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The Activ8 activity monitor: Validation of posture and movement classification

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Abstract

Introduction: To set up and guide interventions with the aim to increase physical activity and lower sedentary behavior valid monitoring of physical behavior is essential. The aim of this study was to evaluate the validity of the single-unit Activ8 activity monitor to classify several body postures and movements.

Methods: Twelve healthy adults performed a series of activities, representative for everyday life, according to a standard protocol. Activ8 was both worn in the trouser pocket (prescribed location) and fixated to the front of the thigh. Activities were video recorded and analyzed thereafter. Postures and movements that were analyzed were lying/sitting, standing, walking, cycling, and running.

Results: The agreement between Activ8 output and video analysis was 89.7% (inter-subject range: 66.0 to 96.6%) for the pocket location and 91.9% (range 85.5 to 95.1%) for the thigh location. Sensitivity and positive predictive value scores for both locations were all above 80%, except for standing (69% or higher). Differences in classified duration of separate postures and movements were within 20% for walking, sitting and running.

Conclusion: The Activ8 is a valid instrument to quantify a defined set of body postures and movements. Because of the smaller time difference, the thigh location is preferred for research purposes.

Keywords

Accelerometry, physical activity, physical activity assessment, piezoelectric devices, rehabilitation devices

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Introduction

Low levels of physical activity and high levels of sedentary behavior are well-known risk factors for the development of secondary health conditions like cardiovascular diseases, cancer, and obesity,[1,2] both in the general population as well as in chronic disorders.[3] Stimulating physical activity and avoiding a sedentary lifestyle nowadays finds large support by clinicians and welfare governments.[4] To set up, guide and evaluate tailored interventions to change physical behavior, valid physical activity monitoring is essential.[5,6]

Currently, many (consumer) devices and smartphone applications exist that focus on objective measurement of volume of physical activity and/or the amount of energy expenditure (EE) resulting from physical activities.[7,8] Unfortunately, for most of these devices, little is known about their validity with respect to the volume of physical activity.[9,10] Besides, many devices and applications provide no or limited information about other relevant components of physical behavior, such as the type, time and frequency of body postures and movements.[11] Information of postures and movements gives more insight in the actual performed activities and the neurological involvement and biomechanical loading of the human body as a result of that.[12] For instance, information about time and frequency of standing and walking are important in stroke patients because rehabilitation is mainly targeted at recovery of motor functioning. Also for elderly, daily life performance of mobility related activities (such as standing or walking) can be considered as

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a key construct of physical activity.[13] Besides, time and frequency of specific postures and movements can be used to compare actual behavior with guidelines and to guide behavioral interventions. Existing devices that are able to measure the type and amount of postures and movements are either expensive and too complex to use in clinical practice[14–16] or do not classify common activities like bicycling and running.[17–19]

The Activ8[20] is a single-unit activity monitor based on a triaxial accelerometer. The advantages over other existing monitors are that it is small and lightweight, it can be worn in the pocket of trousers, it is relatively inexpensive, and it provides information on both body postures and movements and EE. However, so far the validity of the device for detecting body postures and movements in the general population has not been studied. Because of the relevance of the information on postures and movements in itself, the current study focuses on the criterion validity of the detection of body postures and movements.

The prescribed wearing location of the Activ8 is in the trouser pocket. However, differences between trouser pockets may affect the validity of the detection of postures and movements. Therefore, a secondary objective is to study the difference in output between wearing the device in the trouser pocket and wearing it when fixated to the front of the thigh.

Materials and methods

The Activ8[20] is a small device to track physical activity during the day. It contains a three-axis accelerometer, a battery, a real-time clock and a memory for data storage. In the commercially available Activ8, raw acceleration signals (12.5 Hz) are filtered with an exponential moving average filter and converted to postures and movements at a resolution of 1.56 Hz and buffered at 2.56 s intervals. In the output, a summation of time spent in specific postures and movements and energy spend (expressed in METS) over 5 min is given. For the purpose of the validation study, the firmware of the device was adapted so that the results for each 2.56 s interval were available for analysis.

The Activ8 classifies lying/sitting, standing, walking, cycling, and running. These postures and movements are determined from (1) the angular position of the device with respect to the line of gravity and (2) the variability of the signal, which depends on the intensity of the movement.

Twelve healthy participants, four males and eight females, participated in the study. All participants provided written informed consent. The sample size was based on the number of participants in comparable studies.[21,22] Participants were between 18 and 65 years and had sufficient understanding of the Dutch language. All measurements were performed at the department of rehabilitation medicine of the Erasmus MC University Medical Center. The study was approved by the ethical committee of Erasmus MC. Each subject performed a series of consecutive activities according to a pre-defined protocol (see Table 2). The activities were assumed to be representative for everyday life. The duration of the activities ranged from 30 s to 2 min. The researcher gave instructions when to start and stop a specific activity. The total measurement time for one subject was approximately 1 h. Participants had the opportunity to rest in between activities.

Each subject was instrumented with two Activ8 devices: one at the prescribed location in the front right pocket of their trousers, and one fixated to the front of the right thigh. For the latter, the device was attached with Velcro to a strap that was worn around the thigh and was located proximal at one-third of the length of the upper leg (Figure 1). Each activity was recorded with a hand held video camera and was timed with a stopwatch. The video camera and the Activ8 monitors were time synchronized before each measurement. During the measurement, participants wore their own clothes and shoes.

Two independent experienced researchers checked on video whether activities for a set duration were performed consistently and without breaks. If not,

Figure 1. The position of the Activ8 when attached to the thigh.

Activ8 data were not included in the analysis. Consensus between the researches was sought in case of disagreement.

Criterion validity of the Activ8 was determined from the following clinimetric properties:

- Agreement

The proportion of time the Activ8 classified postures and movements correctly, overall and for each activity of the protocol.

- Sensitivity

The proportion of correct classified time by Activ8 for each posture and movement category.

Sensitivity = true positive Activ8 classification/(true positive Activ8 classification + false negative Activ8 classification).

- Positive predictive value

The ratio between correct Activ8 classification and total classified time for each posture and movement category.

Positive predictive value = true positive Activ8 classification/(true positive Activ8 classification + false positive Activ8 classification).

- Absolute time difference

The duration of each posture and movement classified by Activ8 was compared to the actual time spent on the corresponding activities verified on video.

All clinimetric properties were calculated after summing the classification results for both video and Activ8 over all participants. Values for agreement, sensitivity and positive predictive value were considered good when above 75%. Absolute time difference of less than 20% was considered acceptable. Validity was determined for the two wearing locations of the Activ8: the trousers pocket, and fixated to the front of the thigh.

Most activities of the protocol are directly linked to the postures and movements defined by Activ8. For example, all types of walking (on a treadmill, climbing stairs) must be detected as walking. However, for some activities, this relationship is less clear: Jumping rope: this is a high-intensity activity, and the classification "running" was considered as correct. Vacuum cleaning: this activity consists of standing and walking. Since it was not possible to reliably separate walking from standing on the video, it was decided that the classification "standing" or "walking" was correct. Standing on a vibration platform: this activity was included to study the effect of external vibrations on the Activ8 output. Vibrations, e.g., from a car or public transport should not have an effect on the classification accuracy. Therefore, Activ8 should classify this activity as standing. Wheelchair driving with arm or leg propulsion: both activities are "active" activities, but still have to be classified as sitting.

Results

For two participants, data from the Activ8 in the trouser pocket are missing due to incorrect wearing. Not all participants completed the activity protocol: some activities could not be performed by some participants (e.g. running at higher speeds), and sometimes activities were not performed because of practical reasons (e.g. availability of a bike) (Table 1). For one subject, lying data are missing. In one subject, certain walking speeds are missing for the thigh location because the strap around the leg had moved. All other recorded activities were performed consistently and without breaks.

Table 1. Missing protocol items for each participant.

	Gender	Age	Missing items pocket position	Missing items thigh position
1	Male	19		
2	Male	21	Cycling outside	Cycling outside
3	Female	19	Running at 15 km/h; cycling outside	Walking at 3, 4 and 5 km/h; cycling outside
4	Female	23	All	Running at 15 km/h
5	Female	27	All	Running at 11 and 15 km/h
6	Male	28		
7	Female	28	Cycling outside	Cycling outside
8	Female	23	Running at 15 km/h	Running at 15 km/h
9	Female	27	Running at 15 km/h	Running at 15 km/h
10	Female	32	Running at 15 km/h; cycling outside	Running at 15 km/h; cycling outside
11	Male	36	Cycling outside	Cycling outside
12	Female	19	Running at 15 km/h; cycling outside; lying	Running at 15 km/h; cycling outside

Mean overall agreement between video analysis and Activ8 was 89.7% for the pocket location (between-participants range 66.0 to 96.6%), and 91.9% for the thigh location (range 85.5 to 95.1%). Agreement scores between wearing locations were not significantly different (paired T-test). For the pocket location, two participants had clearly lower agreement scores, respectively 79.6% and 66.0%.

Table 2 shows the agreement scores for the separate activities for both wearing locations. Poor to satisfactory agreement (<75%) was found for wheelchair driving with leg propulsion, and for standing on a vibration platform. The remaining activities showed agreement scores of at least 75%. Wheelchair driving with leg propulsion was often classified as cycling; standing on a vibration platform was often classified as walking. Poorest agreements for these activities were found for the Activ8 on the thigh.

Table 3 shows the sensitivity, predictive value and absolute time difference for standard postures and movements (except lying). Sensitivity and predictive value scores for both locations were either acceptable (standing, thigh location) or good (above 75% for the remaining postures and movements). Absolute time differences between Activ8 and video classification above 20% were found for standing (both pocket and thigh location) and cycling (pocket location).

Activities used for the analysis: for walking: walking on a treadmill, walking stairs; for cycling: cycling on a

Table 2. Classification of postures and movements by Activ8 for each activity item of the protocol.

	To be classified as	Time		Walking		Standing		Lying/sitting		Running		Cycling	
		Pocket*	Thigh	Pocket	Thigh	Pocket	Thigh	Pocket	Thigh	Pocket	Thigh	Pocket	Thigh
Walking on a treadmill	Walking												
2 km/h		600	723	**95**	**95**	4	5	1	0	0	0	0	0
3 km/h		597	670†	**100**	**100**	0	0	0	0	0	0	0	0
4 km/h		600	670†	**100**	**100**	0	0	0	0	0	0	0	0
5 km/h		600	663†	**100**	**100**	0	0	0	0	0	0	0	0
6 km/h		597	730	**91**	**87**	0	0	0	0	9	13	0	0
Running on a treadmill	Running												
6 km/h		600	730	30	13	0	0	0	0	**70**	**87**	0	0
9 km/h		605	723	2	0	0	0	0	0	**98**	**100**	0	0
12 km/h		569	652†	0	0	0	0	0	0	**100**	**100**	0	0
15 km/h		300‡	305‡	0	0	0	0	0	0	**100**	**100**	0	0
Sprinting	Running	600	730	6	4	3	2	0	0	**91**	**94**	0	0
Walking stairs up	Walking	600	725	**96**	**97**	4	3	0	0	0	0	0	0
Walking stairs down	Walking	597	725	**100**	**100**	0	0	0	0	0	0	0	0
Cycling on a home trainer	Cycling												
50 r/min		600	725	19	0	0	0	5	4	0	0	**76**	**96**
65 r/min		597	728	20	0	0	0	0	0	0	6	**80**	**94**
80 r/min		600	723	20	0	0	0	0	0	3	6	**77**	**94**
Cycling outside	Cycling												
Slow speed		243§	368¶	0	1	0	1	3	4	0	0	**97**	**94**
Normal speed		240§	357¶	8	0	0	0	0	0	0	0	**92**	**100**
Fast speed		240§	365¶	25	2	0	0	0	0	0	0	**75**	**98**
Jump robe	Running	597	725	7	11	4	3	0	0	**89**	**86**	0	0
Wheelchair driving	Sitting												
Arm propulsion		597	728	1	0	13	0	**86**	**97**	0	1	0	2
Leg propulsion		597	730	0	0	10	0	**61**	**27**	0	0	29	73
Vacuum cleaning	Walking or standing	600	730	**84**	**83**	**16**	**17**	0	0	0	0	0	0
Standing doing the dishes	Standing	563	693	7	10	**93**	**88**	0	2	0	0	0	0
Standing on a vibration platform	Standing	316	365	39	62	**61**	**38**	0	0	0	0	0	0
Sitting office work	Sitting	597	717	0	0	5	0	**95**	**100**	0	0	0	0
Sitting easy chair	Sitting	600	728	0	0	10	0	**90**	**100**	0	0	0	0
Lying supine on a bed	Lying/sitting	543**	670†	1	9	0	0	**99**	**91**	0	0	0	0

Note: Time represents the cumulative time in seconds. The classified time for each activity item is presented as percentage of true time. r/min = revolutions per minute.
Correct classification is presented in bold. *n = 10; †n = 11; ‡n = 5; §n = 4; ¶n = 6; **n = 9.

Table 3. Overall sensitivity, positive predictive value and time difference for the body posture and movement categories.

	Pocket			Thigh		
	Sensitivity (%)	Positive predictive value (%)	Absolute time difference (%)	Sensitivity (%)	Positive predictive value (%)	Absolute time difference (%)
Walking	97	82	19	97	90	9
Cycling	81	92	21	95	85	15
Standing	81	69	36	71	88	21
Lying/sitting	83	98	17	81	97	17
Running	91	97	11	95	94	9

home trainer, cycling outside; for standing: standing doing the dishes, standing on a vibration platform; for lying/sitting: lying on a bed, wheelchair driving, sitting office chair, sitting easy chair; for running: running on a treadmill, sprinting. Absolute time difference was calculated as the absolute difference between actual time spent on one of the five main activities and classified time of the corresponding Activ8 posture or movement class, expressed as percentage of actual time.

Discussion

In the current study, we validated the Activ8 activity monitor with respect to classification of body postures and movements. The overall agreement for both the pocket (89.7%) and thigh location (91.6%) was good. Sensitivity and positive predictive value for walking, cycling, sitting and running were good to excellent for both locations. The results are comparable to other single-unit accelerometer devices[17–19] and almost as good as for more complex multi-sensor devices.[14,23] However, comparison with other devices should be done with care, because data are strongly influenced by the number of body posture and movement categories, type of activities performed, and the distribution and duration of these activities within the protocol.[24]

In general, the separate activities in the protocol were classified well. Notable misclassification was found for cycling, wheelchair driving with leg propulsion, and standing on a vibration platform. Cycling, both on a home trainer and outside, was frequently classified as walking for the pocket location. A relatively high position of the saddle easily results in hip movements similar to walking. Moving a wheelchair with the legs was often detected as cycling, probably because it is a similar movement of the legs. Standing on a vibration platform was frequently detected as walking, especially for the thigh location. This suggests that the thigh sensor measures vibrations more directly and with larger amplitudes than the pocket sensor; the pocket subdues to some extent the acceleration. However, it has to be realized that the signal filters and settings in the device are based on the pocket position. It can be assumed that a thigh position with optimized settings would have resulted in higher agreement scores. When standing was evaluated only during the dish washing task, sensitivity and time difference improved for both locations to acceptable values.

The Activ8 is developed from the perspective to be used in a (trouser) pocket. Although this location is beneficial from a user comfort point of view, it can lead to output variability due to the type of pocket. The Activ8 algorithm assumes that the orientation of the sensor is closely related to the orientation of the upper leg and that the device is located at the front of the leg. Placement of the Activ8 in very "loose" or lateral sided pockets will most likely result in wrong classification. In two participants, cycling and, less frequent, sitting and wheelchair activities were falsely classified as walking or standing by the 'pocket' sensor only. This most likely resulted from the possibility of the sensor to move around within the "loose" trouser pockets. Considering also the better time difference results for the thigh location, this way of wearing the Activ8 is preferred for research purposes.

Another point of consideration is the availability of pockets. During sports activities and in general for women not always a pocket will be available, which may decrease wear-time compliance. For this reason fixation to the thigh may be advantageous in scientific studies. Wrist-worn accelerometers are convenient to wear and, in contrast to phone applications, associated with greater wear-time compliance.[25] However, activity classification is more complex and up till now less accurate.[26]

In this study, the Activ8 was validated during short measurements in different settings: a motion laboratory, an occupational therapy apartment, and outside. Although we tried to make the activity protocol and settings as natural and representative as possible, the amount of activities selected is small and will represent only a small part of the regular activities of people in daily life.[27] Other limitations of this study were the relatively small sample size and the incompleteness of the data for some activities of the protocol. However, findings across subjects were consistent and to our opinion results are representative for the validity of the Activ8 when used in the general population.

Lying and sitting cannot be well distinguished by Activ8 because the device orientation is the same. The Activ8 uses a time and count constraint to separate sitting from lying. Sitting longer than 5 min with zero counts is classified as lying down. As a result, in daily life lying will be underestimated and sitting will be overestimated. Since both lying and sitting are related to sedentary behavior, the lack of discrimination between these postures is not considered as an important weakness.

Compared to other single-unit devices,[17–19] Activ8 is the only monitor that classifies bicycling and running. Another unique feature of Activ8 is that it also (besides the number of counts) uses posture and movement information to determine EE. This combination of information to calculate EE may lead to more accurate estimations. The current study did not focus on the validity of EE because it would require a completely different design and activity protocol. But validating the EE part of the Activ8 system is an important next step.

A second next step is to evaluate the robustness of the algorithm to classify postures and movements in people with mobility problems, such as stroke[28] and cerebral palsy patients and elderly persons. Measuring physical behavior in these populations is of interest because of expected mobility (behavior) changes due to for instance treatment, natural recovery or illness progression.[19]

Conclusions

The Activ8 activity monitor is a valid instrument to quantify common body postures and movements. Together with information on energy expenditure and its access to mobile and web applications, it is a promising tool for monitoring physical behavior. When used in a trouser pocket, the pocket should not be too loose and positioned at the front of the trousers. Fixation to the thigh will improve its validity, although it will lower user comfort and some setting optimization might be needed.

Future research should focus on the validation of energy expenditure, and on evaluating the algorithm in people with mobility problems.

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Contributorship

HK researched literature and conceived the study. HK and HH were involved in protocol development, gaining ethical approval, patient recruitment and data analysis. HB wrote the first draft of the manuscript. All authors reviewed and edited the manuscript and approved the final version of the manuscript.

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