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Review

Measuring intensity during free-living physical activities in people with chronic obstructive pulmonary disease: A systematic literature review

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ABSTRACT

Background: Measuring intensity of physical activity (PA) is important to ensure safety and the effectiveness of PA interventions in chronic obstructive pulmonary disease (COPD).
Objective: This systematic review identified which outcomes, outcome measures and instruments have been used to assess single free-living PA-related intensity in people with COPD and compared the intensity level (light, moderate, vigorous) obtained by different outcome measures.
Methods: PubMed, Scopus, Web of Science, Cochrane Library and EBSCO were searched for original studies of COPD and assessing single free-living PA-related intensity were included. Agreement was calculated as the number of agreements between 2 measures [same intensity level]/ number of comparisons using both measures*100.
Results: We included 43 studies (1282 people with COPD, mean age 66 years, 65% men, 49% $FEV_{1\%pred}$) and identified 13 outcomes, 46 outcome measures and 22 instruments. The most-reported outcomes, outcome measures and instruments were dyspnoea with the Borg scale 0–10; cardiac function, via heart rate (HR) using HR monitors; and pulmonary gas exchange, namely oxygen consumption (VO_2), using portable gas analysers, respectively. The most frequently assessed PAs were walking and lifting, changing or moving weights/objects. Agreement between the outcome measures ranged from 0 ($\%VO_{2peak}$ vs metabolic equivalent of task [MET];$\%HR_{peak}$ vs Fatigue Borg; MET vs walking speed) to 100% ($\%HR_{reserve}$ vs dyspnoea Borg; fatigue and exertion Borg vs walking speed).$\%VO_{2peak/reserve}$ elicited the highest intensity. Hence, Borg scores,$\%HR_{reserve}$ and MET may underestimate PA-related intensity.
Conclusions: Various methodologies are used to assess single free-living PA-related intensity and yield different intensity levels for the same PA. Future studies, further exploring the agreement between the different outcome measures of PA-related intensity and discussing their advantages, disadvantages and applicability in real-world settings, are urgent. These would guide future worldwide recommendations on how to assess single free-living PA-related intensity in COPD, which is essential to optimise PA interventions and ensure patient safety.

Introduction

Chronic obstructive pulmonary disease (COPD) is an escalating global concern, being the third leading cause of death and the sixth cause of disability-adjusted life-years worldwide [1, 2]. Physical activity (PA) is an independent predictor of increased risk of exacerbations, hospitalizations and mortality in COPD [3]. Therefore, the adoption of a physically active lifestyle, targeting the domains defined by the World Health Organization (WHO) (leisure, occupation, home and transport) [4], is a foremost priority for managing COPD [3, 5, 6].

Nevertheless, people with COPD are known to be less physically active than their healthy peers, and only a small proportion fulfil the PA recommendations [3]. Several studies using a wide variety of interventions (e.g., pulmonary rehabilitation, PA counselling, Tai Chi) have emerged to tackle physical inactivity in COPD, but their results are inconsistent [5]. The most recent systematic review of this topic [5] highlighted the incompleteness of the interventions' description, which hinders understanding the PA prescription (frequency, intensity, time, type, volume and progression) [7] and establishment of

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the effectiveness of interventions [8, 9]. Intensity and progression have been the most neglected domains of the interventions' description [10–12]. Intensity refers to "how hard" a certain PA is and usually quantifies how much energy was expended above the resting energy requirements [7, 13]. Measuring and reporting PA-related intensity is important for preventing adverse events and ensuring that interventions meet PA guidelines [4, 14].

The gold standard to measure PA intensity is the double-labelled water (DLW) technique [13, 15, 16]. DLW is invasive and expensive, and data collection usually occurs during a 14-day period, so it cannot be used to measure single PAs [17]. Analysis of pulmonary gas exchange, namely oxygen consumption (VO_2) and carbon dioxide production (VCO_2), through indirect calorimetry, has also been recommended to quantify PA-related intensity [7, 13, 15, 16]. Several other instruments that are more economic, simpler and user-friendly include heart rate (HR) monitors, accelerometers, multisensors, the Borg scale to rate perceived exertion, dyspnoea or fatigue, and the Talk test [7, 16, 18]. Intensity can be measured at the absolute level (absolute intensity; e.g., metabolic equivalent of task [MET] or VO_2) or as a ratio of the individual maximal cardiorespiratory capacity (relative intensity; e.g.,%VO_{2peak} or%$HR_{reserve}$) [7]. Finally, PA intensity can be affected by several individual (e.g., age) and environmental factors (e.g., temperature) [13, 19, 20]. Within the individual factors, health status has an important influence[21] because people with COPD present higher metabolic demands while performing activities of daily living (ADL) as compared with healthy peers [21–24].

Different methodologies will probably yield different PA intensity levels [7]. Exploring which methods have been used to assess single free-living PA-related intensity in people with COPD is essential to understand the underlying advantages, disadvantages, and applicability in real world settings and to inform future recommendations. The primary aim of this systematic literature review was to identify which methodologies (outcomes, outcome measures and instruments) have been used to assess single free-living PA-related intensity in people with COPD. Our secondary aim was to explore the agreement between the intensity level obtained by different outcome measures assessing the same single free-living PA.

Material and methods

This systematic review follows the Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) guidelines (Appendix 1). The protocol is available in the international prospective register of systematic reviews (PROSPERO registration no. CRD42020186053).

Eligibility criteria

Studies were included if they fulfilled the following inclusion criteria: 1) included adults with stable COPD; 2) measured and reported single free-living PA-related intensity (i.e., individual types of PAs performed by participants at their own pace within a restricted period of time) that pertained to one of the domains of PA defined by the WHO [4]: leisure (e.g., sports/exercise programs or recreational PAs), occupation (related to paid or voluntary work), home (e.g., cleaning or gardening) or transport (e.g., walking or cycling outdoor); 3) were original quantitative studies (randomized controlled trials [RCTs], quasi-experimental or observational studies); and 4) were written in Portuguese, English, French, Italian or Spanish. We excluded studies focused on the intensity of pulmonary rehabilitation programmes or their isolated components (e.g., structured aerobic or strength training); breathing interventions (e.g., inspiratory muscle training or pursed-lips breathing); or considering only the proxy-perception of PA-related intensity. Abstracts or single case studies were also excluded.

Search strategy

A systematic literature search of the following electronic databases was conducted in May 2020: PubMed, Scopus, Web of Science, Cochrane Library and EBSCO. The search was complemented by weekly automatic updates reviewed until March 2021 and a hand-search of references in key articles (Appendix 1). Review papers (systematic or narrative) on PA measurement in COPD found in the search process were hand-searched for potential references (Appendix 1). The search strategy involved titles, abstracts and keywords/MeSH terms. Details regarding the search strategy are provided in Appendix 1.

Study selection

After removing duplicates, one reviewer (PR) performed the initial screening of all studies retrieved (titles and abstracts) according to the eligibility criteria. Given the high number of studies, only a random sample of 10% of the abstracts was independently screened by another reviewer (MS) to ensure consistency (Appendix 1), contrary to what had been proposed in the PROSPERO registration. The full texts of potentially relevant studies were then analysed and reasons for their inclusion/exclusion were registered. Disagreements were resolved by consensus, and if agreement could not be reached, the opinion of 2 other reviewers (AM and DB) was obtained.

For the secondary aim, we included only studies that for the same single free-living PA, reported on at least 2 of the outcome measures used by the American College of Sports Medicine (ACSM) and the WHO to classify the intensity of PA:%VO_{2peak},%$VO_{2reserve}$,%HR_{peak},%$HR_{reserve}$, MET, dyspnoea, perceived exertion or fatigue scores on the Borg 0–10 or 6–20 scales and walking speed [4, 7].

Data extraction

One reviewer (PR) extracted the following data by using a predesigned structured table-format from all included studies: characteristics of the study (first author, year of publication, country and study design); population (number of participants, sex proportion, age, percent predicted forced expiratory volume in 1 s [$FEV_{1\%pred}$] and body mass index); type of free-living PA; outcomes, outcome measures and instruments used to assess single free-living PA-related intensity and results on PA intensity. Within the scope of this systematic review, an outcome was defined as any clinical effect related to a change in PA intensity (e.g., dyspnoea or pulmonary gas exchange); an outcome measure specified which parameter of that outcome was measured (e.g., dyspnoea Borg score or VO_2); and an instrument referred to the tool used to measure that outcome (e.g., modified Borg scale or portable gas analyser).

Whenever the information provided in the included studies was not clear or was missing, the authors were contacted via e-mail and requested to provide it. When results on PA intensity were only reported as a figure and the authors did not reply providing the requested data, an online software (WebPlotDigitalizer 4.4) was used to extract data (Appendix 1).

Quality assessment

Two independent reviewers (PR and MT) assessed the quality of all included studies with the QualSys Tool for quantitative studies (Appendix 1). This is a 14-item checklist that can be used in different study designs and appraises the domains research question, study design, study selection, subject characteristics, random allocation, blinding of investigators/subjects, outcome measures, sample size, analytic methods, estimates of variance, confounding, results and conclusions. Each item can be classified as "yes, 2″, "partial, 1″, "no, 0″ or "not applicable". A summary score, ranging from 0% to 100%,

Table 1
Cut-offs proposed by the American College of Sports Medicine and World Health Organization [4, 7] and used to classify the single free-living physical activity-related intensity in this systematic literature review.

Physical activity	$\%VO_{2peak}$	$\%VO_{2reserve}$	$\%HR_{peak}$	$\%HR_{reserve}$	METs	Borg 0–10 score (dyspnoea/exertion/fatigue)	Borg 6–20 score (dyspnoea/exertion/fatigue)	Speed (km/h)
Light	≤45	≤39	≤63	≤39	≤2.9	≤3	≤11	≤4.7
Moderate	46–63	40–59	64–76	40–59	3–5.9	4–6	12–13	4.8–7.2
Vigorous	≥64	≥60	≥77	≥60	≥6	≥7	≥14	≥7.3

HR, heart rate; MET, metabolic equivalent of task; VO_2, oxygen consumption.

was calculated for each study (total sum/total possible sum). The QualSyst tool does not encompass a classification of studies according to their scores; nevertheless, following a previous proposed approach (Appendix 1), the quality of studies with scores ≥ 80% was rated strong, 60% to 79% good, 50% to 59% adequate and < 50% poor.

Data analysis and synthesis

Cohen's kappa statistic was used to calculate the level of inter-rater agreement between the 2 reviewers during the study selection and quality assessment processes (Appendix 1). The Cohen's kappa ranges from 0 to 1 and agreement was interpreted as slight (≤0.2), fair (0.21 to 0.4), moderate (0.41 to 0.6), substantial (0.61 to 0.8), and almost perfect (≥0.81).

For each study considered for the secondary aim, single free-living PA-related intensity was classified as light, moderate or vigorous by converting the results on PA intensity according to the cut-offs proposed by the ACSM and WHO (Table 1) [4, 7].

Then, for each single free-living PA reported in each study, we checked for agreement (yes/no) between the intensity categories assigned by the different outcome measures. Finally, all studies using the same pair of outcome measures (e.g.,$\%VO_{2peak}$ and MET) were grouped to calculate the percentage of agreement between those 2 outcome measures using the following formula:

$$\%\ \text{of agreement} = \frac{\text{no. of comparisons where both outcome measures agreed in the PA intensity category}}{\text{no. of comparisons where both outcome measures were used}} \times 100$$

Furthermore, in case of no agreement, we determined which outcome measure yielded the highest intensity using this formula:

$$\%\ \text{of highest intensity} = \frac{\text{no. of comparisons where the outcome measure studied had the highest intensity}}{\text{no. of comparisons where there was no agreement}} \times 100$$

An example of how the percentage of agreement was calculated is provided in the supplementary material (e-Figure 1). Statistical analysis was performed with IBM SPPS 24.0 (IBM, Armonk, New York, NY, USA).

Results

Study selection

This systematic literature search identified 54,762 records; 43 met our inclusion criteria and were included in the qualitative synthesis (primary aim) and 19 were included in the agreement analysis (secondary aim) (Fig. 1). Inter-rater agreement for study selection was considered substantial (k = 0.73; 95% confidence interval [CI] 0.44–1; p<0.001; percentage agreement=93%).

Quality assessment

Overall, the mean score for the methodological quality assessment was 87% [95%CI 85–89], with 88% (n = 38) of the studies presenting strong quality and the remaining 12% (n = 5) good quality. Inter-rater agreement of the quality assessment was considered substantial (k = 0.80; 95%CI 0.55–1; p<0.001; percentage agreement=92%). The quality assessment scores for all the included studies are in Supplementary e-Table 1.

Study characteristics

Most studies (except 2) [25, 26] were published after 2000. Studies were conducted in Europe (n = 14) [22–35], North America (n = 11) [36–46], South America (n = 10) [20, 47-55], Australia (n = 4) [56–59] and Asia (n = 4) [60–63]. Overall, 32 studies had a cross-sectional design [20, 22-27, 30, 31, 33-38, 40, 42, 44-49, 51-54, 56, 57, 60, 62, 63], 8 were RCTs [28, 32, 39, 41, 50, 55, 58, 59] and 3 were cohort interventional studies [29, 43, 61].

The 43 included studies enroled 1538 participants (1282 COPD and 256 healthy people), with sample sizes ranging from 8 to 117 participants. Participants with COPD were 66 years old, on average (n = 42), most were male (832 [65%] men; n = 42) and the mean $FEV_{1\%pred}$ was 49% (n = 40).

The ADLs were the single free-living PAs most frequently assessed (n = 27) [20, 22-24, 26, 27, 29-31, 33, 37, 38, 42-49, 51-54, 56, 62, 63], namely, walking (n = 12) [20, 24, 27, 37, 38, 42, 43, 45, 46, 49, 56, 63], lifting, changing or moving weights/objects (n = 12) [20, 22-24, 29, 30, 33, 47, 48, 51, 52, 54], sweeping/cleaning the floor (n = 9) [22-24, 29, 30, 33, 47, 53, 54] and climbing stairs (n = 9) [20, 23, 26, 29, 31, 33, 53, 54, 62]. Other types of single free-living PAs assessed included walking-based interventions (n = 5) [28, 34, 35, 39, 41], water-based exercises (n = 5) [25, 32, 50, 55, 58], videogames (n = 3) [36, 40, 59], Tai Chi (n = 2) [57, 60] and QuiGong (n = 1) [61]. Details of the included studies are in the Supplementary e-Table 2.

Methods to assess single free-living PA-related intensity

Overall, 13 outcomes, 46 outcome measures and 22 instruments were identified. The most frequently used outcomes, outcome measures and instruments to assess single free-living PA-related intensity were dyspnoea with the modified Borg scale; cardiac function via HR, measured with HR monitors; and pulmonary gas exchange, especially

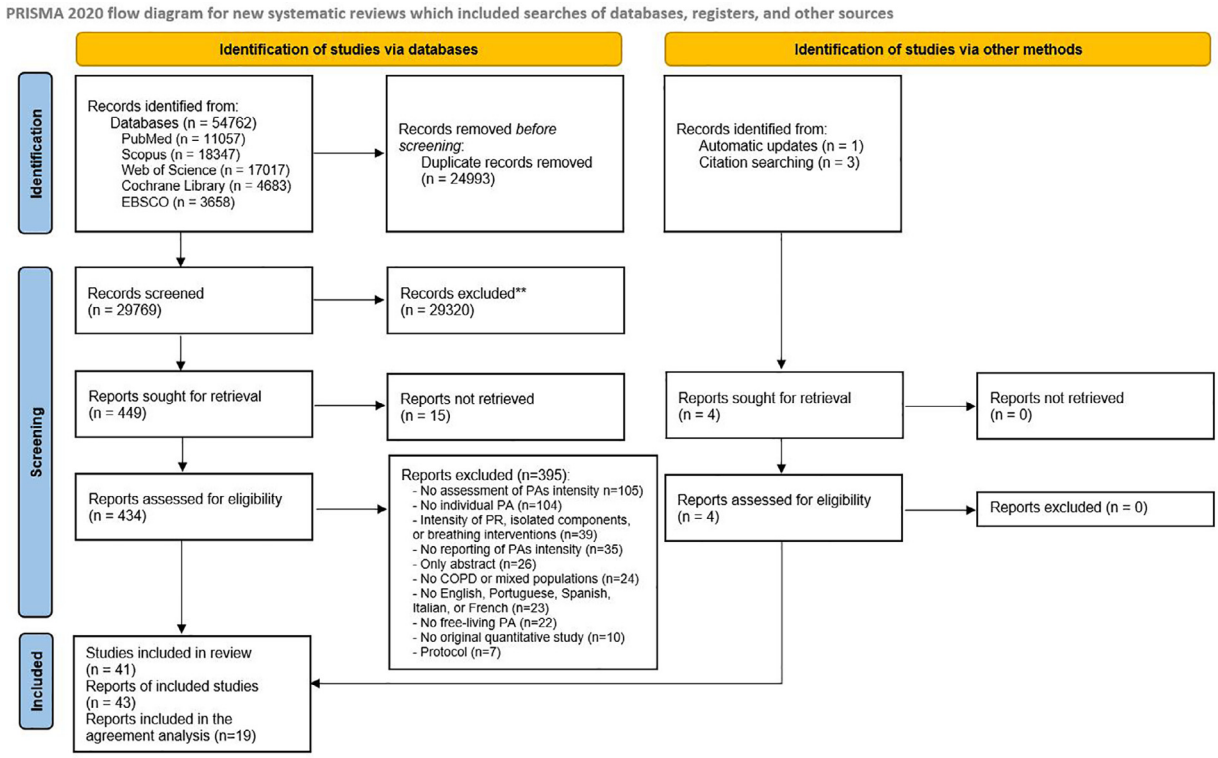

Fig. 1. PRISMA flowchart of the included studies. COPD, chronic obstructive pulmonary disease; PA, physical activity; PR, pulmonary rehabilitation.

VO_2, measured with portable gas analysers. In total, 32 studies referred to absolute intensity [20, 22-28, 30, 31, 33, 34, 36-38, 40-47, 49, 51, 52, 56, 57, 60-63] and 32 to relative intensity [20, 22-26, 29-36, 39, 40, 42, 46-48, 50-55, 57, 58, 60-62]. From the latest studies, 2 estimated maximum intensity using equations [47, 54]. Table 2 lists the outcome measures and instruments found for each outcome.

Agreement between PA-related intensity outcomes

Percentages of agreement ranged from 0% to 100% when comparing the classification of the PA-related intensity (Table 3). Pulmonary gas exchange measures ($\%VO_{2peak}$ and$\%VO_{2reserve}$) elicited the highest intensities.

Discussion

A vast variety of methodologies were reported to assess single free-living PA-related intensity. Dyspnoea was the most frequently reported PA-related intensity outcome (using the modified Borg scale). Agreement between the different outcome measures varied greatly, with VO_2 (peak and reserve) consistently yielding the highest intensity levels.

Methods to assess single free-living PA-related intensity

The Borg scores were used to assess dyspnoea, fatigue and rate of perceived exertion. Borg scales are valid, reliable, quick, user-friendly, and inexpensive tools and thus, widely used in broad free-living settings [18, 64-66]. These instruments have been recommended to prescribe exercise intensity in people with COPD [10] and to assess symptoms during cardiopulmonary exercise test [67]. Nevertheless, Borg scales require a period of familiarization, may be affected by individuals' education and highly depend on patients' subjective experiences, current mood and motivation [64, 65]. Thus, Borg scores may not always express the physiological changes arising from the PA-related intensity.

Measurement of cardiac function and pulmonary gas exchange were also used to assess intensity. From cardiac function measures, we can highlight HR, which has a linear association with VO_2 and is a convenient and practical physiological marker to estimate PA-related intensity [13]. However, the association between HR and PA-related intensity is modulated by several factors, such as age, medication (e.g., betablockers), training mode or level of anxiety [13, 68, 69]. Moreover, because exercise in people with COPD is often not limited by the cardiac overload but instead by ventilatory restraints, HR is usually a poor marker of PA-related intensity in this population [70, 71]. Indeed, HR is not within the recommended outcome measures to prescribe exercise intensity in people with COPD [10]. Most of the studies retrieved in this review assessed pulmonary gas exchange using indirect calorimetry, with VO_2,$\%VO_{2peak}$ and ventilation measures. Indirect calorimetry is an accurate and reliable method; nevertheless, it is highly expensive and requires specialized staff and equipment. Thus, its availability and applicability in real-world settings using large populational cohorts is highly limited [15, 69]. In both cardiac function and pulmonary gas exchange, absolute intensity was used more often than relative intensity. Unlike absolute intensity, relative intensity takes into account the well-known large variability related to multiple individual and environmental factors [13, 19, 20]. This is particularly relevant for people with COPD because they are usually older adults, with low PA baseline levels and altered body composition [72, 73], aspects that are closely related to PA intensity [13]. However, to confidently use relative intensity (measured and not based on prediction equations), a previous submaximal or maximal test, ideally a cardiopulmonary exercise test, is required [68]. Nevertheless, relative intensity is preferred rather than absolute intensity [7].

Walking speed has been commonly measured to assess PA-related intensity, mostly through accelerometery, a reliable and valid instrument to capture body movement and acceleration [74]. However, in our review, movement intensity driven from accelerometery was reported in a single study [24]. Our review included only studies assessing single types of PA during a restricted period of time;

Table 2
Single free-living physical activity-related intensity outcomes, outcome measures and instruments (n = 43).

Outcome	Outcome measures (units)	Instruments and models
Active energy expenditure (n = 6) [20, 34, 36, 40, 42, 49]	- Energy expended (n = 3) (Joules) [40]; (Kcal) [20, 49] - MET (n = 2)[42, 36] - MET-min (n = 1) [34] - MET_{peak} (n = 1) [36]	- Accelerometer (n = 1): Power Walker [49] - Multisensor (n = 4): SenseWear Armband [20, 42, 49]; SenseWear Mini Armband [40] - Pedometer (n = 1): Digiwalker SW701 [20] - Portable gas analyser (n = 4): K4b^2 [42]; MetaMax®3B [34, 36]; VO_{2000} [20]
Cardiac function (n = 18) [20, 22, 23, 25, 26, 29, 31, 32, 34, 36, 40, 47, 51, 52, 54, 57, 60, 61]	- HR (n = 12)(bpm) [20, 23, 25, 26, 31, 36, 40, 51, 52, 57, 60, 61] - HR_{peak} (n = 2)(bpm) [34, 36] - $\%HR_{peak}$ (n = 4) [22, 23, 29, 32] - $\%HR_{reserve}$ (n = 2) [54, 61] - $\%HR_{maximum\ predicted}$ (n = 1) [47] - VO_2/HR (n = 1)(mL/min) [47]	- HR monitor (n = 8): Polar [22, 54, 57]; Vantage XL-Polar Electro [47, 52]; Polar accurex Plus TM [32]; Polar RS800CX [34]; Polar S810 [61] - Portable gas analyser (n = 4): K4b^2 [60]; MetaMax®3B [36]; OxyconMobile [29]; Vista XT Metabolic System [47] - Pulse oximeter (n = 3): Ohmeda Biox3740[25]; Nonin portable pulse oximeter [40]; Spirodoc© device [31] - Radial pulse palpation (n = 1)[26]
Climbing stairs speed (n = 1) [26]	- Cadence (n = 1)(steps/min) [26]	- Direct observation (n = 1) [26]
Cycling speed (n = 1) [27]	- Rotational speed (n = 1)(rpm) [27]	- Direct observation (n = 1) [27]
Dyspnoea (n = 25) [20, 22, 25, 30-36, 39, 40, 42, 47, 48, 50-55, 58-60, 62]	- Borg score (n = 25) [20, 22, 25, 30-36, 39, 40, 42, 47, 48, 50-55, 58-60, 62]	- Borg scale 6–20 points (n = 1) [36] - Modified Borg scale 0–10 points (n = 24) [20, 22, 25, 30-35, 39, 40, 42, 47, 48, 50-55, 58-60, 62]
Rate of perceived exertion (n = 8) [23, 25, 26, 32, 40, 46, 58, 61]	- Borg score (n = 8) [23, 25, 26, 32, 40, 46, 58, 61] - $\%Borg_{peak}$ (n = 1) [23]	- Borg scale 6–20 points (n = 4) [25, 26, 32, 46] - Modified Borg scale 0–10 points (n = 4) [23, 40, 58, 61]
Fatigue (n = 9) [20, 22, 30, 31, 34, 36, 50, 55, 60]	- Borg score (n = 9) [20, 22, 30, 31, 34, 36, 50, 55, 60] - Unpotentiated quadriceps twitch tension (n = 1) [60]	- Borg scale 6–20 points (n = 1) [36] - Magnetic stimulator (n = 1): Magstim 200 stimulator [60] - Modified Borg scale 0–10 points (n = 8) [20, 22, 30, 31, 34, 50, 55, 60]
Lactate production (n = 2) [26, 31]	- Blood lactate concentration(n = 2)(mmol/L) [26, 31]	- Blood lactate test metre (n = 1): Lactate Pro2 [31] - Enzymathic Method of Hohorst (n = 1) [26]
Movement intensity (n = 1) [24]	- Movement intensity (n = 1)(arbitrary units) [24]	- Accelerometer (n = 1): CIRO activity monitor [24]
Muscle strength (n = 3) [24, 50, 55]	- %1-RM (n = 2) [50, 55] - %Maximal muscle effort (n = 1) [24]	- Eletromyograph: Programmable Ambulant Signal Acquisition (PASAQ) (n = 1) [24] - Multigym (n = 1): MultigymCRW3200 [50]
Pulmonary gas exchange (n = 16) [22, 23, 29-31, 33, 34, 36, 44, 47, 51, 52, 54, 57, 60, 62]	- RER (n = 1) [23] - RER_{peak} (n = 1) [34] - RR (n = 6)(cycle/min) [23, 31, 33, 51, 57, 60] - VE (n = 8)(L/min) [23, 30, 31, 33, 36, 47, 57, 60] - VE_{peak} (n = 2)(L/min) [34, 36] - VE/VCO_2 (n = 1) [33] - VCO_2 (n = 4) (mL/kg/min) [34, 47], (L/min) [57, 60] - VCO_{2peak} (n = 1) [34] - VO_2 (n = 11)(mL/kg/min) [22, 36, 44, 47, 60, 62], (mL/min) [23, 30, 52], (L/min) [33, 57] - VO_2/FFM (n = 2)(mL/min/kg) [22, 30] - VO_{2peak} (n = 2)(mL/kg/min) [34, 36] - $\%FetCO_{2peak}$ (n = 1) [36] - $\%RR_{peak}$ (n = 1) [23] - $\%VE_{maximum\ predicted}$ (n = 1) [47] - $\%VE_{peak}$ (n = 6) [22, 23, 29, 30, 33, 36] - $\%VE_{reserve}$ (n = 1) [54] - $\%VO_{2maximum\ predicted}$ (n = 1) [47] - $\%VO_{2peak}$ (n = 8) [22, 23, 29, 30, 33, 36, 60, 62] - $\%VO_{2reserve}$ (n = 2) [54, 57]	- Portable gas analyser (n = 14): Oxycon Mobile [22, 23, 29, 30, 33]; K4b^2 [44, 52, 57, 60]; MetaMax®3B [34, 36]; AEROSPORT KB1-C [62]; Vista XT Metabolic System [47]; VO_{2000} [54] - Spirometer (n = 1): Spirodoc© device [31]
Walking speed (n = 15) [20, 27, 34, 37, 38, 41-43, 45, 46, 49, 50, 55, 56, 63]	- Acceleration magnitude (n = 1) [63] - Cadence (n = 5)(steps/min) [20, 42, 45, 56, 63] - Speed (n = 13)(mph) [37, 38, 41], (m/min) [42, 45, 49, 56], (m/s) [27, 34, 43, 46, 63], (km/h) [20] - Walk ratio (n = 1)(mm.[*steps*/*min*])[63] - %6MWT speed (n = 2) [50, 55]	- 6MWT (n = 2) [50, 55] - Accelerometer (n = 5): ActivPAL [56]; Mimamori-gait system [63]; Power Walker610 [49]; RT3 Research Tracker [37]; StepWatch activity monitor [56] - Biomechanics laboratory (n = 1) [46] - Diary (n = 1) [41] - Direct observation (n = 3) [38, 42, 56] - Multisensor (n = 2): SenseWear Armband [20, 42] - Pedometer (n = 4): DigiwalkerSW701 [20]; Omrom HJ-720ITC [43]; Model342, Sportline [41]; Walking style X Omrom [34] - Tally counter (n = 1) [43] - Videocamera (n = 4) [27, 45, 49]: Sony Cybershot DSC-W120 [20]
Work (n = 2) [26, 28]	- Power output (n = 1)(w) [26] - Work rate (n = 1)(w) [28]	- Diary (n = 1) [28] - Direct observation (n = 1) [26]

Note: Equipment used to assess cardiac function [20, 23, 51],%1-RM [55] and RR [31, 51] was not stated.
1-RM, one repetition-maximum; 6MWT, 6-min walk test speed; FFM, fat-free mass; HR, heart rate; MET, metabolic equivalent of task; MET-min, metabolic equivalent of task minute; RER, respiratory exchange ratio; RR, respiratory rate; VE, ventilation; VCO_2, carbon dioxide production; VO_2, oxygen consumption;$\%FetCO_{2peak}$, end tidal carbon dioxide concentration at effort peak.

Table 3
Percentage of agreement between the different outcome measures assessing the same single free-living physical activity reported in the same study (n = 19).

Outcome measures compared		Quality assessment of the included studies range	% agreement	Outcome measure assigning the highest intensity
$\%VO_{2peak}$	$\%HR_{peak}$ [22, 23, 29, 47]	70–85%	76	50% VO_{2peak} / 50%HR_{peak}
	MET [36]	83%	0	100% VO_{2peak}
	Dyspnoea Borg [22, 30, 33, 36, 47, 60, 62]	70–95%	17	
	Fatigue Borg [22, 30, 36, 60]	75–85%	13	
	RPE Borg [23]	80%	40	
$\%VO_{2reserve}$	$\%HR_{reserve}$ [54]	80%	25	100% $VO_{2reserve}$
	Dyspnoea Borg [54]	80%	25	
$\%HR_{peak}$	Dyspnoea Borg [22, 32, 47]	70–88%	30	100% HR_{peak}
	Fatigue Borg [22]	85%	0	
	RPE Borg [23, 32]	80–88%	36	
$\%HR_{reserve}$	Dyspnoea Borg [54, 61]	80–81%	100	NA
MET	Dyspnoea Borg [36, 42]	100%	60	50% dyspnoea Borg / 50% MET
	Walking speed [42]	100%	0	100% MET
Dyspnoea Borg	Fatigue Borg [20, 22, 30, 31, 34, 36, 50, 55, 60]	75–100%	89	100% dyspnoea Borg
	Walking speed [20, 34, 42]	83–100%	67	
Fatigue Borg	MET [36]	83%	75	100% fatigue Borg
	Walking speed [20, 34]	85–100%	100	NA
RPE Borg	Walking speed [46]	90%	100	NA

Note: the Borg 0–10 and 6–20 scores were analysed together.
HR, heart rate; NA, not applicable; MET, metabolic equivalent of task; RPE, rate of perceived exertion; VO_2, oxygen consumption.

instead, accelerometery and multisensors have been mostly used to measure PA over a long time (> 1 day) [75]. We acknowledge the enormous importance of assessing PA as a behaviour (i.e., quantifying the daily or weekly amount of PA and the total time spent in different PA intensities [15, 75, 76]); however, this was not within the scope of our review. Work,% one-repetition maximum (1-RM) and% 6-min walk test (6MWT), previously recommended outcome measures to prescribe exercise intensity [10], were used only in a few studies. Additionally, lactate production, which provides trustworthy aerobic and anaerobic thresholds [19, 68], was also rarely reported but would be highly challenging to be used routinely as a marker of a single free-living PA-related intensity.

Agreement between PA-related intensity outcomes

$\%VO_{2peak}$ and$\%VO_{2reserve}$, assessed by indirect calorimetry, yielded the highest intensity levels. Thus, Borg scores,$\%HR_{reserve}$ and MET underestimated single free-living PA-related intensity in people with COPD. Comparing Borg scores with$\%VO_{2peak/reserve}$, the agreement ranged from 13% to 40%. The underestimation of the intensity level by the Borg scores compared to the$\%VO_{2peak/reserve}$ was previously verified [70, 77]. Moreover, Borg scores also underrated intensity as compared with$\%HR_{peak.}$ This finding is in contrast with the consensus between these 2 outcome measures previously reported [78, 79]. One possible explanation for these incongruences might be the Borg scores being less reliable at submaximal intensities [65], which is the case for most single free-living PAs included in this systematic review. Interventions using the Borg scale to recommend PA may achieve higher$\%VO_{2peak/reserve}$, thus eliciting sufficient physiological changes to ensure PA benefits. Nevertheless, we recommend caution in the interpretation of the agreement analysis because 8 of the 18 comparisons involved only one study; therefore, future studies are needed to confirm our results and hypotheses.

Implications for clinical practice and future research

This systematic literature review confirmed the existence of a knowledge gap [5, 8, 9, 11, 12] and emphasises the urgent need for recommendations and standardization on how to assess single free-living PA-related intensity to ensure safety and PA effectiveness [11, 12, 14]. Because all outcomes, outcome measures and instruments present distinct advantages and disadvantages, using a combination of 2 or more outcome measures will most likely result in the best estimation of PA-related intensity. The standardized peak exercise perception score, already used in people with COPD [80] but not found in this systematic review, combines the Borg score (widely accessible) with VO_{2peak} (previously collected in a controlled setting or, if not possible, estimated) and could be an adequate approach to assess the intensity of single free-living PAs in real world settings. Multisensors were used by only 4 studies (all used the SenseWear Armband) [20, 40, 42, 49]; however, this is an evolving and promising field [76]. By combining several parameters (e.g., the Intelligent Device for Energy Expenditure and Activity [MiniSun LLC, Fresno, CA] integrates 5 accelerometers and the Zephyr Bioharness [Zephyr Technology Corp., Annapolis, MD] combines accelerometery, HR and respiratory rate), multisensors have the potential to provide more accurate and precise measures of PA-related intensity [76]. Moreover, allying multisensors to telemonitoring future studies would allow for continuously assessing patients' PA-related intensity and provide adequate feedback.

Lastly, the inconsistency found amongst the PA intensity levels yielded by different outcome measures further highlights the need for guidelines on how to assess single free-living PA-related intensity. In addition, our agreement analysis also stresses the need for future studies developing specific cut-offs to classify PA intensity tailored to people with COPD.

Methodological considerations

This study presents some strengths and limitations that should be acknowledged. The review was conducted following the most recent PRISMA guidelines and included a thorough search strategy and various study designs and was performed in different databases. Nonetheless, only full articles in indexed databases were searched. Therefore, additional studies may exist in conference abstracts or in the unpublished grey literature. Finally, the ACSM and WHO cut-offs used in this review to classify the intensity level were developed with healthy people [4, 7]. Therefore, the suitability of these cut-offs for people with COPD is unknown and should be explored in future studies. Another limitation is the language restriction in that some studies focusing on PAs imported from Asia (e.g., Tai Chi) were not included.

Conclusions

This review summarised all the outcomes, outcome measures and instruments used to assess single free-living PA-related intensity. A wide variety of methodologies was found, with dyspnoea measured

with the Borg score the most recurrent intensity outcome measure. The optimal methodology to assess the intensity of single free-living PAs in people with COPD in real-world settings is still unknown. Future studies should further explore the consistency amongst the different outcome measures and possible combinations between them to boost their advantages and minimize disadvantages. Formal guidance on how to accurately measure single free-living PA-related intensity in people with COPD is urgent to fill this literature gap, ensure patient safety, ascertain the benefits of PAs and optimise interventions based on PA.

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Conflict of interest

None declared.

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Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.rehab.2021.101607.

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