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POSITION PAPER

Measuring physical activity with activity monitors in patients with heart failure: from literature to practice. A position paper from the Committee on Exercise Physiology and Training of the Heart Failure Association of the European Society of Cardiology

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The aims of this paper were to provide an overview of available activity monitors used in research in patients with heart failure and to identify the key criteria in the selection of the most appropriate activity monitor for collecting, reporting, and analysing physical activity in heart failure research. This study was conducted in three parts. First, the literature was systematically reviewed to identify physical activity concepts and activity monitors used in heart failure research. Second, an additional scoping literature search for validation of these activity monitors was conducted. Third, the most appropriate criteria in the selection of activity monitors were identified. Nine activity monitors were evaluated in terms of size, weight, placement, costs, data storage, water resistance, outcomes and validation, and cut-off points for physical activity intensity levels were discussed. The choice of a monitor should depend on the research aims, study population and design regarding physical activity. If the aim is to motivate patients to be active or set goals, a less rigorously tested tool can be considered. On the other hand, if the aim is to measure physical activity and its changes over time or following treatment adjustment, it is important to choose a valid activity monitor with a storage and battery longevity of at least one week. The device should provide raw data and valid cut-off points should be chosen for analysing physical activity intensity levels. Other considerations in choosing an activity monitor should include data storage location and ownership and the upfront costs of the device.

Keywords Physical activity • Activity monitor • Motion sensor • Accelerometer • Heart failure

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Introduction

Even modest amounts of regular physical activity in patients with heart failure (HF) are associated with a lower risk of HF-related hospital admissions and mortality, and other health-related outcomes.[1,2] As a result, there are increasing numbers of intervention studies under way exploring the effects of encouraging and increasing physical activity in patients with HF on a variety of primary outcome variables including mortality, morbidity and quality of life.[3] Other studies have focussed on measures of functional capacity, either subjective such as New York Heart Association classification, or objective including the 6-min walk test distance, and peak cardiopulmonary capacity via peak oxygen uptake measurement. These assessments are limited by being snapshots of physical function and do not assess long-term physical activity. Many terms are used to describe outcomes related to physical function, such as physical activity, daily physical activity, non-sedentary behaviour and exercise capacity.

Physical activity is defined as bodily movement produced by skeletal muscles that results in energy expenditure.[4] Both subjective and objective instruments can be used to measure physical activity. Subjective measures include self-reported questionnaires or diaries such as the International Physical Activity Questionnaire (IPAQ) or the Cambridge Physical Activity Index (CPAI), but these are limited by subjectivity, recall bias, or participant burden.[5–7] Self-reported questionnaires can overestimate physical activity by up to 44% in men and 138% in women, and also lack the precision needed to detect changes in physical activity on a day-to-day basis.[8]

Objective methods to measure physical activity include measures that directly assess one or more dimensions of physical activity (e.g. frequency, intensity, time, type), and have the ability to capture a variety of metrics such as number of steps, minutes of activity, intensity of activity, and bouts of activity.[9] Commonly used tools include indirect calorimetry and direct observation as well as wearable devices such as step counters, motor sensors, activity monitors (a device or application for monitoring and tracking physical activity). These objective measurements are considered superior to self-reporting physical activity, as they better capture the intricacies of physical activity dimensions.[10,11] Recently, activity monitors have been used to provide personalized advice, motivate and remind patients to be active, and help them to set realistic goals.[12] Hence, activity monitors that are simpler to use have been proposed as a practical alternative to more formal activity monitors when no accurate measurement is needed, for example in clinical practice.[13–15]

In a more protocolized clinical setting and for research purposes, activity monitors have been considered to quantify and monitor activity counts objectively and continuously over an extended period of time.[16] Activity monitors that sense body accelerations, commonly known as 'accelerometers', capture additional information on the intensity, duration and frequency of physical activity, as well as the number of steps.[9] These devices can therefore capture physical activity intensity levels and provide a more continuous and comprehensive evaluation of free-living activity.[17,18] A relevant proportion of HF patients have a cardiac device such as a cardiac pacemaker, an implantable cardioverter-defibrillator, a cardiac resynchronization therapy device, a wearable shock vest, or ventricular assist devices. Some of these cardiac devices can also measure physical activity in these patients.[19,20] Finally, smartphone and smartwatch-based applications, such as MyHeart Counts, play a role in measuring physical activity.[21,22]

Nevertheless, one challenge is that there is no 'gold standard' for activity monitoring in research on cardiac patients, leading to a large variety of equipment used and values reported. Such a variety of tools, each with limited validation data, hinders the comparability of results and has delayed the growth of a reliable evidence base in terms of assessing the effect of training interventions and other interventions on activity. The challenges outlined above are exacerbated in patients with HF because of their very low physical activity levels, frailty and abnormalities of cognition, such that not all monitors are suitable in all patients. A recently published review[23] assessed the methods used for collecting and processing accelerometer data in cardiology, but more work is needed to address the challenges of comprehensive and consistent collecting, reporting, and analysing of physical activity in patients with HF.

The aims of this paper were to provide an overview of available activity monitors used in research in patients with HF and to identify the most appropriate criteria in the selection of the most adequate activity monitor for collecting, reporting, and analysing physical activity in HF research.

Methods

This study is conducted in three parts. First, we conducted a systematic literature review to identify important physical activity concepts and activity monitors that have been used in research on patients with HF. Second, we performed an additional scoping review using electronic resources and the manuals for the available activity monitors to describe their validation. Third, the most appropriate criteria in the selection of the most adequate activity monitor were identified from the current literature, and were shared and discussed among the members of the Committee on Exercise Physiology and Training of the Heart Failure Association of the European Society of Cardiology. Next to the design and aim of research to measure physical activity, the validity of the measurement, data storage, data access, completeness and costs were considered important criteria in selection of an activity monitor in HF research.

The literature search included online electronic databases (PubMed, Scopus, CINAHL and Web of Science), and was conducted in October 2017 and updated in April 2020. The following search string was utilized across the databases: ('accelerometer' OR 'accelerometry' OR 'motion sensor' OR 'activity monitor') AND ('heart failure'). For inclusion in this analysis, studies were required to be published or in press, peer-reviewed literature and in the English language. Studies that include patients under 18 years old, studies that were not explicitly related to physical activity and studies that were not specifically related to HF were excluded. Additionally, we excluded studies including pedometers measuring only steps, which are often inaccurate at slow gait speed.[24] Measuring steps only can ignore the intensity, duration and frequency of physical activity, which we consider important aspects of measuring physical activity. Two authors (L.K. and M.K.) independently reviewed the results of each search according the inclusion and exclusion criteria. A third author (E.L.) adjudicated in cases of disagreement.

Table 1 Concepts and definition in activity monitoring

Concept	Description
Activity count	Activity that causes an acceleration signal to exceed a threshold is 'counted' as activity; anything below this threshold is ignored. At the end of a measurement period, the number of activity 'counts' is recorded.
Activity trackers and monitors	Device or application for monitoring and tracking physical activity.
Type (dose)	The type and amount of reported or prescribed physical activity.[25]
Time (duration)	The length of time for each session or bout.[25]
Frequency	Sessions or bouts of moderate-to-vigorous physical activity per day or per week.[25]
Intensity	The rate of energy expenditure required to perform any physical activity. It can be measured in METs, kilocalories, joules, or oxygen consumption.
Energy expenditure	The amount of energy that a person needs to carry out physical functions.
Epoch	A particular period of time in a person's life.
Exercise	A subset of physical activity that is planned, structured and repetitive and has as a final or an intermediate objective the improvement or maintenance of physical fitness.[4]
Light-intensity activity	Requires 1.6 to less than 3.0 METs; examples include walking at a slow or leisurely pace (2 mph or less), cooking activities, or standing while scanning groceries as a cashier.[26]
Metabolic equivalent of task (MET)	The objective measure of the ratio of the rate at which a person expends energy, relative to the mass of that person, while performing some specific physical activity compared to a reference. One MET is the rate of energy expenditure while sitting at rest, which, for most people approximates an oxygen uptake of 3.5 mL/kg/min. The energy expenditure of other activities is expressed in multiples of METs. For example, for the average adult, sitting and reading requires about 1.3 METs. Strolling or walking slowly requires about 2.0 METs. Walking at about 3.0 miles/h requires about 3.3 METs, and running at 5 miles/h requires about 8.3 METs. The average rate of energy expenditure for a substantial number of activities has been documented for the general adult population.[26]
Moderate-intensity activity	Requires 3.0 to less than 6.0 METs; examples include walking briskly or with purpose (3 to 4 mph), mopping or vacuuming, or raking a yard.[26]
Physical activity	Any bodily movement produced by skeletal muscles that results in energy expenditure.[4]
Sedentary behaviour	Any waking behavior characterized by an energy expenditure of 1.5 or fewer METs while sitting, reclining, or lying.[27]
Uniaxial, biaxial and triaxial	Uniaxial activity monitors measure acceleration in one plane, usually vertical to the ground. Biaxial and triaxial refer to activity monitors which measure acceleration in two or three planes, respectively.
Vigorous-intensity activity	Requires 6.0 or greater METs; examples include walking very fast (4.5 to 5 mph), running, carrying heavy groceries or other loads upstairs, shoveling snow by hand, mowing grass with a hand-push mower, or participating in an aerobics class.[26]
Vector magnitude unit	The vectorial sum of activity in the three orthogonal directions measured over a 1-min period.
Volume	The quantification of the dose of activity accumulated over a specified length of time. In activity monitors, volume are activity counts or step counts during a set period of time.[25]

Results

Overall, 45 studies from 489 publications were identified as relevant, and full copies were retrieved and assessed (online supplementary *Figure S1* and *Table S1*).

Concepts related to physical activity

The most frequently used concepts in research on activity monitors were physical activity and exercise (*Table 1*).[4,25–27] Physical activity is any bodily movement produced by skeletal muscles that results in energy expenditure. Exercise is a subset of physical activity, but it is planned, structured and repetitive, and its final or intermediate objective is the improvement or maintenance of physical fitness.[4] Physical activity or exercise is prescribed by health care professionals to their patients with HF following the FITT principle (frequency, intensity, time/duration and type). The frequency describes the number of sessions of physical activity per day or per week, and the intensity is the rate of energy expenditure (sedentary-light-moderate to vigorous) required to perform any physical activity.[25] 'Type' indicates the characteristics and the amount of prescribed physical activity, while 'time' describes the duration of each session. Most activity monitors measure activity counts and/or step counts, where activity counts are acceleration signals that exceed a threshold and are therefore 'counted' as activity.

Activity monitors in heart failure research

Seventeen activity monitors were described in the retrieved articles on patients with HF (*Table 2*).[28–43] Of these 17 activity monitors, eight [Actical (Minimitter, Inc., Respironics, Bend, OR, USA), ActiGraph Model GT1M Model and ActiGraph 7164 (ActiGraph, Pensacola, FL, USA), ActivPAL™ (PAL Technologies Ltd., Glasgow, UK), Caltrac (Muscle Dynamics, Torrance, CA, USA), the Chiron

Table 2 Characteristics of activity monitors used in research with patients with heart failure

Activity monitor	Size (weight) Placement	Costs	Data storage	Water resistance	Can assess sleep quality	Outcome (measured)	Outcome (calculated)	Field validation TEE & AEE	Laboratoryvalidation
Uniaxial									
KenzLifecorder EX (KenzLifecorder, Suzuken Co., Ltd., Nagoya, Japan)	7.25 × 4.15 × 2.75 cm (60 g) Waist	10 € Software for free: Physical Activity Analysis Software (PAAS)	200 days	No	No	Steps, activity intensity level	EE, activity intensity level	TEE healthy adults r = 0.83[28]	Healthy adults r = 0.56–0.96[28–31]
Triaxial									
Actigraph GT3X (Actigraph, Pensacola, FL, USA)	4.6 × 3.3 × 1.5 cm (19 g) Hip, ankle, or wrist	1385 Euros for monitor, interface unit, and software	19 days	To 1 m	Yes	AC, physical activity intensity, steps	EE, activity intensity level	TEE healthy adults r = 0.80[28]	Healthy adults r = 0.88[28]
AX3 (Axivity Ltd, Newcastle, UK)	23 × 32.5 × 7.6 mm (11 g) Wrist	124 €, 135 € with wristband Software is open source	14 days (110 Hz)	To 1.5 m	No	AC, physical activity intensity	EE, activity intensity level	TEE healthy adults r = 0.87–0.91[32] AEE healthy adults r = 0.59–0.69[32]	Stroke patients r = 0.63–0.87[33]
Fitbit-Flex (Fitbit Inc., San Francisco, CA, USA)	31.7 × 8.9 × 6.8 mm (23.53 g) Wrist	60 €	5 days	Sweat, rain and splash-proof	Yes	AC, physical activity intensity, steps	EE, activity intensity level	TEE healthy adults r = 0.84[28]	Healthy adults r = 0.90[28]
Stayhealthy RT3 (Stayhealthy, Monrovia, CA, USA)	7.1 × 5.6x 2.8 cm (65.2 g) Hip or waist	462 € for monitor and docking station	21 days	To 1 m	No	AC, VMU	EE	TEE healthy adults r = 0.32[34] AEE chronic disease patients r = 0.67[35]	Healthy/overweight adults r = 0.47[35] Healthy adults r = 0.48–0.94[36–39]
TracmorD (Philips New Wellness Solutions, Lifestyle Incubator, The Netherlands)	3.2 × 3.2 × 0.5 cm (12.5 g) Around the neck, hip, or on lower back	99 €, 15 € monthly abonnement software online	22 weeks	To 3 m	Yes	AC, physical activity intensity	EE, activity intensity level	TEE healthy adults r = 0.46[40] AEE healthy adults r = 0.48[40]	Healthy subjects r = 0.89[41]
Multisensor									
Fitbit Charge HR (Fitbit Inc., San Francisco, CA, USA)	Wrist 31.7 × 8.9 × 6.8 mm (23.53 g)	149 €	5 days	Sweat, rain and splash-proof	Yes	AC, physical activity intensity, steps	EE, activity intensity level	X	X
GENEActiv (Activinsights Ltd., Camps, UK)	43 × 40 × 13 mm (16 g)	205 €	7 days	Waterproof	Yes	AC, physical activity intensity	EE, activity intensity level	X	Healthy adults r = 0.97[42]
Move 4 (Movisens, GmbH, Karlsruhe, Germany)	62.3 × 38.6 × 11.5 mm (25 g) Hip, wrist, or chest	2115 € for monitor, interfaceunit, and software. The possibilities to rent the device for 50 € a week	7 days	Sweat, rain and splash-proof	No	AC, physical activity intensity, steps	EE, activity intensity level	X	Move II healthy adults r = 0.64–0.88[43]

AC, activity count; AEE, active energy expenditure; TEE, total energy expenditure; VMU, vector magnitude unit.

Table 3 Cut-off points for sedentary time, light physical activity, moderate physical activity and vigorous activity in adults and older adults

Age group	Sedentary time	Physical activity		
		Light	Moderate	Vigorous
Adults				
Freedson *et al.*[44]	≤99	100–759	760-5724	≥5725
Troiano *et al.*[45]	≤100	101–2019	2020-5998	≥5998
Older adults				
Copeland *et al.*[46]	≤99	100–1039	≥1040	NA
Davis and Fox[47]	≤199	200–1999	2000–3999	≥4000
Metzger *et al.*[48]	≤149	150–2019	≥2020	NA
Troiano *et al.*[45]	≤100	101–2019	2020–5997	≥5998

NA, not available.

wearable sensor platform, SenseWear Pro3 Armband (BodyMedia, Inc, Pittsburgh, PA, USA) and the Temec activity monitor (Temec Instruments Kerkrade, The Netherlands)] were not available or not yet available to purchase on the market and therefore were not considered. One activity monitor, the HJA-750C Active Style Pro (OMRON Healthcare Co., Ltd., Kyoto, Japan), despite being available outside Japan, only provided software and supporting information in Japanese. This device was also not considered. Another activity monitor, the Move II (Movisens, GmbH, Karlsruhe, Germany), was no longer available, but had been replaced with the Move 4 (Movisens, GmbH, Karlsruhe, Germany) which has all the functionality of the Move II, with user-relevant improvements including better battery longevity and improved water-resistant casing. Given the availability of information on the Move II, we considered the potential of the Move 4 for patients with HF.

The remaining monitors ($n = 9$) were subsequently classified into three groups: uniaxial, triaxial and multisensory. *Table 2* presents data on basic characteristics such as the size, weight, placement, costs, data storage, water resistance, possibilities to measure length and quality of sleep, outcomes and validation of these activity monitors.

Uniaxial activity monitors

Uniaxial monitors measure the degree and intensity of movement in a vertical plane, by identifying periods of standing and stepping activity. Only one activity monitor, the Kenz Lifecorder EX (Suzuken Co., Ltd., Nagoya, Japan), has been used in HF research and is still available. This device (dimensions: 7.25 × 4.15 × 2.75 cm) is worn on the thigh or over the hip, and measures steps. It is not water resistant. The memory capacity allows activity and posture to be recorded continuously for periods of up to 200 days. Data can be transferred with a USB cable to a personal computer running Windows 98SE/Millennium/2000 and XP only.

Triaxial activity monitors

Triaxial activity monitors measure multidirectional movement more efficiently. We identified five triaxial monitors that had been used in HF research: ActiGraph GT3X, AX3, Fitbit Flex, Stayhealthy RT3 and TracmorD. Most of these are worn using an elastic belt or in a clip pouch on the hip or waist. The TracmorD can also be worn as a necklace or on the lower back. One monitor was sweat, rain and splash proof (Fitbit Flex), while two were waterproof up to 1 m (ActiGraph GT3X and Stayhealthy RT3), one up to 1.5 m (AX3) and one up to 3 m (TracmorD). Most of these are acceptably small (ranging from 23 × 32.5 × 7.6 mm to 71 × 56 × 28 mm) and all of them convert accelerations into activity count values, allowing energy expenditure to be calculated. The sum of activity counts in an epoch is linearly related to activity intensity and can be classified into intensities of physical activity based on validated and established activity count cut points (*Table 3*).[44–48]

The monitors differ in terms of memory capacity: the ActiGraph memory allows activity and posture to be recorded continuously for periods of up to 19 days, the Actical up to 45 days, the Stayhealthy RT3 up to 21 days, the Move 4 up to 7 days, the Fitbit Flex up to 5 days, and the TracmorD up to 22 weeks. With some activity monitors, software (compatible with a Windows operating system) is needed to download the data (ActiGraph GT3X, AX3, Stayhealthy RT3) to a personal computer, while with others (Fitbit Flex and TracmorD) the data can be uploaded to a website online, in an online cloud. One activity monitor (ActiGraph) has the option to buy a data hub, which allows data to be transferred (in encrypted form) through a Bluetooth connection to an online cloud.

Multisensory activity monitors

The Fitbit Charge HR, the GENEActiv and the Move 4 are multisensory triaxial activity monitors. The Fitbit Charge HR incorporates a heart rate sensor, the Move 4 has a rotation rate sensor, a pressure sensor and a temperature sensor, and the GENEActiv has an ambient light and temperature sensor. These are small devices (ranging from 43 × 40 × 13 mm to 62.3 × 38.6 × 11.5 mm) that can be worn on the wrist, although the Move 4 can also be worn on the hip or the chest. Two monitors were sweat, rain and splash proof (Fitbit Charge HR and Move 4), while the GENEActiv is totally waterproof. The Fitbit Charge has a battery longevity of

5 days, and the GENEActiv and Move 4 have a battery longevity of 7 days.

For data transfer, two multisensory activity monitors (GENEActiv and Move 4) need to be connected via a USB cable to a personal computer with a software developed for the specific monitor (applicable for Windows operating systems). One activity monitor needs to be connected via a USB cable to a personal computer, where the data can be uploaded to a website (online cloud).

Validation of the activity monitors

For this report we have divided the validation evidence into that collected in the field and that collected in the laboratory (*Table 2*). Field validation is validation of an activity monitor against indirect calorimetry, using the doubly labelled water technique (the gold standard). In the doubly labelled water technique, participants are given a known volume of water which contains 'marker isotopes'. Over a period of days or weeks, samples of body water (from saliva, urine or blood plasma) are assessed for the elimination of these isotopes, which occurs through the body's metabolism. There is a direct correlation between energy expenditure and the amount of carbon dioxide and metabolic water produced. The changes in the isotopes in the body water over time are linked to oxygen usage and carbon dioxide production, both of which are major biochemical components of energy metabolism.[49] Correlation coefficients between total and active energy expenditure measured by the activity monitor and total and active energy expenditure measured with doubly labelled water were extracted.

Laboratory validation involves the comparison of data obtained from the monitor against data from indirect calorimetry during exercise, using either a metabolic cart, a metabolic chamber or direct observation. A metabolic cart measures the oxygen consumed and the carbon dioxide produced by a subject, and then calculates the energy expenditure. A metabolic chamber measures the amount of heat (energy) produced by a subject enclosed within a chamber. With indirect calorimetry, the amount of heat (energy) produced by a subject is measured by determining the amount of oxygen consumed and the quantity of carbon dioxide eliminated. Correlation coefficients between activity monitor outcome and energy expenditure measured by metabolic cart/chamber were extracted.

Field validation

We first analysed studies that included validation of the total energy expenditure activity monitor against the total energy expenditure measured with doubly labelled water. The total energy expenditure for the GENEActiv and the Move 4 was not validated with doubly labelled water. The total energy expenditure was validated in healthy adults using the Kenz Lifecorder ($r = 0.83$), the ActiGraph GT3X ($r = 0.80$), the AX3 ($r = 0.87–0.91$), the Fitbit Flex ($r = 0.84$), the Stayhealthy RT3 ($r = 0.32$) and the TracmorD ($r = 0.48$).

Second, we analysed studies that included the validation of the active energy expenditure measured with the activity monitor against the active energy expenditure measured with doubly labelled water.

The active energy expenditure was validated in healthy adults using the AX3 ($r = 0.59–0.69$) and the TracmorD ($r = 0.48$). The active energy expenditure was validated in patients with a chronic disease using the Stayhealthy RT3 ($r = 0.67$).

Laboratory validation

For the laboratory validation, we looked at the correlations between the activity monitor outcomes and the total energy expenditure measures from indirect calorimetry during laboratory protocols. The Fitbit Charge HR was not validated by laboratory validation. The laboratory validation was carried out on healthy adults using the Kenz Lifecorder ($r = 0.56–0.96$), the ActiGraph GT3X ($r = 0.88$), the Fitbit Flex ($r = 0.90$), the Stayhealthy RT3 ($r = 0.48–0.94$), the TracmorD ($r = 0.89$) and the GENEActiv ($r = 0.97$). The AX3 was laboratory validated for stroke patients ($r = 0.63–0.87$), the Stayhealthy RT3 was validated for healthy and overweight adults ($r = 0.47$), and the GENEActiv was validated for patients with HF.

Discussion

Researchers who either study physical activity in patients with HF or wish to assess the effects of interventions on physical activity face the challenge of choosing the most appropriate monitor for the patient group and the intervention. The difficulties are compounded because no overview exists of the utility of these devices regarding practical and scientific issues. With this paper we have therefore summarized the practical and scientific differences between activity monitors used for research patients with HF.

Decide on the aims

The choice of a monitor should depend on the research aims and design regarding physical activity. For non-pharmacological interventions the aim could be to motivate patients to be active or set goals. A less rigorously tested tool can be considered (e.g. activity tracker, smartphone apps[50,51]). In non-pharmacological and pharmacological interventions, the aim could also be to measure physical activity and its changes over time, such that it is important to choose a valid and reliable activity monitor.

Consider validation

For research purposes, an activity monitor validated with the gold standard (doubly labelled water) is preferred. Three activity monitors, the Fitbit Charge HR, the GENEActiv and the Move 4, were not field validated.

Also, it is important to use validated cut-off points for physical activity levels in patients with HF. Cut-off point to investigate the relationship between activity counts and activity intensity level, should be chosen according to the population that is studied.

Most studies investigating the relationship between activity counts and activity intensity levels in adults, present cut-off points for light, moderate and vigorous physical activity. It is important to note that cut-offs validated in a specific age group might not be valid for other age groups due to different physical activity patterns. Also, in assessing physical intensity levels in patients with HF, we believe that monitoring of sedentary time is important. Therefore, we recommend to use cut-off points for adult patients with HF that can calculate activity counts in sedentary physical activity as moderate to vigorous physical activity (*Table 3*).[44,45]

Only a few have investigated cut-off points for older adults, such as the typical HF population.[45–48] When the study population are the elderly HF patients (with possible multi-comorbid disorders and frailty conditions), we recommend using cut-offs that are advised for use in older adults (*Table 3*) due to different moving patterns between these groups.

Consider data storage, data access and completeness

Data storage is another important feature when choosing the right activity monitor. An accurate measure of physical activity requires at least 4 days of activity data, with a minimum use of 540 min/day.[52] This determines the required battery longevity and the memory capacity. However, if compliance is imperfect, an activity monitor with a larger storage capacity (at least one week) and a battery longevity that does not require frequent charging is recommended for use. For example, the Fitbit Flex and the Fitbit Charge HR have data storage of only 5 days and require frequent charging.

One aspect that is increasingly relevant to all research is the ability to compare data across studies. This was also included in a literature review[23] looking at the methods used for collecting physical activity data in patients with HF. Researchers and clinicians are encouraged to improve the quality and transparency of data collection and processing.

The key to success in this field, therefore, is that devices must be able to provide raw activity data (activity counts) which can then be translated into activity intensity levels. Uniaxial devices provide raw activity counts in one plane only, usually vertical to the ground, translated into number of steps. Since physical activity is often more complex than simple steps, this might not be sufficient for detailed assessment in clinical practice and is unlikely to be useful for research purposes. The data from biaxial, triaxial or multisensory activity monitors are likely to provide a more complete impression. However, we could not find any research on patients with HF using biaxial activity monitors, and the TracmorD software does not give the raw data in activity counts and activity intensity. It is also unclear which cut-offs are programmed in the analysis software to calculate the activity counts and to translate these into activity intensity levels. The TracmorD, Fitbit Flex and Fitbit Charge HR activity monitors are now only available as commercial devices. As a consequence, the collected data are uploaded to a cloud-based storage system, which patients and researchers do not own themselves. As a result, access to the activity counts could be challenging. Cloud-based data also involve ethical issues in clinical research.

Consider costs

Another consideration when choosing an activity monitor is costs, which range between € 10 for a uniaxial monitor and € 2115 for a multisensory monitor. One monitor could be rented for periods of time.

Limitation and future directions

Unfortunately, it is often not possible to field validate activity monitors due to the costs of doubly labelled water testing, the 'gold standard'. Because the doubly labelled water technique is based on body's metabolism, and this will not change due to HF, we believe that devices that are field validated are also considered as validated devices for patients with HF.

When it is not possible to field validate an activity monitor, laboratory validation could be a solution. Unfortunately, we found only laboratory validation in healthy adults, overweight adults or stroke patients but no data around validation in patients with HF. Future research should focus on either field validation of new devices or laboratory validation of devices in patients with HF. Since HF includes a wide variety of phenotypes, with widely differing left ventricular ejection fraction and conditioning levels, an effort to be able to analyse these distinctions with activity monitors, providing a precise phenotype-driven cut-off point, should be pursued.

Pre-determined decisions about data collection (e.g. activity monitor placement, wear time) and processing (e.g. non-wear-time definition, cut-off points) in relation to the study participants and the objective of the study are important when planning research in this area.[53]

Physical activity is the prolongation of cardiac rehabilitation and this was shown to reduce hospitalizations. However, no data exist in a study using activity monitors that showed a reduction in hospitalizations. In order to understand the relationship between physical activity and (re)hospitalization, future research should focus on monitoring patient their long-term physical activity to detect possible deterioration. We also believe that future research should explore the relation between physical activity and traditional measures of functional status (e.g. New York Heart Association class, 6-min walk test, cardiopulmonary exercise testing).

The development of activity monitors is evolving rapidly and therefore we aim to update the data on available activity monitors used in HF research regularly.

Conclusions

The choice of a monitor should depend on the research aims and design regarding physical activity. If the aim is to motivate patients to be active or set goals, a less rigorously tested tool can be considered, such as step counters or smartphone/watch applications. On the other hand, if the aim is to measure physical activity and its changes over time or with treatment, it is important to choose a validated activity monitor (preferable with field validation) and choose activity intensity cut-offs points that are appropriate for the elderly co-morbid population commonly represented in HF. Furthermore, the device needs to have a storage with battery longevity

of at least one week to be able to compare to other research, and must be able to provide raw data. Other considerations in choosing an activity monitor should be where the data are stored, who owns the collected physical activity data and the costs. This article summarizes the practical and scientific differences between activity monitors used in research on patients with HF, to help researchers who study physical activity in patients with HF and who design and evaluate interventions to choose the most appropriate monitor for their requirements.

Supplementary Information

Additional supporting information may be found online in the Supporting Information section at the end of the article.

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