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Original Article

Validity of the detection of wheelchair propulsion as measured with an Activity Monitor in patients with spinal cord injury

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Study design: Validation study.
Objectives: An accelerometry-based Activity Monitor (AM) has proven to be a valid instrument to quantify mobility-related activities (lying, sitting, standing, walking, cycling, general (noncyclic) movement). The aim of this study was to assess whether, additional to other activities, wheelchair propulsion (hand-rim wheelchair propulsion and handbiking) can be validly detected by the AM in patients with spinal cord injury (SCI).
Setting: Rehabilitation center.
Methods: In all, 10 patients with SCI (aged 19–63 years; five patients with poor triceps strength and five patients with good triceps strength) participated. Patients performed a series of representative daily life activities (involving wheelchair propulsion and nonwheelchair propulsion activities), according to a standard protocol, in a seminatural setting. Continuous registrations of signals from body-fixed accelerometers were made and the AM output (after automatic analysis) was compared with visual analysis of simultaneously made video recordings (reference method). Validity scores (agreement, sensitivity, specificity) between the output of the AM and the video analysis were calculated.
Results: Agreement, sensitivity and specificity for the detection of wheelchair propulsion were overall 92 (range, 87–96)%, 87 (76–99)% and 92 (85–98)%, respectively. Sensitivity was smaller in patients with poor triceps strength compared to patients with good triceps strength; 81 (76–89)% and 95 (89–99)%, respectively ($P<0.01$). Mean overestimation in duration of wheelchair propulsion by the AM was 3.9% ($P<0.05$).
Conclusion: Besides already validated other activities, wheelchair propulsion (hand-rim wheelchair propulsion and handbiking) can be validly detected by the AM in patients with SCI, both with good and poor triceps strength. Therefore, the AM offers the possibility to obtain objective and detailed information on all major mobility-related activities performed by patients with SCI.
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Keywords: spinal cord injury; activity monitor; activity detection; activities of daily living; physical activity; wheelchair propulsion

Introduction

Spinal cord injury (SCI) results in a permanent loss of motor, sensory and/or autonomic innervation below the level of damage of the spinal cord. As a consequence, patients with SCI are at risk of developing a hypoactive lifestyle, with possible detrimental effects on physical fitness, social participation and quality of life.[1–3] Furthermore, a hypoactive lifestyle may increase the risk of developing secondary health problems such as cardiovascular disease (CVD) and diabetes.[4,5] CVD is nowadays one of the major causes of morbidity and mortality in the SCI population.[6,7] Therefore, everyday physical activity is an important aspect and outcome measure of the rehabilitation process of patients with SCI. Currently, the (modified) Barthel Index (mBI or BI) and the Functional Independence Measure (FIM) are commonly used in research and clinical practice to assess everyday functioning in patients with SCI.[8–11] The (m)BI and the FIM are both measures of qualitative aspects of self-care and mobility, in which the perfor-

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Figure 1 A subject instrumented with the activity monitor

mance of activities of everyday life is scored by means of observation or interview.[12,13]

The Activity Monitor (AM, see Figure 1) enables the collection of objective and detailed information on several quantitative aspects of everyday physical activity. The AM is based on long-term (more than 24 h) ambulatory monitoring of signals from body-fixed accelerometers during everyday life, aimed at the assessment of mobility-related activities.[14] Information can be obtained on which body postures, motions, and transitions between postures are performed, when, how often, and for how long. Information on the intensity of activities (motility) can also be obtained from the device. Apart from monitoring accelerations, other signals can be measured simultaneously, such as heart rate or ECG.

The aim of the present study was to assess whether wheelchair propulsion (hand-rim wheelchair propulsion and handbiking) can be validly detected by the AM in the SCI population. Validity studies in healthy subjects and in several patient groups, in which simultaneously made video recordings (reference method) were compared with the outcome of the AM, have shown that the AM is a valid instrument to quantify mobility-related activities (lying, sitting, standing, walking, cycling, and general (noncyclic) movement).[14–18] However, the validity of the additional detection of wheelchair propulsion has not yet been established.

If wheelchair propulsion can be validly detected by the AM, this would be of added value for the assessment of everyday physical activity in SCI. In contrast to the (m)BI and FIM, the AM provides objective information on quantitative aspects of activities. A few studies have objectively quantified the level of physical activity in patients with SCI using either a 'rest-time monitor' or a 'Large Scale Integrated Activity Monitor'.[1,19] The AM differs from both these instruments in that, besides assessment of the level of everyday physical activity, the activities and postures can also be specified. Recently, Ding *et al* used in patients with SCI, a data-logger, which was attached to the wheelchair, to assess the distance traveled.[20] The AM differs from devices such as this in that, with the AM, 'active' wheelchair propulsion (wheelchair propulsion as a result of arm power) can be distinguished from 'passive' wheelchair propulsion (eg being pushed while sitting in a wheelchair or by electrical power). Furthermore, the AM provides not only information on wheelchair propulsion but also on other everyday life activities in patients with SCI (lying, sitting, standing, walking, cycling, general (noncyclic) movement). Finally, the option to simultaneously measure ECG by the AM makes it possible to obtain information on physical strain during activities in everyday life.

Materials and methods

Patients

In all, 10 patients with SCI were selected at convenience from the patient group receiving treatment in the Rijndam Rehabilitation Center (Rotterdam, The Netherlands). Inclusion criteria were: age 18–65 years, tetraplegia or paraplegia resulting from SCI (ASIA impairment scale A–D),[21] (partly) wheelchair dependent, and hand-rim wheelchair propulsion by use of two hands.

Depending on the ability to use the triceps actively, patients with SCI show a different movement pattern of the arms to propel the wheelchair. Patients with good strength of triceps brachii muscle (triceps strength; C7 or below) have a pushing movement, whereas patients with poor or no triceps strength (C6 or above) have a pulling movement, initiated from the shoulders with an important role for the biceps muscle.[22] Furthermore, wheelchair propulsion velocity and maximal achieved cadence are significantly lower in patients with C6 SCI than in patients with SCI below the C6 level.[23] To account for these differences in the wheelchair propulsion technique, five patients with poor triceps strength and five patients with good triceps strength were selected. The strength of the triceps was scored on a 6-point scale according to the criteria of 'manual muscle testing'.[24] A sum score of left and right triceps strength $\leqslant 6$ was considered to be poor, a sum score >6 was considered to be good. Furthermore, because handbiking is a faster and more efficient form of propulsion[25] and therefore becoming increasingly popular for moving outdoors, the group was compiled such that at least three of the patients regularly use a handbike.

The study was approved by the Medical Ethics Committee of the Erasmus MC, University Medical Center Rotterdam. Informed consent was obtained from all patients.

Testing procedure
The patients performed a series of consecutive activities according to a standard protocol in a seminatural setting (hallway of the rehabilitation center, and an apartment used for therapy and exercise). The protocol (Table 1) consisted of several activities which were assumed to be representative for everyday life in patients with SCI and included: (1) wheelchair propulsion (hand-rim wheelchair propulsion and handbiking), and (2) activities which could be falsely detected by the AM as wheelchair propulsion.

Patients were asked to perform the activities in their own manner, at their own pace and with their own aids. They performed only those activities which they were able to perform. The duration of each activity ranged from 2 to 4 min; total measurement time was about 45 min per patient. During the performance of activities, simultaneous measurements with the AM and video recordings (reference method) were performed.

Activity monitor
Six ADXL202 (Analog Devices, Breda, The Netherlands, adapted by Temec Instruments, Kerkrade, The Netherlands) piezo-resistive accelerometers (sensors) were used (size about $1.5 \times 1.5 \times 1\,cm^3$). The measured acceleration signal contains a component of the gravitational acceleration and of the inertial acceleration of the sensor.[14] One sensor was attached to the skin at each thigh and at each wrist, and two sensors were attached to the skin over the sternum using Rolian Kushionflex™; medical tape was used to consolidate the attachment. While sitting with the forearm horizontal in the midpro/supination position, the sensitive axis of the sensors at the thigh and wrist was in vertical direction, and the sensitive axes of the sensors attached to the sternum were in anterior–posterior and vertical direction. The sensors were connected to a portable Vitaport3™ data recorder (size: $9 \times 15 \times 4.5\,cm^3$, 700 g; Temec Instruments, Kerkrade, The Netherlands), which was carried in a belt around the waist (Figure 1).

Signals were digitally stored on a memory card (PCMCIA flash card) with a sampling frequency of 32 Hz. After the measurement, data were downloaded onto a computer for analysis. Automatic data analysis was performed by means of a proprietary program, based on the Signal Processing and Inferencing Language (S.P.I.L.™). In this automatic analysis, three parts can be distinguished (for more details see Bussmann *et al*[14]).

Table 1 The activity protocol

Being pushed towards the elevator
Driving towards the practice apartment
Opening the door, driving through the door opening and closing the door
Driving into the apartment towards a chair in the living room
Transfer to the chair
Leaf through a magazine
Transfer back to the wheelchair
Driving to the table
Preparing and eating a sandwich
Driving to the draining board
Doing the dishes (wash/dry a dish, glass, cup and saucer and silverware)
Driving to the bedroom
Transfer to the bed
Lying down, lying supine
Transfer to the wheelchair
Driving towards the hallway, opening the door and driving through the door opening
Donning a coat
Opening the front door and driving through the door opening
Coupling the handbike unit to the wheelchair
Handbiking outdoors
Uncoupling the handbike unit
Transfer back into own wheelchair
Driving back to the clinic (outdoors)

(1) Feature extraction For the classic body posture/motion detection (ie without wheelchair propulsion), three feature signals (angular feature, motility feature, and frequency feature) are derived and continuously computed from each measured accelerometer signal. For the detection of wheelchair propulsion an additional phase feature is computed (besides the above-mentioned features) representing the phase difference between left- and right-arm movement.

(2) Body posture/motion detection In the classic analysis program, 23 (sub)postures and motions are distinguished. Detection of these posture/motion subcategories is based on the three classic feature signals derived from the measured signals of four sensors (wrist sensors not included), and on preset settings in an Activity Detection Knowledge Base (ADKB). For each subcategory and for each feature signal, a minimum and a maximum value is preset in that ADKB. For consecutive moments in time (1 s), for each subcategory and for each feature signal, the distance is calculated from the actual feature signal value to the preset range. The calculated distances of the feature signals are added for each subcategory; the posture/motion subcategory with the lowest total distance in the end will be selected and detected.

(3) Postprocessing After the posture/motion detection there are some (optional) postprocessing procedures:

(a) *From subcategories to main categories:* Although most of the 23 posture/motion subcategories are required initially to avoid misdetection, not all 23 subcategories are necessarily of interest in a later phase. In the present study, the subcategories were reduced to the main categories: lying, sitting, standing, walking, cycling and general movement.

(b) *Duration threshold:* Since error detections are mostly of short duration and because very short-lasting body postures/motions were considered not to be of clinical interest, body postures/motions lasting less than 5 s are disregarded.

(c) *Detection of the category wheelchair propulsion:* All classic AM output samples defined as sitting, cycling or general movement are automatically reanalyzed. Detection of the category wheelchair propulsion (hand-rim wheelchair propulsion and handbiking) is based on the feature signals (including the phase feature) derived from the measured signals of all six sensors (thus including the sensors at each wrist), and on preset settings in the Wheelchair Detection Knowledge Base (WDKB). Similar to the procedures of the classic AM, for each feature signal (of all six sensors), the distance is calculated to the preset ranges in de WDKB. In case the distance to the preset range for the category wheelchair propulsion is smaller than a preset threshold, the sample is redefined as wheelchair propulsion. The knowledge base for the detection of wheelchair propulsion was designed based on information from a previous study (unpublished data). Again, body postures/motions (including wheelchair propulsion) lasting less than 5 s are disregarded.

Reference method

Video recordings were made with a handheld camera. All video recordings were analyzed independently from the AM output by the same person, with a time resolution of 1 s. Similar to the AM analysis, video-recorded activities lasting less than 5 s were automatically disregarded.

Wheelchair propulsion was defined as: 'to propel in order to move oneself to another location, while sitting in a wheelchair or handbike, (partly) as a result of arm power'. Moving around while sitting in a wheelchair, (partly) as a result of arm power but not with the intention to propel to another location (eg turning around or changing from position in the area), was defined as manoeuvring. All other activities were defined as nonwheelchair propulsion. The samples classified as manoeuvring were finally excluded from data analysis, because they consist of a mixture of wheelchair propulsion and other activities ('gray area'). The analyzed video recordings were transferred to a signal in the AM file and synchronized with the accelerometer signal.

Data analysis

The continuous output of the AM was compared with the synchronized, continuous output of the video analysis, both with a time resolution of 1 s. The following measures were calculated:

Agreement: (number of identical samples of video and AM/total number of samples) $\times$ 100%.

Sensitivity: (number of identical samples of video and AM for the video activity category wheelchair propulsion/total number of samples for this video activity category) $\times$ 100%.

Specificity: (number of samples in which wheelchair propulsion is not detected by the AM for video activities other than wheelchair propulsion/total number of samples for video activities other than wheelchair propulsion) $\times$ 100%.

In addition, the duration of wheelchair propulsion as established by the AM and the video recordings was calculated for each measurement. All calculations and comparisons were performed automatically by means of S.P.I.L.™ software.

Statistical analysis

The weighted mean (corrected for duration of activities) was used to describe group results. Differences in agreement, sensitivity and specificity between subgroups (good and poor triceps strength) were tested with the Mann–Whitney *U*-test. The Wilcoxon matched-pairs signed-ranks test was used to test differences in duration of wheelchair propulsion between the video analysis and AM output. All statistical analyses were performed with SPSS 8.0; statistical significance was assumed when $P \leqslant 0.05$.

Results

In all, 10 patients with SCI (seven men and three women; mean (SD) age 41.7 (16) years participated, all under primary rehabilitation (eight in-patient, two outpatient) at the Rijndam Rehabilitation Center after a recent SCI. Table 2 presents the characteristics of the patients.

Of all video recording test samples, 8.1% was defined as 'manoeuvring' and thus excluded from further data analysis. From the remaining 16 039 test samples (267 min), 20.4% was defined as wheelchair propulsion and 79.6% as nonwheelchair propulsion. Table 3 presents the validity scores per measurement together with the weighted mean scores. The overall agreement between the video analysis and the output of the AM was 92%, with agreement per measurement ranging from 87 to 96%.

Sensitivity for the detection of wheelchair propulsion was significantly lower in the subgroup with poor triceps strength than in the subgroup with good triceps strength (81 and 95%, respectively, $P < 0.01$). There were no significant differences in specificity and agreement between the subgroups.

The overall duration of wheelchair propulsion was overestimated by the AM by 3.9% (21.1 *versus* 17.2%). This overestimation was larger ($P < 0.05$) in the subgroup with good triceps strength (24.4 *versus* 16.4%) than in the subgroup with poor triceps strength (18.8 *versus* 17.6%). Differences in the duration of

Table 2 Characteristics of the patient group

Patient	*Gender*	*Age (years)*	*Treatment setting*	*Neurological level*	*ASIA**	*Triceps strength*[a]	*Wheelchair propulsion; hand-rim*	*Wheelchair propulsion; handbike*
1	M	19	In-patient	Cervical	A	⩽6	x	x
2	M	59	In-patient	Cervical	A	⩽6	x	
3	F	24	In-patient	Cervical	A	⩽6	x	x
4	F	48	In-patient	Cervical	B	⩽6	x	
5	F	34	Outpatient	Cervical	B	⩽6	x	x
6	M	49	In-patient	Thoracic	B	>6	x	x
7	M	21	Outpatient	Cervical	D	>6	x	x
8	M	53	In-patient	Thoracic	D	>6	x	
9	M	47	In-patient	Thoracic	D	>6	x	
10	M	63	In-patient	Lumbal	C	>6	x	

*ASIA impairment scale
[a]Triceps strength: sum of left and right triceps strength (according to manual muscle testing)[24]

Table 3 Sensitivity, specificity and agreement for the detection of wheelchair propulsion (hand-rim wheelchair propulsion and handbiking) in 10 patients with SCI

	Sensitivity (%)	*Specificity (%)*	*Agreement (%)*
Patients with poor triceps strength			
1	79	93	92
2	79	96	94
3	83	98	95
4	89	91	91
5	76	93	90
Weighted mean (patients 1–5)	81*	94	92
Patients with good triceps strength			
6	95	88	89
7	89	97	96
8	94	93	94
9	99	85	87
10	99	87	89
Weighted mean (patients 6–10)	95	90	91
Weighted overall mean (patients 1–10)	87	92	92

Data are shown per patient, per subgroup and for all patients together (weighted means; corrected for the duration of wheelchair propulsion)
*Significantly smaller than in the group of patients with good triceps strength ($P<0.01$)

wheelchair propulsion between video analysis and AM output were smaller during movement over longer distances (hallway 5% and outdoors 4%) than during movement in smaller areas (14%) (Table 4). The largest difference in duration between both methods was found during the activities: ‘open the door, drive through the door opening and close the door’, ‘move indoors in a small environment’ and ‘preparing and eating a sandwich’: that is, 29, 14 and 12%, respectively.

Discussion

General

In former studies,[14–18] the AM has proven to be a valid instrument to quantify mobility-related activities (lying, sitting, standing, walking, cycling, general (noncyclic) movement). The aim of this study was to assess whether, additional to other activities, wheelchair propulsion (hand-rim wheelchair propulsion and handbiking) can be validly detected by the AM in patients with SCI.

Table 4 Differences in duration of wheelchair propulsion between the Activity Monitor (AM) and the video analysis (video) per protocol activity.

Protocol activity	*Total duration (s)*	*AM minus video*	
		Absolute difference (s)	*Percentual difference* (%)*
1. Move indoors; in large area (hallway of the clinic)	1517	79	5
2. Move indoors; in small area (apartment)	1244	174	14
3. Move outdoors	1528	54	4
4. Open/close door	75	22	29
5. Leaf through a magazine	1140	27	2
6. Preparing and eating sandwich	1516	186	12
7. Washing the dishes	843	62	7
8. Transfer	2036	139	7
9. Donning a coat	698	47	7
10. Other	5442	283	5
Total	16 039	1073	

*The percentual difference is calculated for each protocol activity as the sum of the absolute differences between the duration of wheelchair propulsion as determined by the AM minus the duration of wheelchair propulsion as determined by video analysis, divided by the total duration of the protocol activity for all measurements

Even though the study population was relatively small, the diversity of physical functioning which exists within the SCI population was, in our opinion, well represented. Selection of patients with poor and with good triceps strength, enabled both marginal and good wheelchair drivers to be studied. Only patients who used both arms to propel a wheelchair were selected, because patients with SCI rarely propel their wheelchair in a different manner; for example, by using both feet, or one foot and one arm. Thus, in our opinion, results of the present study can be generalized to the majority of patients with SCI.

Mean age (41.7 years), man/woman ratio (2.3:1) and percentage complete lesions (33%) in the present patient group is in agreement with characteristics of the SCI population in a comparable Dutch Rehabilitation Center as studied by Schönherr *et al*[26] (45.1 years, 2.2:1 and 27%, respectively). However, the percentage of cervical lesions was higher in the present study (60 *versus* 41% in the study of Schönherr *et al*[26]), due to our selection of five patients with poor triceps strength.

Since the detection of wheelchair propulsion by the AM is largely based on the detection of arm movements in combination with the detection of a sitting position, we were particularly interested in the capacity of the AM to distinguish wheelchair propulsion from other dynamic activities in which both arms are used. Therefore, we purposely included in the protocol several dynamic activities that could be falsely detected by the AM as wheelchair propulsion (such as washing the dishes in sitting position). Furthermore, even though the protocol consisted of activities which were assumed to be representative for normal everyday life, the proportion of dynamic activities was relatively large and those activities alternated quickly within a short period of time. Therefore, as a whole, the protocol was not representative for normal life. Since in the future the AM will be used to quantify everyday physical activity in patients with SCI during long-lasting (48 h) free-living measurements (with relatively more static activities and less frequent changes in activities) the validity of measurements with the AM as found in the present study is expected to be an underestimation of the actual validity during long-lasting measurements.

Validity of the detection of wheelchair propulsion

The present study resulted in high validity scores for the detection of wheelchair propulsion by the AM. Overall agreement (92%) and sensitivity (87%) are comparable with overall agreement (81–93%) and sensitivity (static activities 84–99%; walking 79–86%; cycling 92–97%) as found in previous validity studies of the AM.[14,15,18,27] Specificity for the detection of other mobility-related activities with the AM has not been investigated before. Since we expected an effect of triceps strength on the validity of the detection of wheelchair propulsion by the AM, patients with poor and with good triceps strength were included. The mean sensitivity for the detection of wheelchair propulsion was good in the subgroup with poor triceps strength (81%) but significantly lower than in the subgroup with good triceps strength (95%). However, no significant differences were found with respect to agreement and specificity. These data suggest that wheelchair driving is more validly detected in persons with good triceps strength (and with their different propulsion technique). Visual inspection of the acceleration signals of the wrists shows a clearer cyclical character in case of good triceps strength (and pushing wheelchair propulsion), which will contribute to a better detection of wheelchair propulsion. However, because the propulsion technique is not expected to change essentially during the rehabilitation process, the difference in validity of the AM to detect wheelchair propulsion found between the subgroups is not expected to interfere with future longitudinal studies concerning the course of mobility-related activities during the rehabilitation process of patients with SCI.

Although the characteristics of 'pulling wheelchair propulsion' were already incorporated into the settings of the WDKB, some optimization of the settings may be possible. Another possibility is to change the detection threshold, possibly depending on the type of wheelchair propulsion of a patient. One has to be aware, however, that if changing the threshold is beneficial for the sensitivity scores, it will be negative for the specificity scores: the setting of the threshold is always a matter of balance. From the viewpoint of equal sensitivity and specificity percentages, the data of our study do not indicate that a relevant imbalance exists.

Duration of wheelchair propulsion

Related to the above issues is the overestimation of the duration of wheelchair propulsion by the AM. The general issue is that the data and their interpretation depend on the mutual distribution of wheelchair and nonwheelchair propulsion activities. In case of an equal distribution of wheelchair propulsion and nonwheelchair propulsion activities, the sensitivity and specificity characteristics of the AM as established in this study should lead to an underestimation of the duration of wheelchair propulsion by the AM. However, in our study the proportion of nonwheelchair propulsion activities was considerably larger, which will contribute to an overestimation of the duration of wheelchair propulsion. This shows that the problem of optimization of sensitivity and specificity is rather complex, because the answer depends on the mutual distribution of wheelchair and nonwheelchair activities. For example, the larger overestimation in the patients with good triceps strength can be explained by the higher sensitivity scores, but also because these patients performed more dynamic test activities in a shorter time period. In fact, the settings must depend on the actual distribution of wheelchair and nonwheelchair activities. Ongoing long-term measurements during daily life in this patient group will further elucidate this point.

Misdetection of wheelchair propulsion

The largest percentual difference in duration of wheelchair propulsion between video analysis and AM output was found during the protocol activity 'open the door, drive through the door opening and close the door' (29%, Table 4). However, as a result of excluding the video samples analyzed as 'manoeuvring', this activity only consisted of a few samples. Therefore, the relatively large percentual difference in duration of wheelchair propulsion between both methods should not receive too much attention for this particular activity. The relatively large difference in duration of wheelchair propulsion between video analysis and AM during times that patients moved around indoors in a small area (14%, Table 4), can partly be explained by real detection errors. The detection of wheelchair propulsion by the AM is based on the detection of repeated movements of the arms; therefore, moving around with a wheelchair in a small area (continuous process of turning, accelerating, and decelerating) will be less frequently detected as wheelchair propulsion by the AM compared with moving over a longer distance. Furthermore, the relatively large difference in duration of wheelchair propulsion between both methods can be explained by methodological factors such as discrepancies in moment of onset/end of activities (the latter factor can have an important impact on the validity in protocols with quickly alternating activities). During the activity 'preparing and eating a sandwich' some of the samples were falsely detected by the AM in some patients as wheelchair propulsion (12%, Table 4). This has to be considered as a real detection error. However, because in normal free-living conditions consuming a meal takes more time and consists of more static movements (sitting still, chewing and digesting the food) than the activity as performed in the protocol, the actual detection error during eating is expected to be lower during free-living measurements.

Future studies

In the present study, hand-rim wheelchair propulsion and handbiking are combined as one activity. However, in future studies, the present analysis software will allow to distinguish between hand-rim wheelchair propulsion and handbiking with the AM.

Meanwhile, a large-scale study has started in which measurements with the AM are used to objectively assess the course of everyday physical activity of patients with SCI during the rehabilitation process.

Conclusion

The results of the present study indicate that, besides already validated other activities, wheelchair propulsion (hand-rim wheelchair propulsion and handbiking) can be detected validly with the AM in patients with SCI, both with poor triceps strength and good triceps strength. Therefore, the AM offers the possibility to obtain objective and detailed information on all major mobility-related activities performed by patients with SCI.

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