Journal of the American Heart Association

ORIGINAL RESEARCH

Rapid Improvements in Physical Activity and Sedentary Behavior in Patients With Acute Myocardial Infarction Immediately Following Hospital Discharge

Bram M. A. van Bakel, MD; Iris A. de Koning, MSc; Esmée A. Bakker, PhD; Gheorghe A. M. Pop, MD, PhD; Etienne Cramer, MD, PhD; Robert-Jan M. van Geuns, MD, PhD; Dick H. J. Thijssen, PhD; Thijs M. H. Eijsvogels, PhD

BACKGROUND: Little is known about changes in physical activity (PA) and sedentary behavior (SB) patterns in the acute phase of a myocardial infarction (MI). We objectively assessed PA and SB during hospitalization and the first week after discharge.

METHODS AND RESULTS: Consecutively admitted patients hospitalized with an MI were approached to participate in this prospective cohort study. SB, light-intensity PA, and moderate-vigorous intensity PA were objectively assessed for 24 h/d during hospitalization and up to 7 days after discharge in 165 patients. Changes in PA and SB from the hospital to home phase were evaluated using mixed-model analyses, and outcomes were stratified for predefined subgroups based on patient characteristics. Patients (78% men) were aged 65±10 years and diagnosed with ST-segment–elevation MI (50%) or non–ST-segment–elevation MI (50%). Sedentary time was high during hospitalization (12.6 [95% CI, 11.8–13.7] h/d) but substantially decreased following transition to the home environment (−1.8 [95% CI, −2.4 to −1.3] h/d). Furthermore, the number of prolonged sedentary bouts (≥60 minutes) decreased between hospital and home (−1.6 [95% CI, −2.0 to −1.2] bouts/day). Light-intensity PA (1.1 [95% CI, 0.8–1.6] h/d) and moderate-vigorous intensity PA (0.2 [95% CI, 0.1–0.3] h/d) were low during hospitalization but significantly increased following transition to the home environment (light-intensity PA: 1.8 [95% CI, 1.4–2.3] h/d; moderate-vigorous intensity PA: 0.4 [95% CI, 0.3–0.5] h/d; both $P<0.001$). Improvements in PA and SB were similar across groups, except for patients who underwent coronary artery bypass grafting and who did not improve their PA patterns after discharge.

CONCLUSIONS: Patients with MI demonstrate high levels of SB and low PA volumes during hospitalization, which immediately improved following discharge at the patient's home environment.

REGISTRATION: URL: trialsearch.who.int/; Unique identifier: NTR7646.

Key Words: cardiac rehabilitation ■ coronary artery disease ■ hospitalization ■ myocardial infarction ■ physical activity ■ recovery ■ sedentary lifestyle

Survival rates following myocardial infarction (MI) significantly improved over the past decades because of developments in diagnostic tools, pharmacological improvements, and increasing use of early percutaneous coronary intervention strategies,[1] with a 27% reduction in deaths expected by 2030.[2] Another important factor contributing to improvements in post-MI survival relates to the (early) enrollment in exercise-based cardiac rehabilitation (CR).[3] Nowadays, patients generally have to wait ≈40 days for CR initiation,[4] which may

Correspondence to: Thijs M. H. Eijsvogels, PhD, Department of Physiology, Radboud University Medical Center, Radboud Institute for Health Sciences, PO Box 9101, 6500 HB, Nijmegen, the Netherlands. Email: thijs.eijsvogels@radboudumc.nl

This article was sent to Pamela N. Peterson, MD, Deputy Editor, for review by expert referees, editorial decision, and final disposition.

Supplemental Material is available at https://www.ahajournals.org/doi/suppl/10.1161/JAHA.122.028700

For Sources of Funding and Disclosures, see page 10.

JAHA is available at: www.ahajournals.org/journal/jaha

CLINICAL PERSPECTIVE

What Is New?

- Patients hospitalized with myocardial infarction primarily spent their time sedentary, with little engagement in physical activity (PA) during hospitalization.
- Immediately on discharge, sedentary behavior substantially decreased in favor of a 2- to 3-fold increase in habitual PA levels.
- The home environment is associated with more engagement in PA and limiting time spent sedentary after myocardial infarction, except for patients who underwent coronary artery bypass grafting.

What Are the Clinical Implications?

- High levels of physical inactivity among patients with cardiovascular disease underline the need for novel strategies to target sedentary behavior during hospitalization.
- The abrupt decrease in sedentary behavior immediately after discharge suggests that living environment plays a crucial role in PA patterns, which may influence PA counseling in the early phase after myocardial infarction.

Nonstandard Abbreviations and Acronyms

CR	cardiac rehabilitation
LIPA	light-intensity physical activity
MVPA	moderate-vigorous intensity physical activity
PA	physical activity
SB	sedentary behavior

negatively impact post-MI prognosis and quality of life.[5] It is shown that time from index event to CR enrollment can be reduced by home-based CR, because it may be more practical and feasible.[6] Furthermore, early CR initiation might improve overall CR participation.[7] Currently, little is known about physical activity (PA) patterns during the gap between MI hospitalization and start of CR.

Emerging evidence indicates that PA and sedentary behavior (SB; defined as any low-intensity [energy expenditure of ≤1.5 metabolic equivalent task] behavior while awake in a seated or reclined posture[8]) play a pivotal role in recovery after MI.[9–11] Low levels of PA in combination with high levels of SB are associated with an increased risk for (recurrent) cardiovascular disease events and mortality,[12–15] underlining the need for reactivation of patients after MI. A daily sedentary time >9.5 h/d is associated with increased risk of cardiovascular morbidity and mortality,[2,12,13] independent of traditional risk factors. Despite this strong link with cardiovascular health,[16] changes in PA patterns during the acute phase after MI are largely unknown. Evidence exists that some patients experience fear of exercising after an MI and, if unable to cope with their fear, potentially develop kinesiophobia.[17] A recent study revealed that SB is highly prevalent among MI survivors during the first month after discharge, with only minor changes over time.[18] It is, however, unknown how PA and SB patterns change between hospitalization and the first week after discharge, whereas this information may be helpful for PA counseling during hospitalization and facilitates PA prescriptions for a timely return to activities of daily living directly after discharge.

We evaluated changes in objectively assessed PA and SB from hospitalization to the first week after discharge and performed stratified analyses to identify whether potential changes in PA patterns were different across subgroups. We hypothesized that PA patterns improve following the transition from the hospital to the home environment, with a decrease in time spent sedentary and increases in (light-intensity) PA. To the best of our knowledge, this is the first study objectively assessing SB and PA in patients with MI during both hospitalization and the acute phase after discharge. Insight into factors associated with changes in physical (in)activity could contribute to the development of personalized secondary prevention strategies in the home environment, to bridge the gap until the start of CR.

METHODS

Study Design and Population

We invited hospitalized patients diagnosed with an MI to participate in this prospective cohort study to objectively assess their PA patterns (ie, SB, light-intensity PA [LIPA], and moderate-vigorous intensity PA [MVPA]) during hospitalization and the first week after discharge (≈4 weeks before the start of CR). Acute MI diagnosis was defined according to the fourth universal definition of MI.[19] Consecutively admitted patients hospitalized at the Cardiology Ward of the Radboud University Medical Center (Nijmegen, the Netherlands), aged >18 years and not wheelchair bound, were approached to participate within 7 days after admission. Patients were included between January 30, 2019, and September 16, 2021. Because of the COVID-19 pandemic, inclusion was temporarily suspended from March 17, 2020, to July 14, 2020. The study conforms to the ethical guidelines of the 1975 Declaration of Helsinki and was approved by the local medical ethics committee of the Radboud University Medical Center (reference 2018-4537). All participants provided written informed consent. This study was registered in the Netherlands Trial Register (number NTR7646). Original individual data are available upon reasonable request and can be obtained from the corresponding author.

Measurements

PA and SB patterns were objectively assessed using a validated accelerometer (ActivPAL3 micro; PAL Technologies Ltd, Glasgow, UK).[20] The ActivPAL is a small device (25×45×75 mm), attached to the patient's thigh using hypoallergenic tape. The ActivPAL was sealed with a nitrile sleeve and transparent tape for waterproof protection to allow for continuous monitoring. Patients were instructed to wear the ActivPAL 24 h/d during hospitalization up to 7 days after discharge. Participants completed a sleep diary during the measurement period. After this measurement, the ActivPAL was returned to our research institute by mail. The ActivPAL combines a triaxial accelerometer with an inclinometer, which accurately distinguishes between sitting, standing, and walking.[20]

Raw data were analyzed by a modified version of the script of Winkler et al.[21] In case the sleep diary was missing or incomplete, wake and sleep times were interrogated by the ActivPAL analysis software. Valid wear days were defined as minimum 10 hours awake and at least 1 hour of sleep. Total sedentary time was expressed in hours per day (continuous variable), and accumulation of sedentary time was examined by calculating the number of sedentary bouts, categorized in bouts of (1) <15 minutes; (2) ≥15 and <30 minutes; (3) ≥30 and <60 minutes; and (4) ≥60 minutes. In addition, the daily sedentary time was dichotomized, indicating whether each participant was above or below the upper limit of normal (ie, 9.5 h/d[13]). This cutoff value is based on findings from the general population (middle-aged and older adults), in which a sedentary time ≥9.5 h/d was associated with a higher all-cause mortality risk.[13] Activities were categorized as LIPA (metabolic equivalent task score <3) or MVPA (metabolic equivalent task score ≥3) and expressed in hours per day. We reported sedentary time, LIPA, and MVPA for each day separately during hospitalization and after discharge. Only days with observation in >5% of the total cohort were included for analysis. We calculated the average sedentary time, LIPA, MVPA, and sleep duration during hospitalization phase and during the postdischarge phase, based on available valid days.

Patient characteristics (eg, age, sex, medical history, and index diagnosis), laboratory results, and treatment information were derived from the electronic patient file on hospital admission. All participants received an online questionnaire at 7 days after discharge. The questionnaire inquired about cardiac anxiety, using a validated 18-item questionnaire focusing on heart-related anxiety, which is the fear of cardiac-related stimuli and sensations attributable to perceived negative consequences.[22,23] Each item is rated on a 5-point Likert scale, ranging from never to always. The previously validated total test score is calculated by summing all responses to individual items and dividing the sum by 18, resulting in a score that ranges from 0 to 4, in which a higher score indicates greater cardiac anxiety.[22,23]

Statistical Analysis

Data were reported as number (percentage) for categorical variables, mean±SD for normally distributed continuous variables, and median (interquartile range) for nonnormally distributed continuous variables. Normality of distribution was checked visually and using the Shapiro-Wilk test. The number of missing values was specified, and percentages were calculated on the number of nonmissing observations.

Linear mixed-model analyses were performed to assess day-to-day changes in SB and PA patterns using random intercepts with the dependent variable (sedentary time, sleep duration, LIPA, and MVPA) and a continuous time variable ranging from −4 (days before discharge) to 7 (days after discharge). Because missing data were more often present at days during the hospitalization phase and at the end of the home phase, we incorporated missing data patterns as fixed effects into our mixed model analysis to control for the effects of missingness on outcomes.[24] We used backward selection, removing all terms with P>0.1 from our model. The P values in the final linear mixed-model analysis are from the Wald tests. Separately, we assessed day-to-day changes within hospitalization (ranging from day 4 to day 1 before discharge) and after discharge (ranging from day 1 to 7 after discharge), in 2 additional linear mixed models. To assess changes in SB and PA from hospitalization to the home environment, we performed linear mixed-model analyses using random intercepts with time as categorical variable (hospitalization versus home), with sedentary time, sleep duration, LIPA, or MVPA as the dependent variable. In addition, we performed stratified analyses and interaction tests to assess whether changes in SB and PA following the hospital to home transition were different for women versus men; older (aged ≥75 years) versus younger (aged <75 years) patients; patients who underwent coronary artery bypass grafting (CABG) versus percutaneous coronary intervention or conservative treatment; patients with ST-segment–elevation MI versus non–ST-segment–elevation MI; and patients with high levels of cardiac anxiety (cardiac anxiety score ≥2 versus <2). Subgroups were based on findings of previous research indicating potential association of these patient characteristics on SB and/or PA.[25,26] In sensitivity analyses, we reanalyzed the data after excluding patients who only had valid days available in the home environment, and we performed additional stratified analyses to assess whether changes in SB and PA were impacted by the timing of inclusion (pre–COVID-19 versus post–COVID-19 pandemic). All statistical tests were 2 sided, and significance was set at $P<0.05$. All statistical analyses were performed with IBM SPSS Statistics 25 (IBM Corp, Armonk, NY).

RESULTS

Study Population

In total, 200 patients were included in this study (participation rate, 79%), of which 165 (83%) patients were available for data analysis (Figure 1). Participants were aged 65±10 years, mostly men (78%), and diagnosed with either ST-segment–elevation MI (50%) or non–ST-segment–elevation MI (50%). Patients primarily underwent percutaneous coronary intervention (78%) during hospitalization. Post-MI peak cardiac biomarker concentrations were 968 (337–3454) ng/L for high-sensitivity cardiac troponin T and 525 (192–1318) U/L for creatine kinase. Median duration of hospitalization was 4 (3–5) days (Table).

Sedentary Time

Patients spent 12.6 (95% CI, 11.8–13.7) h/d sedentary during hospitalization for MI, which decreased to 11.1 (95% CI, 10.0–12.2) h/d during the first week at home. The change in sedentary time from the hospital to home environment was −1.8 (95% CI, −2.4 to −1.3; $P<0.001$) h/d. More important, sedentary time did not change across days within hospitalization (0.3 [95% CI, −0.1 to 0.8] h/d; $P=0.14$) but gradually decreased within the home environment (−0.1 [95% CI, −0.2 to −0.03] h/d; $P=0.01$) (Figure 2A). The prevalence of a sedentary time ≥9.5 h/d was 100% during hospitalization and attenuated to 84% in the home environment (Figure S1). Changes in sedentary time between hospitalization and home were comparable across subgroups, although sedentary time did not decrease among patients who underwent CABG (−0.3 [95% CI, −1.2 to 0.5] h/d; $P=0.43$) (Figure 3). Sedentary time was accumulated in sedentary bouts of different duration. Following the transition from hospital to home, patients demonstrated an increase in the number of daily short bouts (<15 minutes; 13.3 [95% CI, 8.8–17.7] bouts/day; $P<0.001$) and medium bouts (15–30 minutes; 2.1 [95% CI, 1.4–2.9] bouts/day; $P<0.001$). The number of bouts

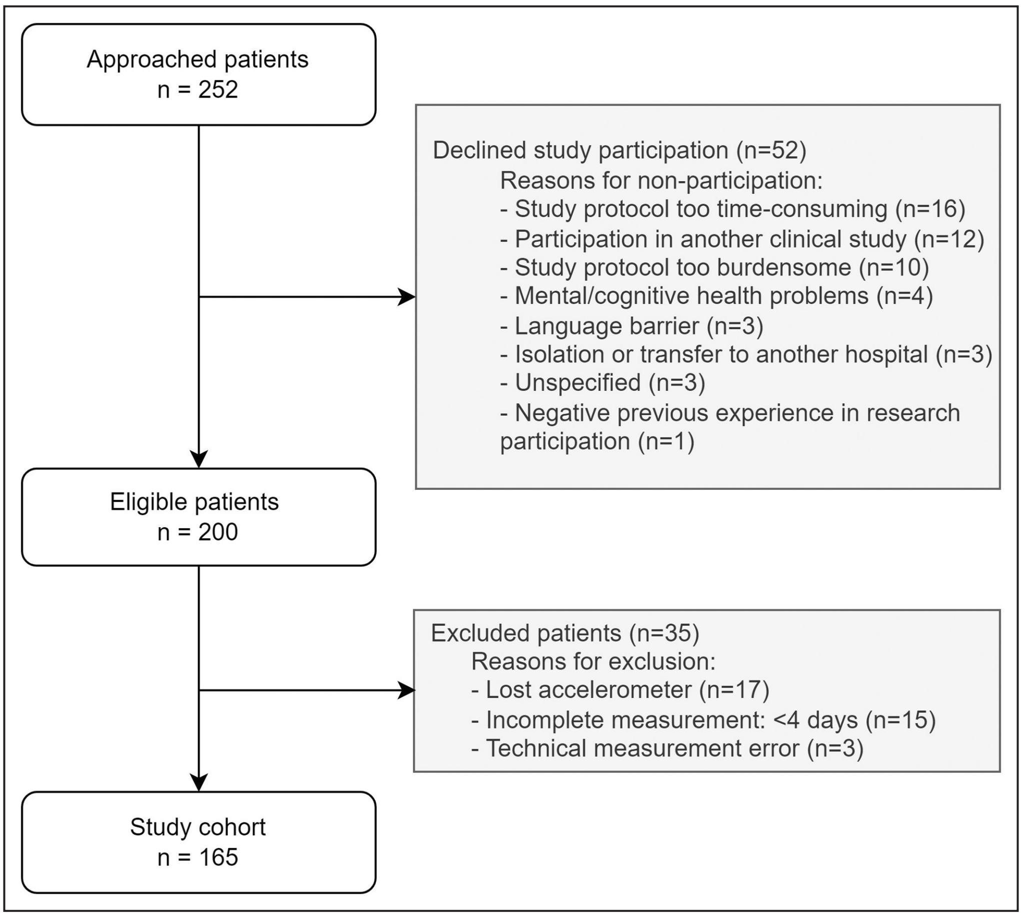


Figure 1. Study flowchart.

Table. Patient Characteristics

Baseline characteristics	Value (n=165)	Missing values, n (%)
Age, y	65±10	0 (0)
Sex (male)	29 (78)	0 (0)
Body mass index, kg/m^2	26.8 (24.2–29.8)	1 (0.6)
Education level		0 (0)
Low	51 (31)	
Middle	57 (35)	
High	57 (35)	
Marital status (married)	122 (74)	0 (0)
Current working status (employed)	72 (44)	0 (0)
Living environment		0 (0)
Rural	79 (48)	
Urban	57 (35)	
Transition	29 (18)	
Alcohol consumption	93 (56)	0 (0)
Units/wk	4 (1–7)	0 (0)
Smoking (current)	39 (24)	0 (0)
Pack-years	27 (13–34)	0 (0)
Smoking (stopped)	78 (47)	0 (0)
Pack-years	10 (4–27)	0 (0)
Comorbidities		
Hypertension	81 (49)	0 (0)
Diabetes	22 (13)	0 (0)
Dyslipidemia	50 (30)	1 (0.6)
Rheumatoid arthritis	5 (3)	0 (0)
Atrial fibrillation	10 (6)	0 (0)
Prior myocardial infarction	34 (21)	0 (0)
Prior CABG	6 (4)	0 (0)
Prior PCI	26 (16)	0 (0)
Heart failure	5 (3)	1 (0.6)
Cerebrovascular disease	12 (7)	0 (0)
Peripheral artery disease	8 (5)	0 (0)
Chronic renal failure (eGFR <30 mL/min per 1.73 m^2 or dialysis)	0 (0)	0 (0)
COPD	8 (5)	0 (0)
Cancer (diagnosed in the past 5 y)	15 (9)	0 (0)
Depression	20 (12)	2 (1.2)
Hospitalization		
Index diagnosis		0 (0)
ST-segment–elevation myocardial infarction	82 (50)	
Non–ST-segment–elevation myocardial infarction	83 (50)	
Cardiac biomarker release		
Peak hs-cTnT, ng/L	968 (337–3454)	8 (4.8)
Peak CK, U/L	525 (192–1318)	1 (0.6)

(*Continued*)

Table. Continued

Baseline characteristics	Value (n=165)	Missing values, n (%)
Treatment		0 (0)
PCI	128 (78)	
CABG	15 (9)	
Conservative (medication only)	22 (13)	
Duration of hospitalization, d	4 (3–5)	0 (0)
In-hospital complications		0 (0)
In-hospital cardiac arrest	1 (0.6)	
Major bleeding	21 (13)	
Reinfarction	2 (1.2)	
Target vessel revascularization	3 (1.8)	
Cardiogenic shock	4 (2.4)	
Follow-up–discharge		
Cardiac anxiety score (range, 0–4)	1.3±0.6	5 (3)
Medical advice to avoid physical activity	27 (17)	1 (0.6)
Self-reported compliance to this device	23 (85)	0 (0)

Data are presented as number (percentage), mean±SD, or median (interquartile range). CABG indicates coronary artery bypass grafting; CK, creatine kinase; COPD, chronic obstructive pulmonary disease; eGFR, estimated glomerular filtration rate; hs-cTnT, high-sensitivity cardiac troponin-T; and PCI, percutaneous coronary intervention.

between 30 and 60 minutes did not change (P=0.27), but the occurrence of prolonged sedentary bouts (≥60 minutes) was significantly reduced (−1.6 [95% CI, −2.0 to −1.2] bouts/day; P<0.001; Figure 4).

Physical Activity

Patients spent 1.1 (95% CI, 0.8–1.6) h/d LIPA and 0.2 (95% CI, 0.1–0.3) h/d MVPA during hospitalization, which increased to 2.9 (95% CI, 2.0–3.8) h/d (LIPA) and 0.6 (95% CI, 0.3–0.9) h/d (MVPA) during the first week at home. Changes in PA time were 1.8 (95% CI, 1.4–2.3; P<0.001) h/d for LIPA and 0.4 (95% CI, 0.3–0.5; P<0.001) h/d for MVPA from the hospital to home environment. No day-to-day changes in LIPA time were observed within the hospitalization and home phase, but MVPA time gradually increased across days at home (0.04 [95% CI, 0.02–0.05] h/d; P<0.001) (Figure 2). Patients who underwent CABG did not increase LIPA or MVPA time after discharge (Figure 3).

Sleep Duration and Sensitivity Analyses

Median sleep duration was 9.7 (95% CI, 8.9–10.5) h/d during hospitalization and 9.1 (95% CI, 8.4–9.9) h/d after discharge. Sleep duration did not change between hospitalization and home (−0.4 [95% CI, −0.8 to 0.0] h/d; P=0.054). Subgroup analysis showed that

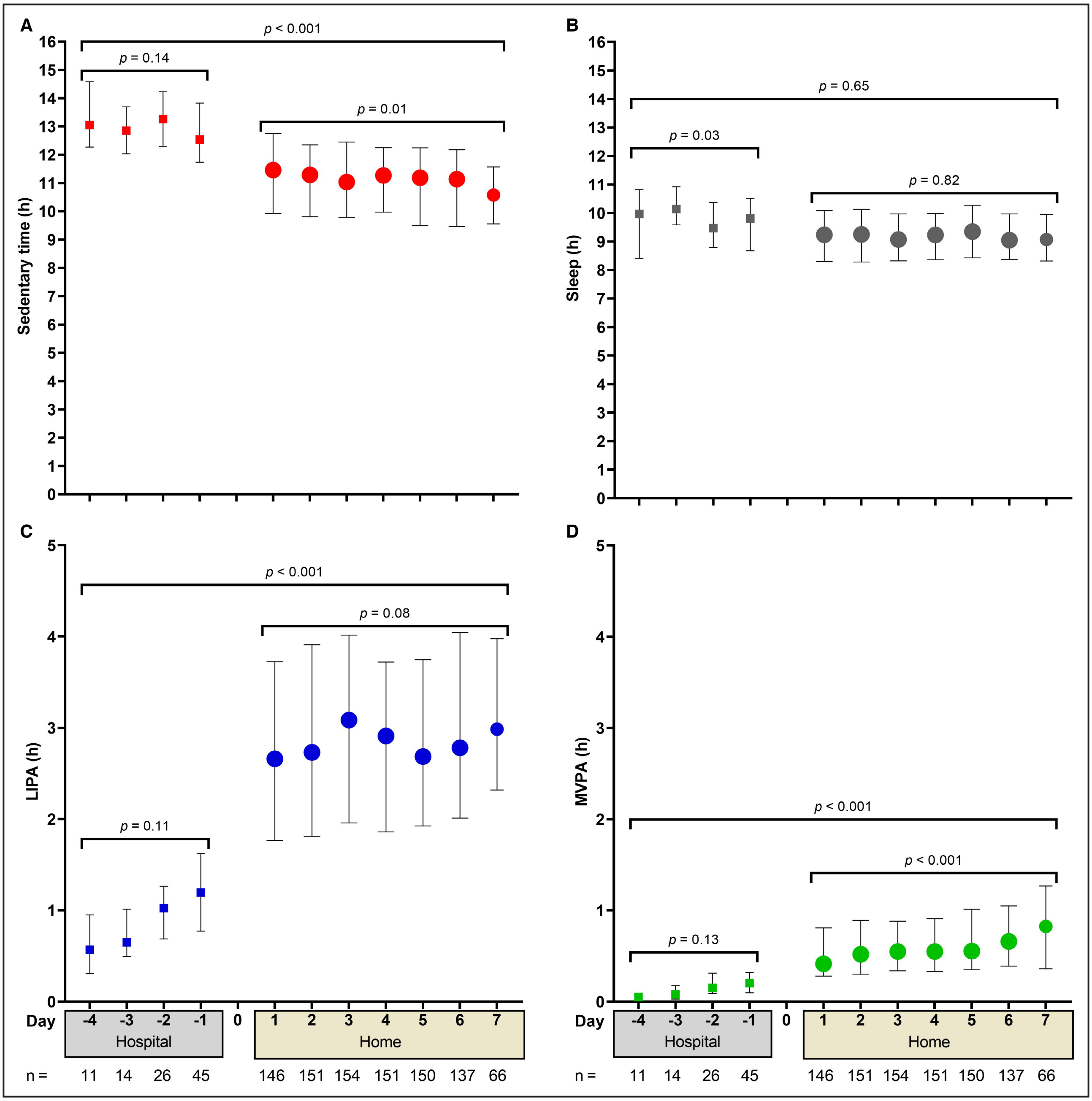


Figure 2. Day-to-day sedentary time (A), sleep duration (B), LIPA time (C), and MVPA time (D) during hospitalization and the first week after discharge.

Data are presented as median with interquartile range. *P* values are derived from linear mixed-model analyses and are reported for overall day-to-day changes during the total measurement period, and day-to-day changes within the hospitalization and postdischarge phase. LIPA indicates light-intensity physical activity; and MVPA, moderate-vigorous intensity physical activity.

sleep duration decreased from hospitalization to postdischarge among women, older patients, and patients with ST-segment–elevation MI (Figure 3). Sensitivity analyses excluding patients who only had valid days available in the home environment did not change our findings (Figure S2). In addition, the timing of inclusion (pre–COVID-19 versus post–COVID-19 pandemic) did not impact changes in SB and PA (Figure S3).

DISCUSSION

The purpose of this study was to assess changes in PA and SB patterns following the transition from hospitalization to the home environment among patients with MI. In line with our hypothesis, and not demonstrated before in previous work using objective accelerometry, we found that hospitalized patients are highly sedentary,

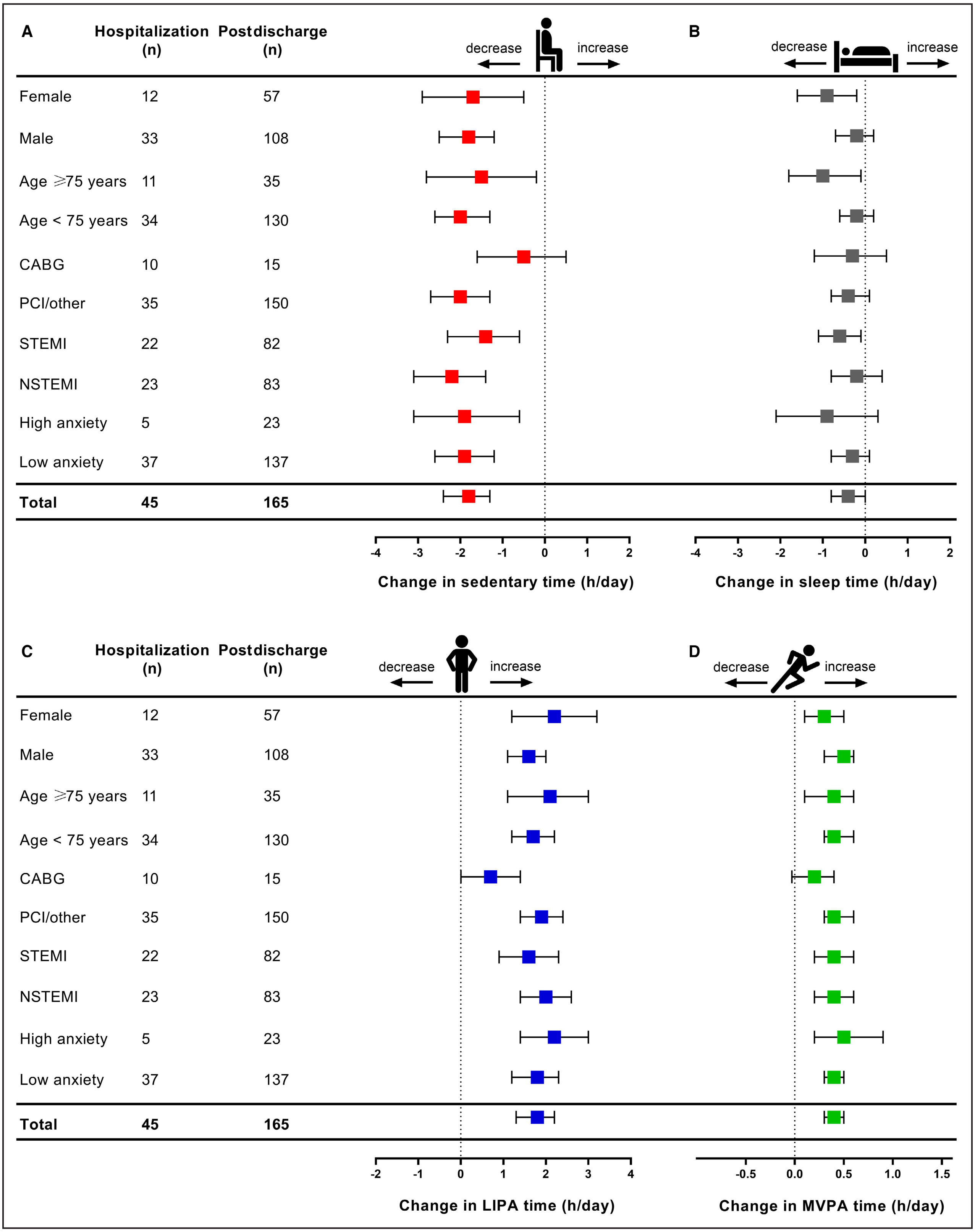


Figure 3. Forest plot with stratified mixed-model analysis on the change in sedentary time (A), sleep time (B), LIPA time (C), and MVPA time (D) between hospitalization and postdischarge.

The black squares indicate the estimates, and the lines represent the 95% CIs of the estimate. CABG indicates coronary artery bypass grafting; LIPA, light-intensity physical activity; MVPA, moderate-vigorous intensity physical activity; NSTEMI, non–ST-segment–elevation myocardial infarction; PCI, percutaneous coronary intervention; and STEMI, ST-segment–elevation myocardial infarction.

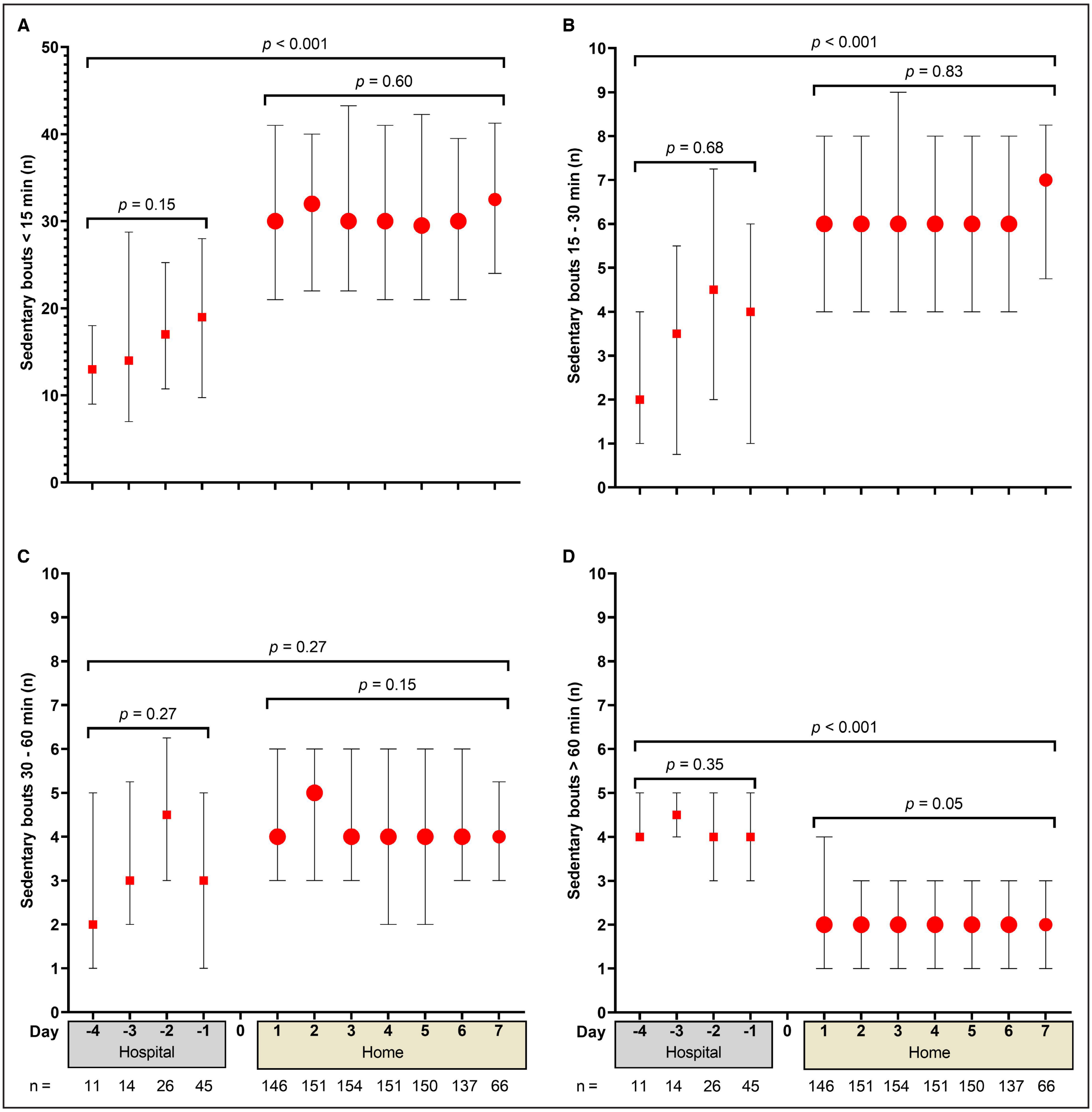


Figure 4. Day-to-day number of sedentary bouts, categorized in bouts of <15 minutes (A); ≥15 and <30 minutes (B); ≥30 and <60 minutes (C); and ≥60 minutes (D).
Data are presented as median with interquartile range. *P* values are derived from linear mixed-model analyses and are reported for overall day-to-day changes during the total measurement period and day-to-day changes within the hospitalization and postdischarge phase.

evidenced by a sedentary time >12.5 h/d in combination with low levels of PA (MVPA: ≈0.2 h/d). Intriguingly, hospital discharge resulted in an immediate 1.8-h/d decrease in the time spent sedentary and an increase in LIPA (1.8 h/d) and MVPA (0.4 h/d) in the home environment. Similar observations were made for SB characteristics, with increases in low- to medium-duration sedentary bouts and reductions in prolonged sedentary bouts. Furthermore, progressive improvements in SB and PA were observed across the number of days spent in the home environment. Observed changes were largely similar across predefined subgroups, although patients who underwent CABG did not reduce sedentary time or increase their LIPA and MVPA levels. Findings from this study provide novel insight into physical (in)activity patterns in the acute phase of an MI, which can importantly contribute to optimization of the prescription of PA between hospital admission and the start of CR.

SB was highly prevalent, whereas only little time was spent in PA during hospitalization. Epidemiological evidence based on objectively measured SB indicates that a daily sedentary time of ≥9.5 hours is associated with a significantly higher risk of death, whereas risk reductions occur from at least 3 hours of LIPA, being optimal at 24 min/d of MVPA.[13] In the hospital, all patients exceeded the sedentary time threshold, and PA levels were too low to gain health benefits. Furthermore, regardless of total sedentary time, prolonged uninterrupted sedentary bouts cause additional detrimental health effects.[27,28] Therefore, also the high number of prolonged sedentary bouts >1 hour is worrisome. SB and PA levels after MI are a potential target to optimize secondary prevention and to improve recovery.

The immediate and substantial improvements in SB and PA characteristics following transition from the hospital to home environment are striking. It has been suggested that patients experience fear of exercising directly after MI,[17] potentially impeding patients to attenuate SB and increase PA during hospitalization. On the other hand, the immediate nature and magnitude of the improvements observed on the first day after discharge imply that it is not a sole matter of mental or physical limitations. The changes in PA and SB patterns may rather be attributable to change of environment and its associated (expected) behavior. For example, contrary to the patient's home environment, daily life during hospitalization is concentrated around the hospital bed.[29] As a consequence, patients stay in their hospital bed during daytime, promoting high levels of SB.[30] However, there are still some challenges to safely facilitate PA during hospitalization. Many patients are prone to falls and are under continuous heart rhythm monitoring, and there is a perceived risk of a recurrent cardiac event. Patients may also experience kinesiophobia and first need to regain confidence to resume PA engagement after experiencing an acute MI. Possibly, technical solutions might enable (intramural) early mobilization during admission. These solutions may include mobile telemetry monitoring, global positioning system trackers to quickly locate patients within the hospital, and wearable cardioverter defibrillators.[31] Future studies are warranted to understand the specific barriers and facilitators related to PA and SB in the acute phase after MI. Taken together, the home environment facilitates patients with MI to engage in more PA, limiting time spent sedentary and the number of prolonged sedentary bouts.

Patients demonstrated a further decline in SB and an increase in MVPA across the first 7 days within the home environment. Isotemporal substitution analyses show that replacing every 30 minutes of sedentary time is associated with a 2% lower risk of mortality and major adverse cardiovascular events[32] and a 2% to 4% improvement in cardiovascular risk factors.[33] In addition, PA has shown beneficial effects on recovery after MI and heart surgery.[34,35] According to current guidelines, exercise prescription in patients with MI is based on an individualized approach after careful clinical evaluation and, especially if exercise is performed at higher intensity, supervised exercise training programs are recommended in the initial phases.[36] However, this should not prevent patients from incorporating more PA at light intensities and thereby reduce their daily time spent sedentary. Ideally, this process already begins during hospitalization to take full advantage of PA-related health benefits in the acute phase of recovery after MI. The gradual improvements in PA and SB patterns in the home environment are promising and demonstrate that patients are physically and mentally capable of achieving this, even before CR enrollment.

Stratified analyses indicated that improvements in PA and SB in the acute phase after MI did not apply to patients who underwent CABG compared with percutaneous coronary intervention or conservative treatment. This could be attributable to the fact that postoperative symptoms, such as pain, fatigue, palpitations, and swelling of the lower limbs, last longer and are not fully recovered at discharge.[37] Alternatively, sternal precautions/wound healing may limit PA engagement.[37] Long-term postoperative SB negatively impacts recovery after CABG and increases risk of muscle loss and falls.[34,38] A recent randomized clinical trial indicates that by adopting an individualized approach, post-CABG patients can safely start CR up to 4 weeks earlier than current guidance, with beneficial effects on their recovery.[39] The next step could be to target SB directly after discharge (eg, by introducing regular short PA breaks at light intensity to further improve post-CABG recovery).

Clinical Relevance

Findings from our study indicate high levels of physical inactivity in the acute phase after MI, underlining the need for strategies targeting SB as early as possible to bridge the gap between hospital admission and the start of CR. Preliminary results of a multicomponent intervention including eHealth, aiming to decrease sedentary time in patients admitted for organ transplantation or vascular surgery, were promising, by means it appeared effective to reduce sedentary time during hospitalization.[40] Another study indicated that a multifaceted intervention to reduce SB in hospitalized patients with cardiovascular disease might reduce SB and increase PA during the hospital stay, but results should be interpreted with caution because this was an explorative study wherein causality could not be confirmed.[41] Targeting SB during hospitalization seems, therefore, feasible and effective and may also yield improvement in PA patterns after discharge, but randomized controlled trials are needed to evaluate strategies to reduce SB and promote PA in the early phase after MI and to assess the impact of early (re-) activation on longer-term PA levels.

Strengths and Limitations

To the best of our knowledge, this is the first study objectively assessing SB and PA patterns in patients with acute MI during both hospitalization and the first week at home. Our study provides a unique insight into daily changes during the early phase after MI, which would not have been detected if assessed only in the home environment. A limitation of this study is the relatively low number of patients with available valid days during hospitalization. By incorporating missing data patterns as fixed effects in our mixed-model analyses, we controlled for the effects of missingness on outcomes. We found that patients with missing data during hospitalization were less sedentary at home compared with patients with a full set of data, but sensitivity analyses without these patients did not change the results, highlighting the robustness of our findings. In addition, when vein grafts were harvested from the leg during CABG, patients might be impeded in moving their leg in the acute postoperative phase. A wrist-worn wearable device that determines arm movement and heart rate may allow more accurate assessment of high-intensity (upper body) exercise, although it is questionable whether this kind of PA can be expected immediately after cardiac surgery. Another limitation of this study is the unfortunate male/female distribution in our study. This undesirable imbalance may ultimately lead to suboptimal cardiovascular care in women, as the underrepresentation of women in CR was recently highlighted.[42] This underlines the need for better referral rates in women but also for individualized CR programming that incorporates sex-specific factors to improve participation rates.[43] Future studies are needed to identify optimal strategies and alternative approaches for the modality, intensity, and frequency of exercise training.[43] In addition, because of a limited number of participants in this study, we were not able to determine whether the lack of improvement in SB and PA patterns after discharge was independent of other patient characteristics, such as age or sex. Given the findings of our study, targeting SB after experiencing an MI would be a promising alternative approach, obviously requiring a larger trial with a representative proportion of female participants.

CONCLUSIONS

Patients hospitalized with acute MI primarily spent time sedentary with little engagement in PA. Immediately on discharge, post-MI patients demonstrate a substantial decrease in SB (1.8 h/d), in favor of a 2- to 3-fold increase in PA levels. Moreover, across the first 7 days within the home environment, patients demonstrate a further decline in SB and an increase in MVPA, although SB levels remain high. The abrupt decrease in SB after discharge suggests that living environment plays a pivotal role in SB, which may have important implications for health care organization and PA counseling in the early phase after MI.

ARTICLE INFORMATION

Received January 25, 2023; accepted March 28, 2023.

Affiliations

Department of Physiology, Radboud University Medical Center, Radboud Institute for Health Sciences, Nijmegen, the Netherlands (B.M.v.B., I.A.d.K., E.A.B., D.H.T., T.M.E.); Department of Cardiology, Radboud University Medical Center, Radboud Institute for Health Sciences, Nijmegen, the Netherlands (G.A.P., E.C., R-J.v.G.), and Research Institute for Sports and Exercise Sciences, Liverpool John Moores University, Liverpool, United Kingdom (D.H.J.T.).

Sources of Funding

This study was supported by the Dutch Heart Foundation (senior E-Dekker grant 2017T051).

Disclosures

None.

Supplemental Material

Figures S1–S3

REFERENCES

1. Timmis A, Vardas P, Townsend N, Torbica A, Katus H, De Smedt D, Gale CP, Maggioni AP, Petersen SE, Huculeci R, et al. European Society of Cardiology: cardiovascular disease statistics 2021. *Eur Heart J*. 2022;43:716–799. doi: 10.1093/eurheartj/ehab892
2. Benjamin EJ, Muntner P, Alonso A, Bittencourt MS, Callaway CW, Carson AP, Chamberlain AM, Chang AR, Cheng S, Das SR, et al. Heart disease and stroke statistics-2019 update: a report from the American Heart Association. *Circulation*. 2019;139:e56–e528. doi: 10.1161/cir.0000000000000659
3. Visseren FLJ, Mach F, Smulders YM, Carballo D, Koskinas KC, Bäck M, Benetos A, Biffi A, Boavida J-M, Capodanno D, et al. 2021 ESC guidelines on cardiovascular disease prevention in clinical practice: developed by the task force for cardiovascular disease prevention in clinical practice with representatives of the European Society of Cardiology and 12 medical societies with the special contribution of the European Association of Preventive Cardiology (EAPC). *Eur Heart J*. 2022;43:4468. doi: 10.1093/eurheartj/ehab484
4. Fell J, Dale V, Doherty P. Does the timing of cardiac rehabilitation impact fitness outcomes? An observational analysis. *Open Heart*. 2016;3:e000369. doi: 10.1136/openhrt-2015-000369
5. Marzolini S, Blanchard C, Alter DA, Grace SL, Oh PI. Delays in referral and enrolment are associated with mitigated benefits of cardiac rehabilitation after coronary artery bypass surgery. *Circ Cardiovasc Qual Outcomes*. 2015;8:608–620. doi: 10.1161/circoutcomes.115.001751
6. Schopfer DW, Whooley MA, Allsup K, Pabst M, Shen H, Tarasovsky G, Duvernoy CS, Forman DE. Effects of home-based cardiac rehabilitation on time to enrollment and functional status in patients with ischemic heart disease. *J Am Heart Assoc*. 2020;9:e016456. doi: 10.1161/JAHA.120.016456
7. Pack QR, Mansour M, Barboza JS, Hibner BA, Mahan MG, Ehrman JK, Vanzant MA, Schairer JR, Keteyian SJ. An early appointment to outpatient cardiac rehabilitation at hospital discharge improves attendance at orientation. *Circulation*. 2013;127:349–355. doi: 10.1161/CIRCULATIONAHA.112.121996
8. Tremblay MS, Aubert S, Barnes JD, Saunders TJ, Carson V, Latimer-Cheung AE, Chastin SFM, Altenburg TM, Chinapaw MJM. Sedentary

behavior research network (SBRN)—terminology consensus project process and outcome. *Int J Behav Nutr Phys Act*. 2017;14:75. doi: 10.1186/s12966-017-0525-8
9. Al-Shaar L, Li Y, Rimm EB, Manson JE, Rosner B, Hu FB, Stampfer MJ, Willett WC. Physical activity and mortality among male survivors of myocardial infarction. *Med Sci Sports Exerc*. 2020;52:1729–1736. doi: 10.1249/mss.0000000000002309
10. Moholdt T, Wisløff U, Nilsen TIL, Slørdahl SA. Physical activity and mortality in men and women with coronary heart disease: a prospective population-based cohort study in Norway (the HUNT study). *Eur J Cardiovasc Prev Rehabil*. 2008;15:639–645. doi: 10.1097/HJR.0b013e3283101671
11. Wu Z, Huang Z, Wu Y, Huang S, Wang Y, Zhao H, Chen S, Wu S, Gao X. Sedentary time, metabolic abnormalities, and all-cause mortality after myocardial infarction: a mediation analysis. *Eur J Prev Cardiol*. 2019;26:96–104. doi: 10.1177/2047487318804611
12. Ekelund U, Steene-Johannessen J, Brown WJ, Fagerland MW, Owen N, Powell KE, Bauman A, Lee IM. Lancet physical activity series 2 executive C, lancet sedentary behaviour working G. Does physical activity attenuate, or even eliminate, the detrimental association of sitting time with mortality? A harmonised meta-analysis of data from more than 1 million men and women. *Lancet*. 2016;388:1302–1310. doi: 10.1016/S0140-6736(16)30370-1
13. Ekelund U, Tarp J, Steene-Johannessen J, Hansen BH, Jefferis B, Fagerland MW, Whincup P, Diaz KM, Hooker SP, Chernofsky A, et al. Dose-response associations between accelerometry measured physical activity and sedentary time and all cause mortality: systematic review and harmonised meta-analysis. *BMJ*. 2019;366:l4570. doi: 10.1136/bmj.l4570
14. Biswas A, Oh PI, Faulkner GE, Bajaj RR, Silver MA, Mitchell MS, Alter DA. Sedentary time and its association with risk for disease incidence, mortality, and hospitalization in adults: a systematic review and meta-analysis. *Ann Intern Med*. 2015;162:123–132. doi: 10.7326/M14-1651
15. Eijsvogels TM, Molossi S, Lee DC, Emery MS, Thompson PD. Exercise at the extremes: the amount of exercise to reduce cardiovascular events. *J Am Coll Cardiol*. 2016;67:316–329. doi: 10.1016/j.jacc.2015.11.034
16. Lavie CJ, Ozemek C, Carbone S, Katzmarzyk PT, Blair SN. Sedentary behavior, exercise, and cardiovascular health. *Circ Res*. 2019;124:799–815. doi: 10.1161/circresaha.118.312669
17. Bäck M, Lundberg M, Cider Å, Herlitz J, Jansson B. Relevance of kinesiophobia in relation to changes over time among patients after an acute coronary artery disease event. *J Cardiopulm Rehabil Prev*. 2018;38:224–230. doi: 10.1097/hcr.0000000000000265
18. Duran AT, Ewing Garber C, Cornelius T, Schwartz JE, Diaz KM. Patterns of sedentary behavior in the first month after acute coronary syndrome. *J Am Heart Assoc*. 2019;8:e011585. doi: 10.1161/jaha.118.011585
19. Thygesen K, Alpert JS, Jaffe AS, Chaitman BR, Bax JJ, Morrow DA, White HD; Group ESD. Fourth universal definition of myocardial infarction (2018). *Eur Heart J*. 2018;40:237–269. doi: 10.1093/eurheartj/ehy462
20. Edwardson CL, Rowlands AV, Bunnewell S, Sanders J, Esliger DW, Gorely T, O'Connell S, Davies MJ, Khunti K, Yates T. Accuracy of posture allocation algorithms for thigh- and waist-worn accelerometers. *Med Sci Sports Exerc*. 2016;48:1085–1090. doi: 10.1249/MSS.0000000000000865
21. Winkler EA, Bodicoat DH, Healy GN, Bakrania K, Yates T, Owen N, Dunstan DW, Edwardson CL. Identifying adults' valid waking wear time by automated estimation in activPAL data collected with a 24 h wear protocol. *Physiol Meas*. 2016;37:1653–1668. doi: 10.1088/0967-3334/37/10/1653
22. van Beek MH, Voshaar RC, van Deelen FM, van Balkom AJ, Pop G, Speckens AE. The cardiac anxiety questionnaire: cross-validation among cardiac inpatients. *Int J Psychiatry Med*. 2012;43:349–364. doi: 10.2190/PM.43.4.e
23. Eifert GH, Thompson RN, Zvolensky MJ, Edwards K, Frazer NL, Haddad JW, Davig J. The cardiac anxiety questionnaire: development and preliminary validity. *Behav Res Ther*. 2000;38:1039–1053. doi: 10.1016/s0005-7967(99)00132-1
24. Son H, Friedmann E, Thomas SA. Application of pattern mixture models to address missing data in longitudinal data analysis using SPSS. *Nurs Res*. 2012;61:195–203. doi: 10.1097/NNR.0b013e3182541d8c
25. Bakker EA, van Bakel BMA, Aengevaeren WRM, Meindersma EP, Snoek JA, Waskowsky WM, van Kuijk AA, Jacobs MMLM, Hopman MTE, Thijssen DHJ, et al. Sedentary behaviour in cardiovascular disease patients: risk group identification and the impact of cardiac rehabilitation. *Int J Cardiol*. 2021;326:194–201. doi: 10.1016/j.ijcard.2020.11.014
26. Charman SJ, van Hees VT, Quinn L, Dunford JR, Bawamia B, Veerasamy M, Trenell MI, Jakovljevic DG, Kunadian V. The effect of percutaneous coronary intervention on habitual physical activity in older patients. *BMC Cardiovasc Disord*. 2016;16:248. doi: 10.1186/s12872-016-0428-7
27. Carter S, Hartman Y, Holder S, Thijssen DH, Hopkins ND. Sedentary behavior and cardiovascular disease risk: mediating mechanisms. *Exerc Sport Sci Rev*. 2017;45:80–86.
28. Loh R, Stamatakis E, Folkerts D, Allgrove JE, Moir HJ. Effects of interrupting prolonged sitting with physical activity breaks on blood glucose, insulin and triacylglycerol measures: a systematic review and meta-analysis. *Sports Med*. 2020;50:295–330. doi: 10.1007/s40279-019-01183-w
29. Ulrich RS. Essay: evidence-based health-care architecture. *Lancet*. 2006;368:S38–S39. doi: 10.1016/S0140-6736(06)69921-2
30. Brown CJ, Redden DT, Flood KL, Allman RM. The underrecognized epidemic of low mobility during hospitalization of older adults. *J Am Geriatr Soc*. 2009;57:1660–1665. doi: 10.1111/j.1532-5415.2009.02393.x
31. Kuehn C, Ruemke S, Rellecke P, Lichtenberg A, Joskowiak D, Hagl C, Hassan M, Leyh RG, Erler S, Garbade J, et al. Wearable cardioverter defibrillator multicentre experience in a large cardiac surgery cohort at transient risk of sudden cardiac death. *Eur J Cardiothorac Surg*. 2022;61:1031–1040. doi: 10.1093/ejcts/ezac086
32. Li S, Lear SA, Rangarajan S, Hu B, Yin L, Bangdiwala SI, Alhabib KF, Rosengren A, Gupta R, Mony PK, et al. Association of sitting time with mortality and cardiovascular events in high-income, middle-income, and low-income countries. *JAMA Cardiol*. 2022;7:796–807. doi: 10.1001/jamacardio.2022.1581
33. Buman MP, Winkler EA, Kurka JM, Hekler EB, Baldwin CM, Owen N, Ainsworth BE, Healy GN, Gardiner PA. Reallocating time to sleep, sedentary behaviors, or active behaviors: associations with cardiovascular disease risk biomarkers, NHANES 2005-2006. *Am J Epidemiol*. 2014;179:323–334. doi: 10.1093/aje/kwt292
34. Eder B, Hofmann P, Von Duvillard SP, Brandt D, Schmid JP, Pokan R, Wonisch M. Early 4-week cardiac rehabilitation exercise training in elderly patients after heart surgery. *J Cardiopulm Rehabil Prev*. 2010;30:85–92. doi: 10.1097/HCR.0b013e3181be7e32
35. Dibben G, Faulkner J, Oldridge N, Rees K, Thompson DR, Zwisler AD, Taylor RS. Exercise-based cardiac rehabilitation for coronary heart disease. *Cochrane Database Syst Rev*. 2021;11:Cd001800. doi: 10.1002/14651858.CD001800.pub4
36. Ambrosetti M, Abreu A, Corra U, Davos CH, Hansen D, Frederix I, Iliou MC, Pedretti RF, Schmid JP, Vigorito C, et al. Secondary prevention through comprehensive cardiovascular rehabilitation: from knowledge to implementation. 2020 update. A position paper from the secondary prevention and rehabilitation section of the European Association of Preventive Cardiology. *Eur J Prev Cardiol*. 2021;28:460–495. doi: 10.1177/2047487320913379
37. Gray E, Dasanayake S, Sangelaji B, Hale L, Skinner M. Factors influencing physical activity engagement following coronary artery bypass graft surgery: a mixed methods systematic review. *Heart Lung: J Crit Care*. 2021;50:589–598. doi: 10.1016/j.hrtlng.2021.04.006
38. Wall BT, Dirks ML, van Loon LJC. Skeletal muscle atrophy during short-term disuse: implications for age-related sarcopenia. *Ageing Res Rev*. 2013;12:898–906. doi: 10.1016/j.arr.2013.07.003
39. Ennis S, Lobley G, Worrall S, Evans B, Kimani PK, Khan A, Powell R, Banerjee P, Barker T, McGregor G. Effectiveness and safety of early initiation of poststernotomy cardiac rehabilitation exercise training: the SCAR randomized clinical trial. *JAMA Cardiol*. 2022;7:817–824. doi: 10.1001/jamacardio.2022.1651
40. Conijn D, van Bodegom-Vos L, Volker WG, Mertens B, Vermeulen HM, Huurman V, van Schaik J, Vliet Vlieland T, Meesters J. A multicomponent intervention to decrease sedentary time during hospitalization: a quasi-experimental pilot study. *Clin Rehabil*. 2020;34:901–915. doi: 10.1177/0269215520920662
41. Koenders N, Potkamp-Kloppers S, Geurts Y, Akkermans R, Nijhuis-van der Sanden MWG, Hoogeboom TJ. Ban bedcentricity: a multifaceted innovation to reduce sedentary behavior of patients during the hospital stay. *Phys Ther*. 2021;101:pzab054. doi: 10.1093/ptj/pzab054
42. Quindry JC, McNamara M, Oser C, Fogle C. Cardiac rehabilitation and resting blood pressure. *J Cardiopulm Rehabil Prev*. 2022;42:E23–E31. doi: 10.1097/hcr.0000000000000638
43. Smith JR, Thomas RJ, Bonikowske AR, Hammer SM, Olson TP. Sex differences in cardiac rehabilitation outcomes. *Circ Res*. 2022;130:552–565. doi: 10.1161/circresaha.121.319894

SUPPLEMENTAL MATERIAL

Figure S1. Day-to-day proportion of patients with a sedentary time ≥9.5 hours during hospitalization and the first week after discharge.

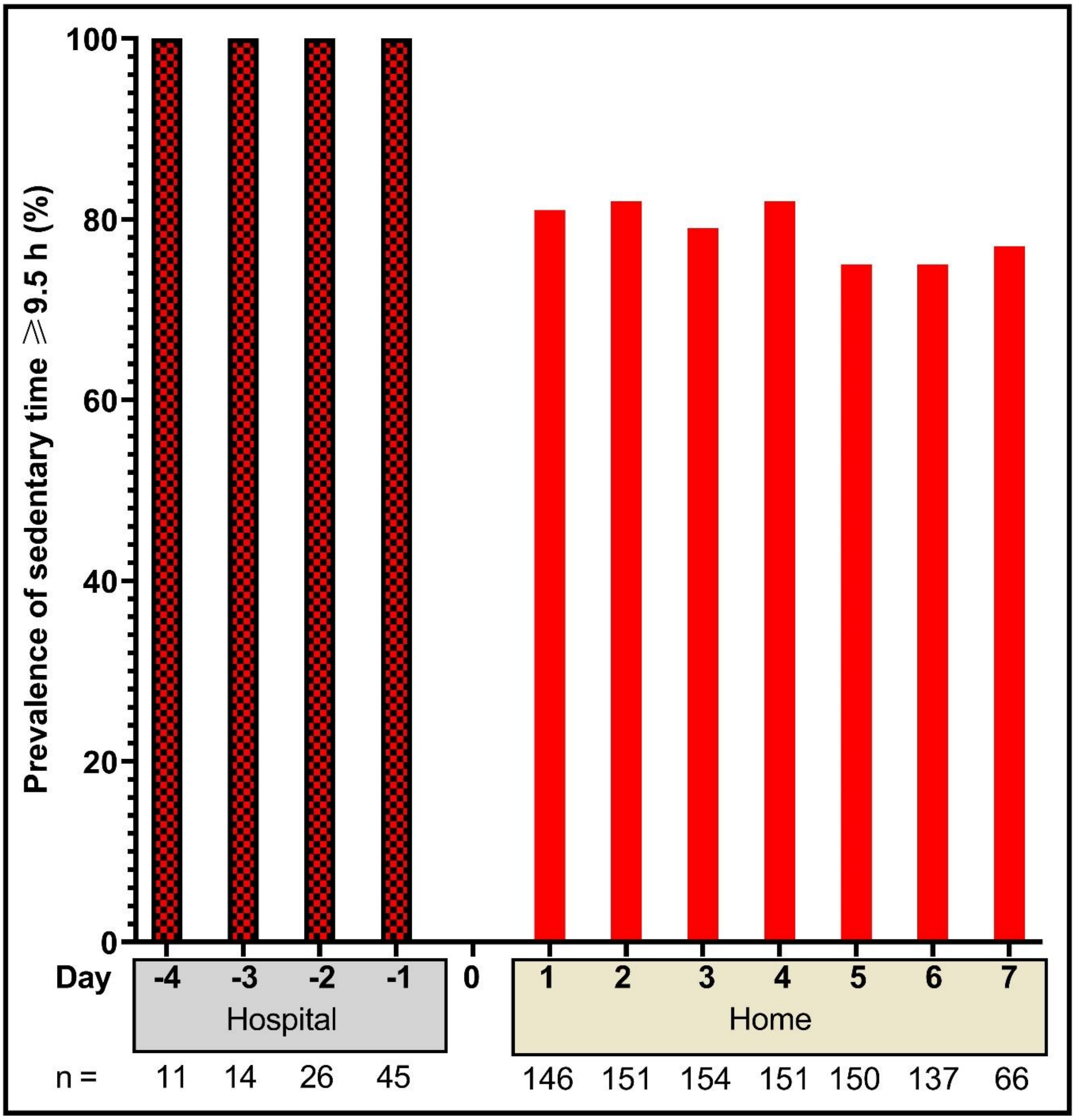
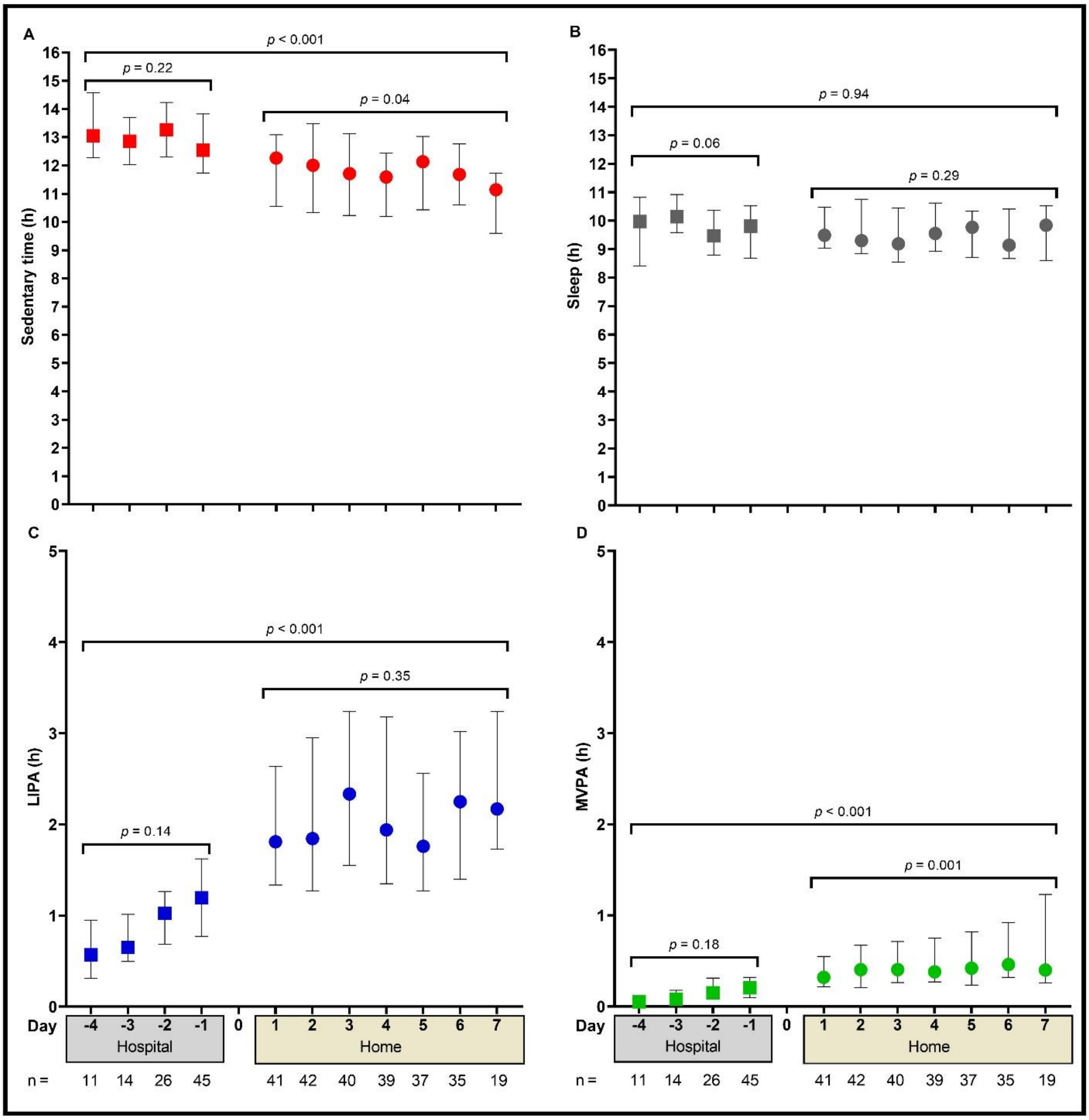
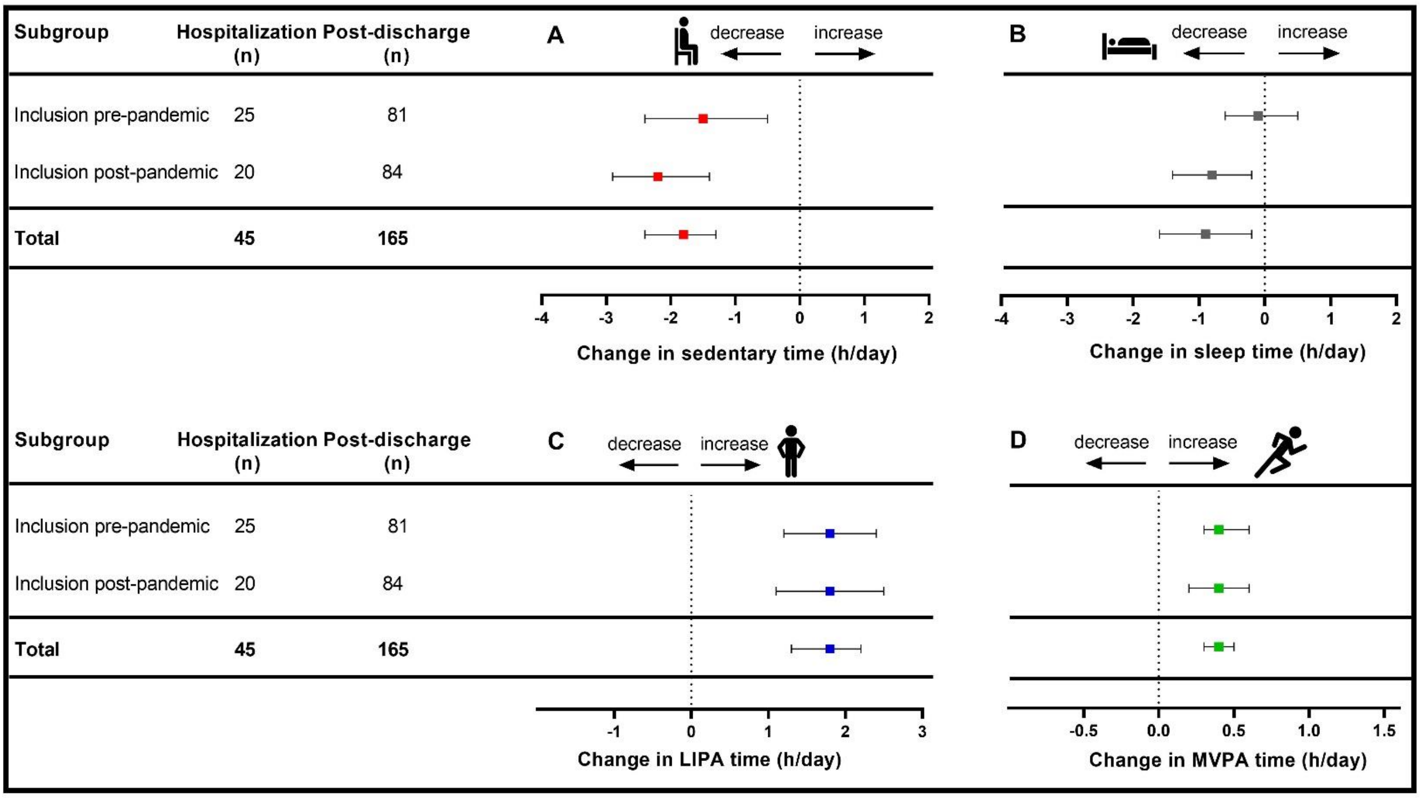


Figure S2. Sensitivity analysis after excluding patients who only had valid days available in the home environment.



Day-to-day sedentary time (**panel A**), sleep duration (**panel B**), light-intensity physical activity (LIPA) time (**panel C**) and moderate-to-vigorous intensity physical activity (MVPA) time (**panel D**) during hospitalization and the first week after discharge. Data are presented as median with interquartile range. P-values are reported for overall day-to-day changes during the measurement period, and day-to-day changes within the hospitalization and post-discharge phase.

Figure S3. Forest plot with mixed model analysis on the change in sedentary time (panel A), sleep time (panel B), light-intensity physical activity (LIPA) time (panel C), and moderate-to-vigorous intensity physical activity (MVPA) time (panel D) between hospitalization and post-discharge, stratified by the timing of inclusion (pre- *versus* post-COVID-19 pandemic.



The black squares indicate the estimates and the lines represent the 95% confidence intervals (CI) of the estimate.