of instrumented physical activity measures in geriatric rehabilitation inpatients using multinomial logistic regression analysis.

	Quintiles of i-PA measures																	
	Active				Moderate active				Low active				Inactive				Very inactive	
	n	OR	95% CI	*p*	n	OR	95% CI	*p*	n	OR	95% CI	*p*	n	OR	95% CI	*p*	n	OR
Ambulation status (FAC), 0-5 points				Upright time														
Crude	26	4.71	2.64-8.42	**<0.0005**	27	2.90	1.78-4.73	**<0.0005**	29	3.97	2.33-6.77	**<0.0005**	29	2.04	1.31-3.18	**0.002**	29	1.00 (ref)
Model 1	26	4.99	2.72-9.14	**<0.0005**	27	3.31	1.95-5.59	**<0.0005**	29	4.37	2.50-7.66	**<0.0005**	29	2.23	1.39-3.59	**0.001**	29	1.00 (ref)
Model 2	26	4.99	2.69-9.24	**<0.0005**	27	3.33	1.95-5.67	**<0.0005**	29	4.33	2.47-7.59	**<0.0005**	29	2.22	1.38-3.58	**0.001**	29	1.00 (ref)
Gait speed, m/s				Number of steps														
Crude	27	84233.61	766.61-9255460.51	**<0.0005**	26	29328.43	288.03-2986372.75	**<0.0005**	29	2262.38	25.30-202271.03	**0.001**	29	51.08	0.47-5527.97	0.100	29	1.00 (ref)
Model 1	27	110916.10	884.23-13913177.72	**<0.0005**	26	36519.47	317.15-4205160.23	**<0.0005**	28	1973.06	19.62-198407.27	**0.001**	27	71.86	0.59-8720.25	0.081	28	1.00 (ref)
Model 2	27	144272.79	1038.08-20051006.31	**<0.0005**	26	47140.98	383.22-5799016.01	**<0.0005**	28	2242.69	21.42-234810.86	**0.001**	27	76.17	0.62-9321.42	0.077	28	1.00 (ref)
				Upright time														
Crude	28	206.84	14.12-3029.57	**<0.0005**	29	111.82	7.83-1596.15	0.001	25	74.53	1.99-1112.19	**0.002**	29	15.70	1.03-239.24	0.048	29	1.00 (ref)
Model 1	27	298.39	17.80-5000.68	**<0.0005**	28	155.38	10.01-2412.23	**<0.0005**	25	74.5	4.77-1163.02	**0.002**	27	19.62	1.23-312.45	0.035	29	1.00 (ref)
Model 2	27	255.3	14.99-4348.65	**<0.0005**	28	148.97	9.55-2324.57	**<0.0005**	25	72.86	4.66-1139.21	**0.002**	27	19.64	1.22-315.21	0.036	29	1.00 (ref)
Physical performance (SPPB), 0-12 points				Number of steps														
Crude	27	4.55	2.17-9.56	**<0.0005**	26	4.35	2.07-9.12	**<0.0005**	26	3.65	1.75-7.63	**0.001**	28	2.32	1.11-4.88	0.026	29	1.00 (ref)
Model 1	27	4.58	2.17-9.69	**<0.0005**	26	4.49	2.12-9.49	**<0.0005**	26	3.71	1.76-7.80	**0.001**	28	2.33	1.10-4.93	0.026	29	1.00 (ref)
Model 2	27	4.48	2.15-9.34	**<0.0005**	26	4.38	2.11-9.10	**<0.0005**	26	3.59	1.74-7.42	**0.001**	28	2.26	1.09-4.68	0.028	29	1.00 (ref)
				Upright time														
Crude	27	1.65	1.23-2.21	**0.001**	29	1.61	1.20-1.15	**0.001**	24	1.52	1.13-2.05	**0.005**	28	1.26	0.93-1.71	0.144	28	1.00 (ref)
Model 1	27	1.64	1.23-2.20	**0.001**	29	1.64	1.22-2.20	**0.001**	24	1.53	1.14-2.06	**0.005**	28	1.26	0.93-1.71	0.143	28	1.00 (ref)
Model 2	27	1.61	1.20-2.17	**0.001**	29	1.62	1.21-2.18	**0.001**	24	1.52	1.13-2.04	0.006	28	1.25	0.92-1.70	0.148	28	1.00 (ref)
Sarcopenia, EWGSOP2 (yes/no)				Number of steps														
Crude	26	0.78	0.14-4.35	0.779	23	0.57	0.09-3.81	0.563	21	1.00	0.18-5.63	1.000	23	3.20	0.72-14.25	0.602	21	1.00 (ref)
Model 1	26	0.75	0.12-4.56	0.756	23	0.68	0.09-4.95	0.704	21	1.11	0.18-6.89	0.911	23	3.14	0.64-15.45	0.160	21	1.00 (ref)
Model 2	26	0.75	0.12-4.91	0.768	23	0.68	0.09-5.00	0.700	21	1.11	0.17-7.09	0.912	23	3.15	0.63-15.86	0.164	21	1.00 (ref)
ADL, 0-6 points				Upright time														
Crude	29	2.99	1.79-4.99	**<0.0005**	29	1.84	1.11-3.06	0.018	29	2.61	1.57-4.33	**<0.0005**	29	1.60	0.96-2.67	0.071	29	1.00 (ref)
Model 1	29	3.42	1.93-6.05	**<0.0005**	29	2.19	1.25-3.84	0.006	29	3.06	1.74-5.37	**<0.0005**	29	1.86	1.06-3.27	0.031	29	1.00 (ref)

(*continued on next page*)

Table 3b (*continued*)

	Quintiles of i-PA measures																	
	Active				Moderate active				Low active				Inactive				Very inactive	
	n	OR	95% CI	*p*	n	OR	95% CI	*p*	n	OR	95% CI	*p*	n	OR	95% CI	*p*	n	OR
Model 2	29	3.45	1.94-6.14	**<0.0005**	29	2.17	1.23-3.82	0.008	29	3.02	1.72-5.32	**<0.0005**	29	1.85	1.06-3.24	0.031	29	1.00 (ref)
Model 3	26	3.64	1.93-6.87	**<0.0005**	27	2.12	1.13-3.95	0.019	23	2.82	1.51-5.28	**0.001**	26	1.75	0.94-3.26	0.076	25	1.00 (ref)

Note: FAC=Functional Ambulation Classification; SPPB=Short Physical Performance Battery; EWGSOP 2 = European Working Group on Sarcopenia in Older People; ADL = Katz Activities of Daily Living; GLIM = Global Leadership Initiative on Malnutrition, ref. = reference quintile; OR = odds ratio; CI = Confidence Interval; *p* = p-value.
Model 1: age and sex adjusted. Model 2: model 1 + comorbidity.
For comorbidity: model 2: model 1 + BMI. For gait speed: model 1: age, sex and height adjusted. For ADL: model 3: model 2 + cognitive function.
Interpretation: One unit increase in the determinant is associated with a higher/lower odds of allocation in the specific quintile when compared to the reference quintile. *Note:* Bonferroni correction: $\alpha = 0.05/8 = 0.006$.
A p-value of <0.006 is considered statistically significant and therefore presented in bold.

all aforementioned studies used sensors worn on the lower extremities (Klenk et al., 2019; Fisher et al., 2011; Evensen et al., 2017; Pedersen et al., 2013), which are known to detect the number of steps accurately (Treacy et al., 2017).

In the present study, the ActivPAL4 was used to assess i-SB and i-PA measures, which is known to be a valid thigh-worn sensor to classify posture and recognize transitions in older adults with impaired function (Taraldsen et al., 2011). The number of steps is underestimated in individuals with slow gait speed, indicating that misclassifications are likely to occur in older adults (Taraldsen et al., 2011). The ActivPAL4 was continuously worn for a period of one week, starting on day five of admission. This wearing period could have influenced the ability to detect a change in i-SB and i-PA, as changes were previously found after two weeks of rehabilitation comparing PA measures from the second and 15th day in geriatric rehabilitation (Klenk et al., 2019). The ActivPAL4 was received well by patients and health care staff, indicating that an extended period of wear should be feasible, enabling the investigation of the determinants of change in i-SB and i-PA.

4.1. *Clinical consequences*

The identified determinants of i-SB and i-PA can help identify geriatric rehabilitation inpatients at risk for in-hospital physical inactivity. It is important to note the bidirectional associations between SB and PA and the identified determinants, including comorbidity, depressive symptoms, and physical and functional performance (Taylor, 2014; Cooper et al., 2017; Gardiner et al., 2018; Steinmo et al., 2014). In addition, the role of nutritional status and its association with preserving muscle mass and physical performance should be noted (Mithal et al., 2013). The findings of this study identify targets for future interventions aiming to improve in-hospital i-SB and i-PA behavior. Addressing low PA in geriatric rehabilitation inpatients is a multifactorial problem that needs to be counteracted by a multidisciplinary team. Especially in geriatric rehabilitation, a multidisciplinary approach has shown to be effective (Prvu Bettger and Stineman, 2007), and teams usually include a medical doctor, a nurse, a physiotherapist, an occupational therapist, and a social worker (Grund et al., 2020). In some countries, a psychologist, a pharmacist, a dietician, and a speech therapist are additionally included (Grund et al., 2020), which could be essential for interventions aiming to improve i-SB and i-PA behavior as supported by the determinants we found. Identification of inpatients is the first step, suggesting that these individuals may benefit most from targeted interventions. However, it still needs to be seen whether, and whom of these individuals are most eligible for change/improvement in i-SB and i-PA and therewith health outcomes in future studies.

4.2. *Strengths and limitations*

This study's strength is the use of CGA to describe the determinants of i-SB and i-PA in geriatric rehabilitation inpatients. A limitation is that this was a single-center study, which might restrict generalizability, as geriatric rehabilitation settings vary between different countries (Grund et al., 2020). However, no selection of any specific inpatient group was made, increasing the generalizability of our study. In addition, other geriatric domains that could have been addressed include sensory function, bowel and bladder function and medication use. Another limitation is the observational character of this specific study in addition to the bidirectional nature of the associations between possible determinants and i-SB and i-PA, which limits us in disentangling cause and effect.

5. Conclusion

In geriatric rehabilitation inpatients, worse morbidity, depressive symptoms, worse physical and functional performance, and worse nutritional status were associated with higher i-SB and lower i-PA.

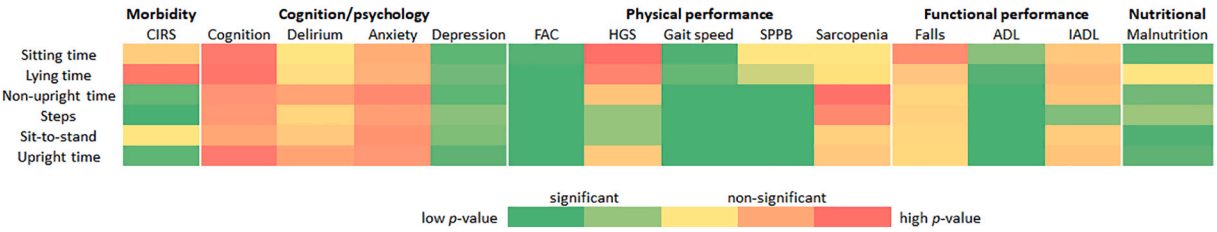

Fig. 1. Overview of the determinants of i-SB and i-PA measures in geriatric rehabilitation inpatients.
Note: CIRS=Cumulative Illness Rating Scale; FAC=Functional Ambulation Classification; SPPB=Short Physical Performance Battery; HGS = Handgrip strength, Falls = History of falls; ADL = Katz index of Activities of Daily Living; IADL = Lawton and Brody Instrumental Activities of Daily Living. STS = sit-to-stand transitions.

These determinants could be used to identify inpatients at risk for physical inactivity, and future intervention studies are suggested to target these determinants by a multidisciplinary team to improve i-SB and i-PA behavior in geriatric rehabilitation inpatients.

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CRediT authorship contribution statement

Conceptualization: all authors. Methodology: AGMR, BCMD, PB, MCT, CGMM, MP, RG, CM, JEK, WKL, AT, LI, EMR, ABM. Formal analysis: AGMR, BCMD, PB. Investigation: AGMR, KAR, RG, CM, JEK, WKL, AT, LI, EMR, ABM. Writing – original draft: AGMR, BCMD, PB. Writing – Review & Editing: all authors. Supervision: MCT, CGMM, MP, ABM.

Decleration of competing interest

None.

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References

Bautmans, I., Njemini, R., Lambert, M., Demanet, C., Mets, T., 2005. Circulating acute phase mediators and skeletal muscle performance in hospitalized geriatric patients. J. Gerontol. A Biol. Sci. Med. Sci. 60 (3), 361–367.
Cederholm, T., Jensen, G., Correia, M.I.T., et al., 2019. GLIM criteria for the diagnosis of malnutrition–a consensus report from the global clinical nutrition community. J. Cachexia. Sarcopenia Muscle 10 (1), 207–217.
Chumlea, W.C., Guo, S., 1992. Equations for predicting stature in white and black elderly individuals. J. Gerontol. 47 (6), M197–M203.
Cooper, A., Lamb, M., Sharp, S.J., Simmons, R.K., Griffin, S.J., 2017. Bidirectional association between physical activity and muscular strength in older adults: results from the UK Biobank study. Int. J. Epidemiol. 46 (1), 141–148.
Cruz-Jentoft, A.J., Bahat, G., Bauer, J., et al., 2019. Sarcopenia: revised european consensus on definition and diagnosis. Age Ageing 48 (1), 16–31.
Evensen, S., Sletvold, O., Lydersen, S., Taraldsen, K., 2017. Physical activity among hospitalized older adults - an observational study. BMC Geriatr. 17 (1), 110.
Ferguson, M., Capra, S., Bauer, J., Banks, M., 1999. Development of a valid and reliable malnutrition screening tool for adult acute hospital patients. Nutrition 15 (6), 458–464.
Fisher, S.R., Goodwin, J.S., Protas, E.J., et al., 2011. Ambulatory activity of older adults hospitalized with acute medical illness. J. Am. Geriatr. Soc. 59 (1), 91–95.
Folstein, M.F., Folstein, S.E., McHugh, P.R., 1975. Mini-mental state. J. Psychiatr. Res. 12 (3), 189–198.
Gardiner, P.A., Reid, N., Gebel, K., Ding, D., 2018. Sitting time and physical function in australian retirees: an analysis of bidirectional relationships. J. Gerontol. A Biol. Sci. Med. Sci. 73 (12), 1675–1681.
Gennuso, K.P., Gangnon, R.E., Matthews, C.E., Thraen-Borowski, K.M., Colbert, L.H., 2013. Sedentary behavior, physical activity, and markers of health in older adults. Med. Sci. Sports Exerc. 45 (8), 1493–1500.
Goonan, R., 2020. RESORT Ending PyJama Paralysis Campaign. Submitted.
Grund, S., van Wijngaarden, J.P., Gordon, A.L., Schols, J., Bauer, J.M., 2020. EuGMS survey on structures of geriatric rehabilitation across Europe. Eur. Geriatr. Med. 11 (2), 217–232.
Guralnik, J.M., Simonsick, E.M., Ferrucci, L., et al., 1994. A short physical performance battery assessing lower extremity function: association with self-reported disability and prediction of mortality and nursing home admission. J. Gerontol. 49 (2), M85–M94.
Hudon, C., Fortin, M., Vanasse, A., 2005. Cumulative illness rating scale was a reliable and valid index in a family practice context. J. Clin. Epidemiol. 58 (6), 603–608.
Inouye, S.K., Director ABC, Life HS, 2014. The Short Confusion Assessment Method (Short CAM): Training Manual and Coding Guide.
Jasper, U., Yadav, L., Dollard, J., Jadczak, A.D., Yu, S., Visvanathan, R., 2020. Sedentary behaviour in hospitalised older people: a scoping review. Int. J. Environ. Res. Public Health 17 (24).
Katz, S., Ford, A.B., Moskowitz, R.W., Jackson, B.A., Jaffe, M.W., 1963. Studies of illness in the aged. The index of Adl: a standardized measure of biological and psychosocial function. JAMA 185, 914–919.
Khan, S.S., Ning, H., Wilkins, J.T., et al., 2018. Association of body mass index with lifetime risk of cardiovascular disease and compression of morbidity. JAMA Cardiol. 3 (4), 280–287.
Klenk, J., Wekenmann, S., Schwickert, L., Lindemann, U., Becker, C., Rapp, K., 2019. Change of objectively-measured physical activity during geriatric rehabilitation. Sensors (Basel) 19 (24), 5451.
Lawton, M.P., Brody, E.M., 1969. Assessment of older people: self-maintaining and instrumental activities of daily living. Gerontologist 9 (3), 179–186.
Mithal, A., Bonjour, J.P., Boonen, S., et al., 2013. Impact of nutrition on muscle mass, strength, and performance in older adults. Osteoporos. Int. 24 (5), 1555–1566.
Nasreddine, Z.S., Phillips, N.A., Bedirian, V., et al., 2005. The Montreal Cognitive Assessment, MoCA: a brief screening tool for mild cognitive impairment. J. Am. Geriatr. Soc. 53 (4), 695–699.
Ostir, G.V., Berges, I.M., Kuo, Y.F., Goodwin, J.S., Fisher, S.R., Guralnik, J.M., 2013. Mobility activity and its value as a prognostic indicator of survival in hospitalized older adults. J. Am. Geriatr. Soc. 61 (4), 551–557.
Pedersen, M.M., Bodilsen, A.C., Petersen, J., et al., 2013. Twenty-four-hour mobility during acute hospitalization in older medical patients. J. Gerontol. A Biol. Sci. Med. Sci. 68 (3), 331–337.
Prvu Bettger, J.A., Stineman, M.G., 2007. Effectiveness of multidisciplinary rehabilitation services in postacute care: state-of-the-science. A review. Arch. Phys. Med. Rehabil. 88 (11), 1526–1534.
Reijnierse, E.M., de Jong, N., Trappenburg, M.C., et al., 2017. Assessment of maximal handgrip strength: how many attempts are needed? J. Cachexia. Sarcopenia Muscle 8 (3), 466–474.
Rojer AGM, KA Ramsey, MC Trappenburg, et al. Patterns of instrumented sedentary behaviour and physical activity and its association with changes in physical and functional performance in geriatric rehabilitation inpatients: the RESORT Ending PyJama Paralysis campaign. Submitted.
Ruchinskas, R.A., Singer, H.K., Repetz, N.K., 2000. Cognitive status and ambulation in geriatric rehabilitation: walking without thinking? Arch. Phys. Med. Rehabil. 81 (9), 1224–1228.
Steinmo, S., Hagger-Johnson, G., Shahab, L., 2014. Bidirectional association between mental health and physical activity in older adults: Whitehall II prospective cohort study. Prev. Med. 66, 74–79.
Storey, J.E., Rowland, J.T., Basic, D., Conforti, D.A., Dickson, H.G., 2004. The Rowland Universal Dementia Assessment Scale (RUDAS): a multicultural cognitive assessment scale. Int. Psychogeriatr. 16 (1), 13–31.
Taraldsen, K., Askim, T., Sletvold, O., et al., 2011. Evaluation of a body-worn sensor system to measure physical activity in older people with impaired function. Phys. Ther. 91 (2), 277–285.

Tasheva, P., Vollenweider, P., Kraege, V., et al., 2020. Association between physical activity levels in the hospital setting and hospital-acquired functional decline in elderly patients. JAMA Netw. Open 3 (1), e1920185.
Taylor, D., 2014. Physical activity is medicine for older adults. Postgrad. Med. J. 90 (1059), 26–32.
Tolea, M.I., Costa, P.T., Terracciano, A., et al., 2010. Sex-specific correlates of walking speed in a wide age-ranged population. J. Gerontol. B Psychol. Sci. Soc. Sci. 65B (2), 174–184.
Treacy, D., Hassett, L., Schurr, K., Chagpar, S., Paul, S.S., Sherrington, C., 2017. Validity of different activity monitors to count steps in an inpatient rehabilitation setting. Phys. Ther. 97 (5), 581–588.
Viosca, E., Martinez, J.L., Almagro, P.L., Gracia, A., Gonzalez, C., 2005. Proposal and validation of a new functional ambulation classification scale for clinical use. Arch. Phys. Med. Rehabil. 86 (6), 1234–1238.
World Medical A, 2013. World Medical Association Declaration of Helsinki: ethical principles for medical research involving human subjects. JAMA 310 (20), 2191–2194.
Zigmond, A.S., Snaith, R.P., 1983. The hospital anxiety and depression scale. Acta Psychiatr. Scand. 67 (6), 361–370.