Eur Respir J 2006; 27: 1040–1055
DOI: 10.1183/09031936.06.00064105

REVIEW

Quantifying physical activity in daily life with questionnaires and motion sensors in COPD

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ABSTRACT: Accurate assessment of the amount and intensity of physical activity in daily life is considered very important due to the close relationship between physical activity level, health, disability and mortality. For this reason, assessment of physical activity in daily life has gained interest in recent years, especially in sedentary populations, such as patients with chronic obstructive pulmonary disease (COPD).

The present article aims to compare and discuss the two kinds of instruments more commonly used to quantify the amount of physical activity performed by COPD patients in daily life: subjective methods (questionnaires, diaries) and motion sensors (electronic or mechanical methods). Their characteristics are summarised and evidence of their validity, reliability and sensitivity is discussed, when available.

Subjective methods have practical value mainly in providing the patients' view on their performance in activities of daily living and functional status. However, care must be taken when using subjective methods to accurately quantify the amount of daily physical activity performed. More accurate information is likely to be available with motion sensors rather than questionnaires. The selection of which motion sensor to use for quantification of physical activity in daily life should depend mainly on the purpose of its use.

KEYWORDS: Accelerometer, chronic obstructive pulmonary disease, motion sensor, physical activity, questionnaire, review

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Received:
June 01 2005
Accepted after revision:
December 18 2005

SUPPORT STATEMENT
F. Pitta is supported by Coordenação de Aperfeiçoamento de Pessoal de Nível Superior (CAPES; Brasilia, Brazil). T. Troosters is a postdoctoral fellow of the Fonds voor Wetenschappelijk Onderzoek (FWO; Vlaanderen, Belgium). M.A. Sruit is a postdoctoral fellow at Katholieke Universiteit Leuven, Leuven, Belgium (PDM/04/230).

European Respiratory Journal
Print ISSN 0903-1936
Online ISSN 1399-3003

Lifestyle, including physical inactivity in daily life, plays an important role in terms of disability and mortality. The fact that regular physical activity may prevent or delay the onset or progress of different chronic diseases is now well recognised [1]. For instance, it is known that in patients with chronic obstructive pulmonary disease (COPD), lower levels of physical activity in daily life are related to higher risk of hospital readmission [2] and shorter survival [3]. Therefore, assessment of the amount and intensity of physical activity in daily life is considered very important due to the close relationship between activity levels and health [4].

Patients with COPD frequently show symptoms such as dyspnoea and fatigue, which lead to functional impairment and disability. Most of the patients with severe COPD are breathless even when performing simple activities of daily living (ADL) or walking around at home [5]. In addition, stable non-oxygen-dependent COPD patients are much less active in daily life when compared with healthy elderly people [6], and oxygen-dependent patients are even less active [7]. Therefore, limited physical activity level is a reflection of the subject's deconditioning and symptoms such as dyspnoea. However, inactivity itself contributes to a further worsening of the physical condition of the subject, and to even more dyspnoea. This configures a vicious circle of inactivity, deconditioning and dyspnoea that has frequently been mentioned in the literature [8, 9]. Consequently, although inactivity can be primarily understood as a consequence of the disease, it can also be a cause of the disease's worsening and progression. Referring to this "COPD vicious circle", the report of the Global Initiative for Obstructive Lung Disease (GOLD) states that "these problems have complex interrelationships and improvement in any one of these interlinked processes can interrupt the vicious circle in COPD so that positive gains occur in all aspects of the illness'' [8]. Therefore, interventions which may help to increase daily physical activity have the potential to break the vicious circle and lead to relevant improvements [10, 11]. For all these reasons, assessment of physical activity in daily life and functional status in COPD patients has gained interest in recent years, and the body of literature has grown considerably.

The present review aims to describe and compare the two kinds of instruments more commonly used to quantify the amount of physical activity performed by COPD patients in daily life: subjective methods (questionnaires, diaries) and motion sensors (electronic or mechanical methods). This review includes instruments that have already been used in studies involving patients with COPD, and popular instruments that can potentially be applied in this population. Their characteristics are summarised and evidence of their validity, reliability and responsiveness are discussed, when available.

METHODS

Using Medline, a literature search was carried out of the last 15 yrs and was finalised in November 2005. References of the relevant studies in the same period were also checked. Strategy of search consisted of the combination of the terms ''COPD and physical activity'' with the terms ''assessment'', ''measurement'', ''quantification'', ''questionnaire'', ''scale'', ''diary'', ''motion sensor'', ''accelerometer'' and ''activity monitor''. Methods aiming to assess functional status [12–16], self-efficacy, performance and independence during ADL [17–27] and the impact of symptoms in usual activities [28–30], as well as health-related quality of life questionnaires with subscales of physical activity [31–33] and methods to assess functional exercise capacity [34, 35], are not discussed in the present review, since they do not aim primarily to quantify the amount and intensity of activity performed in daily life. There were no limitations in terms of study design and sample size, but only articles published in English were included.

The prices of motion sensors mentioned in the present review were obtained through the manufacturers' websites as accessed in the first week of August 2005. In case the price was not found this way, the manufacturer was contacted by e-mail and asked to provide the current commercial price correct in August 2005. If no answer was obtained, the price was described as ''could not be retrieved''. Prices of the different devices which are described in this review do not include extra costs, such as shipping and training.

DEFINITION OF PHYSICAL ACTIVITY IN DAILY LIFE

Physical activity is considered ''any bodily movement produced by skeletal muscles that result in energy expenditure'' [36]. Therefore, physical activity in daily life (or daily physical activity) can be considered ''the totality of voluntary movement produced by skeletal muscles during everyday functioning'' [37].

HOW TO QUANTIFY PHYSICAL ACTIVITY

Physical activity in daily life can be quantified by direct observation, assessment of energy expenditure and the use of physical activity questionnaires and motion sensors.

Direct observation

Direct observation is carried out by observers who watch or videotape activities performed by the subjects and quantify them [38]. This technique is often used in children, since other techniques are difficult to apply in this population. However, it is very time-consuming, intrusive and demanding, and therefore not suitable for large populations.

Energy expenditure

Total energy expenditure is divided into three components: resting metabolic rate, diet-induced energy expenditure and physical activity energy expenditure. Although physical activity in daily life is sometimes expressed or quantified as physical activity energy expenditure, these terms are not synonyms. Physical activity energy expenditure is ''a measure of energy cost of physical activity'' [39] or, in other words, the quantification of the energy spent on physical activities. Methods to assess energy expenditure include calorimetry and the doubly labelled water (DLW) method. The fact that energy spent on physical activity depends on factors such as body mass, movement efficiency and energy cost of the activities [39, 40] may hinder the use of energy expenditure assessment methods, such as DLW, to compare the amount of physical activity performed by different individuals [39]. Furthermore, the high cost is an important limitation of this method. A review with details of this method can be found elsewhere [41]. It is worthwhile underlining that assessment of physical activity energy expenditure does not quantify the duration, frequency and intensity of physical activity performed.

Scope of this review

The literature highlights that direct observation of activities and the energy expenditure assessment (DLW and calorimetry) are criterion methods that are accepted worldwide (or gold standards) [42] in the quantification of physical activities in daily life. However, due to their limitations, these methods are unlikely to be used in the clinical practice or in studies involving large populations, and for these reasons will not be discussed more extensively. Nonetheless, they are mentioned in this review as criterion methods for validation of questionnaires and motion sensors. These are the more common and accessible methods with which to quantify physical activity in daily life, and will be discussed in detail in the following sections of this review.

QUESTIONNAIRES (SUBJECTIVE OR SELF-REPORTED METHODS)

Characteristics

Quantifying physical activity in daily life through questionnaires and diaries has the advantage of being inexpensive and easy to apply. This has led to the widespread use of these methods to gain insight into physical activity habits. However, these techniques are known to depend on the following factors, which may induce inaccuracy or bias in the assessments.

1) Accurate perception and recall of information by the subject. For instance, difficulties may be found when recalling light activities [43] (slow walking at home, self-care, gardening, home management, dressing, *etc.*), particularly over long periods of time. Questionnaires recall physical activities performed in periods of time from 1 h [44] to the entire

lifetime [45, 46]. Due to limitations in memory, the reliability of information generally decreases with the length of the period surveyed [47].

2) The questionnaire's design. Questionnaires with an interval response option (*e.g.* how many days in a week walking is performed) showed higher self-reported amounts of physical activity when compared to ''open'' questions [48]. Additionally, simple questionnaires generally show the highest coefficients of reliability and validity, since subjects may become bored and/or confused by long questionnaires [47, 49].

3) Individual characteristics such as age, cultural factors, work status and cognitive capacity [50–54].

4) The table of energy costs used in case the outcomes of questionnaires and diaries are converted into an estimate of energy expenditure. Energy cost of different activities varies substantially among subjects as it depends on factors such as body mass and movement efficiency [39, 42], and not all activities carried out in daily life have a known energy cost.

An overview of the subjective methods used to quantify physical activity in daily life in COPD patients is presented in table 1.

Reliability

Reliability (or test–retest reliability, or reproducibility) can be understood as the ability of an instrument to yield correlated results when applied to the same population under similar conditions on at least two successive occasions [77]. In the case of questionnaires, special attention has to be given to the fact that different results can be achieved if different interviewers are applying the questionnaire. Lack of reliability may be present, especially in populations characterised by low-intensity activities [78] and in long test–retest intervals [79–81].

None of the studies which used questionnaires to quantify physical activities specifically in COPD patients (table 1) investigated test–retest reliability. The results described below concern only administration of these questionnaires in the general elderly population. The Physical Activity Scale in the Elderly (PASE) showed good test–retest reliability coefficient over a 3- to 7-week interval (0.75; 95% confidence interval 0.69–0.80) [72]. Reliability for mail administration ($r=0.84$) was higher than for the telephone administration ($r=0.68$). VOORRIPS *et al*. [56] investigated the reliability of the Baecke's questionnaire and found a Spearman's correlation coefficient of 0.89 over a test–retest interval of 20 days.

Populations involved in studies investigating the reliability of the Minnesota Leisure Time Physical Activity Questionnaire (Minnesota LTPA Questionnaire) [51, 82–84] were mainly composed of adults and middle-aged subjects, with no specific investigation in elderly people. Results showed very discrepant correlations ranging -0.04–0.92, with higher values corresponding to a shorter time interval between tests. Reliability of the Minnesota LTPA Questionnaire may be hindered in elderly people because it requires recall of activities over the past 12 months, which may be particularly difficult in this group of individuals. The Zutphen Physical Activity Questionnaire (ZPAC) [75, 76] showed good test–retest reliability in a general elderly sample, although the reliability worsens in the oldest patients and in those with cognitive impairment [85].

It is important to notice that low test–retest reliability of questionnaires, as well as in the case of motion sensors, cannot be confounded with the variability in the subject's daily physical activity. Day-to-day variability in habitual physical activity may be largely due factors such as age and employment status [86, 87]. Therefore, a questionnaire cannot be considered unreliable if low test–retest reliability is observed; this may be due to variation in the physical activity performed by the subject, and not a result of lack of reliability of the questionnaire. In addition, seasonal variations in physical activity occur [81], and this has to be taken into consideration when assessing physical activity in daily life.

Validity

A classic definition of validity is the assessment of whether an instrument measures what it intends to measure [77]. Validity has different components, but the instrument should ideally be validated in terms of criterion validity, *i.e.* a combination of predictive value and concurrent validity. This indicates the correspondence of the instrument's score to a more precise assessment, the criterion method (gold standard). However, due to the difficulties in applying the gold standard methods in large populations, other methods to assess physical activity have been used to investigate questionnaires' validity (*e.g.* motion sensors, other physical activity questionnaires and oxygen consumption). Special attention should be given to cultural factors if a questionnaire has been translated into another language [88]. In addition, the literature shows that most physical activity questionnaires are correlated with the outcomes of the criterion methods of high-intensity physical activity, but not in light- or moderate-intensity activity [49]. This is a potential problem when these questionnaires are used in more disabled patient populations, who are not characterised by performing physical activities at high intensity.

When diary-reporting the daily time spent on different activities [44], COPD patients significantly overestimated time spent walking and underestimated time spent standing [66]. Validity of the Baecke, Minnesota LTPA and PASE questionnaires although not specifically studying COPD patients, was investigated in a number of different populations (table 1). The Minnesota LTPA was shown to significantly underestimate physical activity energy expenditure in elderly people [89]. The ZPAC was used in the study by SLINDE *et al*. [76] to describe the small amounts of detectable physical activity in COPD patients. However, an issue raised by the authors is that a questionnaire like the ZPAC is only able to assess a certain amount of the patients' total time in activity, and not the whole active time. This limits its use for accurately determining the amount of physical activity performed and, consequently, to predict the total daily energy requirement.

Although no specific validation study of the Baecke questionnaire was performed in COPD, this questionnaire was used in three different studies [57–59] in which COPD patients had approximately the same airflow obstruction (forced expiratory volume in one second (FEV_1) ranging an average 36–41% predicted) and normal body mass index. In these studies, patients from three different countries (Spain, France

TABLE 1 Subjective instruments applied to quantify physical activity in daily life in patients with chronic obstructive pulmonary disease (COPD; by alphabetical order)

Instrument	Author [ref.]	Basic description	Other characteristics
Baecke Physical Activity Questionnaire	BAECKE *et al.* [55] (adapted by VOORRIPS *et al.* [56], and used in CORONELL *et al.* [57] COUILLARD *et al.* [58] SAEY *et al.* [59] SERRES *et al.* [60])	The questionnaire includes three basic factors: household activities, sporting activities and physical activity during leisure time excluding sport. The subjects are asked to describe the type of activity, $h \cdot week^{-1}$ and the period of the year in which the activity was normally performed during the last year. Higher scores mean higher level of physical activity. The original questionnaire [55] was developed for young adults, and it was afterwards adapted for elderly people [56] by including additional questions on household activities.	Self-administered in the original version, and adapted to be applied as personal interview in elderly people. Focus on classifying subjects as having low-moderate- and high-activity level based on duration and energetic costs of activities performed. Has been used in elderly people [56], adults [61, 62], obese subjects [63], and patients with Parkinson's disease [64] and cardiac disease [65], among others.
Follick's diary	FOLLICK *et al.* [44] (adapted and used by PITTA *et al.* [66])	Originally developed to assess activity time in patients with chronic pain [44], was used in a simplified version by PITTA *et al.* [66]. These authors used only a section in which the patient reports hourly on how much time was spent walking, cycling, standing, sitting and lying in the last hour. Therefore, outcomes consist of time spent in each activity or body position.	Administered in the form of an activity diary, *i.e.* patients report periodically the time spent in different activities. Focus on reporting time spent in basic activities and body positions. Validity was studied in patients with chronic pain [44] and COPD patients [66].
Minnesota Leisure Time Physical Activity Questionnaire (or Survey) (Minnesota LTPA questionnaire, also known as MLTPAQ or MLTPAS)	TAYLOR *et al.* [67] (adapted and used by GARCIA-AYMERICH *et al.* [68])	The questionnaire provides a checklist with different activity types. Patients report which activities were performed (and for how long) in the past year. GARCIA-AYMERICH *et al.* [68] used a simplification of the questionnaire's Spanish version. Patients were asked about the frequency and duration of walking, climbing stairs and any other physical activity in the previous month (and not previous year, as the original).	Administered commonly *via* personal interview or telephone interview [69]. Focus on activities performed during leisure time. Available validation studies include small samples of white, middle age and educated persons [43], black and white females after weight loss [63], patients with arterial occlusive disease [70] and adolescents [71].
Physical Activity Scale for the Elderly (PASE)	WASHBURN *et al.* [72] (used in GOSKER *et al.* [73])	Twelve items (with different weights) involving activities performed in daily life. Six of these items are assessed in terms of $h \cdot day^{-1}$ over a 7-day period; the other six items are scored as 1=engage in that activity or 0=did not engage in that activity in the previous 7 days. The sum of all items of the scale results in an index with scores ranging 0–360. Higher score means higher physical activity level in daily life.	Can be administered by phone, mail or personal interview. Focus on activities commonly performed by elderly people by giving more weight to these activities instead of sports. Has been used in the general elderly population [72] and in patients with renal disease [74], among others.
Zutphen Physical Activity Questionnaire (ZPAC)	CASPERSEN *et al.* [75] (used by SLINDE *et al.* [76])	Subjects report which activities were performed (and for how long) in the past week (for some activities) or month (for other activities). According to the frequency, intensity and duration of these activities, a calculation is performed in order to provide $kcal \cdot kg$ body $mass \cdot day^{-1}$ as outcome.	Self-administered. Focus is on assessing physical activity energy expenditure and the amount of $min \cdot week^{-1}$ spent in light, moderate and heavy physical activity in elderly males. The available study included an elderly male Dutch population [75].

COPD: chronic obstructive pulmonary disease.

and Canada) were assessed using the questionnaire. Patients from Spain, who had the lowest FEV_1 (average 36% pred), showed approximately double the physical activity score (13.1 ± 6.2 points) [57] when compared with patients from Canada (6.4 ± 3.4) [59] and France (7.6 ± 1.9) [58]. This suggests that either physical activity in daily life is largely different between these populations, or the questionnaire has limited validity in COPD patients. Further research is necessary to better explain these findings.

Concerning the PASE questionnaire, SCHUIT *et al*. [90] studied its validity against energy expenditure assessed by DLW, showing a correlation of 0.58 (95% confidence interval: 0.50–0.81) between the outcomes of these two methods. Correlation between PASE questionnaire scores and output from the Actigraph (CSA) or MTI/CSA (MTI Health Services, Ft Walton Beach, FL, USA) in an elderly population in free-living conditions was more modest ($r=0.42$; $p<0.01$) [91].

Although mean differences between subjective methods and objective gold standard methods may not be large in a group basis, the individual variability is large both in COPD patients [66] and in the general elderly population [89]. Hence, the use of subjective methods as estimates of daily physical activity on an individual basis is not recommended. Discrepancies between self-reporting methods and objective assessments were also reported in different populations [63, 92–96].

Responsiveness

When assessing physical activity in daily life, responsiveness (also called sensitivity) of a tool can be understood as its capacity to detect relevant changes over time that are known to occur [97]. It has been suggested that good responsiveness of an instrument should join reliability and validity as necessary requirements for instruments designed primarily to measure change over time [98].

None of the studies that used questionnaires to quantify physical activity in COPD patients investigated their responsiveness to improvements in amount and intensity of physical activity in daily life after interventions. Other questionnaires aiming to assess other aspects of physical activity in daily life (functional status, activities of daily living and quality of life related to physical activity) were responsive to changes after pulmonary rehabilitation programmes [18, 19, 27, 37, 99].

Other potentially useful physical activity questionnaires

Besides the questionnaires already mentioned in this review as being used with COPD patients (table 1), a number of other available questionnaires aim at quantifying physical activity in daily life and might potentially be used in this population. Detailed information on these various physical activity questionnaires can be found in an extensive review by PEREIRA *et al*. [100]. A summary of the characteristics of some widely known questionnaires follows.

College Alumni (or alumnus) questionnaire, also know as Harvard Alumni questionnaire or Paffenbarger Physical Activity questionnaire

In this questionnaire [101, 102], the individual is asked about duration and frequency of walking, stair climbing, recreation and sports played in the past week or year. The questionnaire may be self or interviewer administered. A number of studies used this questionnaire to investigate the relationship between physical activity and various factors such as risk for cardiovascular disease [103], stroke [104], diabetes [105], cancer [106], hypertension and all-cause mortality [107].

Tecumseh Occupational Physical Activity questionnaire

The Tecumseh questionnaire [108, 109] is self or interviewer administered, and assesses physical activity performed in the past year. It focuses on work activities, *i.e.* energy expenditure during the workday and during transportation to and from work. A recent study showed that the combination of the Tecumseh questionnaire with the Minnesota LTPA Questionnaire was useful to estimate mean energy expenditure in employed adult males [110].

Stanford Seven-Day Physical Activity and Stanford Usual Activity questionnaires

Although these two interviewer-administered questionnaires were developed by the same group, they have different designs and have been considered separately [46, 47]. The Stanford Seven-Day Physical Activity questionnaire (also known simply as Stanford Seven-Day Recall) [111] focuses on time spent doing several physical activities and sleeping for the past 7 days. A version of this questionnaire adapted to telephone interview has been developed [112]. The Stanford Usual Activity questionnaire [113] uses a different time frame (the past 3 months) and focuses on moderate and vigorous activities. In a validation study of five questionnaires against a uniaxial accelerometer in healthy adults, the Stanford Seven-Day Recall had the best correlation coefficient ($r=0.79$) [114]. In addition, a large validation study in healthy elderly people including 10 questionnaires showed that only the Stanford Usual Activity questionnaire, the Stanford Seven-Day Recall score and the College Alumni sports score had significant correlations with total energy expenditure assessed by DLW [47].

Conclusions

Patients with COPD are able to appropriately report the perceived limitations and symptoms related to their disability in questionnaires aiming at these outcomes. However, concerning instruments applied specifically to quantify duration, frequency and intensity of physical activity performed in daily life, caution is necessary. Although the results of these subjective methods may be useful as a group estimate, their lack of accuracy and large individual variability indicate that relying on them on an individual basis is not recommended. Results from physical activity questionnaires better reflect heavy-intensity physical activity than light- or moderate-intensity activity, which does not favour their use in chronically disabled populations, such as COPD patients.

Just a few instruments aimed at quantifying physical activity in daily life were used in COPD patients. Evidence concerning reliability, validity and responsiveness of these few instruments in COPD patients is still lacking, since these aspects were poorly studied specifically in this population. Among these, the ones with better-documented validation in elderly and other populations are the Minnesota LTPA Questionnaire, the Baecke questionnaire and the PASE questionnaire. Some questionnaires had not been used in COPD, but might be potentially useful since they performed better than others in validation studies with other chronically disabled or with elderly populations (*e.g.* Stanford Seven Day Recall, Stanford Usual Activity and College Alumni questionnaires).

MOTION SENSORS (ELECTRONIC OR MECHANICAL METHODS)

Characteristics

Great attention has recently been given to objective monitoring of daily physical activity in different populations [39, 115–119], including patients with COPD [37]. Motion sensors are instruments used to detect body movement, which can be used to objectively quantify physical activity in daily life over a period of time. These instruments basically include pedometers (measurement of steps) and accelerometers (detection of body acceleration). An overview of the devices used in investigations with COPD patients is presented in table 2.

Pedometers are small, simple and inexpensive instruments. They are usually worn on the waist and contain a horizontal, spring-suspended lever arm that deflects with vertical acceleration of the hips during walking (the up-and-down motion during ambulation). Since pedometers were designed to detect vertical movement, they most logically assess number of steps. The output from the device is easily understood as a motion count, representing a step. Nevertheless, any movement in the vertical plane, like getting up from a chair, can be eventually detected and will also result in a motion count [120]. The use of pedometers has been promoted to stimulate and monitor walking in the general population, since it is suggested that 10,000 steps per day could be effective for prevention of disease and promotion of a healthier lifestyle [132, 133]. In public health campaigns to increase physical activity levels, pedometers are useful tools because they can be easily worn to determine whether an individual is reaching step recommendations [134]. Disadvantages of these devices include the tendency to underestimate very slow walking [135] and the fact that some devices require that the subjects periodically write down the output of the assessment in case of multiple days of measurement. Moreover, only limited data are provided (counts, distance estimate), with no information about pattern of physical activity and time spent in different activities over the day, as well as the intensity at which these activities are performed.

TUDOR-LOCKE *et al*. [136] compared a pedometer (Yamax Digi-Walker 200; YAMAX USA, Inc., San Antonio, TX, USA) with a uniaxial accelerometer (CSA accelerometer; MTI Health Services) and found a significant difference in mean step counts between the devices. This difference was attributed to a higher threshold of vertical acceleration required to record a step in the Yamax Digi-Walker 200 ($0.35\times g$ for the pedometer *versus* $0.30\times g$ for the accelerometer). In other words, the pedometer was less sensitive than the accelerometer to detect walking. It appears that most pedometers require even higher vertical acceleration as a threshold to detect a step ($0.50\times g$) [137].

Accelerometers are technologically more advanced devices that allow the quantity and intensity of movements to be determined [37]. These devices are able to store data continuously over long periods of time, and the monitors must be worn without interference in the subject's normal pattern of activities. Accelerometers are basically of two kinds: uniaxial and multiaxial. Uniaxial sensors detect motion in only one body dimension (or plane), and may be inaccurate for activities with static trunk movement, such as cycling and rowing [138]. The information provided is comparable to a pedometer, but with the advantages of assessing movement intensity and allowing more detailed analysis in different time frames. Multiaxial devices are able to detect motion in more than one plane of movement. Some multiaxial devices are able to detect a variety of body positions and physical activities, and are often denominated activity monitors. A major advantage of multiaxial accelerometers is that these devices are able to provide more detailed information than the previously mentioned types of motion sensors. Disadvantages of accelerometers include the higher costs compared with pedometers and the need for technical expertise and additional hardware/software to analyse the data (although not in all cases: see table 2 and Other potentially useful motion sensors). In addition, these devices may be sensitive to vibrational artefacts, for example, recording vibration related to being in a vehicle [139, 140]. A limitation of motion sensors worn on the waist, hip or ankle is that activities of the upper extremities of the body are not measured. Another general concern about motion sensors is the subject's compliance to the measurement, although assessments require only slight care from the patients (*e.g.* remembering to put the device on, positioning it correctly, avoiding shocks, checking battery level). In the study by KOCHERSBERGER *et al*. [141], 20% of a sample of elderly subjects did not comply with wearing an accelerometer. These findings are in line with a study in COPD patients, which showed that 19% of the subjects had to be excluded from the study due to non-compliance or technical issues (*e.g.* battery problems) [6].

Reliability

Analysing the test–retest reliability of a pedometer (Fitty 3; Kasper & Richter Company, Uttenreuth, Germany), SCHONHOFER *et al*. [120] found no significant differences in mean daily movement from test–retest results taken 4 weeks apart in a COPD population; the correlation between outputs in the two assessment points was 0.94. STEELE *et al*. [127] evaluated the reliability of a triaxial accelerometer (Tritrac R3D Research Ergometer; Professional Products, Madison, WI, USA; StayHealthy Inc., Monrovia, CA, USA) during three sequential 6-min walk distances (6MWDs). The intraclass correlation coefficient (ICC) during the walking tests was 0.84, and adequately reflected the improvement with each successive walk due to the learning effect of the test. However, variability between devices within the same model may be present. In the study by SCHONHOFER *et al*. [120], two pedometers of the same manufacturer and model were worn simultaneously. Devices from four different manufacturers were tested, and reliability was considered acceptable if the two devices differed by $<10\%$. Only one manufacturer produced pedometers that met this level of reliability (Fitty 3; table 2). In addition, when analysing 20 pedometers of this same model, four did not match the performance of the reference instrument and were discarded. A study with the Tritrac RT3 triaxial accelerometer also concluded that intermonitor variability exists [142]. It is advisable to test the reliability of the chosen device, and to use the same

TABLE 2 Objective methods applied to quantify physical activity in daily life in patients with COPD (by type)

Device	Type	Author [ref.]	Basic description	Other characteristics
Fitty 3 (Kasper & Richter Company, Uttenreuth, Germany)	Pedometer (or step counter)	SCHONHOFER *et al.* [120].	Able to register movement in the longitudinal (or vertical) dimension. Main outcome is counts·day^{-1}. Higher number of counts·day^{-1} means higher activity level.	Worn at the waist Size 5.5 × 6 × 2.9 cm Weight 53 g Price €39.95 (August 2005)
Self Contained Activity Monitor (SCAM; Analog Devices, Norwood, MA, USA)	Uniaxial accelerometer	CORONADO *et al.* [121].	Measures acceleration in the anteroposterior axis. Main outcome is RMS of the acceleration (in *g*). Higher RMS acceleration means higher intensity of activity. Results can also be expressed as a percentage of the total time spent in high-, medium- and low-intensity activities and in inactivity.	Worn at the low back (placed in a belt) Size 11.9 × 5.8 × 2.7 cm Weight 215 g Price could not be retrieved
Z80-32k V1 INT (Gaehwiler Electronics, Hombrechtikon, Switzerland)	Uniaxial accelerometer	SANDLAND *et al.* [7] SINGH *et al.* [122] SEWELL *et al.* [123].	Measures longitudinal acceleration. Main outcome can be expressed as counts·min^{-1}. Higher number of counts·min^{-1} means higher activity level.	Worn at the waist Size 5.1 × 3.6 × 2.1 cm Weight 68 g Price could not be retrieved
Physical activity monitor (PAM type AM100; Pam B.V., Doorwerth, the Netherlands)	Uniaxial accelerometer	MERCKEN *et al.* [124].	Measures acceleration in the vertical direction. Adds up movements and provides the "PAM score", which is an activity index based on percentage of activity energy to the resting energy (AEE/BMR × 100%). Outcomes at the end of each day are the PAM score and the number of minutes in three different zones of activity intensity.	Worn at the waist (hip) Size 5.8 × 4.2 × 1.3 cm Weight 28 g Price €99 (August 2005)
Tracmor (Philips Research, Eindhoven, the Netherlands)	Triaxial accelerometer	GORIS and coworkers [125, 126]	Registers movement along the anteroposterior, mediolateral and longitudinal axes. Main outcome is counts·min^{-1}. Higher number of counts·min^{-1} means higher activity level. Energy expenditure can be estimated based on a specific equation.	Worn at the low back (placed in a belt) Size 7.2 × 2.6 × 0.8 cm Weight 22 g Price could not be retrieved
Tritrac R3D (newer version: RT3; Research Ergometer, Professional Products, Madison, WI, USA; StayHealthy Inc., Monrovia, CA, USA).	Triaxial accelerometer	STEELE and coworkers [127, 128] BELZA *et al.* [129] BEHNKE *et al.* [130]	The three accelerometers are oriented at right angles to one another measuring movement in three dimensions: anteroposterior, mediolateral and longitudinal. Main outcome is called VMU. Higher VMU means more movement for a given time. Energy expenditure can be estimated based on a specific equation. The newer version (RT3) integrates measurements of the three vectors into a single chip.	Worn at the waist Size 7 × 5.6 × 2.8 cm Weight 65 g Price $500 including software, docking station and interface cable (August 2005)
DynaPort activity monitor (McRoberts BV, The Hague, the Netherlands)	Activity monitor (three acceleration sensors)	PITTA and coworkers [6, 66, 131]	Two sensors placed in a recorder box at the waist measure horizontal and vertical acceleration of the trunk, and one sensor on the left thigh measures vertical acceleration. Main outcome is time spent by the subjects on different activities and body positions (walking, cycling, standing, sitting, lying). Higher time spent actively means higher activity level. Movement intensity (in m·s^{-2}) is also assessed.	Worn around the waist (placed in a neoprene belt); one small leg sensor worn in an elastic strap around the left thigh Size of the box 12.5 x 9.5 x 3 cm Weight (total) 375 g Price €4900 (activity monitor, software, neoprene belt, memory card and carrying case (August 2005).

RMS: root mean square; PAM: personal activity monitor; AEE: activity energy expenditure; BMR: basal metabolic rate; VMU: vector magnitude unit.

device in repeated measures, as well as to perform adequate calibration according to the manufacturer's specifications (in case calibration is allowed).

Assessment with the DynaPort activity monitor (McRoberts BV, The Hague, the Netherlands) during 5 days in COPD patients showed that this population has as much day-to-day variability in walking time as healthy elderly people, despite the lower physical activity level (coefficient of variation of ~26%) [6]. This has potential repercussions for longitudinal studies which aim to detect relatively small differences after interventions. Therefore, in longitudinal studies, it seems advisable to obtain more days of assessment to reduce the chance of having a type II error.

Validity

The output of pedometers is highly representative of that produced by uniaxial accelerometers in healthy subjects in free-living conditions [136], although this was never shown in COPD patients. These two instruments basically detect movement in the vertical plane and give, not surprisingly, comparable results. Output from pedometers used in adult healthy subjects was also highly correlated to outputs from triaxial accelerometers [50]. However, pedometers do not measure the intensity of bodily movement. This leads to the general idea that pedometers have lower accuracy in populations characterised by slow walking and inactivity [143], which is the case in COPD patients [6]. In addition, its accuracy may vary with deviations from a normal gait pattern [144].

Accelerometers are more sensitive to detection of physical activity differences in relatively inactive populations, and detect physical activity periods better than subjective methods [93, 94]. In addition, they are more sensitive to light activities [37, 116]. Concerning validity of accelerometers as a measure of daily activity in COPD patients, output of the Tritrac R3D triaxial accelerometer correlated well with the 6MWD ($r=0,74$; $p<0.001$) [127]. The uniaxial accelerometer Z80-32k V1 INT (Gaehwiler Electronics, Hombrechtikon, Switzerland) was able to distinguish between brisk walking and other types of domestic activities in a COPD population [122]. Recently, an accelerometer-based activity monitor (DynaPort) was shown to be as accurate as the gold standard (video recordings) for assessment of time spent walking, cycling, standing, sitting and lying down in daily life in COPD patients [66]. ICC between outcomes from DynaPort and video recordings were between 0.999 for walking time and 0.750 for lying down time. In addition, changes in the intensity at which walking was performed were also accurately detected by the device. Therefore, it is an instrument that is able to measure both the total amount and intensity of spontaneous activities performed throughout the day in the subject's own environment. The Self-Contained Activity Monitor (SCAM; Analog Devices, Norwood, MA, USA), a uniaxial accelerometer used in the study by CORONADO *et al*. [121], was not validated specifically in the COPD population. In overweight adult females [145], the device showed high correlation between accelerometer output and speed during treadmill walking ($r=0.95$; $p<0.01$) and short unconstrained walks ($r=0.86$; $p<0.01$).

Regarding the capacity to distinguish different physical activity levels between subjects (or groups of subjects), the DynaPort activity monitor, the Z80-32k V1 INT accelerometer and the Fitty 3 pedometer were able to detect significant differences between COPD patients and healthy controls [6, 120, 122]. In addition, the DynaPort and the Z80-32k V1 INT were also able to distinguish fast from slow walking in COPD patients [66, 122]. In healthy subjects, it was suggested that a uniaxial accelerometer (Caltrac; Muscle Dynamics, Torrance, CA, USA) did not have the capacity to reflect differences in physical activity levels [146]. However, triaxial devices showed the capacity to discriminate low, moderate and high overall activity levels [147] or to categorise individuals as sedentary, moderately active or active [141].

The number of assessment days may play an important role when measuring physical activity in daily life. In COPD patients, there is evidence that 2 days of assessment with an activity monitor provides an acceptable intraclass reliability coefficient (IRC >0.70) in order to differentiate COPD patients and healthy elderly people, although more days of assessment provide a higher coefficient [6]. In healthy adults, reports in the literature are discrepant and suggest that the number of days necessary to achieve an acceptable IRC may range from $\geqslant 3$ to $\geqslant 7$ days [148–150]. Although the number of days possibly depends on the characteristics of the population studied and the reliability of the device used, it seems that one single assessment day is not acceptable both for healthy adults [151] and for COPD patients [6].

GORIS *et al*. [125] showed the validity of a triaxial accelerometer (Tracmor; Philips Research, Eindhoven, the Netherlands) combined with assessment of basal metabolic rate in order to estimate energy expenditure. The authors developed formulas to calculate energy expenditure based on the output of the accelerometer plus estimation or measurement of basal metabolic rate. They validated these formulas against DLW, concluding that there were no significant differences between the methods (an average difference of $2.7 \pm 8\%$). In healthy subjects, it has been shown that the accelerometer's output is significantly correlated to energy expenditure [152, 153], although this was never shown in COPD patients. However, the literature shows conflicting results concerning the accuracy of energy expenditure estimation using accelerometers [143, 154–157], with some studies suggesting underestimation and others overestimation. This illustrates the limitations of using accelerometry to estimate energy expenditure in daily life. It has been suggested that accelerometers are more accurate for quantification and differentiation of body movements than for estimation of energy expenditure, especially at slow speeds [158]. PLASQUI *et al*. [159] have recently shown that triaxial accelerometers are superior to uniaxial devices when estimating energy expenditure. Therefore, in order to improve accuracy, the use of triaxial accelerometers is indicated. In addition, there is evidence that the combination of heart rate monitoring with body movement registration improves the precision of energy expenditure assessment [160–162], although this has not been shown in subjects with slow walking speeds, such as COPD patients.

Responsiveness

The available studies aimed at investigating changes in the amount of daily physical activity after pulmonary rehabilitation assessed by motion sensors in COPD showed conflicting results. Two studies showed either very modest or no improvement in the motion sensors' output after programmes lasting 3 and 8 weeks [121, 128]. However, it is not clear whether the modest changes shown by these studies derive from methodological issues of the assessment method (*e.g.* the outcomes used) or from lack of improvement by the patients due to characteristics of the rehabilitation programs applied (*e.g.* duration, intensity, frequency). In contrast to the aforementioned studies, two other studies found significant improvements after programs of 7 and 8 weeks of duration [123, 124]. Differences in the programs used and in the populations involved may explain the conflicting results. Available evidence shows that, in chronically ill patients, daily physical activity may not change significantly after exercise training programmes; this is clearly due to lack of improvement and not methodological issues. A study in patients with severe heart failure showed that daily energy expenditure was not improved after exercise training when measured both with an accelerometer (Caltrac) and with the gold standard method, DLW [163]. These findings are not in favour of the hypothesis that improvements were not captured by the accelerometer, but rather suggest that the programme did not result in significant changes in daily energy expenditure. Furthermore, even if the amount of physical activity does not increase, rehabilitation may have still been beneficial because existing activity may have become easier and resulted in less breathlessness [27]. However, methods used to objectively quantify the amount and intensity of physical activity performed in daily life are not able to detect if physical activity is more easily performed or results in less breathlessness. This is subjective and requires specific instruments (questionnaires, in this case) which aim at investigating symptoms and performance during activities of daily living or exercise [18, 19, 22, 27]. It is therefore suggested that objective methods for assessment of daily physical activities and subjective methods for assessment of functional status or ADL have complementary roles in assessing disability in COPD patients [39]. It also has to be taken into consideration that the patients themselves may not aim at increasing daily activity as a primary objective [164].

Some issues concerning the responsiveness of motion sensors to changes after interventions deserve consideration. First, some activities performed during exercise programmes and during daily life which do not include total body movement, such as static exercise, isolated upper extremity activity and stationary cycling, may not be well documented by activity monitors. The inability to measure this kind of activity configures a limitation to the use of motion sensors in rehabilitation settings where cycling and strength training are performed; however, walking is considered the most important and common type of physical activity performed in daily life [39, 165]. Walking more in daily life is an important indicator of improvement after rehabilitation protocols, and this can indeed be accurately assessed by motion sensors. Secondly, as previously mentioned, day-to-day variability in habitual physical activity may be large and may hide improvements after interventions, especially in very low levels of activity where improvements may be small but clinically significant. Care must be taken to ensure that studies are sufficiently powered to detect accurately the potential changes after interventions.

Other potentially useful motion sensors

As described for questionnaires, and also in the case of motion sensors, there are several potentially useful devices which have not yet been used in studies involving COPD patients. Detailed technical information concerning a number of motion sensors can be found in a recently published supplement devoted to this topic [166]. A summary of some widely known devices is provided below.

Pedometers

A large comparison of 13 models of pedometers was performed by SCHNEIDER *et al*. [167] over a 24-h period during daily life in healthy adults. One of the best known models of pedometer (Yamax Digi-Walker 200) was used as criterion device. It was chosen because in controlled laboratory settings, this device has consistently been shown to be among the most accurate, besides showing similar accuracy in normal weight, overweight and moderately obese individuals [168]. The models that showed no significant difference when compared with the criterion device were the Kenz Lifecorder, the New-Lifestyles NL-2000 (New-Lifestyles Inc., Lee's Summit, MO, USA), the Sportline 330 (Sportline, Yorkers, NY, USA), the Yamax Digi-Walker SW-701 and the criterion device itself, the Yamax Digi-Walker 200. One of these models, the Sportline 330, was shown to have lower reliability in another study [169]. The cost of the pedometers included in the study by SCHNEIDER *et al*. [167], according to the authors, ranged \$10–200.

The recent technological evolution of pedometers generated the StepWatch (Cyma Corp., Seattle, WA, USA), a microprocessor-linked motion sensor worm at the ankle which not only counts steps, but provides a profile of walking activity. It provides features such as sustained activity (*i.e.* number of steps achieved during an interval of specified duration) and peak activity index (*i.e.* highest mean step rate during given intervals of the assessment period). It measures $6.5 \times 5 \times 1.5$ cm, weighs 65 g and costs \$1,995, which includes activity monitor, docking station and software (August 2005). In stroke patients, the StepWatch was shown to be more accurate than the Caltrac accelerometer [170] for detection of daily ambulatory activity. Furthermore, it was the most accurate among four devices used to detect walking in a study of nursing-home elderly people with dementia [171].

Accelerometers

Actigraph or MTI/CSA

This uniaxial accelerometer measures vertical accelerations. It was worn on the waist, wrist or ankle in different studies, although placement at the waist has been suggested to result in higher accuracy [172]. It measures $5 \times 3.8 \times 1.5$ cm, weighs 43 g and costs \$389 per unit (August 2005), with no reader interface required for the newest model. The output is activity counts (or step counts). It was used in a wide variety of populations, including adults [173] and children [174]. In elderly patients with coronary artery disease, the output from the device was highly correlated with energy expenditure ($r=0.85$; $p<0.001$), although the equation chosen to estimate energy expenditure has an important role in the accuracy of the results [175].

Caltrac

The Caltrac is a very popular uniaxial device which measures vertical accelerations. It counts body movements, whereas energy expenditure may be estimated by entering anthropometric data of the wearer. The regular price is $99.95 (sale price $69.95, August 2005). It measures $7 \times 7 \times 2$ cm and is worn on the waist (hip). It has been used in various populations, including patients with stroke [170], peripheral arterial disease [176] and congestive heart failure [163]. Under laboratory conditions, the Caltrac (as well as the Actigraph/MTI/CSA) showed acceptable validity for estimation of energy expenditure for groups, but there was a wide range of variability concerning both devices on an individual basis [177]. In elderly people under free-living conditions, it has been shown that the Caltrac may significantly underestimate daily physical activity energy expenditure in both in males and females [89].

Mini Motionlogger Actigraph

The Mini Motionlogger (Ambulatory Monitoring, Ardsley, NY, USA) has multiple programmable parameters and collects information of different variables linked to motor activity, sleep and circadian rhythms. It is worn on the wrist as a watch, and a variety of models are available, with various features (memory size, recording modes, displays, feedback, user input). Prices begin at $550 per unit (no software included; August 2005). It measures $6.3 \times 8.9 \times 1.9$ cm and weighs 85 g, although smaller and lighter new models are available. Populations in which the device was used included healthy adults [139] and hyperactive children [178], among others. In elderly people, the Mini Motionlogger showed a correlation of 0.77 ($p=0.0001$) with the Tritrac triaxial accelerometer [141].

Armband SenseWear

Armband SenseWear (BodyMedia Inc., Pittsburgh, PA, USA) is a relatively new device worn on the upper arm. It measures $8.8 \times 5.6 \times 2.1$ cm and weighs 82 g. The device contains a biaxial accelerometer (longitudinal and transverse), although it also collects a variety of data through other multiple sensors (*e.g.* heat and temperature). It has been introduced as a fitness accessory or an energy consumption monitor since it provides an estimation of energy expenditure based on specific algorithms. It also provides the duration of activities performed by the individual above a determined level of intensity (*e.g.* 2.5 metabolic equivalents), as well as the number of steps. The price of the device depends on the type of accompanying software: if a ''wearer'' software (more simple) is chosen, the kit is sold for €800 (tax not included), whereas if a ''research'' software (more detailed) is chosen, the price is €3,000 (tax not included; August 2005). The device was validated against indirect calorimetry in young adults and provided valid estimates of energy expenditure, although it was necessary to apply exercise-specific algorithms to enhance the accuracy of the estimation [179]. A recent study compared estimation of energy cost during treadmill exercise performed by five different motion sensors [180]. Although the Actigraph (CSA) showed the best estimation for walking and jogging and the Tritrac R3D showed the best estimation for running, the Armband showed the best estimation overall, *i.e.* at most speeds. It has also been used in patients with cardiac disease [181], among others.

ActiReg

The recently developed ActiReg system (PreMed AS, Oslo, Norway) uses the combined recording of body position and motion to estimate energy expenditure and to describe physical activity patterns. It measures $8.5 \times 4.5 \times 1.5$ cm, weighs 60 g, and the current price is ~€440 for the device and €380 for the licence of the calculation programme (August 2005). The device can optionally be used simultaneously with equipment for heart rate monitoring. It was validated against DLW in young healthy subjects [161]. The ActiReg provided a valid estimate of energy expenditure at the group level, although with considerable variation at the individual level. Underestimation of energy expenditure was consistently observed, although it was reduced by the addition of heart rate monitoring to the assessment.

Conclusions

There are different types of motion sensors. They vary from simple and inexpensive devices which basically quantify steps (pedometers) to technologically advanced devices which assess the amount and intensity of physical activity in daily life (multiaxial accelerometers). These devices were shown to provide an accurate overall estimate of physical activity in daily life. However, there is evidence that accelerometers are more accurate for quantification and differentiation of body movement than for estimation of energy expenditure, especially in populations characterised by slow walking speeds. As is seen in subjective methods, more solid evidence concerning reliability, validity and responsiveness of these tools specifically in the COPD population is still lacking. However, technology is rapidly evolving, and further research adding more features to the devices (*e.g.* heart rate, temperature, upper extremity movement) may further increase insight into daily physical activities.

The selection of a motion sensor for quantification of physical activity level in daily life requires careful consideration of the instrument's convenience, validity, reliability, responsiveness, cost, and, above all, the purpose of its use. Simple pedometers are able to provide information on movement counts, although their use may be limited in slow-walking patients. Since accelerometers are more sensitive for detection of light-intensity activities, they may be more useful in inactive populations, such as COPD patients. More technologically advanced devices, such as multiaxial accelerometers and activity monitors, provide more detailed information on activity patterns, time and intensity of activities.

GENERAL CONCLUSIONS

In clinical practice, there are situations in which questionnaires are the only available method to assess disability in patients with COPD. Despite their limitations, self-reported methods have practical value, especially in providing the patients' view on their performance in activities of daily living, independence and functional status. Subjective methods for assessment of functional status and objective methods for quantification of daily physical activity provide different but complimentary approaches with which to assess physical activity in daily life. However, caution is necessary when using questionnaires aiming to quantify duration, frequency and intensity of physical activity performed in daily life. The results of these questionnaires may be useful as a group estimate, but they should not be relied upon on an individual basis. More accurate, individualised and detailed information on body movement and walking is likely to be available with motion sensors rather than questionnaires, although both motion sensors and questionnaires still present limited validity in estimating energy expenditure during physical activity. The selection of which motion sensor to use for quantification of physical activity in daily life should depend mainly on the purpose of its use. If the purpose is only a simple quantification of steps or counts, a reliable pedometer may be sufficient. However, in a population characterised by inactivity, such as patients with chronic obstructive pulmonary disease, the use of devices more sensitive to light activities (*i.e.* accelerometers) may result in higher accuracy. In addition, if description of activity patterns, time and intensity of activities is needed, the use of multiaxial devices and activity monitors is indicated in order to provide more accurate, varied and detailed outcomes.

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