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ORIGINAL REPORT

ACCELEROMETRY: A FEASIBLE METHOD TO MONITOR PHYSICAL ACTIVITY DURING SUB-ACUTE REHABILITATION OF PERSONS WITH STROKE

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Objective: **To investigate the feasibility of using accelerometers to monitor physical activity in persons with stroke admitted to inpatient rehabilitation.**

Design: **Longitudinal observational study.**

Participants: **Persons with stroke admitted to a specialized rehabilitation centre for sub-acute rehabilitation were recruited between August and December 2016.**

Methods: **Volume and intensity of physical activity were assessed with accelerometers throughout the rehabilitation period. Indicators of feasibility included processes (recruitment, protocol adherence and participants' experiences) and scientific feasibility, which assessed the accelerometers' ability to detect change in physical activity among stroke survivors who ambulate independently and those who are dependent on a mobility device.**

Results: **Twenty-seven out of 31 eligible individuals took part in this study, with 23 (85%) completing it. In total, 432 days of rehabilitation were monitored and valid physical activity data were obtained for 408 days (94%). There were no indications that the measurement interfered with participants' ability to participate in rehabilitation. Despite the subjects' ambulation status, the number of steps and time spent in moderate-to-vigorous physical activity increased significantly across the first 18 days of rehabilitation, whereas sedentary time was unchanged.**

Conclusion: **This study supports the feasibility of using accelerometers to capture physical activity behaviour in survivors of stroke during inpatient rehabilitation.**

Key words: functional recovery; mobility; motion sensor; sedentary; wearable sensors.

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Stroke results in unprecedented changes in human functioning (1–3). Of those individuals who survive the initial stroke, nearly two-thirds experience immediate problems with mobility, mainly due to hemiparesis (4, 5). Recovery, in terms of functional ability and participation, requires the subject to be mobile and physically active from very early on after stroke (6–8). Evaluation of physical activity (PA) after stroke is therefore important for the development of targeted interventions, which could impact the overall burden of stroke (9, 10).

Assessment of PA is not straightforward, and its validity is highly questionable when self-assessments are made (11). Individuals tend to overestimate their PA level and intensity (12). Reporting PA may be particularly difficult for people with stroke, as up to one-third experience cognitive impairment (13). One approach to combat this issue is by applying accelerometers (motion sensors), which provide objective information about the amount of activity (e.g. number of steps) and time spent exercising at different intensities, which are important domains of PA behaviour in relation to health (14, 15).

The body of knowledge is growing with respect to quantifying PA behaviour after stroke, especially among community-dwelling survivors in the chronic phase (for review see (16, 17)). However, little is known about PA behaviour earlier on after stroke when most recovery of motor functioning occurs (18, 19). Previous studies investigating PA in the acute and sub-acute phases report sedentary behaviour as a problematic area in need of remediation (20, 21). However, these studies made use of less quantifiable methods, such as self-report and behavioural mapping (20, 21), while the only objective information about PA early after stroke has been restricted to cross-sectional inquiries (22). To our knowledge, no previous studies have used accelerometers to monitor PA behaviour throughout sub-acute rehabilitation.

In order to promote the use of accelerometry in the early phases after stroke, the feasibility of this method needs to be ascertained. Feasibility studies are becoming increasingly important in the presence of limited resources for healthcare and innovations by asserting researchers and decision-makers of the potential impact of a specific healthcare solution (23). As a first step towards establishing objective information about PA early after stroke, this study aimed to investigate the feasibility of accelerometers in monitoring PA in stroke survivors with different ambulation status admitted to sub-acute inpatient rehabilitation. The specific objectives of this study were to determine: (*i*) whether

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stroke survivors would adhere to objective monitoring of PA during their rehabilitation; and (*ii*) whether accelerometers could detect changes in the volume and intensity of PA throughout the rehabilitation period, and whether changes in PA reflect similar directions of change in functional mobility.

METHODS

Study design

A longitudinal observational study was conducted to investigate the feasibility of using wearable sensors to capture PA without influencing the content or process of stroke rehabilitation.

Participants

Participants were recruited between August and December 2016, from a specialized rehabilitation centre in Stockholm, Sweden, following their referral from an acute hospital for inpatient rehabilitation after stroke. The timing of transition from acute care at a hospital to the rehabilitation centre was primarily dependent on the subject's medical condition. Thus, all participants were medically stable and able to walk short distances with or without a physical aid (e.g. by using a mobility device) on admission to rehabilitation. Exclusion criteria were cognitive impairment and receptive aphasia, affecting the understanding of the study and the ability to provide informed consent. The inclusion criteria were deliberately not too restrictive in order to assess the potential reach of accelerometers among diverse survivors of stroke. The study was conducted in accordance with the principles of the Declaration Helsinki, and all participants provided written informed consent prior to entering the study.

Inpatient rehabilitation

All participants received multidisciplinary inpatient rehabilitation, including standard treatment consisting of ≥ 60 min of physiotherapy and/or occupational therapy, delivered individually or as group sessions every weekday. The content and intensity of each therapy session was individualized to the needs of each participant by the treating therapists. Overall, the rehabilitation focused on independence in all activities of daily living and other life areas, by encouraging patients to be as active as possible during the day and to find new strategies for independency.

Data collection and management

Data collection was performed in 3 stages. Firstly, on admission to the rehabilitation centre, structured interviews were used to collect data regarding age (years), sex (male/female), type of stroke, and duration of acute stroke care (days) and activities of daily living. Body mass index was calculated (kg/m^2) via weight measured on a portable digital scale and height measured using a stadiometer. Barthel Index was used to describe the level of independency in activities of daily living (e.g. basic mobility, self-care activities and functions of bladder and bowel continence) on admission to rehabilitation (24).

Secondly, functional mobility and walking were assessed using the Timed Up & Go test and the 10-Meter Walk Test as descriptors of mobility status on admission to rehabilitation. The Timed Up & Go test measured the time it took for an individual to stand up from a standard armchair, walk a distance of 3 m, turn 180°, walk back to the chair, and sit down again (25, 26). For the 10-Meter Walk Test, participants were instructed to walk at a comfortable pace for 10 m and the mean gait speed (m/s) of 3 trials was used for analysis (25, 27). Participants were allowed to use a mobility device or physical support during mobility assessment. To assess changes in walking ability throughout the rehabilitation period, walking was also reassessed at discharge from rehabilitation as an indicator of improvement in walking ability. The Barthel Index (24), Timed Up & Go test (25, 26) and the 10-Meter Walk Test (25, 27) have proven reliable and valid in stroke survivors. All assessments were conducted by a physiotherapist with experience in working with survivors of stroke, who was not responsible for the participants' rehabilitation.

Thirdly, accelerometers (Actigraph GT3X+, Pensacola, FL, USA) were used to measure PA across the rehabilitation period. The GT3X+ records acceleration (30 Hz) in 3 axes and stores the data as an arbitrary unit termed counts (28). Participants wore the accelerometer (attached with an elastic band) around the hip slightly above the iliac crest over the lateral side of their non-paretic side. Participants were instructed to wear the accelerometer during all waking hours and were only permitted to remove the device when showering and at night. Participants were asked to fill in a diary in order to keep track of the times the device was worn. The ward staff provided support with the management of the accelerometer (e.g. attaching the sensor around the waist) and the activity diary, if needed.

PA data were downloaded and processed with ActiLife 6 software (ActiGraph, Pensacola, FL, USA). The start and end of the daily accelerometer recordings were determined by visually inspecting the accelerometer data in the ActiLife software and from the activity diaries. Periods of non-wear time (i.e. when the device was not worn) were identified from the activity diaries and excluded from the analysis. Thereafter, daily wear time was calculated by subtracting non-wear time from the total time for each day, and only days with ≥8 h of wear time were included in the analysis. The number of steps per day was used to reflect the volume of daily PA, while the following cut-off points were used for intensity categories: sedentary (0–99 counts/min), light intensity PA (100–1,041 counts/min) and moderate-to-vigorous PA (MVPA) (≥1,042 counts/min) (29, 30).

Feasibility of accelerometers to measure physical activity during stroke rehabilitation

The feasibility typology described by Thabane et al. (2010) (23) was used for the evaluation of process feasibility (i.e. recruitment, protocol adherence and participants' experiences) and scientific feasibility (i.e. the ability of accelerometers to capture change throughout the rehabilitation period). For the recruitment domain, we assessed the number of people with stroke who were willing to participate in objective monitoring of PA throughout their rehabilitation with respect to the total number of eligible individuals. To capture adherence, the number of participants dropping out of the study and the number of valid days of PA monitoring (i.e. ≥8 h) were monitored, along with the reasons for dropping out and invalid days. Participants' perceptions were centred towards the ways in which the accelerometer inhibited day-to-day rehabilitation. For scientific feasibility, we tested whether the accelerometer could detect changes in PA throughout the rehabilitation period in individuals with different ambulation status, i.e. independent ambulators and mobility device users on admission to rehabilitation. This sub-group analysis was performed as we expected survivors of stroke with different functional mobility status to have varying requisitions for PA during inpatient rehabilitation. For both groups, we also determined whether changes in PA were accompanied by improvements in walking speed where an increase of ≥0.14 m/s was used as a cut-off for meaningful change (31).

Statistical analysis

Descriptive statistics, mean (min–max) and numbers (percentages), were used to present demographics, stroke-related variables and mobility status on admission to rehabilitation. For scientific feasibility, we calculated the mean PA for epochs summarizing 3 consecutive days. As 90% of the participants had valid PA data across the first 18 days of rehabilitation (i.e. 6 epochs), this period was used for analyses. Daily wear time remained unchanged across the 6 epochs of rehabilitation ($p=0.29$) and therefore the time in different PA intensities were analysed in absolute numbers (i.e. min/day). A mixed-model analysis was used to investigate the patterns of change in PA outcomes between the groups (independent ambulators vs. mobility device users) and across time (epochs 1–6). The mixed-model analysis was applied, since this model accommodates for missing data without using data imputation. Data were presented as mean values and standard errors. The level of significance was set at $p\leq0.05$. Statistical analyses were carried out using IBM SPSS, version 23.0 (SPSS Inc., Chicago, IL, USA).

RESULTS

Process feasibility

Out of 31 persons with stroke assessed for eligibility, 27 (87%) were included in this study (see Fig. 1). Four participants dropped out, while 3 reported reasons related to the measurement of PA; 2 experienced discomfort due to the accelerometer and 1 stress related to managing the accelerometer. Of the 23 participants completing the study, 14 (61%) were independent ambulators, while 9 (39%) were dependent on a mobility device on admission to rehabilitation (participants' characteristics are seen in Table I).

In all, we monitored 432 days of rehabilitation, of which valid PA data were obtained for 408 days (94%). Disabling the device over weekend days ($n=11$, 46%) was the leading reason for lack of adherence, followed by those having permission to go home for a few days during their rehabilitation ($n=6$, 25%), unknown reason ($n=6$, 25%) and medical assessment at the rehabilitation centre ($n=1$, 4%). Of the 24 invalid PA days, a majority of these days occurred in the group ($n=16$, 67%) who ambulated independently. There were no documented indications that the measurement of PA interfered with participants' ability to partake in their rehabilitation.

Scientific feasibility

As illustrated in Fig. 2a–b, independent ambulators overall demonstrated a greater number of steps per day and more time spent in MVPA compared with mobility device users ($p=0.02$). In contrast, no differences between the groups were observed for time spent in light PA or sedentary ($p\geq0.22$). While both ambulation groups increased the number of steps per day and time spent in MVPA across the first 18 days of rehabilitation ($p<0.01$, Fig. 2a–b), no changes were observed for the time spent in light PA and sedentary behaviour ($p\geq0.20$, Fig. 2c–d). For the independent ambulating subgroup, the number of steps per day increased by 43% (mean: 3,609 steps, SE: 752 steps vs. mean: 5,170 steps, SE 750 steps) and time spent in MVPA per day by 53% (mean: 30 min, SE: 7 min vs. mean: 46 min, SE 7 min) between the first and sixth epoch. Similarly, for mobility device users, the number of steps per day increased by 74% (mean: 1,188 steps, SE: 926 steps vs. mean: 2,070 steps, SE 932 steps) and time per day spent in MVPA by 67% (mean: 9 min, SE: 9 min vs. mean: 15 min, SE 9 min) between the first and sixth epoch. In line with the increase in PA, a meaningful change in walking speed between admission to and discharge from rehabilitation was observed in 10 (71%) and 6 (67%) of the participants in the group of independent ambulators and mobility device users, respectively.

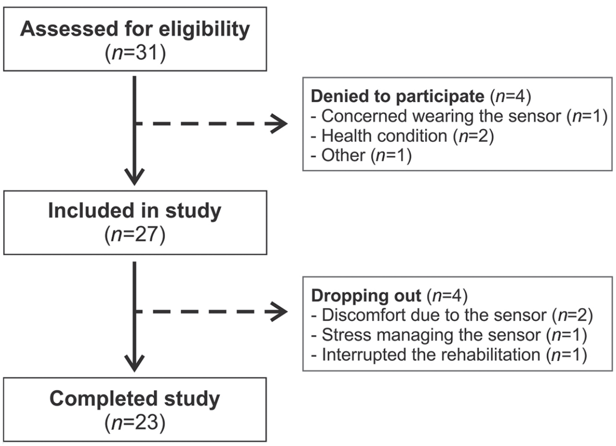

Fig. 1. Study flowchart.

Table I. Participant characteristics of the independent ambulators and mobility device users at admission to rehabilitation

Variables	Independent ambulators ($n=14$)	Mobility device users ($n=9$)
Age, years, mean (SD)	65 (11)	67 (7)
Male, *n*	10	6
Body mass index, mean (SD)	27 (5)	28 (4)
Ischaemic stroke, *n*	11	8
Side of paresis, right/left/none, *n*	6/4/4	2/6/1
Time since stroke, days, mean (SD)	9 (3)	13 (10)
Length of sub-acute rehabilitation, days, mean (SD)	21 (5)	23 (5)
Timed Up and Go, s, mean (SD)	12 (4)	26 (11)
Gait, mean (SD)	1.06 (0.26)	0.55 (0.18)
Barthel Index, mean (SD)	95 (7)	66 (34)

SD: standard deviation.

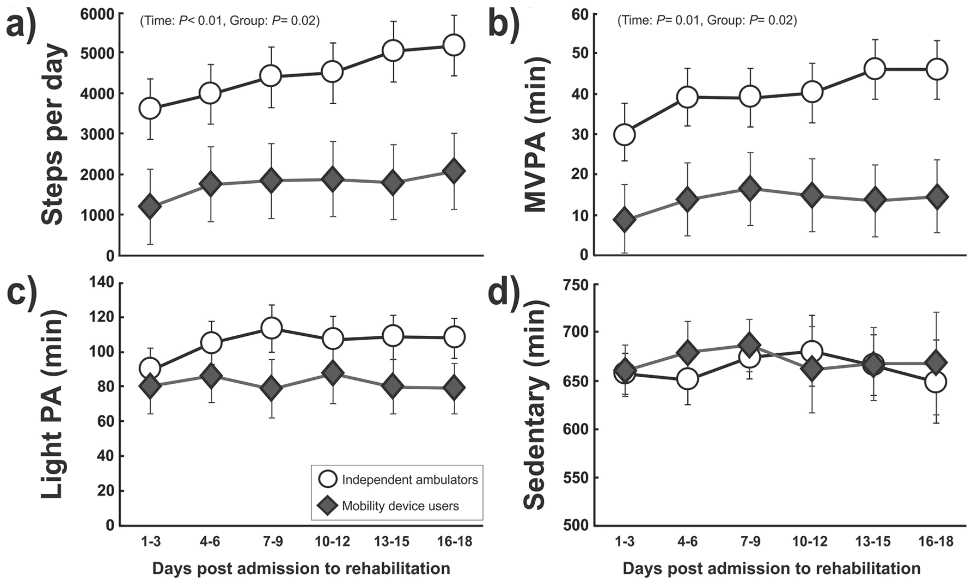

Fig. 2. (a) Number of steps per day. (b) Time spent in moderate-to-vigorous physical activity (MVPA). (c) Light physical activity. (d) Sedentary behaviour for independent ambulators and mobility device users during the first 18 days of inpatient rehabilitation. Data are plotted as mean values and standard errors.

DISCUSSION

The feasibility of using accelerometers to measure PA among survivors of stroke in a healthcare context was supported in this study by sufficient participation, high protocol adherence and predominantly valid data. Our findings also support the feasibility of using accelerometers to monitor changes in PA behaviour throughout stroke rehabilitation. Altogether, this study ascertains the use of accelerometers in monitoring PA in the sub-acute phase post-stroke, which is in an important step towards the development of programmes aimed at improving PA after stroke.

According to the feasibility typology (23), assessment of processes revealed acceptable alignment between the eligibility criteria and number of persons recruited in this study. This is an important issue when applying new healthcare innovations; demonstrating sufficient reach with regard to the inclusion of people with varying disease characteristics. For example, stroke survivors often have a low capacity to ambulate and, thus it is a group in which PA monitoring and evaluation is useful (32). The current results supporting the feasibility of using accelerometers among survivors of stroke with diverse ambulation status (e.g. range of walking speed in the present sample: 0.37–1.67 m/s) are therefore encouraging. In addition, we found sufficient adherence to the protocol, with 94% of monitored days being valid, which is even more promising considering the recommendation of measuring PA data between 4 and 7 days at a time (16, 33, 34). This offers great potential for evaluating the effects of therapeutic treatments on PA behaviour, which may substantiate the importance of certain rehabilitation content. Concerning adherence, participants were able to, almost fully, comply with wear time protocols and keeping their diaries, while participants expressed minimal interference of the device on their rehabilitation programmes. The fact that missing data occurred predominantly over weekends suggests the role staff has in promoting adherence, and this needs to be considered when measuring PA in the subacute stage after stroke.

In support of the scientific feasibility, our findings demonstrated a significant increase in the number of steps and time spent in MVPA across the first 18 days of rehabilitation. In line with previous findings (20, 21), the results of this study showed that inpatient rehabilitation after stroke primarily targeted more intensive PA domains, whereas lower intensities of PA (e.g. sedentary) remained unchanged throughout rehabilitation. The strength of this study is the use of objective measurements, whereas the aforementioned studies used more subjective approaches (e.g. behavioural mapping), which neglects the time spent in different PA intensities. Consequently, this study provides the first objectively assessed estimates of PA (e.g. steps per day and PA intensity) during inpatient stroke rehabilitation, which facilitates a more direct comparison with current PA guidelines. With specific PA recommendations set for persons with stroke (i.e. ≥150 min of moderate-intensity PA per week) (35) and the importance of reducing sedentary time (16, 36, 37), objective measures of PA early after stroke could be used to develop appropriate interventions for different subgroups. Although PA targets as presented in guidelines for persons with stroke are not immediately relevant following the onset of stroke, they could be used as yardsticks to assess progress towards those targets, as well as to determine the efficacy of therapeutic interventions adopted to address this important goal. Furthermore, establishing objective information about PA after stroke could be important for our understanding of the mediating effect of PA on neuroplasticity and functional recovery after stroke. The literature suggests that aerobic exercise facilitates neuroplasticity through the production of brain-derived neurotrophic factor, which, in turn, allows the central nervous system to undergo structural and functional changes as a response to PA (for review see (38)). Understanding of the relationship between these mechanisms of neural plasticity and PA may facilitate the development of novel effective rehabilitation interventions (39).

Although the present sample size was appropriate for a feasibility study, we used convenience sampling from one rehabilitation centre, which probably resulted in inadequate representation of the heterogeneity of survivors of stroke attending inpatient rehabilitation. Thus, the generalization of our results might be somewhat limited. Future large-scale studies should be carried out to confirm whether our findings are generalizable to the population of people with stroke in need of inpatient rehabilitation, including persons with cognitive impairment. Furthermore, the cut-off points used to define PA intensities (sedentary, light, and MVPA) are not stroke specific as they have been developed for older adults (30). To improve the accuracy of PA assessment in the stroke population, it is important to develop PA intensity cut-offs specific for the disabilities experienced by the stroke population.

In conclusion, this study supports both the process and the scientific feasibility of using accelerometers to capture PA behaviour in stroke survivors during inpatient rehabilitation. Our findings suggest that the volume and time spent in high-intensity PA increased during rehabilitation, whereas sedentary time remained unchanged. Accelerometers could be a useful method in the development of programmes aimed at improving PA early after stroke by aligning rehabilitation content with desired PA patterns and intensities.

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