Analyzing Free-Living Physical Activity of Older Adults in Different Environments Using Body-Worn Activity Monitors

P. Margaret Grant, Malcolm H. Granat, Morag K. Thow, and William M. Maclaren

This study measured objectively the postural physical activity of 4 groups of older adults (≥65 yr). The participants (N = 70) comprised 3 patient groups—2 from rehabilitation wards (city n = 20, 81.8 ± 6.7 yr; rural n = 10, 79.4 ± 4.7 yr) and the third from a city day hospital (n = 20, 74.7 ± 7.9 yr)—and a healthy group to provide context (n = 20, 73.7 ± 5.5 yr). The participants wore an activity monitor (activPAL) for a week. A restricted maximum-likelihood-estimation analysis of hourly upright time (standing and walking) revealed significant differences between day, hour, and location and the interaction between location and hour (p < .001). Differences in the manner in which groups accumulated upright and sedentary time (sitting and lying) were found, with the ward-based groups sedentary for prolonged periods and upright for short episodes. This information may be used by clinicians to design appropriate rehabilitation interventions and monitor patient progress.

Keywords: postural activity, sedentary behavior, activity profiles

In clinical practice one of the principal aims in the rehabilitation of older adults is to maintain or increase physical activity. There are numerous health benefits attributed to physical activity (Booth, Gordon, Carlson, & Hamilton, 2000; Chakravarthy, Joyner, & Booth, 2002; Pedersen & Saltin, 2006; World Health Organization, 2002), and there is evidence that conserving or increasing activity in older people maintains their function and independence (Keysor, 2003; Laukkanen, Leskinn, Kauppinen, Sakari-Rantala, & Heikkinen, 2000; Nelson et al., 2007; Taylor et al., 2004; Van der Bij, Laurant, & Wensing, 2002). More recently, the detrimental effects on health of sedentary behavior have been highlighted (Hamilton, Hamilton, & Zderic, 2007; Hamilton, Healy, Dunstan, Zderic, & Owen, 2008), and it is apparent that it is not only the total sedentary time that is of concern but also the length of continuous sedentary periods (Healy et al., 2008). This knowledge highlights the need for accurate measurement of inactivity, as well as physical activity, in older adults.

In facilities dealing with the care of older adults, an individual’s status and progress are often measured by performance on functional tests. Because functional
outcome measures reveal what a person is capable of in a specific test rather than what the individual does throughout the day, these tests provide only part of the full picture to the clinician. The advent of body-worn activity monitors has allowed researchers and clinicians greater opportunities to discover what people actually do throughout the day in respect to both physical activity and inactivity. The data gathered from this type of monitoring are information rich and present a challenge to researchers and clinicians in deciding which information is significant when assessing an individual.

This article presents data recorded by body-worn activity monitors from three groups of patients receiving physiotherapy with the specific treatment goal of increasing general physical activity and mobility. Data from a convenience sample of healthy older adults are also presented to provide some context in which to consider the activity of the patient groups.

The primary purpose of this study was to investigate the differences in upright time (standing and walking) between the four groups. Specifically, differences in upright time across the hours of the day and days of the week were explored. The secondary aim of the study was to quantitate, in the four groups, patterns of sedentary behavior and upright activity during the daytime (8 a.m. to 8 p.m.).

**Method**

**Participants**

The patient groups were recruited from two Scottish hospitals, one situated in a city and the other in a rural location. Patients were considered for the study if they were medically stable and undergoing active physiotherapy in which promoting physical activity was central to their management. Individuals were excluded if they required substantial external assistance with mobility as demonstrated by a score of less than 10 on the Elderly Mobility Scale (Smith, 1994) or were cognitively impaired with an Abbreviated Mental Test score below 7 (Hodkinson, 1972). These measures were routinely recorded in the clinical units. Two patient groups were recruited from the city hospital: one group comprised community dwellers who were attending a day hospital and the second included inpatients from a rehabilitation ward. The rural hospital group consisted of ward-based patients undergoing rehabilitation. The wards in the city and rural hospitals provided similar rehabilitation care for the patients. A convenience sample of healthy older adults, to provide context, was recruited through contacts of university colleagues.

Approval for the study was granted by the ethics committee of the School of Health and Social Care, Glasgow Caledonian University, NHS Greater Glasgow, Clyde West Glasgow Ethics Committee, and NHS Borders Ethics Committee. The purpose of the study and the consequences of taking part were discussed with all individuals, and informed written consent was obtained from all participants.

**Instrument**

The activPAL (PAL Technologies Ltd., Glasgow, UK) is a small, single-unit, uniaxial, accelerometer-based system that can continuously monitor activity for up to 10 days. The monitor attaches to the front of the thigh, under clothing, and
when in position is unobtrusive and does not impede movement, making it suitable for use with older adults. The system produces a real-time signal conveying thigh inclination and limb movement. From this signal, proprietary software classifies posture as sitting/lying, standing, or walking, allowing the measurement of both activity and inactivity. The data from the device are time stamped, allowing a comprehensive profile of the patterns of daily activity to be produced. Signal changes during walking permit step numbers and cadence to be calculated. In a pilot study with a comparable population the monitor was tolerated well by the users because the device itself requires no adjustment when worn. The monitor has been shown to be valid and reliable for measuring posture and postural transition in asymptomatic young adults (Godfrey, Culhane, & Lyons, 2007; Grant, Ryan, Tigbe, & Granat, 2006) and for step number and cadence in healthy young adults and community-dwelling older adults (Ryan, Grant, Tigbe, & Granat, 2006; Grant, Dall, Mitchell, & Granat, 2008).

Although the activPAL has been validated for use with younger adults and community-dwelling older adults, no validity data were available for frail older adults. Preliminary unpublished work undertaken by this research group compared direct observation with the activPAL in monitoring activity in frail elderly hospital patients (53 hr of recording). All postural transitions were correctly identified, so the monitor was considered valid for use in identifying upright and sedentary postures in this population. However, it was found that although the raw acceleration signal from the monitor identified lower limb movement in frail older adults, the software algorithms did not accurately classify the signals as steps. Consequently, when compared with observation, the monitor underrecorded step counts. It is extremely difficult to accurately quantify step numbers in this population, either visually or using an instrument, because patients are often hesitant, shuffle, and pause frequently in the course of a short walk. By whatever means of monitoring, this makes identifying purposeful steps very difficult, so in this study periods of standing and walking were combined to provide an outcome measure of upright time.

**Procedure**

The activPAL monitor was attached by a PALstickie (double-sided hydrogel adhesive pad) to the skin on the midline of the anterior aspect of the participant’s thigh. The monitor was worn at all times, except, because it is not waterproof, during bathing or showering. All participants were advised to renew the PALstickie after removal of the monitor and were both shown and given written instructions on how to replace the adhesive pad and position the monitor correctly. They were required to wear the monitors for 8 days to allow 7 full calendar days of data to be analyzed. Thirteen activPAL monitors were used in the study.

**Data Analysis**

The activity profile for every individual over the 7 days was inspected, and all abnormal periods of activity that appeared out of character for an individual were identified. Examples of these included protracted periods of standing during the night and prolonged sedentary spells during the daytime in an individual who, on other days, changed position regularly. The raw acceleration signals from the
abnormal periods were inspected in detail, and if the acceleration signal remained constant throughout, the monitor was considered to have been attached incorrectly and the data were excluded from the analysis.

All analyses were performed using SPSS version 16, GenStat release 11.1, and Excel. Demographic and functional differences between groups were analyzed with Kruskal–Wallis tests, and significant findings were explored further with Mann–Whitney tests. For each participant, the total upright time (standing and walking) for every hour of recording was calculated, and group data according to location were compared. The ANOVA factors in the study were location, day, and hour (fixed effects) and participants (random factor). The data set was unbalanced as a result of some missing values, so a restricted-maximum-likelihood estimation of the hourly time upright was required for the full analysis (Brown & Kempton, 1994; Diggle, Heagerty, Liang, & Zeger, 2002). After preliminary analysis using the restricted-maximum-likelihood-estimation model, plots of residuals versus predicted times upright showed pronounced inhomogeneity of variance. Specifically, the variation in time upright increased with mean time upright. A logarithmic transformation was applied to time upright (more precisely, to time upright plus 1 min, because zero times occurred throughout the data), and this produced approximate homogeneity of variance. A significance level of 5% was set for all testing procedures.

In this study, the time period between 8 a.m. and 8 p.m. was classified as daytime. This period was selected based on ward routines. The daytime activity was examined further, and each upright and sedentary posture was defined as an event. The length of each daytime upright and sedentary event was determined for all participants in each group and was assigned to a time category (<5 min, 5–10 min, 10–30 min, 30–60 min, or >60 min). For each group, the total time spent upright in each category of event was calculated as a percentage of the total time upright. This procedure was repeated for sedentary time. The patterns for the city- and rural-ward groups were very similar, so in this part of the study the two ward-based groups were considered together.

**Results**

**Participants**

In the patient groups, there were many clinical reasons for hospital admissions and referrals to the day hospital. In addition to the presenting condition, all patients had at least one coexisting disease. The common factors in the patient groups in this study were that they were medically stable, they had been considered suitable candidates for rehabilitation, and the primary objectives of physiotherapy were to increase mobility and promote physical activity.

Demographic details of the participants are presented in Table 1. The 2 ward-based patients were slightly older than the community-dwelling groups, and a Kruskal–Wallis test revealed a significant difference between the groups. Post hoc analyses found the differences to be between the community group and both ward groups and between the day-hospital and city-ward groups. No group differences were found for height, weight, or body-mass index.

The median and range of Abbreviated Mental Test scores for the groups are displayed in Table 1. Significant differences were found between the day-hospital
group and rural ward ($p = .05$) and between city ward and rural ward ($p = .04$). In both cases, the rural-ward group scored less than the city groups. No difference was found between the day hospital and city ward. The Elderly Mobility Scale scores are shown in Table 1. The median score in the day-hospital group was higher than in the ward-based groups, suggesting that, as a group, the day-hospital participants were functionally more able ($p < .01$). Using the same criterion, it can be inferred that the functional ability of the rural-ward group was superior to that of the city-ward group ($p < .01$).

**Activity Data**

Data from 70 individuals representing 11,760 hr of monitoring were retrieved for analysis, and 508 hr of data (4.3%) were excluded. The excluded data were primarily from the ward-based patient groups, and these lost data comprised 400 hr of recording, plus 84 hr from the day-hospital group and 24 hr from the healthy comparison group.

The daily upright (standing or walking) time for each group is presented in Table 2, and the mean values for each hour are displayed in Figure 1. The healthy group was most active, being upright for approximately 6 hr/day. The day-hospital group spent just under 4 hr/day walking or standing. The ward-based patients were

<table>
<thead>
<tr>
<th>Location</th>
<th>$M \pm SD$</th>
<th>Minimum</th>
<th>Maximum</th>
</tr>
</thead>
<tbody>
<tr>
<td>Community</td>
<td>360.4 ± 112.1</td>
<td>206.1</td>
<td>615.0</td>
</tr>
<tr>
<td>Day hospital</td>
<td>233.3 ± 112.5</td>
<td>47.5</td>
<td>404.1</td>
</tr>
<tr>
<td>Ward (city)</td>
<td>70.3 ± 50.4</td>
<td>16.1</td>
<td>141.4</td>
</tr>
<tr>
<td>Ward (rural)</td>
<td>80.3 ± 41.1</td>
<td>17.9</td>
<td>139.1</td>
</tr>
</tbody>
</table>

**Table 1** Participant Characteristics

<table>
<thead>
<tr>
<th></th>
<th>Day hospital ($n = 20$)</th>
<th>City ward ($n = 20$)</th>
<th>Rural ward ($n = 10$)</th>
<th>Community ($n = 20$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Male:Female ($n$)</td>
<td>9:11</td>
<td>4:16</td>
<td>2:8</td>
<td>10:10</td>
</tr>
<tr>
<td>Age (years), $M \pm SD$</td>
<td>74.7 ± 7.9</td>
<td>81.8 ± 6.7</td>
<td>79.4 ± 4.7</td>
<td>74.0 ± 5.3</td>
</tr>
<tr>
<td>Height (m), $M \pm SD$</td>
<td>1.6 ± 0.1</td>
<td>1.6 ± 0.1</td>
<td>1.7 ± 0.1</td>
<td>1.7 ± 0.1</td>
</tr>
<tr>
<td>Weight (kg), $M \pm SD$</td>
<td>70.4 ± 15.4</td>
<td>63.7 ± 14.5</td>
<td>70.9 ± 9.2</td>
<td>73.1 ± 15.4</td>
</tr>
<tr>
<td>Body-mass index (kg/m²), $M \pm SD$</td>
<td>26.8 ± 6.4</td>
<td>25.4 ± 5.8</td>
<td>25.3 ± 2.4</td>
<td>25.6 ± 5.1</td>
</tr>
<tr>
<td>AMT (0–10), median (range)</td>
<td>10 (8–10)</td>
<td>10 (7–10)</td>
<td>9 (7.5–10)</td>
<td>n/a</td>
</tr>
<tr>
<td>EMS (0–20), median (range)</td>
<td>17 (12–20)</td>
<td>11 (10–18)</td>
<td>15 (11–17)</td>
<td>n/a</td>
</tr>
</tbody>
</table>

*Note.* AMT = Abbreviated Mental Test; EMS = Elderly Mobility Scale.
**Figure 1** — Mean time upright by hour and location.
considerably less active than both community groups, spending just over an hour each day upright (city 70.3 min and rural 80.3 min).

The hourly pattern (Figure 1) clearly shows an increase in activity from 6 a.m., with the healthy community and day-hospital groups peaking around 12 p.m. In these community-based groups there was a dip in activity after 12 p.m., followed by a slight increase in the afternoon before decreasing in the evening. The patterns of activity of the two ward groups were fairly similar, with low levels of activity throughout the day.

No obvious variations in group activity were revealed when the data were considered according to the day of the week (Figure 2). The activity of the healthy community-based group and the day-hospital group dipped slightly on Sunday, whereas the activity of the ward-based groups was relatively constant across the week. There was more variation in the upright time of community groups, with standard deviations ranging from 12 to 18 min between days. In the ward-based groups, the standard deviations ranged from 4 to 6 min. When the data were considered together, the mean hourly upright time on Sunday was less than the other days of the week. However, the actual decrease in activity was less than a minute.

The restricted-maximum-likelihood-estimation analysis revealed no significant interactions between location and day, day and hour, or location, day, and hour. An additional random effect, the interaction between participant and day, included to test for day-to-day differences in between-participants variability, was also found to be nonsignificant. Significant differences were found between day, hour, and location (all \( p < .001 \)), and the interaction between location and hour was also significant (\( p < .001 \)). Further analysis revealed no significant difference in mean time spent upright averaged over day and hour between the city ward and rural ward.

The length of sedentary and upright events throughout the day (8 a.m. to 8 p.m.) demonstrated group differences in activity patterns (Figure 3). Three distinctly different patterns of activity occurred. For ward patients (Figure 3[a]) almost 70% of total upright time was accrued in short standing or walking events of less than 5 min duration. In this group, upright events lasting 30–60 min were responsible for only 1.2% of total upright time, and nobody in this group was upright for a continuous period lasting more than an hour. The sedentary behavior reveals an inverse pattern in which most sitting or lying time (60.5%) was accumulated in sedentary periods longer than an hour. In this group, shorter sitting events were responsible for only a small amount of the total sedentary time.

In comparison with the ward patients, those attending the day hospital were more likely to be upright for longer periods at a time (Figure 3[b]). Although sedentary events were less likely to be excessively long (>1 hr), most sedentary time (61.9%) in day-hospital patients was accumulated in events lasting more than 30 min. The healthy community participants showed greater variation in how upright and sedentary time were accumulated (Figure 3[c]).
Figure 2 — Mean hourly time upright by day and location.
Figure 3 — (a) Ward, (b) day-hospital, and (c) community daytime upright and sedentary time represented by event length (error bars represent 1 SD).
Discussion

Using a single body-worn activity monitor, it was possible to quantify and compare, over an extended time period, the physical activity of four groups of older adults (≥65 years). The findings from this cross-sectional observational study provide a novel description of the physical activity and sedentary behavior of older adults in different settings. This study has shown that there are clear differences between the groups and has identified where variations in sedentary behavior and physical activity occur. The causal factors responsible for the variations have not been explored; however, there were differences between the groups in terms of age and cognitive and functional abilities as measured by the Abbreviated Mental Test and Elderly Mobility Scale.

There were significant differences in upright time between location, hour, and day and in the interaction between location and hour. The difference in upright time between locations (Table 2) was anticipated because of the contrast in the health status of the groups. Further analysis found no difference between the ward-based groups, which was not surprising because both units were caring for older adults with similar problems and health needs.

The monitor was worn continuously, allowing a full profile of daily activity to be collected, and the variation of activity over the 24-hr period, in all locations, is apparent in Figure 1. The increased activity in the daytime was most noticeable in the community dwellers. This finding reflects a recent Actigraph accelerometer study involving healthy older adults, in which significantly more activity was observed in the morning and afternoon than in the evening (Copeland & Esliger, 2009).

The significant difference in mean hourly upright time between days was most likely a result of the overall drop in activity on Sunday (Figure 2). Although statistically significant, the size of the difference was less than a minute every hour, so the impact of this on health is equivocal.

The healthy community group was sedentary for about 18 hr/day. When daytime activity was considered (8 a.m. to 8 p.m.), the sedentary behavior amounted to roughly 7 hr, or 57.5% of the day. These findings are comparable to those of Matthews et al. (2008), who reported that adults age ≥60 years in the United States were sedentary for approximately 60% of their waking day. In the American study, energy expenditure was measured indirectly by Actigraph accelerometers, and sedentary behavior was identified using activity count values. It is therefore possible that some quiet standing periods may be classified as sedentary by the Actigraph but upright by the activPAL monitor. On average, the Actigraph was worn for 13.9 hr/day, whereas in the current study the daytime calculation was for 12 hr (8 a.m. to 8 p.m.). It is evident from Figure 1 that activity is lower outside these hours, and it is likely that the percentage of sedentary time would increase slightly if all waking hours were considered. Despite the methodological differences in the two studies, the findings are remarkably similar.

The overall low levels of physical activity among the ward-based groups were anticipated because similar findings have been reported for older patients and people in care (Callen, Mahoney, Grieves, Wells, & Enloe, 2004; MacRae, Schnelle, Simmons, & Ouslander, 1996; Patterson, Blair, Currie, & Reid, 2005). It has been suggested that walking is the most important activity to measure in sedentary populations (Tudor-Locke & Myers, 2001), but accurate objective recording of
steps in the frail elderly is challenging (Cyarto, Myers, & Tudor-Locke, 2004; Le Masurier, Lee, & Tudor-Locke, 2004) and upright activity may be a more realistic outcome measure in this patient group. The brief active upright times displayed by the ward-based patients were interspersed with prolonged sedentary periods (Figure 3[a]). Prolonged sedentary behavior has been shown to have detrimental effects on health (Healy et al., 2008), so these findings should be of concern. To increase general physical activity in this population, rehabilitation goals should focus on breaking up the inactive periods and increasing overall upright time. These goals could be achieved by increasing the number and extending the length of upright events (including standing and walking).

Promoting walking in rehabilitation wards for older adults can present a dilemma to hospital staff because patients are at a greater risk of falling than people in the community (National Health Service, 2008). Despite the undisputed beneficial effects of physical activity, the tension between promoting physical activity and preserving patient safety may result in limited encouragement for patients to be independently active. The problem is escalated in this patient group because many may be affected by multiple risk factors associated with falls (Skelton & Todd, 2004) and they might be reluctant to stand up because of a fear of falling. The motivation and opportunity to be active can be limited for patients in ward settings because many interactions occur at the patients’ bedside or in the day room. Consequently, a false perception of general activity in the ward may be derived from the steady traffic of staff and relatives (Mackey, Ada, Heard, & Adam, 1996).

The total upright time (Table 1) and the activity patterns of the patients attending the day hospital (Figure 3[b]) were different from the ward-based group, with day-hospital patients being physically more active. It is reasonable to assume that these patients were further along the rehabilitation pathway and had returned to, or remained in, the community because they were independent or required minimal support. The cross-sectional design of this study does not allow mobility changes during the rehabilitation process to be revealed, and further research is required to determine whether the activity differences between ward and day-hospital patients are the result of ability, opportunity, or motivation.

In this study all participants were compliant and wore the monitors, but some data were excluded from analysis. Most of the excluded data came from the inpatient groups, who, compared with the other participants, probably required more external assistance in bathing and other activities of daily living. It is possible that ward routines involving different personnel resulted in some monitors being positioned incorrectly or left unattached for extended periods. It is unlikely that the missing data had any impact on the overall results because the total time excluded was 3.2% of the total, with 6.8% of inpatient time being lost.

These results should be interpreted with some caution because the groups were not controlled for many factors known to influence physical activity in healthy adults, such as gender, socioeconomic status, and medications (Chad et al., 2005; Strath, Swartz, & Cashin, 2009). As for recruiting a healthy comparison group, it is likely that activity research is of greater interest to active than inactive people, so the sample may not be representative of the general population. One of the limitations of this study is that the activity monitor provided postural data and was unable to describe the behavior and interactions of the participants. The hospital clinicians also reported that some therapy sessions involved seated activity classes,
and, because of the attachment of the monitor to the thigh, upper limb and trunk physical activity were not recorded.

It has been noted that research providing objective information concerning the physical activity of older adults is limited, even though physical activity and sedentary behavior are pertinent to health in this age group (de Bruin, Hartmann, Uebelhart, Murer, & Zijlstra, 2008). Common outcome measures used in clinical practice can indicate physical capacity, but these tests do not reveal the actual physical activity performed by individuals (Ashe, Eng, Miller, & Soon, 2007). This study addressed that deficit and provided detailed, objective data on the physical activity of hospitalized and community-dwelling older adults over an extended time period. The manner in which active and inactive periods are accumulated has not previously been explored, and we suggest that this may be relevant as an outcome measure in the early rehabilitation of older adults.

Acknowledgments

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