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 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).

Better physical performance (higher Functional Ambulation Classification, gait speed, and Short Physical Performance Battery score) was associated with lower i-SB measures (OR range: 0.29–0.98). 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). 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 ≤ 0.003) and higher i-PA measures (OR range: 1.60–3.64, p < 0.0005). Being undernourished was associated with lower i-PA measures (OR range: 0.29–0.32, p ≤ 0.004).

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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; Evesen 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 to 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 of 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 were 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/m².

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) (Hudson 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 510, Biospace Co., Ltd., Seoul, South Korea). BIA measured appendicular skeletal muscle mass (ASMM) in kilograms and this measure was adjusted for body size using

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.
height squared (m^2) (ASMH/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., 2015). 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 (Ruchinksas 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: α = 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 ≤ 0.004), and higher non-upright time in all adjusted models (p ≤ 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 < 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
sedentary quintile based on sitting time compared to the very low sedentary quintile (p ≤ 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 higher gait speed and SPPB score were associated with a higher odds of allocation in the active quintiles compared to the very inactive quintile higher gait speed and SPPB score were associated with a higher odds of allocation in the active quintiles compared to the very inactive quintile higher gait speed and SPPB score were associated with a higher odds of allocation in the active quintiles compared to the very inactive quintile higher gait speed and SPPB score were associated with a higher odds of allocation in the active quintiles compared to the very inactive quintile higher gait speed and SPPB score were associated with a higher odds of allocation in the active quintiles compared to the very inactive quintile higher gait speed and SPPB score were associated with a higher odds of allocation in the active quintiles compared to the very inactive quintile higher gait speed and SPPB score were associated with a higher odds of allocation in the active quintiles compared to the very inactive quintile higher gait speed and SPPB score were associated with a higher odds of allocation in the active quintiles compared to the very inactive quintile.

3.4. Functional performance domain

A higher ADL score was associated with lower lying time, lower non-upright time (p ≤ 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 ≤ 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 ≤ 0.002), and lower upright time (p ≤ 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 ≤ 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 (Klunk 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 (Buxmanns 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.

| Morbidity domain | 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                         |
| Comorbidity (CIRS, 0–56 points) | 145 | 1.03 0.98–1.05 0.325 | 0.99 0.95–1.10 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 0.95–1.10 0.892 | 1.08 1.02–1.14 0.006 |
| Cognition/psychology domain |                  |                                |                                |                                    |
| Cognitively impaired (yes/no) | 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) | 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) | 136 | 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          | 136 | 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          | 136 | 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) | 136 | 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          | 136 | 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          | 136 | 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), 0–55 points | 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                         |
| Crude                              | 140 | 1.38 1.11–1.70 0.003 | 0.68 0.55–0.84 <0.0005 | 0.48 0.38–0.66 <0.0005 |
| Model 1                            | 140 | 1.37 1.11–1.70 0.003 | 0.68 0.55–0.84 <0.0005 | 0.48 0.37–0.66 <0.0005 |
| Model 2                            | 140 | 1.39 1.12–1.72 0.003 | 0.68 0.55–0.84 <0.0005 | 0.48 0.37–0.66 <0.0005 |
| Handgrip strength, z-score         | 131 | 1.00 0.74–1.35 0.987 | 0.93 0.68–1.26 0.636 | 0.82 0.61–1.22 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 0.70–1.52 0.813 | 0.86 0.63–1.18 0.357 |
| Gait speed, m/s                    | 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 | Table 3a                          | | 0.23 0.08–0.67 0.007 | 0.07 0.02–0.22 <0.0005 |
| Physical performance (SPPB, 0–12 points) | 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)       | 136 | Proportional odds not met. See results | Table 3a. | | Table 3a. | Table 3a. |
| Model 3                            | 136 | Table 3a. | | | | |
| Nutritional domain                 |                  |                                |                                |                                    |
| Malnutrition, GLIM (yes/no)        | 119 | Proportional odds not met. See results | Table 3a. | | Table 3a. | Table 3a. |

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.

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: α = 0.05/8 = 0.006.
### Table 2b
The associations between determinants and quintiles of instrumented physical activity measures in geriatric rehabilitation inpatients.

| Cognition/psychology domain | Cognitively impaired (yes/no) | History of falls (yes/no) | Delirium (yes/no) | ADLs, 0–6 points | IADLs, 0–8 points | Malnutrition, GLIM (yes/no) |
|-----------------------------|-------------------------------|---------------------------|------------------|----------------|----------------|------------------------|
| Crude                       | 145                           | 0.78                      | 0.53             | 1.45           | 1.51           | 0.38                   |
| Model 1                     | 145                           | 0.81                      | 0.56             | 1.48           | 1.50           | 0.37                   |
| Model 2                     | 145                           | 0.88                      | 0.50             | 1.48           | 1.50           | 0.37                   |

| Morbidity domain | Comorbidity (CIRS), 0–56 points | Functional performance domain | Ambulation status (FAC), 0–5 points |
|------------------|---------------------------------|---------------------------------|----------------------------------|
| Crude            | 145                             | 2.88                            | 1.58                            |
| Model 1          | 145                             | 2.88                            | 1.58                            |
| Model 2          | 145                             | 3.02                            | 1.58                            |

| Cognitively impaired (yes/no) | Depression (HADS), 0–21 points |
|-------------------------------|-------------------------------|
| Crude                         | 105                           |
| Model 1                       | 105                           |
| Model 2                       | 105                           |

| Physical performance domain | Crude | Model 1 | Model 2 |
|-----------------------------|-------|---------|---------|
| Crude                       | 140   | 136     | 136     |
| Model 1                     | 140   | 136     | 136     |
| Model 2                     | 140   | 136     | 136     |

| Functional performance domain | Crude | Model 1 | Model 2 |
|--------------------------------|-------|---------|---------|
| Crude                         | 143   | 143     | 143     |
| Model 1                       | 143   | 143     | 143     |
| Model 2                       | 143   | 143     | 143     |

**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: α = 0.05/8 = 0.006.
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 95% CI p |
| **Gait speed, m/s**        |                       |                  |            |               |                   |
| Crude                     | 28 11.15 1.23-101.73 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 39.39 3.97-387.49 0.002 | 29 7.97 0.82-77.76 0.074 | 27 1.00 (ref) |
| **Sitting time**          |                       |                  |            |               |                   |
| Crude                     | 26 0.70 0.19-2.63 0.597 | 26 0.71 0.17-3.03 0.642 | 26 0.71 0.17-3.07 0.649 | 24 0.21 0.04-1.20 0.080 | 24 0.47 0.11-1.97 0.299 |
| Model 1                   | 24 1.00 (ref)         | 24 0.23 0.04-1.43 0.114 |
| Model 2                   | 24 0.71 (ref)         | |
| **Sarcopenia (yes/no)**   |                       |                  |            |               |                   |
| Crude                     | 20 0.12 0.01-1.14 0.065 | 26 0.70 0.19-2.63 0.597 | 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 0.10 0.01-0.99 0.049 | 24 1.00 (ref)  |
| Model 2                   | 20 0.10 0.01-0.99 0.049 | 24 0.23 0.04-1.43 0.114 |
| **Lying time**            |                       |                  |            |               |                   |
| Crude                     | 20 1.98 0.41-9.59 0.397 | 23 3.38 0.76-14.98 0.109 | 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 0.10 0.01-0.99 0.049 | 24 0.71 (ref)  |
| Model 2                   | 20 0.10 0.01-0.99 0.049 | 24 0.23 0.04-1.43 0.114 |
| **Non-upright time**      |                       |                  |            |               |                   |
| Crude                     | 21 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                   | 21 0.10 0.01-0.99 0.049 | 24 0.71 (ref)  |
| Model 2                   | 21 0.10 0.01-0.99 0.049 | 24 0.23 0.04-1.43 0.114 |
| **History of falls (yes/no)** |                       |                  |            |               |                   |
| Crude                     | 25 0.86 0.16-4.79 0.867 | 25 0.52 0.08-3.37 0.492 | 25 0.54 0.08-3.53 0.521 | 22 1.00 (ref) |
| Model 1                   | 25 0.52 0.08-3.37 0.492 | 25 0.54 0.08-3.53 0.521 |
| Model 2                   | 25 0.52 0.08-3.37 0.492 | 25 0.54 0.08-3.53 0.521 |

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    |
| Ambulation status (FAC), 0-5 points |    |      |        |      |    |      |        |      |    |      |        |      |
| 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 |
| 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 |
| 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 |
| Gait speed, m/s           |    |      |        |      |    |      |        |      |    |      |        |      |
| Crude                     | 27 | 842.33 | 766.61-9255460.51 | 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 | 884.23-13911377.72 | 317.15-4205161.23 | <0.0005 | 29 | 1973.06 | 19.62-198407.27 | 0.001 | 29 | 71.86 | 0.59-8720.25 | 0.081 | 28 | 1.00 | (ref) |
| Model 2                   | 27 | 144272.79 | 1038.08-20051006.31 | 383.22-5799016.01 | <0.0005 | 29 | 2242.69 | 234810.86 | 0.001 | 27 | 76.17 | 0.62-9321.42 | 0.077 | 28 | 1.00 | (ref) |
| Physical performance (SPPB), 0-12 points |    |      |        |      |    |      |        |      |    |      |        |      |
| Crude                     | 28 | 206.84 | 14.12-3029.57 | 7.83-1596.15 | <0.0005 | 29 | 111.82 | 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 | 10.01-2412.23 | <0.0005 | 28 | 155.38 | 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 | 9.55-2324.57 | <0.0005 | 28 | 148.97 | 4.66-1139.21 | 0.002 | 27 | 19.64 | 1.22-315.21 | 0.036 | 29 | 1.00 | (ref) |
| Upright time              |    |      |        |      |    |      |        |      |    |      |        |      |
| Physical performance (SPPB), 0-12 points |    |      |        |      |    |      |        |      |    |      |        |      |
| Crude                     | 27 | 4.55 | 2.17-9.56 | 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 | 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 | 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) |
| Model 1                   | 27 | 1.65 | 1.23-2.21 | 1.20-1.15 | 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 |
| Model 2                   | 27 | 1.64 | 1.23-2.20 | 1.22-2.20 | 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 |
| Sarcopenia, EWGSOF2 (yes/no) |    |      |        |      |    |      |        |      |    |      |        |      |
| Crude                     | 26 | 0.78 | 0.14-4.35 | 0.799 | 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 |
| Model 1                   | 26 | 0.75 | 0.12-4.56 | 0.756 | 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 |
| Model 2                   | 26 | 0.75 | 0.12-4.91 | 0.768 | 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 |
| ADL, 0-6 points           |    |      |        |      |    |      |        |      |    |      |        |      |
| Crude                     | 29 | 2.99 | 1.79-4.99 | 0.18 | 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 |
| Model 1                   | 29 | 3.42 | 1.93-6.05 | 0.006 | 21 | 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 |

(continued on next page)
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 ActiVPA4 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 ActiVPA4 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 ActiVPA4 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 Betiger 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.
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.

Declaration of competing interest

None.

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