Reliable assessment of physical activity in disease: an update on activity monitors

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REVIEW

Reliable assessment of physical activity in disease: an update on activity monitors

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Purpose of review
Physical activity is the main determinant of variability of individual energy expenditure. Reliable assessment of the activity level of an individual provides information on energy requirement and vital health. Here, evidence is presented on the validity of methods to assess physical activity as applied in health and disease.

Recent findings
Improvement of technology has resulted in a growing number of physical activity monitors to evaluate the activity level of an individual. Outcome measures vary from raw data on body acceleration and posture to activity levels derived from proprietary algorithms based on body acceleration combined with sensor information on additional activity-induced physiological responses. Data interpretation is limited by evidence-based studies on the value of measured parameters for the assessment of physical activity.

Summary
The optimal tool for reliable assessment of physical activity is an accelerometer providing a valid measure of body movement. Overall validity is derived from studies using doubly labelled water-assessed activity-induced energy as a reference. Thus, out of the large range of activity monitors, three came out with a better validity. The ultimate tool is a single unobtrusive device allowing valid and long-term monitoring of activity with regard to type and intensity.

Keywords
accelerometers, body movement, doubly labelled water, energy expenditure, physical activity

INTRODUCTION

Physical activity is an important determinant of health and well-being. On the contrary, physical activity is negatively affected by disease. Thus, assessment of physical activity is important for understanding relations between physical activity and health and for determining the effectiveness of interventions. As stated by a recent guide to the assessment of physical activity, ‘deleterious health consequences of physical inactivity are vast, and they are of paramount clinical and research importance. Risk identification, benchmarks, efficacy, and evaluation of physical activity behaviour change initiatives for clinicians and researchers all require a clear understanding of how to assess physical activity’ [1▪].

Methods for the assessment of physical activity have evolved from behavioural observation and self-report through interviews, questionnaires, and diaries, to physiological markers including heart rate, calorimetry, and motion sensors. The doubly labelled water method has become the gold standard for the validation of methods of assessing physical activity behaviour [2]. Physical activity is defined as ‘any bodily movements produced by skeletal muscles that result in energy expenditure’ [3]. Doubly labelled water allows measuring total energy expenditure (TEE) in unrestrained individuals over a time interval of 1–4 weeks [4]. In combination with a measurement of resting energy expenditure (REE), activity-induced energy expenditure (AEE) can be calculated as $AEE = 0.9\ TEE - REE$. The calculation assumes that diet-induced energy expenditure is a constant fraction of 10% of TEE in individuals consuming a mixed diet and eating according to what they need [5]. Alternatively, physical activity can be calculated as

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KEY POINTS

- Accelerometry is the most promising method to objectively assess physical activity behaviour as a reflection of metabolic health or determinant of metabolic risk.
- The outcome of activity monitors is best evaluated when signals are accessible as raw data.
- Overall validity of activity monitors is judged with doubly labelled water-assessed activity energy expenditure or PAI as a reference.
- Out of the large range of activity monitors, three came out with a better validity.
- The ultimate activity monitor is a single unobtrusive device allowing valid and long-term monitoring of activity with regard to type and intensity.

the physical activity index (PAI) = TEE/REE. The PAI is a figure to compare physical activity, as derived from energy expenditure, between individuals of different size [6]. Overall reliability of a method to assess physical activity can be judged with doubly labelled water-assessed AEE or PAI as a reference.

Validation studies of methods for the assessment of physical activity with doubly labelled water as a criterion method have shown accelerometry to be superior to self-report and heart rate monitoring. With self-report, individuals easily overestimate or underestimate activity intensity and the time spent in activities. Heart rate is affected by more factors than physical activity and data conversion to physical activity needs individual calibration against oxygen consumption. Thus, heart rate monitoring remains a proxy measure for physical activity.

Accelerometry is the most promising method to objectively assess physical activity behaviour as a reflection of metabolic health or determinant of metabolic risk. Critical output parameters include time inactive, moderately active, and vigorously active. The purpose of the current review is to evaluate recent evidence on the validity of monitors to assess physical activity behaviour as applied in health and disease.

ACTIVITY MONITORS: PRACTICAL ASPECTS AND OUTCOME PARAMETERS

There is a large range of activity monitors from pedometers and load transducers, for walking activity, to accelerometers and multiple sensor systems, to monitor total physical activity. A review on the validity of accelerometers and multiple sensor systems in health and disease as published from 2000 to 2012 already included 40 different devices [7▪]. Aspects presented here are wearing comfort including size and placement, and outcome including data processing and storage capacity; validity is discussed in the next section.

Wearing comfort of a monitor for habitual physical activity should be such that it does not interfere with physical activity behaviour. One should forget about wearing a monitor. Modern technology allowed impressive miniaturization without loss of performance. We started in 1985 with an accelerometer weighing 350 g, including the unit for data storage, with the battery life of 7 days. Our current accelerometer weighs 12.5 g, has a battery life of 3 weeks, and can store data for up to 22 weeks [8]. Placement remains an issue. Theoretically, a monitor for the detection of total physical activity should be located near the centre of mass of the body since movements of the centre of mass reflect movements of the total body. Alternatively, monitors should be attached to the locations of the body where they would register the most activity, that is, the legs during walking and cycling. Thus, multiple accelerometers are used to classify activity modes. The ultimate monitor classifies activity modes with algorithms based on signals at one location, where sensors at more than one location reduce wearing comfort. Smart phones have a potential as activity monitor because people wear them everyday [9].

Outcome parameters of activity monitors are a function of specifications such as sampling frequency and dynamic range of the acceleration signal and of data transformation. Sampling frequency and dynamic range determine whether a monitor successfully filters accelerations from active movement and can be easily checked from the output during passive transport. Transformation of raw data is performed to increase storage capacity and thus observation time, and to translate the acceleration signal into physical activity outcomes such as activity time, type, and intensity including energy expenditure. Critical aspects are the inclusion of additional, not necessarily, activity-related parameters in the transformation process and in the use of proprietary equations. Outcome is best evaluated when signals are accessible as raw data [10▪]. Outcome should not be a function of proprietary equations where agreement between subsequent versions can be large [11].

VALIDATION

Activity monitors are designed to assess physical activity behaviour with a focus on time pattern and intensity. As stated in the introduction, overall validity is judged with doubly labelled water-assessed AEE or PAI as a reference. Then, the optimal observation time is 1 or 2 weeks. This is the optimal interval for valid doubly labelled water assessment of AEE or PAI. Observation for 1 or 2 weeks of free-living activity is likely to include the full range of physical activity behaviour of an individual. Laboratory validations during standardized activities, mainly walking and running, are discouraged. The walking component of physical activity is better detectable than other activities of daily living and thus not representative for overall validity.

Two reviews evaluated the performance of 18 different activity monitors against doubly labelled water, as published until 2012, resulting in a large heterogeneity in outcome [7▪,10▪]. Here, the main outcomes and conclusions are presented for validations of 11 monitors as published more recently (Table 1). Most monitors explained less than 50% of the variation in AEE or PAI. Only three out of the 11 tested, Actigraph GT3X, Dynaport, and TracmorD, came out better. Actiheart performed well in one study [15], whereas four other studies concluded that the performance was poor [13,14,16,17]. In only one study, the SenseWear armband explained more than 50% of the variation in AEE [22], whereas three other studies concluded poor performance as well.

APPLICATION IN HEALTH AND DISEASE

Of the three monitors selected above, Actigraph GT3X (ActiGraph, LLC., Pensacola, FL) is most widely applied. In 2003, Actigraph 7164, an earlier uniaxial model, was already introduced in the 'National Health and Nutrition Examination Survey' in the USA. Aggregated data resulted in decision rules to facilitate conclusions on physical activity from accelerometer output [26]. The size of the Actigraph GT3X, in combination with a memory and battery capacity for 1-month data collection, facilitates longitudinal assessment of physical activity in relation to disease parameters [27▪▪].

The Dynaport monitor (DynaPort MiniMod, McRoberts, The Hague, The Netherlands) is typically applied for the assessment of movement quality. In addition to overall physical activity, the monitor allows accurate assessment of postural stability and postural changes [28,29].

TracmorD (DirectLife, Philips Consumer Lifestyle, Amsterdam, The Netherlands) is applied in health and disease research and as a consumer product, in combination with a personal website and e-coach. Studies of obese individuals allowed the assessment of physical activity in relation to weight loss and weight maintenance [30,31]. A web-based intervention study showed the potential to increase physical activity, thus improving metabolic health [32▪▪].

In free-living individuals, physical activity shows large variation within a day and between

Table 1. Summary of doubly labelled water evaluation studies of activity monitors as published since 2012, with number of individuals (*n*), explained variation of activity-induced energy expenditure (R^2), and main conclusion

Monitor	*n*	R^2	Conclusion
Actigraph GT3X	39	70	Better-to-best performance out of six monitors tested [12▪▪]
Actiheart	18	17	Poor performance in adolescents [13]
	12	41	Not valid and considerable equipment failure [14]
	35	70	Good performance when individually calibrated [15]
	19	42	Underestimation of physical activity [16]
	75	0–6	No or little explanation of variation in physical activity [17]
Actiwatch	40	18	Moderate performance out of six monitors tested [12▪▪]
DynaPort	40	53	Better-to-best performance out of six monitors tested [12▪▪]
3DNX	155	6	Moderate explanation of variance in physical activity [18]
	49	18	Similar performance to uniaxial accelerometer [19]
EW4800P	16	20	No precise measurement of physical activity [20]
IDEEA	14	36	Capable of identifying activity, wiring limits use in daily life [21]
Lifecorder	40	10	Poor performance out of six monitors tested [12▪▪]
RT3	35	22	Reasonable in lean and poor performance in obese individuals [15]
	39	7	Poor performance out of six monitors tested [12▪▪]
SWA	73	8	Poor performance out of six monitors tested [12▪▪]
	19	38	Underestimation of physical activity [16]
	28	60	Considerable individual bias [22]
	62	–	Validity limited by large individual variation [11]
	14	16	No significant association with physical activity [23]
TracmorD	30	50	Moderate-to-strong validity in children [24]
	36	58	Valid in overweight and obese individuals [25]

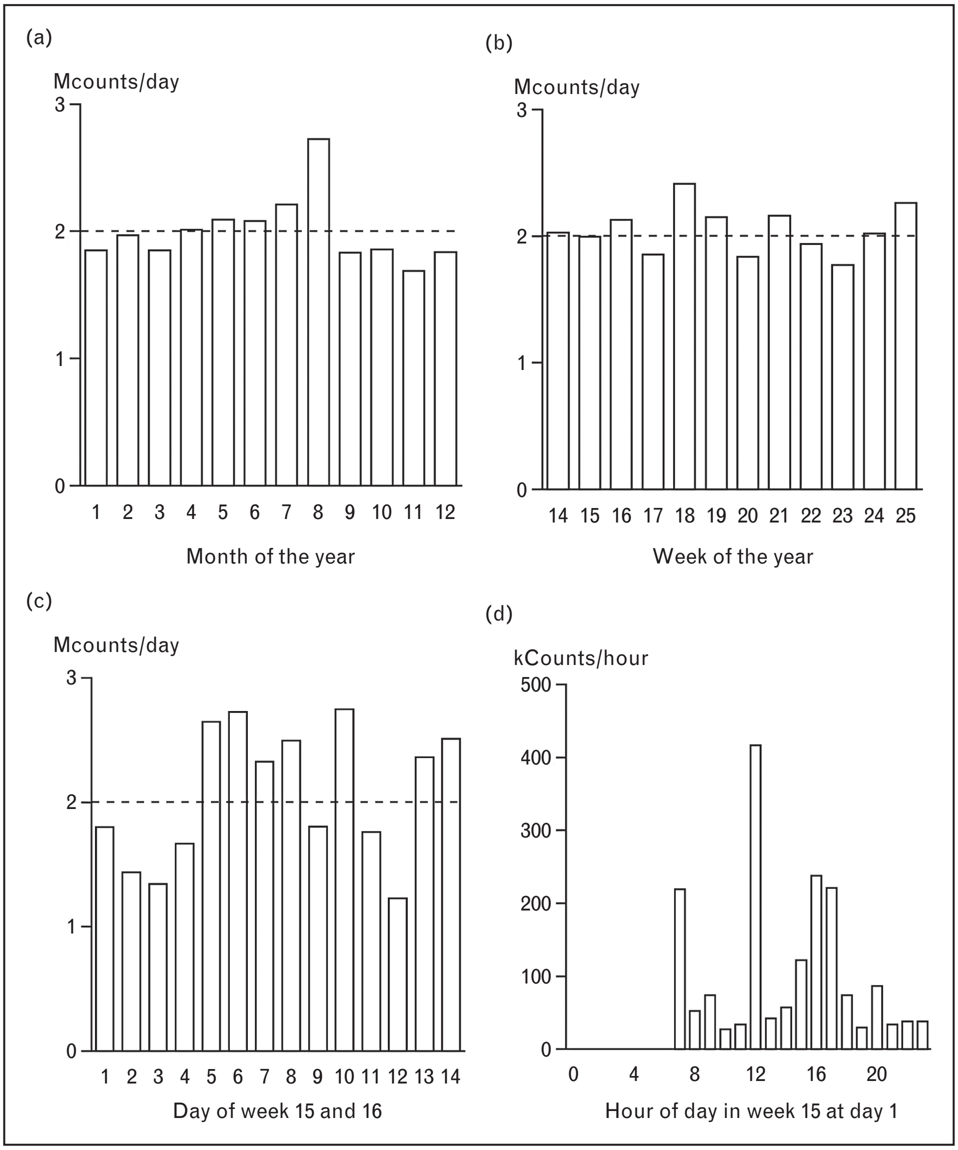

FIGURE 1. Physical activity of a typical individual monitored for 1 year with TracmorD, integrated over intervals of a (a) month, (b) week, (c) day, and (d) hour.

days. The variation is illustrated by activity data of a typical individual, as monitored with TracmorD and integrated over intervals of a month, week, day, and hour (Fig. 1). Thus, accelerometer output is usually evaluated over intervals of at least one or more weeks.

DISCUSSION

Out of the large range of activity monitors, three came out with a better validity as evaluated under free-living conditions with doubly labelled water-derived activity energy expenditure as a reference. The final choice of a valid monitor depends on further specifications including memory and battery capacity, additional options for data processing including movement quality, and options for user feedback and coaching.

Activity monitors with better validity explained 50–70% of the variation in AEE or PAI, leaving at least 30% of the variation unexplained. Further improvement could be reached with monitors allowing the assessment of activity type. The relationship between activity counts and energy expenditure varies according to activity type [33]. Identification of activity types improved the assessment of energy expenditure compared with activity counts only [34,35].

Interpreting physical activity outcomes based on activity monitors requires adjustment for body size when comparing individuals of different size. Obese individuals are more sedentary than individuals of normal weight while AEE might be similar [36]. Excess weight increases energy cost of movement and decreases movement economy. A weight correction factor will be higher for ambulatory activities and lower for sedentary activities. Activity energy expenditure is commonly corrected for differences in body weigh by dividing AEE (J/min) by the square root of body weight [35]. A standard way of comparing outcomes of an activity monitor between individuals of different size is by converting the outcomes into a PAI value.

Activity monitors are often validated under laboratory conditions during standardized activities, mainly walking and running. The walking component of physical activity is better detectable than other activities of daily living and thus validity during walking is not representative for overall validity. Additionally, in relation to health, light-intensity activities might be as important as high-intensity activities. Light-intensity activity breaks decrease the well known risk of thrombosis associated with excessive sitting [37]. To detect uninterrupted bouts of inactivity, an activity monitor should detect minimal body movement to prevent mistaking uninterrupted bouts of inactivity for nonwear time [38].

CONCLUSION

Accelerometry is the most promising method to objectively assess physical activity behaviour as a reflection of metabolic health or determinant of metabolic risk. The validity of accelerometer-based activity monitors is judged with doubly labelled water-assessed activity energy expenditure or PAI as a reference, where the optimal observation time is 1 or 2 weeks. The outcome of an activity monitor should not be a function of proprietary equations where agreement between subsequent versions can be large. Most monitors explained less than 50% of the variation in activity energy expenditure or PAI. Only three out of the 11 tested, Actigraph GT3X, Dynaport, and TracmorD, came out better. The final choice of a valid monitor depends on further specifications including memory and battery capacity, additional options for data processing including movement quality, and options for user feedback and coaching.

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Conflicts of interest

There are no conflicts of interest.

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