ORIGINAL ARTICLE

Effect of wearing an activity monitor on the amount of daily manual wheelchair propulsion in persons with spinal cord injury

JBj Bussmann¹, MA Kikkert^{1,2}, TAR Sluis², MP Bergen², HJ Stam¹ and HJG van den Berg-Emons¹

¹Department of Rehabilitation Medicine, Erasmus, MC University Medical Center, Rotterdam, The Netherlands and ²Rijndam Rehabilitation Centre, Rotterdam, The Netherlands

Study design: An experimental study.

Objectives: To assess the effect of reactivity related to wearing a multi-sensor activity monitor (AM) on the amount of manual wheelchair propulsion during daily life in wheelchair-bound persons with spinal cord injury (SCI). In addition, to establish the subjectively experienced burden of wearing the AM.

Setting: Rehabilitation centre and home-based study.

Methods: In 10 persons with SCI, during a 7-day period, the daily amount of manual wheelchair propulsion was measured by means of a rotation counter. During this period, an AM was worn for 1 day (AM+ day) by the participants. Experienced burden was measured by a questionnaire based on visual analogue scale scores.

Results: The overall median of the number of rotations per minute was 1.38 (range 0.63–1.83). No significant difference was found in the amount of daily manual wheelchair propulsion between AM+ and AM− days ($P=0.33$, median difference: -0.06 rotations per minute). Experienced burden was not different between subgroups that differed in reactivity.

Conclusion: The results seem to indicate that wearing the AM of this study does not systematically influence the amount of daily manual wheelchair propulsion. Although low to moderate burden was experienced when wearing the AM, this does not seem to affect the amount of manual wheelchair propulsion.

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Introduction

Many persons referred to a rehabilitation specialist have loss of motor function and, as a consequence, are at risk of developing an inactive lifestyle with possible detrimental effects on physical fitness, social participation, and quality of life.^{1–5} In addition, an inactive lifestyle may increase the risk of developing secondary health problems, such as cardiovascular disease.^{6,7}

Several techniques can be used for assessment of physical activity,⁸ but instruments based on body-fixed motion sensors—generally referred to as actigraphs, actometers, and activity monitors—are increasingly used. These devices provide data on the amount of physical activity and/or energy expenditure during daily life, or give more detailed information on body postures and motions. They may differ considerably in characteristics (e.g. size and weight, number

and type of sensors, site of attachment, maximal number of measurement days, outcome measures), but have in common that they objectively measure actual daily behaviour in a person's own environment during a prolonged time period.⁹

Although motion-sensor-based instruments have their advantages, such as objectivity and measurement of actual behaviour, other factors potentially threaten their validity and, therefore, limit their usability. One such factor is participant reactivity, which refers to the mechanism, whereby persons adapt their normal behaviour because they are being observed or studied.¹⁰ Reactivity can be attributed not only to awareness, but also to experiencing burden from the instrument. This latter component will probably have a greater function when larger, heavier, more complex, and bulky systems are involved.

One of the devices that measures daily life behaviour in a person's own environment is the Activity Monitor (AM), which is based on multiple body-fixed sensors providing 1-s detection of a large set of body postures and motions (Figure 1). Although this AM has been extensively validated

Correspondence: Dr JBj Bussmann, Department of Rehabilitation Medicine, Erasmus MC University Medical Center, PO Box 2040, Rotterdam, 3000 CA, The Netherlands.

E-mail: j.b.j.bussmann@erasmusmc.nl

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Figure 1 The configuration of the AM. An 'S' indicates each sensor and an 'R' the recorder.

and used in several patient groups,^{11,12} earlier studies did not explore the validity aspects related to reactivity. To our knowledge, reactivity has not been studied in other motion-sensor-based devices.

As one of the activities detected by the AM is manual wheelchair propulsion, the AM can be used in wheelchair-dependent populations, such as patients with spinal cord injury (SCI).¹² The main aim of this study was to assess the effect of reactivity related to wearing the AM on the amount of manual wheelchair propulsion during daily life in a wheelchair-bound SCI sample. To gain insight into the role of the burden component of reactivity, we also investigated the experienced burden of wearing the AM and whether this burden was related to a change in the level of manual wheelchair propulsion on the day the AM was worn.

Materials and methods

Protocol

Everyday physical activity was operationalized, as the amount of daily manual wheelchair propulsion was measured by a rotation counter (RC). The measurement started on Day 1 (being Monday, Tuesday, or Wednesday) after the researcher had attached the AM and the RC, somewhere between 9.00 a.m. and 5.00 p.m. The AM was removed by the researcher at Day 3 (Wednesday, Thursday, or Friday, respectively) at the moment the patient had just awakened and had not done any wheelchair propulsion, generally about 8.00 a.m. The RC registration continued until Day 8 (Monday, Tuesday, or Wednesday of the next week, respectively), when it was stopped somewhere between 9.00 a.m. and 5.00 p.m. Owing to this protocol, the measurement period also included the weekend days. Before the measurement, the participants were instructed to continue their ordinary daily life during the measurement period. However,

Table 1 Characteristics of the study population

Subject	Age (years)	Sex	Tetra/para plegia	ASIA score completeness ¹³	Rehabilitation phase
1	53	M	Para	A	T2
2	55	F	Para	A	T4
3	49	M	Para	A	T3
4	64	M	Para	A	T2
5	58	M	Tetra	B	T1
6	43	M	Tetra	B	T2
7	24	M	Tetra	A	T1
8	56	M	Para	A	T3
9	26	M	Tetra	A	T3
10	42	F	Tetra	A	T4

Abbreviations: ASIA impairment scale A, complete; ASIA impairment scale B, incomplete; F, female; M, male; T1, subject is able to sit in the wheelchair for at least 4 h; T2, 3 months after T1; T3, at discharge from the rehabilitation centre; T4, 1 year after discharge.

participants were not allowed to swim or take a bath or shower on the days they wore the AM.

Participants

Subjects with SCI who were completely dependent on a manual wheelchair were recruited from the Rijndam Rehabilitation Centre (Rotterdam, the Netherlands). Subjects in four different stages of the rehabilitation process were recruited (Table 1). Exclusion criteria were using more than one wheelchair or more than one pair of wheels, a mental disorder restrictive for participation (as assessed by a physician), insufficient knowledge of the Dutch language, and the wheelchair not suitable for attachment of the RC. To avoid measurement bias, we did not explain the study aims to the participants until after all measurements had been made; all participants agreed with this procedure. The Medical Ethics Committee of Erasmus Medical Centre Rotterdam approved the study and written informed consent was obtained from all participants. We certify that all applicable institutional and governmental regulations concerning the ethical use of human volunteers were followed during the course of this research.

Activity monitor

The AM configuration used in wheelchair-dependent subjects consists of a portable data recorder (9 × 15 × 1 cm, 700 g), six piezo-resistive accelerometers (1.5 × 1.5 × 1.0 cm), and a three-electrode bipolar lead system for electrocardiogram. Using adhesive material, two accelerometers are fixed to the participant's sternum: one accelerometer to each upper leg and one to each forearm. Each accelerometer and the electrocardiogram leads were connected with a data recorder, which was placed in a belt worn around the waist.¹¹

Instruments

Rotation counter. To measure the number of rotations of the wheelchair wheel, we developed the RC consisting of a magnet, magnetic field sensor, and data recorder. The sensor was attached to the frame of the wheelchair, and the magnet was attached to the wheel spokes (Figure 2). The data

Figure 2 Rotation counter attached to the wheelchair: the magnet (M) is placed in the wheel spokes and the sensor (S) on the frame of the wheelchair. The data logger is not visible.

Table 2 Experienced burden of wearing the activity monitor as assessed with a visual analogue scale

Burden category	n	Median (range)
<i>Device related</i>		
Belt and bag	10	4.4 (0.3–9.3)
Cables	10	2.3 (0–7.8)
Adhesive plasters	10	4.3 (0–9.6)
Device sub-score	10	4.0 (0.4–7.8)
<i>Activity related</i>		
Self-hygiene	10	4.9 (0–9.5)
Manual wheelchair propulsion	10	0.8 (0–3.9)
Making transfers	9	3.5 (0–7.3)
Using the lavatory	6	2.7 (0.3–7.6)
Sleeping	10	3.5 (0.1–7.8)
Activities sub-score	10	2.5 (1.5–5.6)

recorder ($9 \times 15 \times 3.5$ cm, 500 g) was placed in a bag and attached to the back of the wheelchair. Whenever the magnet passed the sensor, a block pulse was generated, which was stored on the data recorder (sample frequency 64 Hz). After measurement, the data were downloaded to a computer. Consecutive pulses with an interval smaller than 0.4 s were considered as being one pulse (for example, when the participant wobbled in the wheelchair).

The validity of the RC we used in this study was checked beforehand in several trial tests. In these tests, a subject manually propelled a wheelchair at different velocities and in different circumstances (outdoors and indoors). Observation counts were compared with the data from the RC. The agreement between the number of counted rotations and the registered number of pulses recorded by the data recorder was >99%.

Experienced burden questionnaire. A specially compiled eight-item questionnaire was used to obtain insight into the experienced burden of wearing the AM (Table 2). The items

of this questionnaire were based on our earlier experience in clinical AM studies in many patient groups with chronic conditions, SCI populations included, and in consultation with physical therapists and rehabilitation specialists with extensive experience in SCI. Each item was assessed by a horizontal visual analogue scale (VAS; 0 = no burden at all and 10 = maximal burden). Three items were device related, and the remaining five were activity related. Assessment of experienced burden took place at the end of the measurement period (at Day 8).

Diary. All subjects filled in a daily log and registered the estimated total duration of the periods that other people pushed their wheelchair. Participants also registered the time of going out and in bed and whether a day had been 'typical' and, if not, the reasons for this (for example, sickness, hospital visit).

Data analysis

Data of the first measurement day (Day 1) and of the weekend days were not included in the analysis. This resulted in one registration day with the AM (AM+) and three registration days without the AM (AM–). In addition, also excluded from analysis were those measurement days when a day was indicated as not being 'typical' for normal daily activity and which was not related to wearing the AM. Days on which a participant was pushed in the wheelchair by someone else for more than 30 min were included in the analysis of the effects of reactivity.

Registered data were analysed with a custom-made programme, providing the overall number of rotations per day as measured with the RC. The moment of the first and the last registered pulse on the RC was used to calculate the minutes per day of the participant being awake, which was checked from the diary. The number of rotations was also time normalized by dividing the number of rotations by the number of minutes, resulting in the average number of rotations per minute for awake hours.

Statistics

For statistical analysis, the SPSS version 12.0 was used. On account of the number of participants included, we used medians and ranges in descriptive analyses, and non-parametric tests to make comparisons between days and groups. To assess the effect of wearing the AM on the level of daily manual wheelchair propulsion, the number of rotations (absolute and per minute) on the AM+ day was compared with the average number of rotations on the AM– days (Wilcoxon signed rank test). For assessment of between-day differences in these days, we used the Friedman test. An α -level of 0.05 was used to indicate a significant effect.

Results

A total of 10 subjects with SCI were included in the study, with a median age of 51 years (Table 1). On account of technical problems, no RC data was recorded for the third

AM– day for subject 2, and for the second and third AM– days for subject 5. No days were excluded for other reasons, and none of the participants was pushed in the wheelchair by someone else for more than 30 min on a particular day. The median duration of the awake period on the AM+ day was 777 min (range 526–983) and on the AM– days 792 min (range 547–970); this difference is not significant ($P=0.24$). As the results of the absolute and time-normalized RC data were similar, we only present the time-normalized data.

Reactivity effect of wearing the AM

Figure 3 shows the time-normalized daily manual wheelchair propulsion of the individual participants on the AM+ day and on each AM– day. Figure 4 presents averaged data on the

Figure 3 Amount of manual wheelchair propulsion during the day that the AM was attached (AM+) and during the 3 days without the AM (AM–). In participant 5, data were available only for the AM+ day and the first AM– day, and in participant 2, only for the AM+ day and the first and second AM– day.

Figure 4 Amount of manual wheelchair propulsion during the day the AM was attached (AM+), the mean over the 3 days without the AM (AM–), and their difference (AM+ minus AM–).

AM– days and differences compared with the AM+ day. The overall median number of rotations per minute was 1.38 (range 0.63–1.83). There was no significant difference in the amount of daily manual wheelchair propulsion between the AM+ and the average of the AM– days (Wilcoxon; $P=0.33$, median difference: -0.06 rotations per minute), neither were there differences between all measurement days (Friedman; $P=0.44$). A more detailed analysis showed that five subjects (2, 4, 6, 8, and 9) were less active on the AM+ day (median difference: -0.38 rotations per minute), whereas the amount of manual wheelchair propulsion on the AM+ day was about the same as or higher in the other five subjects (median difference: $+0.08$ rotations per minute). On the basis of this finding, we divided the sample in an 'effect group' and a 'non-effect group', respectively.

Experienced burden

The median VAS score of the device-related and activity-related items was 4.0 and 2.5, respectively (Table 2). From the activity-related items, manual wheelchair propulsion was the item with the lowest burden (median score: 0.8; median VAS score of the other activity-related items: 3.8). On the basis of Mann–Whitney test, no significant differences were found between the effect and non-effect group for the device sub-score ($P=0.92$; median VAS score: 4.4 vs 5.3, respectively), for the activities sub-score ($P=0.31$; 4.2 vs 2.2), and for the item manual wheelchair propulsion ($P=0.12$; 1.3 vs 0.5).

Discussion

The most important finding among our study population is that wearing the AM does not seem to lead to a systematic reactivity effect on the amount of manual wheelchair propulsion during a day. The validity studies performed so far focused on concurrent validity and did not include threats of validity related to the effects of wearing the AM.^{11,12} Therefore, the results of the present study provide additional support for the validity of AM measurements.

The between-day variability within participants was relatively high; *post hoc* analyses showed a between-day variance of 0.20 rotations per minute. This indicates that when the AM is used in clinical practice, a 1- or 2-day measurement focusing on the amount of manual wheelchair propulsion may not be sufficient to record habitual physical level of a person. Owing to the load on the patient, the current configuration of the AM does not allow a measurement period of more than 2 days. This may not be a problem in group studies, but when reliable statements are required on the individual level, more measurement days will be needed. In the literature, a 5- or 7-day period is recommended.^{14,15} Other devices, such as the activPAL,¹⁶ already allow measurements for a week or longer. Besides that, the activPAL is one of the few instruments that is used to assess long-term mobility in an SCI population. However, although originally a body-fixed system, in the reported study¹⁶ it is attached to the wheelchair and, therefore, it

classifies, in contrast to the AM of this study, all types of wheelchair movement, that is being pushed and movement of an electric wheelchair included. In the near future, the AM will be updated to a wireless system that allows measurement for over 5 days.

In the present study, because of the large variation between and within subjects, as well as the relatively small study sample, a type II error may have occurred, which means that an actual, but probably small or medium effect has not been detected. However, data are mainly suspected to have a type II error if a relevant difference exists that is not significant. The median of the difference between the AM+ and AM- days (-0.06 rotations per minute) is sufficiently small that we feel that this issue is not of primary importance. However, some caution is needed when interpreting the results.

Reactivity encompasses both awareness and experienced burden. The present study explored the combined effect of both these components; the study design does not allow a clear distinction between and separation of these two components. The results from the burden questionnaire indicate a low to moderate experienced burden of wearing the AM. The scores of burden during specific activities were relatively low, with the lowest scores during manual wheelchair propulsion. This suggests that although people may experience a burden of wearing the AM, this burden is especially small during manual wheelchair propulsion. Furthermore, the results do not indicate that experienced burden is related to the effect of wearing the AM, although caution is required when drawing conclusions. In addition, the results do not rule out the effect of the AM on activities other than manual wheelchair propulsion. For example, the AM does not allow bathing and showering, which may prevent participants from sporting or other strainful activities. The results do not suggest that this effect occurred, but this still has to be kept in mind.

Comparing our results with other studies is difficult because data on this topic are scarce and variable. Moreover, the effects of wearing an AM will depend to some extent on the characteristics of the study population and on the device itself. For example, Warms and Belza¹⁷ investigated the acceptability of a wrist-worn monitor in subjects with SCI and reported an acceptable level of burden when wearing the device. However, such results do not necessarily indicate that reactivity (and especially the awareness component) is not an issue. Compliance is another topic to be considered.^{14,15} For our AM measurements, however, compliance is not an issue because the subjects cannot detach the instrument by themselves. It can be stated that reactivity is an issue, which is commonly overlooked in the field of measurement of physical activity, and our study must be considered as a first step. Future studies should focus on activities other than manual wheelchair propulsion (e.g. walking), on other patient groups, and on the determinants of reactivity; for example, activities related to personal characteristics (such as age), disease characteristics (such as lesion level), stage of the rehabilitation process, and activity level. In addition, because reactivity will probably be associated

with device characteristics, results from studies similar to this one cannot be automatically generalized to other devices.

Limitations

Some study limitations need to be addressed. The between-day variability and the small study population have already been discussed. Furthermore, focusing on a specific population (SCI) and on a specific activity (manual wheelchair propulsion) limits generalization of the results. Finally, the disadvantage of an RC is that the registration itself gives no information as to who has propelled the wheel—the subject involved or someone else. We anticipated this problem by asking each subject for an estimation of the time that he/she was pushed in their wheelchair by someone else, and to look for differences between AM+ and AM- days. Although we did not observe any differences, some bias may be present.

Conclusions

The results of this study seem to indicate that wearing the AM of this study does not systematically influence the amount of daily manual wheelchair propulsion. Although low to moderate burden was experienced when wearing this AM, this does not seem to affect the amount of manual wheelchair propulsion.

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