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Movement Patterns in Older Adults Recovering From Hip Fracture

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The aim of this study was to quantify physical activity and sedentary behavior in older adults recovering from hip fracture and to identify groups based on movement patterns. In this cross-sectional cohort study, older adults (≥70 years) were included 3 months after surgery for proximal femoral fracture. Patients received an accelerometer for 7 days. Demographics and outcomes related to physical function, mobility, cognitive functions, quality of life, and hip fracture were assessed. In total, 43 patients with sufficient accelerometer wear time were included. Across all groups, participants engaged in very low levels of physical activity, spending an average of 11 hr/day in prolonged sedentary behavior. Based on the extracted components from a principal component analysis, three groups with substantial differences in levels of physical activity and sedentary behavior could be distinguished.

Keywords: geriatric rehabilitation, sedentary behavior, accelerometer

Key Points

- Based on actual movement patterns recorded by accelerometers, three distinct groups of older adults recovering from hip fracture could be distinguished, with distinct levels of physical activity and sedentary behavior.

Hip fractures are an increasingly frequent consequence of falls in older adults and are becoming a significant concern. It is estimated that 30%–60% of older adults who suffer a hip fracture experience permanent limitation to mobility or to their general level of independence (Dyer et al., 2016).

Previous studies suggest that older adults recovering from a hip fracture undertake few physical activities and exhibit sedentary behavior over prolonged daytime periods (Ekegren et al., 2018; Fleig et al., 2016; Resnick et al., 2011; Taraldsen et al., 2013; Zusman et al., 2018, 2019). High levels of sedentary behavior are associated with a reduction in muscle mass and strength (Gianoudis et al., 2015), increased risk of falls (Thibaud et al., 2012), and even mortality (Chau et al., 2013). Reducing sedentary behavior and encouraging regular physical activities can help preserve an acceptable level of mobility and independence among older adults, and is especially important among older adults recovering from a hip fracture, since activity also increases the likelihood of recovery (Talkowski et al., 2009).

The first step to overcoming this problem is a better understanding of physical activity and sedentary behavior. Physical activity refers to any body movement that raises energy expenditure above resting levels and is often categorized by intensity (Caspersen et al., 1985). Sedentary behavior is defined as behavior resulting in energy expenditure ≤1.5 metabolic equivalents (METs) while in a sitting, reclining, or lying posture (Tremblay et al., 2017). Although physical activity and sedentary behavior share some attributes, each should be considered a distinct domain. However, an increase in physical activity does not necessarily result in a reduction of sedentary behavior (Prince et al., 2014). For example, an older adult recovering from hip fracture might receive 30 min of therapy during the morning, but spend the rest of the day sitting. In recent times, the use of wearable activity sensors such as accelerometers have made it possible to obtain a reliable, objective representation of physical activity and sedentary behavior (Hart et al., 2011; Klenk et al., 2019). Nonetheless, it is important to properly assess and interpret accelerometer measurements, an issue that is particularly challenging in the case of sedentary behavior as there are numerous ways, ranging from simple to complex, to assess this behavior (Boerema et al., 2020). Recent literature supports a focus on the pattern of accumulation of sedentary behavior, the main benefit of which is sensitive quantification of (changes in) sedentary behavior (Boerema et al., 2020; Chastin et al., 2015).

A second important step to improve recovery after hip fracture is the identification of subgroups of older adults defined by levels

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of physical activity and sedentary behavior. This is important because it enables us to provide tailored interventions that are likely to be more effective in improving the chance of recovery (White et al., 2020).

Therefore, the aims of this study were (a) to quantify physical activity and sedentary behavior using an accelerometer and (b) to identify groups based on movement patterns and correlate functional and mental characteristics in older adults recovering from hip fracture.

Methods

Design and Population

This study was part of the inception cohort-based study HIP CARE (Hip fractures: Inventorization of Prognostic factors and their Contribution towArds Rehabilitation in older pErsons; NTR NL7491). The goal of the HIPCARE study was to determine functional recovery, quality of life, and health care use during the first year after a hip fracture and was initiated in 2018 (van der Sijp et al., 2021). HIPCARE study participants are older adults (≥70 years) who in most cases were admitted to geriatric rehabilitation facilities in the Netherlands with a proximal femoral fracture. This is a single-center study in which patients are followed from one single hospital, to multiple regional geriatric rehabilitation facilities and home. Patients with high energy trauma or pathological fractures were excluded.

In the current cross-sectional cohort study, between January 2019 and March 2020, a selection of eligible patients of the HIPCARE cohort received an accelerometer for 7 days after an outpatient check-up 3 months after surgery. The goal was to obtain descriptive insights in the activity of the independent mobile patients of the HIPCARE cohort included. Patients were instructed to wear the accelerometer on their waist 24 hr/day for seven consecutive days. For the reliable estimation of movement variables, we only included patients who wore the accelerometer for at least 13 hr for a minimum of 2 days (van Schooten et al., 2015). As the accelerometer could not clearly distinguish between sleeping and sedentary behavior, accelerometer data between 23:00 p.m. and 7:00 a.m. were excluded to avoid misclassification of sedentary behavior as sleep.

Assessments

Baseline characteristics were assessed during admission for surgery and comprised age, sex, and body mass index, as well as general health status using the American Society of Anesthesiologists classification (Parenti et al., 2016). The following assessments were registered during the outpatient check-up 3 months after surgery. Cognition was evaluated using the 6-Item Cognitive Impairment Test (6CIT; range 0–28, lower scores indicate better cognitive functioning; O'Sullivan et al., 2016). Activities of daily living (ADL) functioning was measured using the Katz Index of Independence in ADL (range, 0–6, higher scores indicate better ADL functioning; Katz et al., 1970). Mobility was assessed using The Parker Mobility Score (range, 0–9, higher scores indicate better mobility; Parker & Palmer, 1993), Short Physical Performance Battery Living (SPPB, range, 0–12, higher scores indicate better lower extremity; Guralnik et al., 1994), Functional Ambulation Classification (FAC, ranges from 0: *non-functional walking* to 5: *independent walking outside*; Holden et al., 1984), and Timed Up & Go test (TUG, lower scores indicate better mobility; Podsiadlo & Richardson, 1991). Fear of falling was evaluated using the Falls Efficacy Scale International (FES, range 16–64, higher scores indicate greater fear of falling; Jørstad et al., 2005). Evaluation of hip fracture was assessed using the Harris Hip Score (HHS), which is a disease-specific measure for measuring outcomes after hip arthroplasty and includes the domains pain, function, deformity, and range of motion (range 0–100, higher scores indicate better functioning; Harris, 1969). Quality of life was measured using the Dutch version of EuroQol (EQ-5D-5L) and the Visual Analog Scale of EuroQol (EQ-5D-5L VAS; Group, 1990).

Movement variables were measured using the Dynaport MoveMonitor (Dynaport MoveMonitor, McRoberts BV), which is an accelerometer that records acceleration in a triaxial direction. Based on the measured accelerations, the DynaPort MoveMonitor classifies three postures (lying down, sitting, and standing) and four movements (walking, cycling, climbing stairs, and shuffling). Physical activity is quantified as movement intensity (average body acceleration during a specific activity), which can be subdivided into the activity levels light, moderate, or vigorous, based on METs (Haskell et al., 2007). Movement variables included in this study were mainly derived from a recent review on this topic (Boerema et al., 2020) and are described in further detail in Box 1.

Box 1 Types of Movement Variables

Physical activity variables	
Steps	Total steps per day (mean steps/day)
Light activities	Time spent in light activities below 3 METs (mean hours/day; Haskell et al., 2007)
Moderate activities	Time spent in moderate activities above or equal to 3 METs and below 6 METs (mean hours/day; Haskell et al., 2007)
Vigorous activities	Time spent in vigorous activities above or equal to 6 METs (mean minutes/day; Haskell et al., 2007)
Sedentary behavior variables	
Sedentary behavior	A minimal duration of 1 min in consecutive lying or sitting (mean hours/day)
Sedentary bouts ≥60 min per day	Time spent in sedentary bouts (uninterrupted periods of sitting and lying down) equal or above 60 min. Provides an indication of time spent in prolonged sedentary behavior (median number of bouts/2 days)
Half-life bout duration (W50%)	A weighted median bout duration in which the bout duration above and below half of all sedentary time is accumulated. Provides a good indication of centrality given the distribution of bout length (minutes; Chastin & Granat, 2010; Chastin et al., 2015)
Alpha	A scaling parameter that provides an indication of the distribution of sedentary bouts. A lower alpha indicates that sedentary time is largely accumulated in long bouts (unit-less variable; Chastin & Granat, 2010)

Statistical Analysis

Principal Component Analysis

In preparation for the cluster analyses, a principal component analysis (PCA) was performed to reduce the number of dimensions of the included movement variables described in Box 1 while maintaining maximum information (Von Luxburg, 2010). Movement variables were standardized using *z* scores. Prior to analysis the Kaiser–Meyer–Olkin measure was used to assess the suitability of the overall PCA model. Individual movement variables with at least one correlation coefficient greater than .3 and a (Kaiser–Meyer–Olkin) measure greater than .6 were included in the PCA (Statistics, 2015). Components with eigenvalues ≥1 were used for extraction. A Pearson's product–moment correlation was run to assess the relationship between the extracted components.

Cluster Analysis

"Components" extracted from the PCA were used to identify different movement pattern groups using *k*-means clustering. Due to the exploratory nature of the present study, the optimal number of clusters was determined using Silhouette analysis (Rousseeuw, 1987).

Normality of data was tested using the Shapiro–Wilk test. Differences between patient characteristics and movement variables were evaluated using one-way analysis of variance for normally distributed data and are presented as means with *SD*s (±). The Kruskal–Wallis test was used for nonnormally distributed data and is presented as medians with interquartile range. Baseline data and assessments outcomes 3 months after surgery were compared for all patients included in the HIPCARE study, and for groups identified through cluster analysis. Data were analyzed with SPSS (version 25.0).

Physical activity levels over 1 day were visualized in multiple series line graphs (Microsoft Excel) for individual clusters of each group's mean percentage activity for each 60-min period.

Results

Fifty-six eligible patients agreed to additional data collection 3 months after surgery, which was 27% of patients from the original HIPCARE study between January 2019 and March 2020. Forty-three patients had sufficient accelerometer wear time of 2 days or more and were included in the analysis. Patient's characteristics are described in detail in Table 1. The median (interquartile range) age of patients was 81 (interquartile range 75–89), and 29 patients (67%) were female. Regarding patient's fractures, 22 (51%) had a femoral neck fracture, 19 (44%) had a pertrochanteric femoral fracture, and two (6%) had a subtrochanteric fracture. Surgical treatments included osteosynthesis/internal fixation (29 patients, 67%) or a prosthesis/arthroplasty treatment (14 patients, 33%). Except for age (75 vs. 81, $p \leq .01$) and The Parker Mobility (5.8 vs. 5.7, $p = .02$), there were no significant differences at baseline between patients included in the current study and patients in the overall HIPCARE study regarding demographics (sex, $p = .34$; body mass index, $p = .59$; American Society of Anesthesiologists classification, $p = .82$; postoperative discharge location, $p = .14$) and assessments 3 months after surgery regarding mobility (FAC, $p = .09$; TUG, $p = .21$), fear of falling (FES, $p = .90$), physical function (KATZ-ADL, $p = .23$; SPPB, $p = .83$), hip fracture (HHS, $p = .45$), cognitive function (6CIT, $p = .09$), or quality of life (EQ-5D-5L, $p = .43$; EQ-5D-5L VAS, $p = .23$).

Movement Patterns

PCA revealed two components that had eigenvalues ≥ 1, which together explained 71% of the total variance. The Kaiser–Meyer–Olkin for the complete PCA model was 0.74, indicating that the model was middling (Kaiser, 1974). The first, sedentary behavior component (accounting for 58% of variance) mostly included movement variables related to sedentary behavior, with strong positive loadings of mean time spent in sedentary behavior, mean time spent in sedentary bouts ≥ 60 min per day, half-life bout duration (W50%), mean time spent in light activities, and negative loadings of mean steps per day, mean time spent in moderate activities, and alpha. Higher values in the sedentary behavior component indicate more sedentary behavior. The second, physical activity component (13% variance) included movement variables related to physical activity with strong positive loadings of mean steps per day, mean time spent in moderate activities, mean time spent in vigorous activities, and negative loading of mean time

Table 1 Patient Characteristics (Mean±, Median IQR)

	Baseline	3 months after surgery
Age (y)	81 (75–88)	—
Sex, female (%)	29 (67%)	—
BMI (kg/m^2)	24.0 ± 3.0	—
Comorbidity (ASA)	2 (2–3)	—
Time since fracture (days)		92.2 ± 6.8
Postoperative discharge location		—
Home	9 (21%)	—
Geriatric rehabilitation	34 (79%)	—
Length of stay rehabilitation (days)	48 (42–66)	—
Current level of received care		—
Independent		41 (96%)
Unknown		2 (4%)

Note. BMI = body mass index; ASA = American Society of Anesthesiologists classification; IQR = interquartile range.

spent in sedentary bouts ≥60 min/day. Higher values on the physical activity component indicate more active behavior. Component loadings are described in Supplementary Material (available online). Three groups could be identified through *k*-means clustering, and the mean silhouette score for all clusters was 0.54. A scatterplot of the clusters and components can be found in Figure 1. Movement variables per group are presented in Table 2 and visualized in Figure 2.

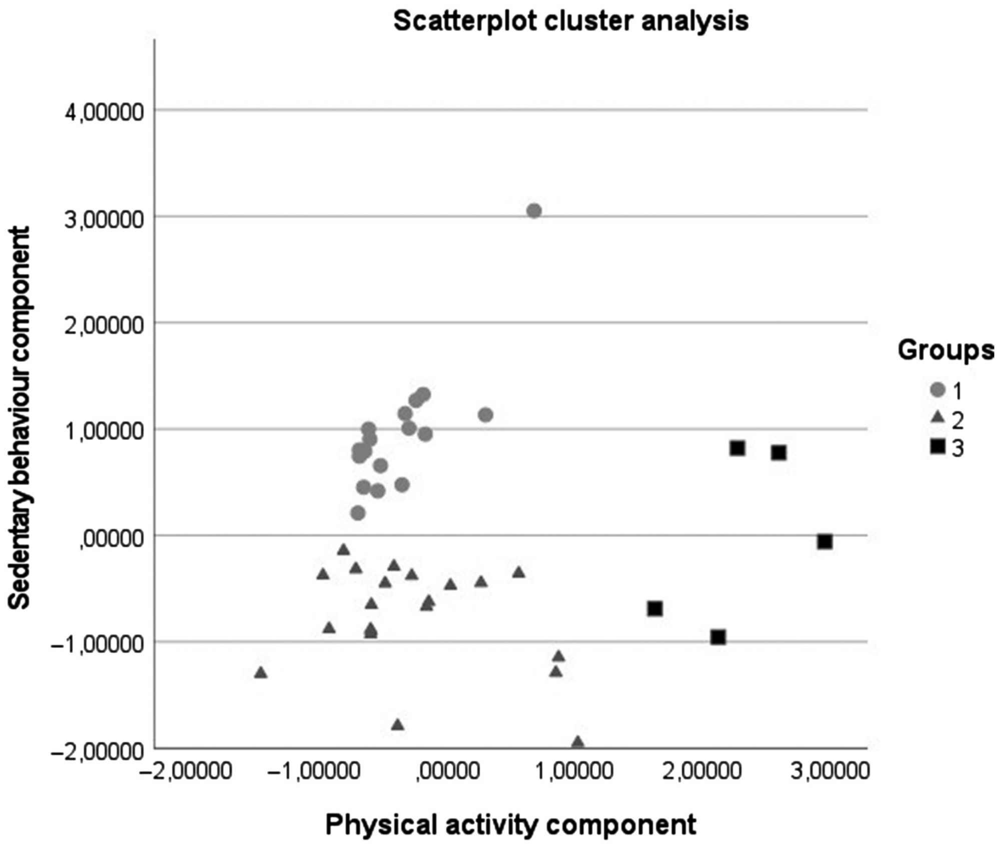

Figure 1 — Scatterplot cluster analysis. The graph presents the groups in relation to the two components. The sedentary behavior component included movement variables related to sedentary behavior, for example, mean time spent in sedentary behavior, mean time spent in sedentary bouts ≥60 min per day, half-life bout duration (W50%), alpha, and mean time spent in light activates. The physical activity component included variables related to physical activity: mean steps per day, mean time spent in moderate activities, and mean time spent in vigorous activities.

Table 2 Movement Variables per Group (Mean ±, Median Interquartile Range)

	Group 1 (n = 17)	Group 2 (n = 21)	Group 3 (n = 5)	Total	p
Steps	232.6 (32.6–623.1)	1,786.2 (920–4,319.9)	7,392.5 (4,242.2–7,392.5)	1,235.9 (387.4–3,034.3)	<.01*,§
Sedentary behavior	13.3 ± 0.7	10.5 ± 1.3	10.6 ± 1.5	11.6 ± 1.8	<.01§,†
Light activities	14.3 ± 0.7	12.9 ± 1.1	12.7 ± 0.8	13.4 ± 1.2	<.01*,§
Moderate activities	0.2 (0.1–0.4)	0.9 (0.4–1.4)	1.9 (1.4–2.1)	0.5 (0.2–1.2)	<.01*,§
Vigorous activities	0.3 (0.2–0.6)	0.4 (0.2–1.0)	3.8 (2.9–4.6)	0.4 (0.2–1.0)	<.01§,†
Sedentary bouts ≥60 min/day	24.0 (15.0–26.5)	8.0 (3.0–14.0)	4.0 (1.5–12.5)	13.0 (5.0–23.0)	<.01*,§
Half-life bout duration (W50%)	124.0 (92.5–162,5)	36.0 (30.5–60.5)	30.0 (22.5–42.5)	56.0 (32.0–104.0)	<.01*,§
Alpha	1.3 ± 0.1	1.5 ± 0.1	1.5 ± 0.0	1.4 ± 0.1	<.01*,§
Worn time	14.6 (14.1–13.8)	13.9 (13.3–14.6)	14.7 (14.1–15.2)	14.5 (13.7–13.8)	.06
Sedentary behavior component	1.0 ± 0.4	–0.8 ± 0.5	–0.0 ± 0.8	0.0 ± 1.0	<.01*,§,†
Physical activity component	–0.4 ± 0.4	–0.3 ± 0.6	2.3 ± 0.5	0.0 ± 1.0	<.01*,§,†

Note. Higher values in the sedentary behavior component indicate more sedentary behavior and higher values on the physical activity component indicate more active behavior.

*Statistically significant differences between Groups 1 and 2. §Statistically significant differences between Groups 1 and 3. †Statistically significant differences between Groups 2 and 3.

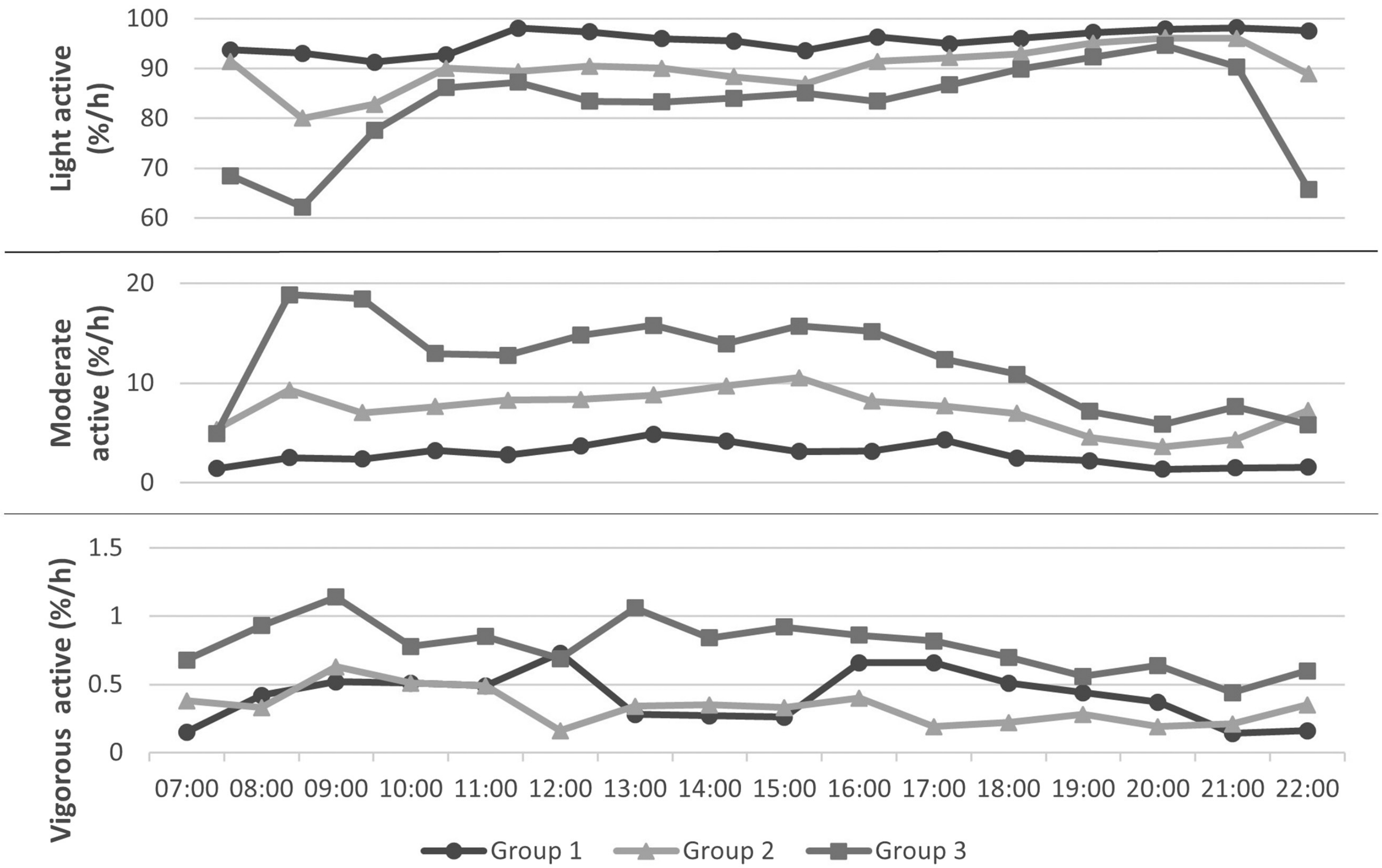

Figure 2 — Physical activity distributed over day time and visualized per group. Physical activity levels for individual clusters mean percentage activity for each 60-min period.

Group 1 ($n = 17$, 39.5% of all included patients) was characterized by a very low step count, a very low level of physical activity, and a very high level of sedentary behavior that was largely accumulated (long sedentary bouts). Group 2 ($n = 21$, 48.8%) was characterized by a moderate step count, a low level of physical activity, and a high level of sedentary behavior that was more evenly distributed across moderate sedentary bouts. Group 3 ($n = 5$, 11.6%) was characterized by a high step count, a moderate level of physical activity, and a moderate level of sedentary behavior that was relatively evenly distributed across shorter sedentary bouts.

Assessments

At baseline, there were no significant differences between the groups regarding mobility (The Parker Mobility, $p = .22$), physical function (KATZ-ADL, $p = .29$), quality of life (EQ-5D-5L, $p = .79$; EQ-5D-5L, VAS, $p = .26$), or cognitive function (6CIT, $p = .71$). Due to the assessment on the day of the hip fracture the SPPB, TUG, FES, HHS, and FAC could not be assessed at baseline. While the HHS differed significantly between all groups, there were no significant differences between the groups on specific items such as pain (HHS, domain pain; $p = .06$) or the locomotion functions of the hip joint (HHS, domain locomotion; $p = .194$) that could independently affect physical function. Furthermore, there was a small significant difference between all groups regarding type of surgical treatment ($p = .03$). There was no significant difference regarding postoperative discharge location ($p = .07$).

Assessments by group during the outpatient check-up 3 months after surgery are described in Table 3. Between all groups, there were no differences regarding physical function (KATZ-ADL, $p = .19$) and cognitive function (6CIT, $p = .95$). Except for physical function (SPPB, $p = .272$), mobility (FAC, $p = .60$), and quality of life (EQ-5D-5L, $p = .28$) all assessments were statistically significant different between Groups 1 and 2. Between Groups 1 and 3, all assessment were statistically different. Groups 2 and 3 differed on mobility (FAC, $p = .27$; TUG, $p = .15$; TPB, $p = .79$), fear of falling (FES, $p = .37$), and quality of life (EQ-5D-5L, $p = .26$; EQ-5D-5L, VAS, $p = .76$).

Discussion

Principal Findings

In this study of older adults recovering from hip fracture 3 months after surgery, we identified three groups as defined by divergent levels of physical activity and sedentary behavior. Our two main findings were: (a) across all groups older adults recovering from a hip fracture engaged in very low levels of physical activity and spent an average of 11 hr/day in prolonged sedentary behavior and (b) based on movement patterns, we identified three distinct groups with substantial differences in levels of physical activity and sedentary behavior. Finally, no relationship was found between patient characteristics at baseline and movement patterns 3 months after surgery.

Table 3 Patient Characteristics and Assessments per Group (Mean±, Median IQR)

	Group 1 ($n = 17$)	Group 2 ($n = 21$)	Group 3 ($n = 5$)	Total	p
Characteristics					
Age	81 (73–90)	80 (73–90)	76 (73–80)	81 (75–88)	.43
Sex, female (%)	12 (70%)	14 (67%)	3 (60%)	29 (67%)	.90
Surgical treatment					.03†
Osteosynthesis/internal	11 (65%)	17 (81%)	1 (20%)	29	—
Prosthesis/arthroplasty	6 (35%)	4 (19%)	4 (20%)	14	—
Postoperative discharge location					.07
Home	3 (18%)	3 (14%)	3 (60%)	9	—
Geriatric rehabilitation	14 (82%)	18 (86%)	2 (40%)	34	—
Physical function					
KATZ-ADL	1.0 (0.0–2.0)	0.0 (0.0–1.5)	0.0 (0.0–0.0)	0.0 (0.0–2.0)	.193
SPPB	5.4 ± 2.4	6.8 ± 3.0	10.8 ± 0.8	6.8 ± 3.1	<.01§,†
Hip fracture					
HHS	57.0 ± 12.3	66.7 ± 13.4	91.8 ± 5.8	66.4 ± 16.2	<.01*,§,†
Mobility					
FAC	4.0 (3.0–4.0)	4.0 (4.0–4.5)	5.0 (4.0–5.0)	4.0 (4.0–4.0)	<.01§
TUG	31.9 (23.1–35.1)	18.2 (13.1–23.1)	10.0 (8.5–11.2)	20.4 (12.2–35.0)	<.01*,§
TPM	4.0 (2.5–6.0)	6.0 (6.0–6.5)	9.0 (6.5–9.0)	6.0 (4.0–6.0)	<.01*,§
Fear of falling					
FES	12.0 (9.5–15.0)	9.0 (7.0–11.7)	7.0 (7.0–7.5)	9.5 (7.0–12.3)	<.01*,§
Cognitive function					
6CIT	2.0 (0.0–5.5)	2.0 (0.0–3.5)	2.0 (0.0–8.5)	2.0 (0.0–4.2)	.948
Quality of life					
EQ-5D-5L	0.6 (0.4–0.7)	0.7 (0.6–0.8)	0.9 (0.8–0.9)	0.7 (0.6–0.8)	<.01§
EQ-5D-5L VAS	60 (50.0–72.5)	75.0 (67.5–80.0)	80.0 (70.0–80.0)	70.0 (60.0–80.0)	.02*,§

Note. KATZ-ADL = the Katz Index of Independence in Activities of Daily Living; SPPB = Short Physical Performance Battery Living; HHS = Harris Hip Score; FAC = Functional Ambulation Classification; TUG = Timed Up & Go test; TPM = The Parker Mobility Score; FES = Falls Efficacy Scale International; 6CIT = the 6-Item Cognitive Impairment Test; EQ-5D-5l = Dutch version of EuroQol; EQ-5D-5L VAS = Visual Analog Scale of EuroQol; IQR = interquartile range.
*Statistically significant differences between Groups 1 and 2. §Statistically significant differences between Groups 1 and 3. †Statistically significant differences between Groups 2 and 3.

Comparison With Previous Studies

A unique aspect of our study was the evaluation of the pattern of sedentary behavior. Our results suggest a clear difference between the three groups in terms of the pattern of sedentary behavior, with Group 1 showing a significantly higher proportion of long sedentary bouts. While previous studies have indicated that older adults recovering from a hip fracture tend to show very little physical activity and devote a significant amount of time to sedentary behavior (Fleig et al., 2016; Zusman et al., 2018, 2019), none of these studies evaluated the pattern of sedentary behavior. By interrupting prolonged sedentary periods, associated risks can be reduced, since prolonged sedentary behavior poses a health risk independent of total sedentary time (Dunstan et al., 2012; Duvivier et al., 2017; Sardinha et al., 2015). Evaluating patterns of sedentary behavior may provide a better understanding of the effects of interventions designed to disrupt prolonged sedentary periods (Chastin et al., 2015). Furthermore during the early phase of rehabilitation planned and individually delivered comprehensive geriatric care in a geriatric hospital ward with particular focus on mobilization could improve physical activity and reduce sedentary behavior (Taraldsen et al., 2013). However, the extent to which a reduction in sedentary behavior reduces certain health risks remains to be determined (Lewis et al., 2016).

Based on accelerometery, we identified three groups of patients that differed regarding sedentary behavior and the intensity of activity. When we compared the clinically assessed data associated with these three groups, a clear pattern emerged: a low intensity of physical activity in combination with sedentary behavior correlated with lower scores for mobility, physical function, hip fracture, and quality of life, as well as a greater fear of falling. However, no significant differences were found between Group 2 and Group 3 on assessments related to mobility. This may indicate that patients in Group 2 are functionally able to increase physical activity and reduce sedentary behavior, but did not display these movement patterns. Another potential explanation may be that current assessments related to mobility are unable to account for the difference in physical activity or sedentary behavior between Groups 2 and 3. Accelerometery-based observation of objective activity intensity and sedentary behavior can, thus provide early indications of a changing health status, allowing timely tailored interventions (White et al., 2020).

While the number of patients per group varied widely, Group 3 was considerably smaller compared with Groups 1 and 2. This distribution may be attributable to the cluster technique used, which does not allow for the size of clusters. Earlier studies of physical activity and sedentary behavior variables that used similar clustering techniques also reported uneven distributions of patients per group, these studies also found that the smallest group consisted of the most physically active and least sedentary patients (Mesquita et al., 2017; Wondergem et al., 2019).

We found no relation between patient characteristics at baseline and factors including pain, locomotion functions of the hip, and movement patterns. However, we did observe a significant difference in terms of type of surgical treatment. In Group 3, relatively more patients were treated by prosthesis/arthroplasty compared with osteosynthesis/internal fixation. Previous studies reported that patients after hip fracture who were treated by osteosynthesis/internal fixation had a higher reoperation rate, higher long-term mortality, and lower quality of life after 4 months, compared with patients treated by prosthesis/arthroplasty (Gjertsen et al., 2008; Moerman et al., 2016). Furthermore, although we found no significant difference in postoperative discharge location, we observed that the number of patients discharged to geriatric rehabilitation in Group 3 was relatively lower than in Groups 1 and 2. This may indicate that patients in Group 3 had better health status postoperatively and did not need geriatric rehabilitation. As the number of patients in Group 3 is small, it is not possible at this time to draw a clear conclusion as to whether the difference in surgical treatment and discharge location has an effect on the movement patterns found. Finally, the differences found could potentially be explained by "confounding by indication": the choice of surgical procedure is not random but related to the complexity of the fracture injury.

Nevertheless, other factors besides physical components likely impact the intensity of physical activity and sedentary behavior. Previous qualitative research identified several barriers that can constrain engagement in physical activities and encourage sedentary behavior, such as fear of falling, lack of motivation, fatigue, lack of time, or lack of knowledge (Gorman et al., 2012; Moraes et al., 2020; Nicholson et al., 2013; Salmon et al., 2003). Theory-based behavior change techniques, in combination with a stepwise approach that begins by targeting prolonged sedentary bouts, might help lower these barriers (Dogra et al., 2022; Prince et al., 2014).

In our study, "light activity" was defined as time spent in all activities below 3 METs. This meant that "sedentary behavior" also included all light activities. Other studies that have examined light activities in older adults recovering from a hip fracture chose other cut off points for levels of activity, which resulted in the exclusion of activities related to sedentary behavior (Fleig et al., 2016; Zusman et al., 2019). This difference in classification method may have impacted our results, as the amount of light activity in our study was significantly higher than in comparable studies.

Finally, of the two components from the PCA, the sedentary behavior component consisted almost entirely of variables related to sedentary behavior, while the physical activity component consisted of physical activity variables. This might indicate that physical activity and sedentary behavior are not interdependent, suggesting that both can be influenced independently to achieve improvements in health status (Gardner et al., 2016; Prince et al., 2014).

Strengths and Limitations

A strength of this study was the use of an accelerometer and a strict data inclusion protocol in which we only used data from patients who wore the accelerometer for at least 13 hr for a minimum of 2 days. This provided an objective, accurate, and reliable assessment of physical activity and sedentary behavior. Another strength was the comprehensive description of all groups in terms of physical activity, sedentary behavior, and other assessments. Through PCA and *k*-means clustering, we obtained a particularly good picture of a subgroup of older physically very inactive adults who therefore might have a higher risk of further functional decline. While we were able to objectively assess sedentary behavior using an accelerometer, our protocol did not allow us to distinguish between sedentary behavior in a sleeping or awake state. Although exclusion of data between 23:00 p.m. and 7:00 a.m. likely included the bulk of sleep data, our ability to accurately distinguish sedentary behavior from sleep was nevertheless limited and may have influenced our results. This approach was chosen because including night sleep as "sedentary behavior" would have diluted relative activity and thus, reduced sensitivity to discriminate groups based on activity. Furthermore, during this study, we did not record whether patients also received physical therapy during the accelerometer wearing period. This may have some effect on the results found, leading to a slight overestimation of the physical activity measures. Another limitation was the small sample size, partly because we had a strict inclusion protocol for the sensor data. We did not perform a sample size calculation prior to the study, as the current research question was secondary in the HIPCARE study. However, this did limit the inclusion of movement variables in the PCA. Finally, no significant differences were found at baseline between the current participants and those included in the HIPCARE study.

Conclusions

Our primary conclusion is that older adults recovering from a hip fracture indeed engage in very low levels of physical activity and spend prolonged periods of time in sedentary behavior. Second, based on actual movement patterns recorded by a wearable accelerometer, three distinct groups of older adults recovering from a hip fracture could be distinguished, each with distinct levels of intensity of physical activity and temporal sedentary behavior. Third, within these three groups, a clear association was found between a low intensity of physical activity in combination with long sedentary periods and lower scores for mobility, physical function, hip fracture and quality of life, as well as a greater fear of falling. Finally, we argue that evaluation of the pattern of sedentary behavior is essential when assessing the effectiveness of interventions aimed at reducing sedentary behavior.

Future research should focus on determining the level of reduction in sedentary behavior required to lower health risks. Classification of sedentary behavior should exclude sleep periods and light activities. Furthermore, multidisciplinary rehabilitation programs need to place greater emphasis on the contribution of sedentary behavior by not only promoting physical activity, but by also including interventions designed to reduce sedentary behavior. Those interventions should be tailored and include theory-based behavior change techniques, in combination with a stepwise approach that starts by targeting prolonged sedentary bouts.

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