Validation of the Active8 Activity Monitor: detection of body postures and movements

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SUMMARY

Rationale: Inactivity is a well-known risk factor for the development of secondary health conditions (SHCs) in the general population as well as in people with chronic disorders. Physical activity (PA) can counteract these problems and may lead to potential health benefits. To support interventions aimed at PA or lifestyle change, it is useful to measure people's physical behaviour objectively. Recently, the Activ8 system has been developed for this purpose. A basic characteristic of this system is the automatic detection of a set of body postures and movements (P&M).

Objective: How valid can body postures and movements be determined by the Activ8 system?

Study design: An observational validation study

Study population: 12 healthy adults

Methods: To test de validity of the Activ8 system participants performed a series of consecutive activities according to a standard protocol. Two Activ8 systems were used: one in the (trouser) pocket (the prescribed location), the other attached at the front of the thigh. During the testing procedure the activities of the participants were videotaped, and analysed thereafter (reference method). P&M categories that were analyzed were sitting, standing, walking, cycling, and running.

Main study parameters/endpoints: The following primary outcomes were calculated: overall agreement, and sensitivity and predictive value for the 5 P&M categories. Additionally, duration (number of samples) of these categories were compared.

Results: The agreement between Activ8 output (pocket) and video analysis was 90.1% (inter-subject range: 67.0 to 96.6%). Sensitivity scores of P&M categories ranged from 81 to 98%, predictive value scores from 85-98%.

Conclusion: The Activ8 system appears to be a valid instrument to quantify body postures and motions. Some critical issues - such as the influence of type of pocket and pocket position- are discussed and some potential improvements are suggested.

1. INTRODUCTION AND RATIONALE

Inactivity is a well-known risk factor for the development of secondary health conditions (SHCs) in the general population as well in chronic disorders [1]. Physical activity (PA) can counteract these problems and may lead to potential health benefits [2], and therefore it is important to stimulate an active lifestyle. To support interventions aimed at PA or lifestyle change, it is useful to know how physical active persons are in daily living. In this way interventions can be tailored to the level of daily PA and the needs of persons. Additionally, the effectiveness of interventions can be objectively measured [3-4].

Currently, many devices exist that focus on objective measurement of volume of PA and/or energy expenditure (EE). In general, these instruments can be characterized by limitations in validity with respect to the estimation of volume of PA and EE, relatively high costs, and no or limited possibilities to provide data on body postures and movements.

The Activ8 system [5] is a relatively new activity monitor, which is based on a 3D accelerometer as most other activity monitors do. However, the device significantly differs in some other aspects: it is very small and lightweight, its prescribed position it the (trouser) pocket, it aims to detect a set of body postures and movements, and this information is used to estimate EE, which has the potential to improve this estimation. However, so far the validity of the device to detect body postures and movements and EE has not been studied. Because of the relevance of the posture and movement information in itself (i.e. independent from EE), and because a valid body posture and movement detection is a prerequisite for a valid EE estimation, the current study focuses on the validity of the body posture and movement detection.

2. OBJECTIVES

Primary objective:

- How valid can body postures and movements be determined by the Activ8 system?

Secondary objective:

- To what extent affects the position of the Activ8 the determination of body postures and movements?

3. STUDY DESIGN

The study entailed an observational validation study. This study took place in Erasmus MC at the Rehabilitation department. Before the validation study, 5 measurements were performed to

optimize settings within the Activ8 device. After that optimization phase, 12 validation measurements were done.

4. STUDY POPULATION

4.1 Population

12 healthy subjects (age > 18 yrs)

4.2 Inclusion & exclusion criteria

Inclusion criteria:

- Age 18-65 yrs
- Able to perform the activities of the activity protocol, running at high speeds excepted (see section 6.3 for testing procedure)

Exclusion criteria:

- Insufficient knowledge of the Dutch language to understand the purpose of the study and the testing methods.

4.3 Sample size calculation

Based on comparable studies [6-7] this study included at least 10 persons. This amount of participants was considered sufficient to assess the validity of the Activ8 system.

5. METHODS

5.1 Study parameters/endpoints

Main study parameter/endpoint

Agreement: (Number of identical samples of video and Activ8 / total number of samples) X 100%.

Sensitivity: the degree to which each P&M that is actually performed is detected correctly by the Activ8 system. This is calculated according to:
*(*Number of identical samples of video and Activ8 for a video P&M category / total number of samples for this video P&M category) X 100%.

Predictive value: the degree to which each Activ8 P&M category agrees with the P&M category that is actually performed. This is calculated according to:

(Number of identical samples of video and Activ8 for an Active8 P&M category / total number of samples for this Activ8 P&M category) X 100%.

Secondary study parameters/endpoints

- Comparison of duration (samples) of each P&M category between video and Activ8

- Comparison of the data from the prescribed (pocket) wearing location, and the device attached to the front of the thigh.

5.2 Study procedures

Testing procedure

To test de validity of Activ8, subjects performed a series of consecutive activities according to a standard protocol. Subjects wore their own clothes and shoes. They wore two Activ8 devices: one at the prescribed location (in the pocket), and one attached with a strap to the front of the thigh. During the testing procedure activities were timed with a stopwatch. In addition the activities of the participants were video-taped. All devices were synchronized before each measurement.

Activity protocol

The activity protocol (see Table 1) consisted of several activities which were assumed to be representative for everyday life, or to be challenging for the Activ8 device from a theoretical point of view. The duration of each activity in the protocol ranged from 30 seconds to 2 minutes. The total measurement time was 1 hour maximally. There was the opportunity to rest between the activities. Participants could stop any time during testing procedure.

Table 1. Activity protocol

Walking different speeds on treadmill
- 2 km/h
- 3 km/h
- 4 km/h
- 5 km/h
- 6 km/h
Walking on a normal surface
- Slow/strolling
- Normal
- Fast
Running on treadmill
- 6 km/h
- 9 km/h
- 12 km/h
- 15 km/h

Climbing the stairs

Walking down the stairs

Cycling home trainer
- frequency / resistance combination 1
- frequency / resistance combination 2
- frequency / resistance combination 3

Exercise
- Jumping rope

Wheelchair
- driving with the arms
- with feet propulsion

Vacuum cleaning

Cycling outside
- Slow
- Normal
- Fast

Doing the dishes

Watching television from the couch

Lying on bed
- Supine

Reading the paper

Standing on a vibration platform

Activ8

The Activ8 [5] physical activity monitor is a small device to track physical activity during the day. The Activ8 contains a three-axis accelerometer, a battery, a real-time clock and a medium for data storage. In the foreseen Activ8 applications, raw signals are not stored, but converted to postures and motions (P&M), and to EE. The storage interval of the device is (about) 5 minutes. In each storage interval, 60 times (i.e. sample intervals of about 5 seconds) the P&M category is determined. The sum of samples belonging to each P&M category is calculated and subsequently stored. The P&M categories are: lying, sitting, standing, walking, cycling, and running. These P&M categories are mainly determined by 1) the angular position of the unit - the system is based on a position that is to some extent parallel to the front side of the trouser/thigh - and 2) by the variability of the signal, which depends on the intensity of movement. The detection of lying is

based on the absence of movement/signal variability for a longer time interval (> 5 minutes). Because the activity protocol included activities with a maximum duration of 2 minutes, lying could not be detected and is therefore no part of the validation study.

For each storage interval (5 min) the total EE (expressed in METS) of each P&M category is determined and stored. For the purpose of the validation study, the devices were slightly adapted:

- raw signals were not only measured, but also stored
- the 5 minute storage interval was lowered to (about) 2.5 sec
- the sample interval was lowered to (about) 0.6 sec (4 samples per storage interval).

Reference method

All activities were timed en noted during the measurement. Video recordings were made with a handheld digital video camera and which was used as reference method for the Activ8. Two experienced researchers analyzed and scored the video tape. From the video tape, the time interval of each performed activity of the activity protocol was determined. Additionally, it was checked whether activities were performed consistently and without breaks and interruptions. Video recordings were also used as check in case of error detections.

6. DATA ANALYSIS

The validity of the Activ8 device was determined by descriptive statistics (see paragraph *Study parameters and endpoints*). For most activities of the protocol a direct relationship exists between activity and Activ8 P&M category. E.g. all types of walking (different speeds on a treadmill, walking outside the lab, climbing stairs) must be detected as walking. For some activities this relationship was less clear:

- Jumping rope: is a high-intensity activity, and the detection as "running" was considered as correct;
- vacuum cleaning/doing dishes: are both activities consisting of standing and walking. Therefore the detection of both these P&M categories is considered as correct. The ratio between these P&M categories were assumed to differ: during vacuum cleaning walking should be more prevalent, and standing during doing dishes
- lying on a bed: as already described, lying could not be detected because of duration reasons. Therefore, in our study the detection as sitting was considered correct.
- standing on a vibration platform: this activity was included to study the effect of external vibrations on the Activ8 output. Despite the vibrations, Activ8 should detect this activity as standing.

- wheelchair driving with arms and legs: both activities are "active" activities, but still has to be considered as sitting.

7. RESULTS

Twelve subjects participated, 4 males and 8 females. For 2 subjects (4 and 5) the pocket unit data could not be used because of reasons not related to the devices or their feasibility and validity. Not all subjects performed the complete activity protocol: some activities (e.g. running at higher speeds) were not possible for some subjects, and sometimes activities were not performed because of practical reasons (e.g. availability of a bike). In one subject (4) walking at the higher speeds (thigh unit) was not included in the analyses because the strap was moved downwards.

Agreement

The overall agreement between video analysis and Activ8 was 90.1 (between-measurement range 67.0 to 96.6)%, and 92.0 (range 87.3 to 95.8)% for the pocket unit and the thigh unit, respectively. Table 2 shows the agreement data per measurement. Agreement scores between both units were not significantly different. However, in the pocket location, two persons (2 & 12) had clearly lower agreement percentages (79.6 and 67.0, respectively).

Measurement	Pocket unit agreement (%)	Thigh unit Agreement (%)
1	95.3	92.8
2	79.6	85.5
3	89.5	88.8
4	n.a.	88.9
5	n.a.	87.3
6	90.0	93.7
7	96.3	94.3
8	96.6	94.7
9	96.5	95.2
10	94.2	91.4
11	92.4	94.8
12	67.0	95.8

Table 2. Agremeent between video analysis and Activ8 per subject/measurement. Scores are provided for both pocket unit as thigh unit.

Table 3 & 4 shows the cumulative (summed over all measurements) samples per performed activity from the protocol. The rows represent the activities from the activity protocol, the columns the P&M categories of the Activ8 device. Table 3 provides the data of the pocket unit, Table 4 of the thigh unit.

Protocol activity	Total	Walking	Standing	Lying	Sitting	Running	Cycling
Stairs up	920	886	33	0	1	0	0
Stairs down	916	914	0	0	2	0	0
Cycling hometrainer R1	920	174	4	0	45	0	697
Cycling hometrainer R2	916	184	0	0	0	0	732
Cycling hometrainer R3	920	184	0	0	0	24	712
Walking 2 km/h	920	874	38	0	8	0	0
Walking 3 km/h	916	916	0	0	0	0	0
Walking 4 km/h	920	920	0	0	0	0	0
Walking 5 km/h	920	920	0	0	0	0	0
Walking 6 km/h	916	831	0	0	0	85	0
Running 6 km/h	920	277	0	0	0	643	0
Running 9 km/h	928	23	0	0	0	905	0
Running 12 km/h	872	0	0	0	0	872	0
Running 15 km/h	460	0	0	0	0	460	0
Vacuum cleaning	920	775	145	0	0	0	0
Doing dishes	884	74	810	0	0	0	0
Sitting easy chair	920	0	92	0	828	0	0
Office work	916	1	44	0	871	0	0
Lying	1204	5	0	0	1199	0	0
Standing vibrat plate	484	187	297	0	0	0	0
Jumping rope	916	60	38	0	0	818	0
Wheelchair - feet	916	2	92	0	555	0	267
Wheelchair driving	916	5	120	0	787	0	4
Cycling outside slow	372	0	0	0	13	0	359
Cycling outside normal	368	31	0	0	0	0	337
Cycling outside fast	368	92	0	0	0	0	276
Sprint	920	53	26	0	0	841	0

Table 3. Pocket unit: cumulative number of samples of all measurements for each activity of the protocol. The total number of samples is presented (second column) and the number per Activ8 posture and movement category. Yellow cells indicate the correct detection.

Protocol activity	Total	Walking	Standing	Lying	Sitting	Running	Cycling
Stairs up	1112	1073	38	0	0	1	0
Stairs down	1112	1112	0	0	0	0	0
Cycling hometrainer R1	1112	0	0	0	48	1	1063
Cycling hometrainer R2	1116	0	0	0	0	65	1051
Cycling hometrainer R3	1109	0	0	0	0	72	1037
Walking 2 km/h	1108	1054	54	0	0	0	0
Walking 3 km/h	1028	1028	0	0	0	0	0
Walking 4 km/h	1028	1028	0	0	0	0	0
Walking 5 km/h	1016	1016	0	0	0	0	0
Walking 6 km/h	1120	975	0	0	0	144	1
Running 6 km/h	1120	145	0	0	0	975	0
Running 9 km/h	1108	5	0	0	0	1103	0
Running 12 km/h	1000	0	0	0	0	1000	0
Running 15 km/h	468	0	0	0	0	468	0
Vacuum cleaning	1120	935	185	0	0	0	0
Doing dishes	1088	149	916	0	23	0	0
Sitting easy chair	1116	0	0	0	1116	0	0
Office work	1100	0	0	0	1100	0	0
Lying	1400	96	0	0	1304	0	0
Standing vibrat plate	560	348	212	0	0	0	0
Jumping rope	1112	118	32	0	0	962	0
Wheelchair - feet	1120	3	0	0	300	0	817
Wheelchair driving	1120	0	0	0	1093	6	21
Cycling outside slow	564	5	4	0	23	0	532
Cycling outside normal	548	0	0	0	0	0	548
Cycling outside fast	560	14	0	0	0	0	546
Sprint	1120	42	28	0	0	1050	0

Table 4. Pocket unit: cumulative number of samples of all measurements for each activity of the protocol. The total number of samples is presented (second column) and the number per Activ8 posture and movement category. Yellow cells indicate the correct detection.

Sensitivity and predictive value

Table 5 shows the sensitivity and predictive value scores for the 5 body P&M categories. The lowest scores are the PV for standing (72%, pocket unit) and the sensitivity for standing (79%, thigh unit).

	Pocket		Thigh	
	Sensitivity (%)	**PV (%)**	**Sensitivity (%)**	**PV (%)**
Walking	98	85	97	92
Cycling	81	92	95	85
Standing	87	72	79	89
Sitting	87	98	84	98
Running	90	98	94	95

Table 5. Overall sensitivity and Predictive Value (PV) scores for the main body posture and movement categories.

Duration

Table 6 & 7 show the total duration (expressed in total number of Activ8 samples) of the 5 P&M categories, as determined from video and by Activ8.

Activity	**Number of samples video**	**Number of samples Activ8**	**Difference Activ8 vs. video (%)**
Walking	7,277	8,388	+15
Cycling	3,864	3,384	-12
Standing	1,439	1,739	+21
Sitting	4,872	4,309	-12
Running	5,016	4,648	-7

Table 6. Total duration (~total number of samples) of the 5 body posture and movements, as determined from video and by Activ8 (pocket location).

Activity	**Number of samples video**	**Number of samples Activ8**	**Difference Activ8 vs. video (%)**
Walking	8,608	9,146	+6
Cycling	5,009	5,616	+12
Standing	1,661	1,469	-12
Sitting	5,856	5,007	-14
Running	5,928	5,847	-1

Table 7. Total duration (~total number of samples) of the 5 body posture and movements, as determined from video and by Activ8 (thigh location).

Error analyses

Addionial analyses showed that some factors considerably influenced the validity data as described above:

- in two subjects (2 & 12), activities that assumes a (more or less) horizontal position of the thighs (such as cycling, sitting, and wheelchair activities) were for some or the larger part detected as standing or walking. This could be attributed to the pocket unit that was insufficiently located to the front side of the thigh. Correct classification would have resulted in an increase of the overall agreement from 90.1 to 94.0%, with the lowest agreement per measurement percentage increasing from 67.0 to 89.0.

- standing on a vibration plate was - especially for the thigh location - for an important part detected as "walking". Correct classification would have increased the overall agreement from 92.0 to 93.0%. The effect on the pocket sensor data was smaller: increase of the overall agreement from 90.1 to 91%.

- moving a wheelchair with the legs was often detected as cycling. Classification as sitting would have lead to an increase of the overall agreement from 90.1 to 91.8% (pocket unit) and from 92.0 to 95.0% (thigh unit).

8. DISCCUSSION

In the current study we validated the Activ8 device with respect to the detection of body postures and movements. Although we didn't define a strict criterion before the study in which case the device would be judged as valid or not, we feel that the conclusion is allowed that the posture and movement detection part of Activ8 is sufficiently valid for further application. This conclusion is partly based on the data as presented in the Results section, but also on additional quantitative and qualitative analyses. Some of them we will discuss in this section.

General interpretation of the results

The overall agreement for the Activ8 pocket location was 90.1%, and 92.0% for the thigh location. These scores are only a bit lower than the percentages previously found for more complex multi-sensor devices, as the Vitaport Activity Monitor. However, comparison with other devices should be done with care, because data are strongly influenced by number of body posture and motion categories, type of activities performed, and the distribution and duration of these activities within the protocol.

Interpretation of specific activities

We will shortly discuss – in order of the activity protocol tables – some specific issues.

- Walking and walking stairs were generally well detected. Some samples walking stairs was determined as standing – probably the result of actual standing.

- A small part of running and sprinting – especially at the lower running speeds – was determined as walking, which seems not crucial.

- Cycling was generally well detected . Sometimes it was determined as walking, especially in the data from the pocket sensor. This will be discussed later is this Discussion Section (paragraph “Pocket location”). In some situations the false detection was also the result of cycling on the home trainer with quite "vertical" legs, as a result of a high-positioned saddle.

- Vacuum cleaning and Doing dishes: were not analysed per sample, but assumed to be combination of walking and standing, with Vacuum cleaning being primarily walking, and with doing the dishes being primarily standing. The data support the validity of the Activ8 device in this respect.

- Sitting activities, lying included (see the “lying, sitting and non-wear” paragraph) were generally well detected. Sometimes sitting activities were detected as standing (see: paragraph "Pocket location").

- Standing on the vibration platform was regularly detected as walking. This will also be discussed further on (paragraph "External vibrations")

Lying, sitting and non-wear

The Activ8 device determines body postures & movements from a position close to the front of the thigh. Because the position of the thigh is similar in sitting and lying supine, discriminating between these body postures will not be straightforward. In the Activ8 device, differentiation between these body postures is based upon a combined time and movement criterion: sitting is defined as a “horizontal” thigh with small amounts of movement, while lying is defined as no movement at all for a longer period (>5 minutes). Because the latter situation also occurs in case of non-wear (e.g. the device placed on a table), the Activ8 system uses one combined category of “lying/non-wear”. The current protocol didn’t focus on the validity of the detection of this category, because it requires a prolonged period of no movement at all. Lying was part of the activity protocol, but it was known that this activity could and would not detected as lying. Therefore, we interpreted the detection lying as correct when it was classified as sitting. Future research will have to consider the validity of the non-wear/lying category.

Pocket location

The Activ8 is developed from the perspective to be used in a (trouser) pocket. This position is beneficial from a user comfort point of view. However, it is also clear that this position results in variability within and between persons. The current validation study indicates that the Activ8 device is quite robust in this respect. However, in two subjects the detection of cycling and - less frequent - sitting was falsely determined as walking/standing. This probably resulted from very "loose" clothes (e.g. jogging or sporting jeans) with a pocket that allowed the sensor to move and turn. The Activ8

device is assumed to be positioned at the front side of the thigh. Placement of the sensor in pockets at the lateral or back side will surely result in wrong detections.

Another point of consideration is the availability of pockets. Although we didn't had problems with this issue in our study, it can be assumed that especially women will not always have a pocket available. In such cases, the Activ8 device actually cannot be validly used with respect to posture and movement detection. Additionally, people can have different trousers with different types of pockets. This might result in different results and validity between days, persons and measurements.

Thigh placement

A solution for some of the issues discussed in the previous paragraph might be a fixed attachment of the sensor at the thigh. From a theoretical point of view, this position has to result in higher levels of validity. This assumption is to some extent supported by our results. The overall agreement scores from the pocket and thigh position differed only slightly, but two measurements had clearly lower agreement scores, and these data belonged to the pocket unit. Although we feel that the pocket location can still be used if some caution is considered with respect to the type of pocket, the thigh position is advantageous, e.g. in case the device is used as measurement device in scientific studies.

It is interesting to observe that some activities are determined better with the pocket device, and other activities with the thigh device. The data suggests that the thigh sensor measures movements more directly and with larger amplitudes; the pocket subdues to some extent the acceleration. This is e.g. clear in the data from standing on a vibration platform: the pocket sensor data more often determines standing instead of walking. However, it has to be realized that the settings in the device are based on the pocket position. It can be assumed that a thigh position with optimized settings will results in higher agreement scores.

External vibrations

The Activ8 device is based upon a sensor that is sensitive to accelerations. The human body is mostly responsible for these accelerations, but sometimes also external sources (e.g. car, public transport, tools) will cause accelerations that cannot be interpreted as being the result of human movement. Therefore, most activity monitor devices use a high-pass filter, that diminishes the effect of external vibrations on movement counts and posture and movement detection. To get some idea about the functioning of the Activ8 system in these circumstances, standing on a vibrating platform was added to the protocol. The results of this activity showed some effect of vibration on the posture and movement detection: in a considerable number of cases the standing on the vibrating plate was determined as walking, showing that the external vibrations were not sufficiently filtered out. Future research and application will have to consider the magnitude and relevance of this effect in regular use.

Duration of P&M categories

Discrepancies over 10% were found for the duration estimation of Activ8 compared to video. These can be explained by the error causes already described in this section. For example, the overestimation of the duration of walking can be explained by the well Activi8 determination of

walking activities, and by the determination as walking of some non-walking activities (e.g. standing on the vibration platform, running at 6 km/h). Similarly, the largest relative error (21%, standing, pocket unit) is mainly the result of the already described "pocket issue" in 2 subjects, related to loose clothes and/or non-optimal pocket position, which resulted in the detection of some sitting activities as standing.

Ecological validation and prolonged use

In this study the Activ8 device was validated during short measurements in different settings: a movement laboratory, a 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 still is small and they will represent only a small part of the regular activities of people in their daily life. Therefore, we propose – especially in the early phases of further use and application – special interest in the validity of the Activ8 device in these natural settings, e.g. by combining with simple activity diaries.

Energy expenditure

The activity detection within the Activ8 device has a dual function: feedback on the postures and movements performed is relevant in itself, but posture and movement information is also used for the estimation of energy expenditure. The current study did not focus on the validity of energy expenditure. This was done because validating EE estimation requires a completely different design and activity protocol, and because the validity of EE depends on the quality of the activity detection. We feel that validating the EE part of the Activ8 system is an important next step.

Conclusions and recommendations

The Activ8 system appears to be a valid instrument to quantify body postures and motions. If used in a (trouser) pocket, the type and position of the pocket has to be considered: a sufficiently valid functioning of the device requires a unit that is (to some extent) positioned at the front side of the thigh, without (too much) tilting. A more direct fixation to the thigh will improve its validity, although this will lower user comfort and some setting optimization might be needed.

Next phases need to include validation and/or critical analysis of prolonged measurements in a natural setting, further insight in the validity of the "lying/non-wear" category, the responsiveness on external vibrations, and the validation of the estimation of energy expenditure.

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