Sports Medicine
https://doi.org/10.1007/s40279-021-01539-1

SYSTEMATIC REVIEW

Resting Oxygen Uptake Value of 1 Metabolic Equivalent of Task in Older Adults: A Systematic Review and Descriptive Analysis

Javier Leal-Martín[1,2] · **Miguel Muñoz-Muñoz**[1,2] · **Sarah Kozey Keadle**[3] · **Francisco Amaro-Gahete**[4] · **Luis M. Alegre**[1,2] · **Asier Mañas**[1,2] · **Ignacio Ara**[1,2]

Accepted: 5 August 2021

Abstract

Background It is important for sport scientists and health professionals to have estimative methods for energy demand during different physical activities. The metabolic equivalent of task (MET) provides a feasible approach for classifying activity intensity as a multiple of the resting metabolic rate (RMR). RMR is generally assumed to be 3.5 mL of oxygen per kilogram of body mass per minute (mL O_2 kg^{-1} min^{-1}), a value that has been criticized and considered to be overestimated in the older adult population. However, there has been no comprehensive effort to review available RMR estimations, equivalent to 1 MET, obtained in the older adult population.

Objective The aim of this review was to examine the existing evidence reporting measured RMR values in the older adult population and to provide descriptive estimates of 1 MET.

Methods A systematic review was conducted by searching PubMed, Web of Science, Scopus, CINAHL, SPORTDiscus, and Cochrane Library, from database inception to July 2021. To this end, original research studies assessing RMR in adults $\geq$ 60 years old using indirect calorimetry and reporting results in mL O_2 kg^{-1} min^{-1} were sought.

Results Twenty-three eligible studies were identified, including a total of 1091 participants (426 men). All but two studies reported RMR values lower than the conventional 3.5 mL O_2 kg^{-1} min^{-1}. The overall weighted average 1 MET value obtained from all included studies was 2.7 ± 0.6 mL O_2 kg^{-1} min^{-1}; however, when considering best practice studies, this value was 11% lower (2.4 ± 0.3 mL O_2 kg^{-1} min^{-1}).

Conclusion Based on the results of this systematic review, we would advise against the application of the standard value of 1 MET (3.5 mL O_2 kg^{-1} min^{-1}) in people $\geq$ 60 years of age and encourage the direct assessment of RMR using indirect calorimetry while adhering to evidence-based best practice recommendations. When this is not possible, assuming an overall value of 2.7 mL O_2 kg^{-1} min^{-1} might be reasonable. Systematic review registration: International Prospective Register of Systematic Reviews on 30 September 2020, with registration number CRD42020206440.

Asier Mañas and Ignacio Ara equally contributed.

✉ Ignacio Ara
ignacio.ara@uclm.es

1 GENUD Toledo Research Group, Universidad de Castilla-La Mancha, Avda. Carlos III S/N, 45071 Toledo, Spain

2 CIBER of Frailty and Healthy Aging (CIBERFES), Madrid, Spain

3 Department of Kinesiology and Public Health, California Polytechnic State University, San Luis Obispo, USA

4 Department of Physiology, Faculty of Medicine, University of Granada, Granada, Spain

Published online: 21 August 2021

Key Points

The weighted average value of 1 MET obtained from 1091 older adults was 23% lower than the standard 1 MET (3.5 mL O_2 kg^{-1} min^{-1}).

Assuming the 3.5 mL O_2 kg^{-1} min^{-1} standard 1 MET in the older population could lead to an important physical activity intensity misclassification.

The scientific community is encouraged to directly derive the individual 1 MET through a referenced RMR protocol or, if this is not possible, it might be reasonable to assume an estimated evidence-based value of 2.7 mL O_2 kg^{-1} min^{-1}.

1 Introduction

Physical inactivity and sedentary behavior are two major concerns in the public health community [1–4]. A wealth of evidence supports their independent role as important risk factors of cardiovascular disease, cancer, and all-cause mortality [5–7]. Providing precise and simple interpretable physical activity-intensity metrics is paramount for determining daily energy expenditure, assessing compliance with physical activity guidelines and holistic nutritional interventions. The metabolic equivalent of task (MET) provides a feasible approach for classifying physical effort by expressing activity intensity as a multiple of resting metabolic rate (RMR) [8].

The RMR, also termed resting energy expenditure, is defined as the energy needed to maintain essential body functions in an awake, restful, postabsorptive and thermoneutral state, and is usually measured by indirect calorimetry [9]. When the RMR cannot be directly assessed, an RMR value of 3.5 mL O_2 kg^{-1} min^{-1} is commonly assumed, originally derived from a single 70-kg, 40-year-old man [8, 10–12], and is generally regarded as *1 standard MET*. However, studies conducted by Kozey et al. [13], Byrne et al. [11] or Ainsworth et al. [14] have shown this reference value may be overestimated for several population subgroups including older adults.

Keys et al. [15] reported an age-related decrease in RMR at a rate of 1–2% per decade after 20 years old of age. This decline is closely linked to aging-attributable factors such as loss of fat-free mass, impairment of metabolic processes and health deterioration [16, 17]. To date, however, only studies with limited sample sizes are available and no comprehensive effort has been made to bring together all published evidence. Accordingly, the main aim of this systematic review was to examine all available publications directly assessing the RMR in older adults ≥ 60 years of age, and to provide descriptive estimates of 1 MET in the older adult population.

2 Methods

The study protocol for this systematic review was registered at PROSPERO (International Prospective Register of Systematic Reviews) on 30 September 2020, with registration number CRD42020206440, and complied with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) 2009 guidelines [18].

2.1 Literature Search

Two authors (JLM and MM) systematically searched for published peer-reviewed articles, from database inception to 14 July 2021, from six electronic databases: PubMed, Web of Science, Scopus, CINAHL, SPORTDiscus, and Cochrane Library. The search syntax and the adapted search strategy for Scopus are available in the electronic supplementary material (ESM). A secondary search of other sources was conducted using the reference lists of the included publications and researchers' personal databases to identify additional articles for possible inclusion.

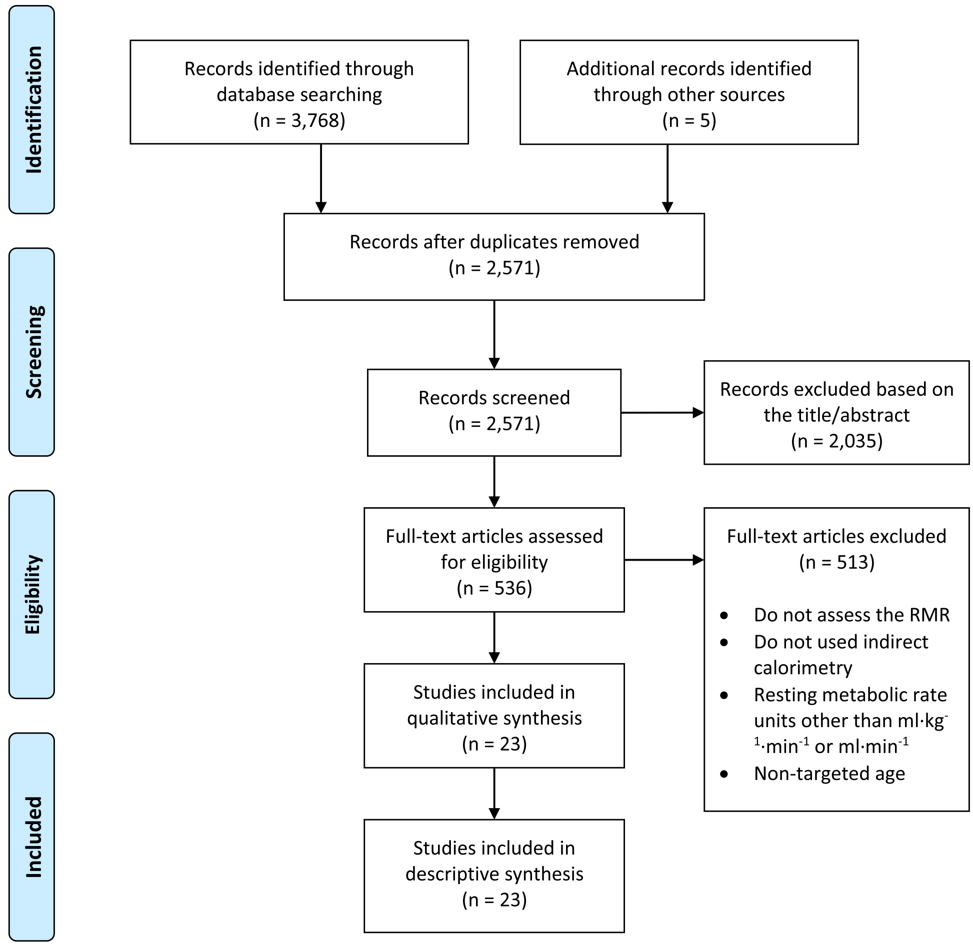
2.2 Study Selection

Studies were selected in a two-stage process. First, titles and abstracts from the electronic searches were independently examined by two authors (JLM and MM) and those meeting inclusion criteria were collected. The inclusion criteria were as follows: (i) articles of all designs (excluding conference papers, books, case studies, and reviews); (ii) articles published in the Journal Citation Reports; (iii) articles written in English or Spanish; (iv) articles involving participants ≥ 60 years of age; (v) articles assessing the RMR using the indirect calorimetry method; (vi) articles expressing the RMR in mL O_2 kg^{-1} min^{-1} or mL O_2 min^{-1} with standard deviation (SD). Second, examination of the full-text articles led to a final decision concerning inclusion or exclusion. Any disagreements were resolved after discussion with a third reviewer (AM). A graphical overview is given in Fig. 1.

2.3 Data Extraction

Two authors (JLM and MM) independently extracted the following data from each study: number of participants, number of participants in each group, characteristics of participants, characteristics of RMR protocols, and results.

Fig. 1 Flow diagram



Data were extracted, when available, as mean and standard deviation. This information was reviewed by a third author (AM) to ensure accuracy and completeness. A summary of this data is reported in Tables 1 and 2.

2.4 Quality Assessment of RMR Protocols

As there is currently no specific scale for quality assessment of RMR protocols, we tailored one based on the review by Fullmer et al. [19]. This study describes a set of RMR assessment best practice items categorized according to the level of evidence. For the present systematic review, the following eight items describing several measurement dimensions were selected and subsequently categorized as subject conditions (1–4), environmental conditions (4–6) and data processing (7–8): (1) to have a fasting period of at least 7 h; (2) to refrain from caffeine ingestion for at least 4 h; (3) to refrain from nicotine ingestion for at least 140 min; (4) to maintain a room temperature between 22 and 25 °C or to provide a blanket during the measurement; (5) to perform the assessment with the participant resting in a supine position; (6) to ensure a prior rest period of at least 20 min; (7) to discard the first 5 min of the record period; (8) to use a validated steady-state definition to determine the RMR value. Each item was scored as 'Yes' ($Y=1$ point) if the study complied with the item, 'No' ($N=0$ point) if it did not comply or report the item, or 'Cannot determine' (CND = 0 point) when information was ambiguous. A total score was derived for each article (0–8) and each item (0–24), respectively.

2.5 Analysis

Study results were reported as indicated in the original articles (Table 2), with the exception of Logan and Spriet [20]. For this article, the RMR value was converted from mL min^{-1} into mL kg^{-1} min^{-1}. Based on study samples, overall weighted averages and weighted standard deviations (SD) were derived. The following formulas were used using the Excel software (Microsoft Corporation, WA, USA).

$$\bar{x} = \frac{\sum_{i=1}^{n} w_i x_i}{\sum_{i=1}^{n} w_i} \quad \sigma = \sqrt{\frac{\sum_{i=1}^{n} w_i (x_i - \bar{x})^2}{\sum_{i=1}^{n} w_i}}.$$

An overall 1 MET value was derived from all studies, accounting for the most integrative RMR value of each

Table 1 Main characteristics of included studies

Source (study)	Demographic data (mean ± SD)	Sample status	1 MET (mean ± SD)
Abizanda et al. 2016 [21]	402 subjects (189 men); 76.2 ± 4.3 y; 29.4 ± 4.5 kg m^{-2} Non-frail group: 134 subjects (45 women); 75.0 ± 3.7 y; 29.0 ± 3.7 kg m^{-2} Pre-frail group: 233 subjects (93 men); 76.7 ± 4.3 y; 29.6 ± 4.9 kg m^{-2} Frail group: 35 subjects (7 men); 77.5 ± 4.9 y; 29.1 ± 4.6 kg m^{-2}	Community-dwelling older adults with different functional status General group: Health status: CI: 1.0 ± 1.3 (mean ± SD); Functional status: BI: 96.4 ± 7.0 (mean ± SD); BADL disability: 35 ± 8.7 (mean ± SD); GSp 0.89 ± 0.32 m s^{-1} (mean ± SD); GSt: 25.0 ± 10.7 kg (mean ± SD); Fitness status: NR; Physical activity level: NR Non-frail group: Health status: CI: 0.7 ± 0.9 (mean ± SD); Functional status: BI: 98.4 ± 3.0 (mean ± SD); BADL disability: 0 ± 0.0 (mean ± SD) GSp 1.05 ± 0.24 m s^{-1} (mean ± SD); GSt: 33.2 ± 9.4 kg (mean ± SD) Pre-frail group: Health status: CI: 1.0 ± 1.3 (mean ± SD); Functional status: BI: 96.9 ± 5.1 (mean ± SD); BADL disability: 19 ± 8.2 (mean ± SD); GSp: 0.84 ± 0.32 m s^{-1} (mean ± SD); GSt: 21.6 ± 8.9 kg (mean ± SD); Fitness status: NR; Physical activity level: NR Frail group: CI: 1.8 ± 2.1 (mean ± SD); BI: 85.7 ± 14.9 (mean ± SD); BADL disability: 16 ± 45.7 (mean ± SD); GSp: 0.54 ± 0.21 m s^{-1} (mean ± SD); GSt: 16.2 ± 4.8 kg (mean ± SD); Fitness status: NR; Physical activity level: NR	General group: 2.2 ± 0.7 mL O_2 kg^{-1} min^{-1} Non-frail group: 2.1 ± 0.6 mL O_2 kg^{-1} min^{-1} Pre-frail group: 1.2 ± 0.7 mL O_2 kg^{-1} min^{-1} Frail group: 2.3 ± 0.6 mL O_2 kg^{-1} min^{-1}
Aguilar-Farias et al. 2019 [22]	40 subjects (17 men) 65–74 y group: 17 subjects (9 men); 70.1 ± 2.4 y; 26.0 ± 3.22 kg m^{-2} ≥ 75 y group: 23 subjects (8 men); 82.7 ± 6.46 y; 25.9 ± 4.05 kg m^{-2}	Community-dwelling older adults; 65–74 y group: Health status: SRH (fair): 0%; SRH (good): 47.1%; SRH (very good): 35.3%; SRH (excellent): 17.7%; Functional status: NR; Fitness status: AC: 8.8 METs [7.11–10.63] (median [IQR]); PAL (inactive): 6.2%: PAL (≤ 1 h $week^{-1}$): 31.3%; PAL (> 1 h $week^{-1}$): 62.5% ≥ 75 y group: Health status: SRH (fair): 17.4%; SRH (good): 39.1%; SRH (very good): 26.1%; SRH (excellent): 17.4%; Functional status: NR; Fitness status: AC: 5.7 METs [4.45–6.89] (median [IQR]); Physical activity level: PAL (inactive): 13.1%: PAL (≤ 1 h $week^{-1}$): 52.2%; PAL (> 1 h $week^{-1}$): 34.8%	65–74 y group: 3.4 ± 0.5 mL O_2 kg^{-1} min^{-1} ≥ 75 y group: 3.2 ± 0.5 mL O_2 kg^{-1} min^{-1}
Ashley et al. 2018 [23]	11 subjects (4 men) 74 ± 7 y; 23.8 ± 0.9 kg m^{-2}	Community-dwelling older adults Health status: NR; Functional status: NR; Fitness status: NR; Physical activity level: NR	General group: 3.0 ± 0.2 mL O_2 kg^{-1} min^{-1}
Avelar et al. 2011 [24]	18 subjects (3 men) 72 ± 6 y	Community-dwelling older adults; Health status: NR; Functional status: NR; Fitness status: NR; Physical activity level: NR	General group: 3.3 ± 0.1 mL O_2 kg^{-1} min^{-1}

Table 1 (continued)

Source (study)	Demographic data (mean ± SD)	Sample status	1 MET (mean ± SD)
Barnett et al. 2016 [25]	45 subjects (16 men) 70.2 ± 7 y; 27.4 ± 4.0 kg m^{-2}	Community-dwelling older adults; Health status: NR; Functional status: NR; Fitness status: NR; Physical activity level: NR	General group: 2.8 ± 0.6 mL O_2 kg^{-1} min^{-1}
Bartolomeu et al. 2017 [26]	18 subjects (18 women) 65.1 ± 5.8 y	Community-dwelling older adults; Health status: NR; Functional status: NR; Fitness status: AC: 5.79 ± 1.15 METs (mean ± SD); Physical activity level: NR	Women group: 4.0 ± 0.6 mL O_2 kg^{-1} min^{-1}
Campbell et al. 2003 [27]	11 subjects (11 women) 66.7 ± 0.9 y; 25.6 kg m^{-2}	Community-dwelling older adults; Health status: NR; Functional status: NR; Fitness status: Peak MET: 7.6 ± 0.4 METs (mean ± SE); VO_{2peak}: 21.80 ± 0.91 mL O_2 kg^{-1} min^{-1} (mean ± SE); Physical activity status: NR	Women group: 2.8 ± 0.1 mL O_2 kg^{-1} min^{-1}
Chow et al. 2018 [28]	16 subjects (8 women) 70.7 ± 5.6 y Men group: 8 subjects; 69.8 ± 6.5 y; 23.3 ± 2.8 kg m^{-2} Women group: 8 subjects; 71.6 ± 4.7 y; 23.9 ± 1.6 kg m^{-2}	Community-dwelling older adults; Health status: NR; Functional status: NR; Fitness status: NR; Physical activity level: NR	Men group: 2.3 ± 1.1 mL O_2 kg^{-1} min^{-1} Women group: 2.3 ± 1.3 mL O_2 kg^{-1} min^{-1}
Cortes et al. 1997 [29]	23 subjects (5 men) 79.2 ± 7.8 y; 26.2 kg m^{-2}	Community-dwelling older adults with moderate-to-heavy chronic disease burdens Health status: CDP (hypertension) 78%; CDP (degenerative joint disease) 64%; CDP (coronary artery disease) 43%; CDP (peripheral vascular disease) 35%; CDP (hypothyroid): 23%; CDP (diabetes) 22%; PM (> 5 drugs): 75%; PM (> 10 drugs): 25%; Functional status: NR; Fitness status: 20.27 ± 10.48 mL O_2 kg^{-1} min^{-1}; Physical activity level: NR	General group: 2.3 ± 0.7 mL O_2 kg^{-1} min^{-1}
Cunha et al. 2019 [30]	9 subjects (4 women) 70.3 ± 4.8 years; 27.4 ± 3.0 kg m^{-2}	Community-dwelling older adults; Health status: NR; Functional status: NR; Fitness status: NR; Physical activity level: NR	General group: 2.4 ± 0.5 mL O_2 kg^{-1} min^{-1}
Hall et al. 2013 [31]	20 subjects (5 women); 75.0 ± 8.9 y; 29.1 ± 3.9 kg m^{-2}	Community-dwelling older adults; Health status: number of chronic conditions: 2.6 ± 1.4 (mean ± SD); Functional status: GSp: 1.50 ± 0.25 m s^{-1} (mean ± SD); Fitness status: NR; Physical activity: NR	General group: 2.7 ± 0.6 mL O_2 kg^{-1} min^{-1}
Hooker et al. 2011 [32]	23 subjects (11 women) 74 ± 6 y; 26 ± 5 kg m^{-2}	Community-dwelling older adults; Health status: NR; Functional status: NR; Fitness status: NR; Physical activity level: NR	General group: 3.0 ± 0.6 mL O_2 kg^{-1} min^{-1}

Table 1 (continued)

Source (study)	Demographic data (mean ± SD)	Sample status	1 MET (mean ± SD)
Kwan et al. 2004 [33]	70 subjects (35 women) Men group: 35 subjects; 73.9 ± 6.2 y; 24.09 ± 3.7 kg m^{-2} Women group: 35 subjects; 71.4 ± 5.2 y; 24.29 ± 4.2 kg m^{-2}	Community-dwelling older adults; Health status: NR; Functional status: NR; Fitness status: NR; Physical activity level: NR	Men group: 2.8 ± 0.3 mL O_2 kg^{-1} min^{-1} Women group: 2.8 ± 0.4 mL O_2 kg^{-1} min^{-1}
Lerma et al. 2017 [34]	20 subjects (9 men); 68.1 ± 6.5 y; 27.8 ± 4.1 kg m^{-2}	Community-dwelling older adults; Health status: NR; Functional status: NR; Fitness status: NR; Physical activity level: NR	General group: 3.2 ± 0.2 mL O_2 kg^{-1} min^{-1}
Logan et al. 2015 [20]	24 subjects (24 women) 66 ± 1 y Fish oil group: 12 subjects; 26.3 ± 1.0 kg m^{-2} Placebo group: 12 subjects; 27.9 ± 1.3 kg m^{-2}	Community-dwelling older adults Fish oil group: Health status: NR; Functional status: Combined GSt: 57.4 ± 2.3 kg (mean ± SE); TUG: 7.3 ± 0.2 s (mean ± SE); 30 s STS: 15 ± 0.9 rep (mean ± SE); Fitness status: NR; Physical activity level: PASE: 120 ± 21 pts (mean ± SE) Placebo group: Health status: NR; Functional status: Combined GSt: 49.9 ± 2.8 kg (mean ± SE); TUG: 7.6 ± 0.2 s (mean ± SE); 15 ± 1.7 rep; Fitness status: NR; Physical activity level: PASE: 149 ± 15 pts (mean ± SE)	Women fish oil group: 2.3 ± 0.1 mL O_2 kg^{-1} min^{-1} Women placebo group: 2.6 ± 0.1 mL O_2 kg^{-1} min^{-1}
Migueles et al. 2021 [35]	78 subjects (38 women) Calibration group: 59 subjects (29 women); 78.7 ± 5.7 y; 26.5 ± 3.6 kg m^{-2} Cross-validation group: 19 subjects (9 men); 75.5 ± 4.6 y; 28.3 ± 3.0 kg m^{-2}	Community-dwelling older adults; Health status: NR; Functional status: NR; Fitness status: NR; Physical activity level: NR	Calibration group: 3.0 ± 0.7 mL O_2 kg^{-1} min^{-1} Cross-validation group: 2.7 ± 0.7 mL O_2 kg^{-1} min^{-1}
Nakagata et al. 2019 [36]	20 subjects (7 women); Men group: 13 subjects; 71.6 ± 5.4 y; 23.0 ± 1.8 kg m^{-2} Women group: 7 subjects; 69.3 ± 3.3 y; 21.8 ± 1.6 kg m^{-2}	Community-dwelling older adults; Health status: NR; Functional status: NR; Fitness status: NR; Physical activity level: NR	Men group: 3.2 ± 0.3 mL O_2 kg^{-1} min^{-1} Women group: 3.3 ± 0.2 mL O_2 kg^{-1} min^{-1}
Panayiotou et al. 2013 [37]	19 subjects (19 men); Control group: 8 subjects; 65.4 ± 1.1 y Statins group: 11 subjects; 66.9 ± 1.0 y	Community-dwelling older adults with hypercholesterolemic older adults Health status: NR; Functional status: NR; Fitness status: NR; Physical activity level: NR	Men control group: 2.6 ± 0.1 mL O_2 kg^{-1} min^{-1} Men statins group: 2.5 ± 0.1 mL O_2 kg^{-1} min^{-1}
Park et al. 2011 [38]	20 subjects (4 men); 67.3 ± 2.7 y; 26.4 ± 3.6 kg m^{-2}	Community-dwelling older adults; Health status: NR; Functional status: NR; Fitness status: NR; Physical activity level: NR	General group: 3.8 ± 0.9 mL O_2 kg^{-1} min^{-1}
Sergi et al. 2010 [39]	81 subjects (81 women); 70.4 ± 3.9 y; 26.6 ± 3.1 kg m^{-2}	Community-dwelling older adults; Health status: NR; Functional status: GSt: 16.0 ± 5.5 kg; SPPB: 10.5 ± 1.2 pts (mean ± SD); Fitness status: VO_{2max}: 17.5 ± 2.8 mL kg^{-1} min^{-1} (mean ± SD); Physical activity level: NR	Women group: 2.9 ± 0.4 mL O_2 kg^{-1} min^{-1}

Table 1 (continued)

Source (study)	Demographic data (mean ± SD)	Sample status	1 MET (mean ± SD)
Taylor et al. 2012 [40]	19 subjects (4 men); 70.7 ± 6.4 y; 27.6 ± 6.1 kg m^{-2}	Community-dwelling older adults; Health status: NR; Functional status: TUG: 10.2 ± 1.8 s (mean ± SD); Fitness status: NR; Physical activity level: NR	General group: 3.4 ± 0.7 mL O_2 kg^{-1} min^{-1}
Trutschnigg et al. 2013 [41]	20 subjects (20 women); Control group: 11 subjects; 76.0 ± 5.5 y; 24.9 ± 2.4 kg m^{-2} Cancer group: 9 subjects; 73.2 ± 8.0 y; 26.2 ± 4.5 kg m^{-2}	Community-dwelling older adults with cancer Control group: Health status: NR; Functional status: NR; Fitness status: 6MWT: 480.4 ± 49.0 m (mean ± SD); 6MWT: 1.33 ± 0.14 m s^{-1} (mean ± SD); Physical activity level: NR Cancer group: Health status: NR; Functional status: NR; Fitness status: 6MWT: 337.2 ± 92.0 m (mean ± SD); 6MWT: 0.94 ± 0.26 m s^{-1} (mean ± SD): Physical activity level: NR	Women control group: 2.5 ± 0.5 mL O_2 kg^{-1} min^{-1} Women cancer group: 2.7 ± 0.6 mL O_2 kg^{-1} min^{-1}
Yeung et al. 2020 [42]	84 subjects (30 men); 78.3 y; 27.2 ± 5.0 kg m^{-2}; Melbourne group: 58 subjects (19 men); 77.2 y; 27.9 ± 5.0 kg m^{-2} Amsterdam group: 26 subjects (11 men); 81.1 y; 25.6 ± 4.6 kg m^{-2}	Community-dwelling older adults with mobility problems General group: Health status: No. of diseases: 6 [5–8] (median [IQR]); Polypharmacy: 66%; Functional status: SPPB: 8 [5–10] (mean [IQR]); TUG 14.0 s [10.7–19.6] (mean [IQR]); Fitness status: NR; Physical activity level: NR Melbourne group: Health status: No. of diseases: 7 [4–8] (median [IQR]); Polypharmacy: 47%; SPPB: 8 [5–10] (mean [IQR]); Functional status: TUG 13.3 s [10.6 – 18.2] (mean [IQR]); Fitness status: NR; Physical activity level: NR Amsterdam group: Health status: No. of diseases: 6 [5–8] (median [IQR]); Polypharmacy: 19%; Functional status: SPPB: 9 [6 – 10] (mean [IQR]); TUG 16.2 s [12.8–21.8] (mean [IQR]); Fitness status: NR; Physical activity level: NR	General group: 2.9 ± 0.6 mL O_2 kg^{-1} min^{-1} Melbourne group: 2.7 ± 0.4 mL O_2 kg^{-1} min^{-1} Amsterdam group: 3.5 ± 0.6 mL O_2 kg^{-1} min^{-1}

AC aerobic capacity, *BADL* basic activities of daily living, *BI* Barthel index, *BMI* body mass index, *CDP* chronic disease pattern, *CI* Charlson index, *GSp* gait speed, *GSt* grip strength, *IQR* interquartile range, *MET* metabolic equivalent of task, *NR* not reported, *PAL* physical activity level, *PASE* physical activity scale for the elderly questionnaire, *PM* prescribed medications, *SD* standard deviation, *SE* standard error, *SPPB* short physical performance battery, *SRH* self-reported health, *STS* sit to stand test, *TUG* timed up and go test, VO_2max maximal oxygen uptake, VO_2peak peak oxygen uptake, *6MWT* 6-min walking test

Table 2 Main characteristics of the RMR protocols of the included studies

Study	Subject conditions			Measurement protocol	
	Fasting conditions	Other recommendations	Setting	Indirect calorimeter	Measurement periods
Abizanda et al. 2016 [21]	Fasting: 12 h Caffeine: 12 h Nicotine: 12 h	Physical activity: 24 h Sleep: NR Transportation: NR	Subject: Lying at rest Environment: Quiet room, at 23 °C	FitMate Portable Metabolic Analyzer (Cosmed SRL, Rome, Italy)	Previous rest: 15 min Record period: 20 min Selected period: NR
Aguilar-Farias et al. 2019 [22]	Fasting: NA Caffeine: NA Nicotine: NA	Physical activity: NR Sleep: NR Transportation: NR	Subject: Lying at rest, remaining silent Environment: Quiet room	MetaMax 3B (Cortex Biophysik GmbH, Leipzig, Germany)	Previous rest: 5 min Record period: 5 min Selected period: NR
Ashley et al. 2018 [23]	Fasting: 4 h Caffeine: ≥ 12 h Vitamins: ≥ 12 h Supplements: ≥ 12 h Nicotine: NR	Physical activity: NR Sleep: NR Transportation: NR	Subject: Standing at rest Environment: NR	Ultima CardioO2 (MedGraphics, St. Paul, MN, USA)	Previous rest: NR Record period: 5 min Selected period: Last 2 min
Avelar et al. 2011 [24]	Fasting: NR Caffeine: NR Nicotine: NR	Physical activity: NR Sleep: NR Transportation: NR	Subject: Sitting at rest and awake Environment: Closed and dimly lit room	Cosmed K4b2 (COSMED, Rome, Italy)	Previous rest: NR Record period: 10 min Selected period: Last 5 min
Barnett et al. 2016 [25]	Fasting: 5 h Caffeine: Overnight Nicotine/Alcohol: 2 h	Physical activity: 2 h (MPA) 14 h (VPA) Sleep: NR Transportation: NR	Subject: Lying at rest Environment: Quiet room, at 22 °C	MetaMax 3B (Cortex Biophysik GmbH, Leipzig, Germany)	Previous rest: 20 min Record period: 10 min Selected period: Lowest 5-min moving average
Bartolomeu et al. 2017 [26]	Fasting: 3 h Caffeine: NR Nicotine: NR	Physical activity: Prior to testing Sleep: NR Transportation: NR	Subject: Lying at rest, awake, remaining silent Environment: Dimly lit room	MetaMax 3B (Cortex Biophysik GmbH, Leipzig, Germany)	Previous rest: NA Record period: 15 min Selected period: Last 10 min
Campbell et al. 2003 [27]	Fasting: 12 h Caffeine: NR Nicotine: NR	Physical activity: 24 h (VPA) Sleep: Encouraged to rest well the evening prior	Subject: Lying at rest, awake and relaxed Environment: Dimly lit and quiet room, approximately at 22 °C	Ergo-oxyscreen (Jaeger, Hoechberg, Germany)	Previous rest: 5 min Record period: 8 min Selected period: 8 min
Chow et al. 2018 [28]	Fasting: 4 h Caffeine: NR Nicotine: NR	Physical activity: NR Sleep: Not found Transportation: NR	Subject: Resting Environment: At 21–24 °C	Cosmed K4b2 (COSMED, Rome, Italy)	Previous rest: 30 min Record period: 3 min Selected period: 1-min steady state (not explained)
Cortes et al. 1997 [29]	Fasting: NR Caffeine: NR Nicotine: NR	Physical activity: NR Sleep: NR Transportation: NR	Subject: Sitting at rest, remaining silent Environment: NR	Ametek Ozand COz analyzers (Pittsburgh, PA, USA)	Previous rest: NR Record period: 5 min Selected period: Last 1 min
Cunha et al. 2019 [30]	Fasting: 8 h Caffeine: 24 h Alcohol: 24 h Soft drinks: 24 h Nicotine: NR	Physical activity: 24 h Sleep: NR Transportation: Minimum effort when travelling to the laboratory	Subject: Lying at rest Environment: Quiet room, at 21–24 °C and relative humidity ranged from 50 to 70%	VO2000 analyzer (Medical Graphics™, Saint Louis, MO)	Previous rest: 10 min Record period: 40 min Selected period: Last 5 min (mean)

Table 2 (continued)

Study	Subject conditions			Measurement protocol	
	Fasting conditions	Other recommendations	Setting	Indirect calorimeter	Measurement periods
Hall et al. 2013 [31]	Fasting: NR Caffeine: NR Nicotine: NR	Physical activity: NR Sleep: NR Transportation: NR	Subject: Sitting at rest, remaining silent Environment: NR	MedGem metabolic analyzer (HealtheTech Inc., Golden, CO, USA)	Previous rest: NR Record period: 5 – 11 min Selected period: 'Steady-state'
Hooker et al. 2011 [32]	Fasting: 4 h Caffeine: 12 h Alcohol: 12 h Nicotine: NR	Physical activity: 6 h Sleep: Not found Transportation: NR	Subject: Lying at rest, awake, remaining silent, limiting body movements Environment: Controlled room temperature	Cosmed K4b2 (COSMED, Rome, Italy)	Previous rest: 30 min Record period: 13 min Selected period: Last 5 min
Kwan et al. 2004 [33]	Fasting: 10 h Caffeine: NR Nicotine: NR	Physical activity: NR Sleep: NR Transportation: NR	Subject: NR Environment: NR	Deltatrac (Datex Division Instrumentarium Corp., Helsinki, Finland) – Canopy system	Previous rest: NR Record period: NR Selected period: NR
Lerma et al. 2017 [34]	Fasting: NR Caffeine: NR Nicotine: NR	Physical activity: NR Sleep: NR Transportation: NR	Subject: Sitting at rest Environment: NR	Cosmed K4b2 (COSMED, Rome, Italy)	Previous rest: NR Record period: 5 min Selected period: NR
Logan et al. 2015 [20]	Fasting: Overnight Caffeine: 24 h Nicotine: NR	Physical activity: 24 h Sleep: NR Transportation: NR	Subject: Lying at rest Environment: Dimly lit room	MOXUS metabolic system (AEI Technologies, Pittsburgh, PA, USA)	Previous rest: 15 min Record period: 15 min Selected period: NR
Migueles et al. 2021 [35]	Calibration group Fasting: NR Caffeine: NR Nicotine: NR Cross-validation group Fasting: 7 h Caffeine: 4 h Nicotine: 4 h	Calibration group Physical activity: NR Sleep: NR Transportation: NR Cross-validation group Physical activity: 12–48 h Sleep: NA Transportation: Use any kind of not physically demanding transportation	Calibration group Subject: Sitting at rest Environment: NR Cross-validation group Subject: Lying at rest, awake, remaining silent, limiting body movements Environment: Dimly lit and quiet room, approximately at 22–25 °C	Calibration group: Cosmed K4B2 (COSMED, Rome, Italy) Cross-validation group: Cosmed k5 (COSMED, Rome, Italy)	Calibration group Previous rest: NR Record period: 10 min Selected period: last 5 min Cross-validation group Previous rest: 30 min Record period: 30 min Selected period: 5 min least variable within the last 25 min (CV < 10% for VO_2, VCO_2 and VE; CV < 5% for RER)
Nakagata et al. 2019 [36]	Fasting: 4 h Caffeine: NR Nicotine: NR	Physical activity: Abstention from the day before Sleep: NR Transportation: NR	Subject: Sitting at rest Environment: At 20 °C and 50% humidity	Aeromonitor AE-300S (Minato Medical Science, Osaka, Japan)	Previous rest: ≥ 30 min Record period: 30 min Selected period: Last 10 min
Panayiotou et al. 2013 [37]	Fasting: 10–12 h Caffeine: NR Nicotine: NR	Physical activity: NR Sleep: NR Transportation: NR	Subject: Lying at rest in a comfortable bed Environment: Dimly lit, quiet and thermoregulated room (12 m^2; 22 °C)	Vmax-29 (SensorMedics, Yorba Linda, CA, USA)	Previous rest: ~ 30 min Record period: 40 min Selected period: NA

Table 2 (continued)

Study	Subject conditions			Measurement protocol	
	Fasting conditions	Other recommendations	Setting	Indirect calorimeter	Measurement periods
Park et al. 2011 [38]	Fasting: 12 h Caffeine: 12 h Alcohol: 12 h Nicotine: NR	Physical activity: 12 h Sleep: NR Transportation: NR	Subject: Sitting at rest Environment: NR	Cosmed K4b2 (COSMED, Rome, Italy)	Previous rest: NR Record period: 5 min Selected period: NR
Sergi et al. 2010 [39]	Fasting: Overnight fast Caffeine: NR Nicotine: NR	Physical activity: NR Sleep: 8 h Transportation: NR	Subject: Lying at rest, awake and emotionally undisturbed Environment: Under thermo-neutral conditions	Vmax-229 (SensorMedics, Yorba Linda, CA, USA)	Previous rest: 30 min Record period: 30–40 min Selected period: 5 min when both VO_2 and VCO_2 varied by < 5%
Taylor et al. 2012 [40]	Fasting: NR Caffeine: NR Nicotine: NR	Physical activity: NR Sleep: NR Transportation: NR	Subject: Lying at rest Environment: NR	Metalyser II (Cortex, Bio-physik, Walter-Köhn-Str. 2d 04,356 Leipzig, Germany)	Previous rest: NR Record period: 10 min Selected period: NR
Trutschnigg et al. 2013 [41]	Fasting: 12 h Caffeine: NR Nicotine: NR	Physical activity: NR Sleep: NR Transportation: NR	Subject: Lying at rest, remaining silent Environment: under thermo-neutral conditions	Cosmed K4b2 (COSMED, Rome, Italy)	Previous rest: NR Record period: 30 min Selected period: NR
Yeung et al. 2020 [42]	Fasting: NA Caffeine: NA Nicotine: NA	Physical activity: NA Sleep: NR Transportation: NR	Subject: Lying at rest, awake, remaining silent, limiting body movements Environment: Quiet room	Melbourne group: FitMate GS (Cosmed SRL, Rome, Italy) Amsterdam group: Quark RMR (COSMED, Rome, Italy)	Previous rest: NA Record period: 20–30 min Selected period: Last 15–25 min when VO_2 varied by < 10%

CV coefficient of variation, *MPA* moderate physical activity, *NA* not applied (NA was concluded when the article provided the information, or the author responded to the request for information), *NR* not reported (NR was concluded when the article did not provide the information, or the author did not respond to the request for information), *PA* physical activity, *RER* respiratory exchange ratio, VCO_2 volume of exhaled carbon dioxide, *VE* minute ventilation, VO_2 volume of oxygen uptake, *VPA* vigorous physical activity

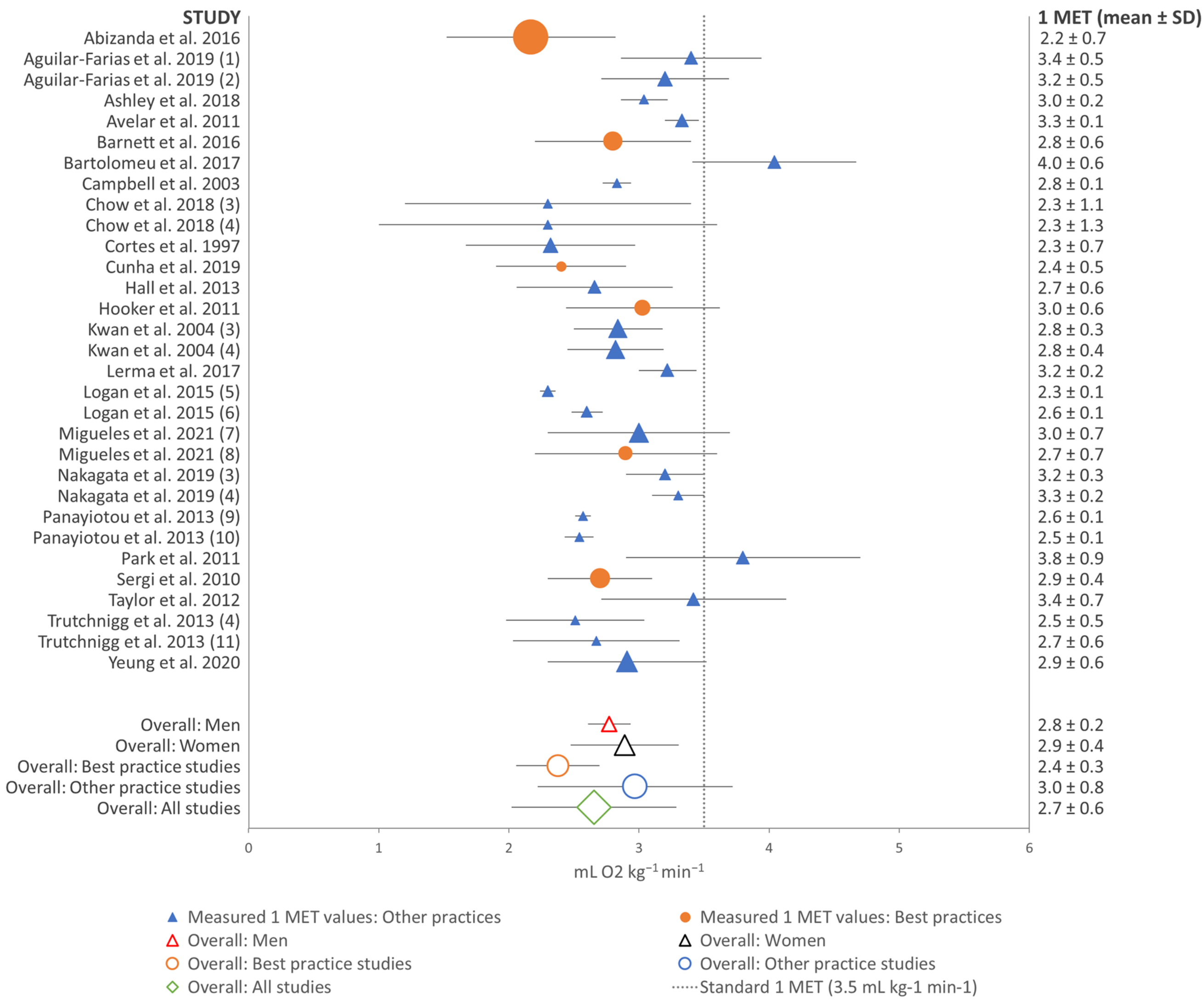


Fig. 2 Average metabolic equivalent of task (MET) values. (1): 65–75 years group; (2): ≥ 75 years group; (3): Men group; (4): Women group; (5): Placebo group; (6): Fish oil group; (7): Calibration group; (8): Cross-validation group; (9): Control group; (10): Statins group; (11): Cancer group; Smallest sample size: Chow et al. 2018 (4); Largest sample size: Abizanda et al. 2016

study. Average 1 MET values were also calculated from studies including non-clinical population and studies reporting RMR values by sex (Table 1). According to the score obtained in the RMR protocols' quality assessment, studies were also classified as 'best practice' when obtaining at least half of the total possible score (4/8 points) and 'other practice' when they did not. Averaged 1 MET values for 'best practice' and 'other practice' studies were also derived. Finally, 1 MET values were graphically reported for both studies and overall weighted averages (see Fig. 2). When no study's general 1 MET values were found, subgroups' values were presented.

3 Results

The database searches returned 3768 results (PubMed 341, Web of Science 537, Scopus 483, CINAHL 983, SPORTDiscus 1334, and Cochrane Library 85) and five additional studies were imported from other sources. After removing duplicates and reading the titles and abstracts, 536 articles remained for full-text screening. Finally, 23 articles [20–42] met all predefined inclusion criteria and were included in the final analysis (see Fig. 1).

3.1 Study Characteristics

A total sample of 1091 subjects (426 men) aged ≥ 60 years was included in the systematic review. All but five of the 23 articles focused on community-dwelling non-clinical older populations. The five exceptions addressed the evaluation of frailty syndrome [21], moderate-to-heavy chronic disease burdens [29], hypercholesterolemia [37], cancer [41], and mobility problems [42] (Table 1).

For the most part, the included trials did not provide a detailed description of the physical activity restrictions before the RMR test, the selected period and/or the measurement conditions. However, all of them used the indirect calorimetry method and reported mean values and SD.

3.2 Assessment of RMR Protocols

Only the cross-validation group from Migueles et al. [35] met all eight proposed requirements according to best practice evidence [19], and only six studies met at least four of them [21, 25, 30, 32, 35, 39].

In relation to the dimension of subject conditions, ten articles met the condition of a fasting period of at least 7 h [20, 21, 27, 30, 33, 35, 37–39, 41], seven articles met the requirement to refrain from caffeine in the 4 h prior to the test [21, 23, 25, 30, 32, 35, 38] and only two studies required participants to not ingest nicotine in the previous 140 min [21, 35].

Considering the environmental conditions and measurement protocols, seven studies assessed the RMR with a temperature ranging from 22 to 25 °C [21, 25, 27, 28, 30, 35, 37], 14 evaluated the RMR with participants lying in a supine position [20–22, 25–27, 30, 32, 35, 39–42], and seven used a pre-recording rest period of at least 20 min [25, 28, 32, 35–37, 39].

Finally, regarding data processing, eight studies discarded the first 5 min of measurement [24–26, 30, 32, 35, 36, 42]; however, only four applied a valid, referenced steady-state criterion for RMR derivation [25, 35, 39, 42].

3.3 Metabolic Equivalent of Task

All but two studies reported RMR values lower than the standard 3.5 mL O_2 kg^{-1} min^{-1} (Fig. 2). Bartolomeu et al. [26] reported the greatest value of 4.0 ± 0.6 mL O_2 kg^{-1} min^{-1} ($n = 18$) and Abizanda et al. [21] reported the lowest value of 2.2 ± 0.7 mL O_2 kg^{-1} min^{-1} ($n = 402$).

When all study samples were considered, a 23% lower value compared with the standard 1 MET was obtained, with a determined weighted average of 2.7 ± 0.6 mL O_2 kg^{-1} min^{-1}. Similarly, a 0.1 mL O_2 kg^{-1} min^{-1} higher value than the overall 1 MET, including clinical patients, was obtained when only the 21 studies with non-clinical populations were accounted. Moreover, these differences were even greater when those studies categorized as 'best practice' were considered. In accordance, a 20% and 31% lower 1 MET value from the 'best practice' (2.4 ± 0.3 mL O_2 kg^{-1} min^{-1}), compared with the 'other practice' (3.0 ± 0.8 mL O_2 kg^{-1} min^{-1}), and the standard 1 MET values were obtained, respectively. Finally, for studies reporting results stratified by sex, an overall 1 MET value of 2.8 ± 0.2 mL O_2 kg^{-1} min^{-1} for men and 2.9 ± 0.4 mL O_2 kg^{-1} min^{-1} for women was obtained.

4 Discussion

To our knowledge, this is the first systematic review to bring together all available estimates of 1 MET values in older adults ≥ 60 years of age. Moreover, when all estimates were averaged, a substantially lower value than the conventionally accepted 3.5 mL O_2 kg^{-1} min^{-1} was found, and it was even lower when only the 'best practice' studies were considered. Based on our findings, we would strongly recommend direct assessment of RMR or, if this is not possible, the application of an estimated value of 2.7 mL O_2 kg^{-1} min^{-1} might be reasonable.

It has been estimated that the RMR decreases 1–2% per decade after 20 years of age [15, 43]. This is consistent with a study by Kwan et al. [33], included in this review, which found a significantly different 1 MET value between young (men: 3.0 mL O_2 kg^{-1} min^{-1}; women: 3.3 mL O_2 kg^{-1} min^{-1}) and older populations (men: 2.8 mL O_2 kg^{-1} min^{-1}; women: 2.8 mL O_2 kg^{-1} min^{-1}). Similarly, a large body of evidence has highlighted potential overestimation bias when assuming a 1 MET value of 3.5 mL O_2 kg^{-1} min^{-1} in the older population [11, 25, 31, 33]. Consistent with this, our present results reveal a weighted average of 2.7 ± 0.6 mL O_2 kg^{-1} min^{-1} from 1091 adults ≥ 60 years old, which is 23% lower than the assumed standard 1 MET. Comparable results were reported by Hall et al. [31] and Barnett et al. [25], with average values of 2.7 mL O_2 kg^{-1} min^{-1} and 2.8 mL O_2 kg^{-1} min^{-1}, respectively. Therefore, the RMR in the older population is likely to be overestimated when a value of 3.5 mL O_2 kg^{-1} min^{-1} is assumed.

In terms of sex stratification, it should also be noted that hardly any differences between men and women were found, with a 3% lower overall 1 MET value reported in men. This contrasts with existing evidence suggesting a significantly lower RMR value in women compared with men [44]. Both the extreme values in the female population [20, 28] and the dissimilar overall sample size among groups (204 women; 75 men) may be distorting obtained results. Therefore, the extent to which differences among sex persist into older adulthood needs to be further examined.

Our review also identifies a remarkable variability among reported RMR values, ranging from 2.2 mL O_2 kg^{-1} min^{-1} [21] to 4.0 mL O_2 kg^{-1} min^{-1} [26], with two studies reporting values over the assumed 3.5 mL O_2 kg^{-1} min^{-1} [26, 38]. It is well known that while the variance in RMR is determined by multiple factors, fat-free mass (FFM) is accepted as its main contributor, accounting for 50–85% of RMR variance [45–47]. FFM is composed of tissues and organs with both low (e.g., bones, extracellular mass, etc.) and high (e.g., skeletal muscle, brain, liver, and kidney) metabolic activity [48]. Accordingly, understanding the factors affecting FFM components in the older population is of primary interest.

The aging process has been shown to be significantly associated with a decline in metabolically active tissues, mainly from the organs and musculoskeletal mass [49–53]. Furthermore, catabolic processes related to chronic diseases have also been observed to cause a decline in the RMR through metabolically active body mass loss [54–56]. A recent study by Zampino et al. [57] revealed a significant long-term role of cachexia-associated diseases such as chronic heart failure, chronic kidney disease, or cancer in RMR decline. This is in accordance with a study by Trutschnigg et al. [41], also included in this review, which reported an RMR value of 2.7 mL O_2 kg^{-1} min^{-1} in nine older adults with clinically diagnosed advanced cancer. Additionally, health disorders affecting physical performance could also impact on the RMR. Frailty syndrome is a highly prevalent geriatric and multicomponent condition characterized mainly by impaired physical function and significant loss of muscle mass [21, 58–61]. This is particularly relevant as skeletal muscle represents > 50% of FFM and 18–25% of RMR [52, 62–65]. However, other clinical conditions have also been found to be associated with an incremental effect on the RMR value. In this regard, a multitude of health conditions such as osteoarthritis, type 2 diabetes mellitus, hyperthyroidism, hypertension, morbid obesity, or sepsis have been identified. This effect appears to be promoted by both acute or chronic inflammatory responses and defense mechanism activation against stressors [57, 66, 67]. This systematic review identified five studies based on clinical older adult populations. However, the heterogeneity in the addressed health conditions and the applied methodologies avoided consistent and meaningful conclusions. Furthermore, only a 0.1 mL O_2 kg^{-1} min^{-1} difference was found when comparing the overall 1 MET, including the clinical studies, with the non-clinical 1 MET value. In accordance, this systematic review strongly recommends prioritizing direct assessment of RMR for 1 MET derivation in older adults with clinical conditions. Future experimental studies should aim to elucidate the extent to which each health condition may affect the 1 MET value and how it could differ from healthy older adults.

The results from this systematic review also highlight that applied methodological procedures can play an important role in RMR interpretation. For instance, the RMR value was 20% lower in the six studies complying with best practice recommendations (2.4 ± 0.3 mL O_2 kg^{-1} min^{-1}) compared with those that did not. RMR overestimation seems to occur when evidence-based protocols are not fully implemented. Factors that might play a significant role in altered RMR values include residual thermogenic effect of food [68], stimulants (caffeine or nicotine) [69, 70], effects of environmental thermoregulation (i.e., cool temperature) [71, 72], unsuitable recording protocols (insufficient prior rest period or upright/seated body position) [73, 74], or careless data processing (steady-state criteria) [75] (Table 3). However, these results should be considered with caution as they are based on limited evidence, and future research should confirm these findings. Even so, we encourage future investigations evaluating the RMR to implement best practice recommendations to improve both the validity and comparability among studies.

4.1 Practical Implications

Our findings have important implications from a public health perspective. Firstly, practical methodologies are required to quantify physical activity levels and the related energy cost in the older population. The MET system is the method on which most quantification tools are based, generally assuming a standard 1 MET of 3.5 mL O_2 kg^{-1} min^{-1}. Considering the results of this systematic review, we would advise against the use of these standardized tools in the older population, as they may underestimate the actual physical activity intensity. For instance, a physical activity performed by an older adult requiring 10 mL O_2 kg^{-1} min^{-1} would be classified as light physical activity (2.9 METs), when it should actually be classified as moderate physical activity (3.7 METs) if assuming a 1 MET of 2.7 mL O_2 kg^{-1} min^{-1}. What appears to be a small difference when comparing 1 MET values can be equivalent to a difference of 0.8 METs when translated into an activity, which is sufficient to misclassify a person's actual intensity.

A frequently applied tool based on the standard 1 MET is the Ainsworth Compendium of Physical Activities [14, 76, 77]. This is a widespread resource developed to provide exercise scientists and health professionals with a comprehensive list of physical activities and their associated energy cost. Because of its simple use and low time demands, it is usually included in epidemiologic and surveillance studies to evaluate self-reported behavior from questionnaires, diaries, and records. However, some studies have revealed significant differences between derived compendium METs and measured METs for many activities [31, 78]. This calls for a more comprehensive evaluation of the energy cost of activity specifically for older adults to inform a potential compendium revision.

Similarly, MET-based thresholds are commonly used in accelerometer devices, which are activity monitors that

Table 3 Assessment of RMR protocols

Study	1	2	3	4	5	6	7	8	Score (0–8)
Abizanda et al. 2016 [21]	Y	Y	Y	Y	Y	N	N	N	5
Aguilar-Farias et al. 2019 [22]	N	N	N	N	Y	N	N	N	1
Ashley et al. 2018 [23]	N	Y	N	N	N	N	N	N	1
Avelar et al. 2011 [24]	N	N	N	N	N	N	Y	N	1
Barnett et al. 2016 [25]	N	Y	N	Y	Y	Y	Y	Y	6
Bartolomeu et al. 2017 [26]	N	N	N	N	Y	N	Y	N	2
Campbell et al. 2003 [27]	Y	N	N	Y	Y	N	N	N	3
Chow et al. 2018 [28]	N	N	N	Y	CND	Y	N	CND	2
Cortes et al. 1997 [29]	N	N	N	N	N	N	N	N	0
Cunha et al. 2019 [30]	Y	Y	N	Y	Y	N	Y	N	5
Hall et al. 2013 [31]	N	N	N	N	N	N	N	CND	0
Hooker et al. 2011 [32]	N	Y	N	CND	Y	Y	Y	N	4
Kwan et al. 2004 [33]	Y	N	N	N	N	N	N	N	1
Lerma et al. 2017 [34]	N	N	N	N	N	N	N	N	0
Logan et al. 2015 [20]	Y	N	N	N	Y	N	N	N	2
Migueles et al. 2021 (1) [35]	N	N	N	N	Y	N	N	N	1
Migueles et al. 2021 (2) [35]	Y	Y	Y	Y	Y	Y	Y	Y	8
Nakagata et al. 2019 [36]	N	N	N	N	N	Y	Y	N	2
Panayiotou et al. 2013 [37]	Y	N	N	Y	CND	Y	N	N	3
Park et al. 2011 [38]	Y	Y	N	N	N	N	N	N	2
Sergi et al. 2010 [39]	Y	N	N	CND	Y	Y	CND	Y	4
Taylor et al. 2012 [40]	N	N	N	N	Y	N	N	N	1
Trutschnigg et al. 2013 [41]	Y	N	N	CND	Y	N	N	N	2
Yeung et al. 2020 [42]	N	N	N	N	Y	N	Y	Y	3
[a]Score (0–24)	10	7	2	7	14	7	8	4	

No.	Item	Category (Level of evidence)
1	Fasting period of at least 7 h	Subject conditions (Grade II)
2	Refrain from caffeine ingestion for at least 4 h	Subject conditions (Grade III)
3	Refrain from nicotine ingestion for at least 140 min	Subject conditions (Grade III)
4	Temperature between 22 °C and 25 °C or providing a blanket during the measurement	Environmental conditions (Grade II)
5	The participant rests in supine position	Recording protocol (Grade II)
6	Prior rest period of at least 20 min	Recording protocol (Grade I)
7	Discard the first 5 min of record period	Data processing (Grade III)
8	Use a validated steady-state definition to determine RMR	Data processing (Grade III)

Score: Y = 1, N and CND = 0; (1): Calibration group; (2): Cross-validation group

Grade I: Strong level of evidence; Grade II: Fair level of evidence; Grade III: Weak level of evidence

CND cannot determine, *N* No, *RMR* resting metabolic rate, *Y* Yes

[a]The total number of included studies was 23, but 24 assessment protocols were analyzed

record the amount and intensity of body movements during physical activities [79]. The intensity of each movement is determined by applying a set of validated cut points of derived acceleration units (e.g., counts, Euclidean Norm Minus One, etc.) [80]. However, validated cut points for older adults are scarce and cut points based on the general population are usually applied in this group, generally assuming 3.5 mL O_2 kg^{-1} min^{-1} as 1 MET [81, 82]. Indeed, a study by Barnett et al. [25] showed that applying cut points determined from younger adults in an older adult population may lead to a 20% lower absolute energy expenditure estimation during a 3-MET activity engaged in by this group. Therefore, accelerometer thresholds based on the standard 1 MET also seem to be potential sources of activity intensity misclassification in the older population.

Our findings may be revealing that, to some extent, assuming the standard 1 MET value in the older population could lead to a light physical activity overestimation by a moderate-to-vigorous intensity activities misclassification. Furthermore, from a nutritional perspective, misleading estimations of energy requirements would lead to nutrient imbalance and contribute to inefficacy of dietary interventions. Accordingly, the scientific community is encouraged to directly derive the individual 1-MET value through an evidence-based RMR protocol or to instead assume an average value of 2.7 mL O_2 kg^{-1} min^{-1}.

4.2 Strengths and Limitations

This work has several strengths and limitations. As far as we know, this is the first systematic review providing RMR values equivalent to 1 MET in older adults ≥ 60 years of age. The results were obtained from studies using the indirect calorimetry method, which is considered the gold standard procedure for RMR determination. This review also assessed the quality of applied RMR study protocols and highlighted methodological constraints. However, there was a small number of studies reporting RMR results in mL O_2 kg^{-1} min^{-1} or mL O_2 min^{-1}, most sample sizes were small, and RMR assessment protocols were generally of poor quality. Accordingly, while this review is an important step forward in the 1-MET redefinition in the older population, it also underlines major methodological deficiencies in RMR determination. Future studies should apply evidence-based methodologies on larger sample sizes to verify our conclusions.

5 Conclusions

An overall 1 MET weighted average value of 2.7 ± 0.6 mL O_2 kg^{-1} min^{-1} was obtained from available estimates in older adults ≥ 60 years of age. This value was 11% lower (2.4 ± 0.3 mL O_2 kg^{-1} min^{-1}) when only 'best practice' studies were considered. Therefore, adhering to the conventional 1 MET value (3.5 mL O_2 kg^{-1} min^{-1}) may lead to physical activity intensity and energy expenditure miscalculations in this population. This systematic review encourages the direct measurement of RMR using the indirect calorimetry method while adhering to best practice recommendations. Failing this, it might be reasonable to assume a 1 MET value of 2.7 mL O_2 kg^{-1} min^{-1}. Future experimental studies should further investigate the reported findings.

Supplementary Information The online version contains supplementary material available at https://doi.org/10.1007/s40279-021-01539-1.

Declarations

Funding This work was supported by the Biomedical Research Networking Center on Frailty and Healthy Aging (CIBERFES), by the Ministerio de Educación y Ciencia (Red EXERNET DEP2005-00046), the Junta de Comunidades de Castilla-La Mancha (SBPLY/19/180501/000312), and by FEDER funds from the European Union (CB16/10/00477 and CB16/10/00456). JLM received a PhD grant from the Universidad de Castilla-La Mancha, Spain (2019-PREDUCLM-11385) and MM from the Ministerio de Ciencia e Innovacion (FPU19/01276). The funders had no role in study design, data collection and analysis, decision to publish, or preparation of the manuscript.

Conflicts of interests Javier Leal-Martín, Miguel Muñoz-Muñoz, Sarah Kozey Keadle, Francisco Amaro-Gahete, Luis M. Alegre, Asier Mañas, and Ignacio Ara declare that they have no conflicts of interest.

Availability of data and material Not applicable.

Code availability Not applicable.

Author contributions JLM drafted the original manuscript. JLM and MM performed the literature search, selected articles, appraised their quality and extracted data. AM, SKK, and FAG performed major manuscript corrections. JLM and AM contributed to conception of the study, interpreted the data, and revised and edited the manuscript. LMA contributed to the conception and design of the study and revised and edited the manuscript. IA provided funding, revised the manuscript, and coordinated the study. All authors read and approved the final manuscript.

Ethics approval Not applicable.

Consent to participate Not applicable.

Consent for publication Not applicable.

References

1. Kohl HW 3rd, Craig CL, Lambert EV, Inoue S, Alkandari JR, Leetongin G, et al. The pandemic of physical inactivity: global action for public health. Lancet. 2012;380(9838):294–305. https://doi.org/10.1016/s0140-6736(12)60898-8.

2. Owen N, Sparling PB, Healy GN, Dunstan DW, Matthews CE. Sedentary behavior: emerging evidence for a new health risk. Mayo Clin Proc. 2010;85(12):1138–41. https://doi.org/10.4065/mcp.2010.0444.
3. Blair SN. Physical inactivity: the biggest public health problem of the 21st century. Br J Sports Med. 2009;43(1):1.
4. Hamilton MT, Hamilton DG, Zderic TW. Role of low energy expenditure and sitting in obesity, metabolic syndrome, type 2 diabetes, and cardiovascular disease. Diabetes. 2007;56(11):2655–67. https://doi.org/10.2337/db07-0882.
5. de Rezende LF, Rodrigues Lopes M, Rey-López JP, Matsudo VK, Luiz OC. Sedentary behavior and health outcomes: an overview of systematic reviews. PLoS One. 2014;9(8): e105620. https://doi.org/10.1371/journal.pone.0105620.
6. Booth FW, Roberts CK, Thyfault JP, Ruegsegger GN, Toedebusch RG. Role of inactivity in chronic diseases: evolutionary insight and pathophysiological mechanisms. Physiol Rev. 2017;97(4):1351–402. https://doi.org/10.1152/physrev.00019.2016.
7. Ekelund U, Tarp J, Steene-Johannessen J, Hansen BH, Jefferis B, Fagerland MW, et al. Dose-response associations between accelerometry measured physical activity and sedentary time and all cause mortality: systematic review and harmonised meta-analysis. BMJ. 2019;366: l4570. https://doi.org/10.1136/bmj.l4570.
8. McArdle WD, Katch FI, Katch VL. Essentials of exercise physiology. 4th ed. Philadelphia: Lippincott Williams & Wilkins; 2011.
9. Farkas GJ, Pitot MA, Gater DR Jr. A systematic review of the accuracy of estimated and measured resting metabolic rate in chronic spinal cord injury. Int J Sport Nutr Exerc Metab. 2019;29(5):548–58. https://doi.org/10.1123/ijsnem.2018-0242.
10. Jetté M, Sidney K, Blümchen G. Metabolic equivalents (METS) in exercise testing, exercise prescription, and evaluation of functional capacity. Clin Cardiol. 1990;13(8):555–65. https://doi.org/10.1002/clc.4960130809.
11. Byrne NM, Hills AP, Hunter GR, Weinsier RL, Schutz Y. Metabolic equivalent: one size does not fit all. J Appl Physiol (1985). 2005;99(3):1112–9. https://doi.org/10.1152/japplphysiol.00023.2004.
12. Patterson JA, Naughton J, Pietras RJ, Gunnar RM. Treadmill exercise in assessment of the functional capacity of patients with cardiac disease. Am J Cardiol. 1972;30(7):757–62. https://doi.org/10.1016/0002-9149(72)90151-8.
13. Kozey S, Lyden K, Staudenmayer J, Freedson P. Errors in MET estimates of physical activities using 3.5 ml x kg(-1) x min(-1) as the baseline oxygen consumption. J Phys Act Health. 2010;7(4):508–16. https://doi.org/10.1123/jpah.7.4.508.
14. Ainsworth BE, Haskell WL, Herrmann SD, Meckes N, Bassett DR Jr, Tudor-Locke C, et al. 2011 Compendium of physical activities: a second update of codes and MET values. Med Sci Sports Exerc. 2011;43(8):1575–81. https://doi.org/10.1249/MSS.0b013e31821ece12.
15. Keys A, Taylor HL, Grande F. Basal metabolism and age of adult man. Metabolism. 1973;22(4):579–87. https://doi.org/10.1016/0026-0495(73)90071-1.
16. Manini TM. Energy expenditure and aging. Ageing Res Rev. 2010;9(1):1–11. https://doi.org/10.1016/j.arr.2009.08.002.
17. Karakelides H, Nair KS. Sarcopenia of aging and its metabolic impact. Curr Top Dev Biol. 2005;68:123–48. https://doi.org/10.1016/s0070-2153(05)68005-2.
18. Moher D, Liberati A, Tetzlaff J, Altman DG, The PG. Preferred reporting items for systematic reviews and meta-analyses: the PRISMA statement. PLoS Med. 2009;6(7): e1000097. https://doi.org/10.1371/journal.pmed.1000097.
19. Fullmer S, Benson-Davies S, Earthman CP, Frankenfield DC, Gradwell E, Lee PS, et al. Evidence analysis library review of best practices for performing indirect calorimetry in healthy and non-critically ill individuals. J Acad Nutr Diet. 2015;115(9):1417-46.e2. https://doi.org/10.1016/j.jand.2015.04.003.
20. Logan S, Spriet L. Omega-3 fatty acid supplementation for 12 weeks increases resting and exercise metabolic rate in healthy community-dwelling older females. PLoS One. 2015;10(12): e0144828. https://doi.org/10.1371/journal.pone.0144828.
21. Abizanda P, Romero L, Sanchez-Jurado PM, Flores Ruano T, Salmeron Rios S, Fernandez SM. Energetics of aging and frailty: the FRADEA study. J Gerontol Ser A Biol Sci Med Sci. 2016;71(6):787–96. https://doi.org/10.1093/gerona/glv182.
22. Aguilar-Farias N, Brown WJ, Skinner TL, Peeters G. Metabolic equivalent values of common daily activities in middle-age and older adults in free-living environments: a pilot study. J Phys Act Health. 2019;16(3):222–9. https://doi.org/10.1123/jpah.2016-0400.
23. Ashley J, Kim Y, Gonzales JU. Impact of L-citrulline supplementation on oxygen uptake kinetics during walking. Appl Physiol Nutr Metab. 2018;43(6):631–7. https://doi.org/10.1139/apnm-2017-0696.
24. Avelar NC, Simão AP, Tossige-Gomes R, Neves CD, Mezencio B, Szmuchrowski L, et al. Oxygen consumption and heart rate during repeated squatting exercises with or without whole-body vibration in the elderly. J Strength Cond Res. 2011;25(12):3495–500. https://doi.org/10.1519/JSC.0b013e3182176664.
25. Barnett A, van den Hoek D, Barnett D, Cerin E. Measuring moderate-intensity walking in older adults using the ActiGraph accelerometer. BMC Geriatr. 2016;16(1):211. https://doi.org/10.1186/s12877-016-0380-5.
26. Bartolomeu RF, Barbosa TM, Morais JE, Lopes VP, Bragada JA, Costa MJ. The aging influence on cardiorespiratory, metabolic, and energy expenditure adaptations in head-out aquatic exercises: differences between young and elderly women. Women Health. 2017;57(3):377–91. https://doi.org/10.1080/03630242.2016.1164272.
27. Campbell JA, D'Acquisto LJ, D'Acquisto DM, Cline MG. Metabolic and cardiovascular response to shallow water exercise in young and older women. Med Sci Sports Exerc. 2003;35(4):675–81. https://doi.org/10.1249/01.Mss.0000058359.87713.99.
28. Chow H-W, Ho C-H. Does the use of outdoor fitness equipment by older adults qualify as moderate to vigorous physical activity? PLoS One. 2018. https://doi.org/10.1371/journal.pone.0196507.
29. Cortes CW, Mehal W, Wang RY, Poznek EJ, Bradley KD, Goetz JM, et al. Reliability of exercise cardiopulmonary responses in older persons with moderate-to-heavy chronic disease burdens. Meas Phys Educ Exerc Sci. 1997;1(3):153.
30. Cunha FA, Gomes GSM, Carvalho J, da Silva NSL. Concurrent exercise circuit protocol performed in public fitness facilities meets the American College of Sports Medicine guidelines for energy cost and metabolic intensity among older adults in Rio de Janeiro City. Appl Physiol Nutr Metab. 2019;44(5):477–84. https://doi.org/10.1139/apnm-2018-0513.
31. Hall KS, Howe CA, Rana SR, Martin CL, Morey MC. METs and accelerometry of walking in older adults: standard versus measured energy cost. Med Sci Sports Exerc. 2013;45(3):574–82. https://doi.org/10.1249/MSS.0b013e318276c73c.
32. Hooker SP, Feeney A, Hutto B, Pfeiffer KA, McIver K, Heil DP, et al. Validation of the actical activity monitor in middle-aged and older adults. J Phys Act Health. 2011;8(3):372–81.
33. Kwan M, Woo J, Kwok T. The standard oxygen consumption value equivalent to one metabolic equivalent (3.5 ml/min/kg) is not appropriate for elderly people. Int J Food Sci Nutr. 2004;55(3):179–82. https://doi.org/10.1080/09637480410001725201.
34. Lerma NL, Swartz AM, Rowley TW, Hotaka M, Strath SJ. Increasing the energy expenditure of seated activities in older adults with

a portable elliptical device. J Aging Phys Act. 2017;25(1):99–104. https://doi.org/10.1123/japa.2015-0277.

35. Migueles JH, Cadenas-Sanchez C, Alcantara JMA, Leal-Martín J, Mañas A, Ara I, et al. Calibration and cross-validation of accelerometer cut-points to classify sedentary time and physical activity from hip and non-dominant and dominant wrists in older adults. Sensors (Basel). 2021. https://doi.org/10.3390/s21103326.
36. Nakagata T, Yamada Y, Naito H. Metabolic equivalents of body weight resistance exercise with slow movement in older adults using indirect calorimetry. Appl Physiol Nutr Metab. 2019;44(11):1254–7. https://doi.org/10.1139/apnm-2018-0882.
37. Panayiotou G, Paschalis V, Nikolaidis MG, Theodorou AA, Deli CK, Fotopoulou N, et al. No adverse effects of statins on muscle function and health-related parameters in the elderly: an exercise study. Scand J Med Sci Sports. 2013;23(5):556–67.
38. Park SA, Lee KS, Son KC. Determining exercise intensities of gardening tasks as a physical activity using metabolic equivalents in older adults. HortScience. 2011;46(12):1706–10. https://doi.org/10.21273/hortsci.46.12.1706.
39. Sergi G, Coin A, Sarti S, Perissinotto E, Peloso M, Mulone S, et al. Resting VO_2, maximal VO_2 and metabolic equivalents in free-living healthy elderly women. Clin Nutr. 2010;29(1):84–8. https://doi.org/10.1016/j.clnu.2009.07.010.
40. Taylor LM, Maddison R, Pfaeffli LA, Rawstorn JC, Gant N, Kerse NM. Activity and energy expenditure in older people playing active video games. Arch Phys Med Rehabil. 2012;93(12):2281–6. https://doi.org/10.1016/j.apmr.2012.03.034.
41. Trutschnigg B, Kilgour RD, Morais JA, Lucar E, Hornby L, Molla H, et al. Metabolic, nutritional and inflammatory characteristics in elderly women with advanced cancer. J Geriatr Oncol. 2013;4(2):183–9. https://doi.org/10.1016/j.jgo.2012.09.002.
42. Yeung SSY, Reijnierse EM, Trappenburg MC, Meskers CGM, Maier AB. Clinical determinants of resting metabolic rate in geriatric outpatients. Arch Gerontol Geriatr. 2020;89: 104066. https://doi.org/10.1016/j.archger.2020.104066.
43. Elia M, Ritz P, Stubbs RJ. Total energy expenditure in the elderly. Eur J Clin Nutr. 2000;54(Suppl 3):S92-103. https://doi.org/10.1038/sj.ejcn.1601030.
44. Arciero PJ, Goran MI, Poehlman ET. Resting metabolic rate is lower in women than in men. J Appl Physiol (1985). 1993;75(6):2514–20. https://doi.org/10.1152/jappl.1993.75.6.2514.
45. Nielsen S, Hensrud DD, Romanski S, Levine JA, Burguera B, Jensen MD. Body composition and resting energy expenditure in humans: role of fat, fat-free mass and extracellular fluid. Int J Obes Relat Metab Disord. 2000;24(9):1153–7. https://doi.org/10.1038/sj.ijo.0801317.
46. Illner K, Brinkmann G, Heller M, Bosy-Westphal A, Müller MJ. Metabolically active components of fat free mass and resting energy expenditure in nonobese adults. Am J Physiol Endocrinol Metab. 2000;278(2):E308–15. https://doi.org/10.1152/ajpendo.2000.278.2.E308.
47. Gallagher D, Belmonte D, Deurenberg P, Wang Z, Krasnow N, Pi-Sunyer FX, et al. Organ-tissue mass measurement allows modeling of REE and metabolically active tissue mass. Am J Physiol. 1998;275(2):E249–58. https://doi.org/10.1152/ajpendo.1998.275.2.E249.
48. Müller MJ, Bosy-Westphal A, Kutzner D, Heller M. Metabolically active components of fat-free mass and resting energy expenditure in humans: recent lessons from imaging technologies. Obes Rev. 2002;3(2):113–22. https://doi.org/10.1046/j.1467-789x.2002.00057.x.
49. He Q, Heshka S, Albu J, Boxt L, Krasnow N, Elia M, et al. Smaller organ mass with greater age, except for heart. J Appl Physiol (1985). 2009;106(6):1780–4. https://doi.org/10.1152/japplphysiol.90454.2008.
50. Krems C, Luhrmann PM, Strassburg A, Hartmann B, Neuhauser-Berthold M. Lower resting metabolic rate in the elderly may not be entirely due to changes in body composition. Eur J Clin Nutr. 2005;59(2):255–62. https://doi.org/10.1038/sj.ejcn.1602066.
51. Bosy-Westphal A, Eichhorn C, Kutzner D, Illner K, Heller M, Muller MJ. The age-related decline in resting energy expenditure in humans is due to the loss of fat-free mass and to alterations in its metabolically active components. J Nutr. 2003;133(7):2356–62.
52. St-Onge MP, Gallagher D. Body composition changes with aging: the cause or the result of alterations in metabolic rate and macronutrient oxidation? Nutrition. 2010;26(2):152–5. https://doi.org/10.1016/j.nut.2009.07.004.
53. Sparti A, DeLany JP, de la Bretonne JA, Sander GE, Bray GA. Relationship between resting metabolic rate and the composition of the fat-free mass. Metabolism. 1997;46(10):1225–30. https://doi.org/10.1016/s0026-0495(97)90222-5.
54. Gong J, Zuo L, Guo Z, Zhang L, Li Y, Gu L, et al. Impact of disease activity on resting energy expenditure and body composition in adult Crohn's disease: a prospective longitudinal assessment. JPEN J Parenter Enteral Nutr. 2015;39(6):713–8. https://doi.org/10.1177/0148607114528360.
55. Cao DX, Wu GH, Zhang B, Quan YJ, Wei J, Jin H, et al. Resting energy expenditure and body composition in patients with newly detected cancer. Clin Nutr. 2010;29(1):72–7. https://doi.org/10.1016/j.clnu.2009.07.001.
56. Bogardus C, Taskinen MR, Zawadzki J, Lillioja S, Mott D, Howard BV. Increased resting metabolic rates in obese subjects with non-insulin-dependent diabetes mellitus and the effect of sulfonylurea therapy. Diabetes. 1986;35(1):1–5. https://doi.org/10.2337/diab.35.1.1.
57. Zampino M, AlGhatrif M, Kuo PL, Simonsick EM, Ferrucci L. Longitudinal changes in resting metabolic rates with aging are accelerated by diseases. Nutrients. 2020. https://doi.org/10.3390/nu12103061.
58. Fried LP, Tangen CM, Walston J, Newman AB, Hirsch C, Gottdiener J, et al. Frailty in older adults: evidence for a phenotype. J Gerontol A Biol Sci Med Sci. 2001;56(3):M146–56. https://doi.org/10.1093/gerona/56.3.m146.
59. Weiss CO, Cappola AR, Varadhan R, Fried LP. Resting metabolic rate in old-old women with and without frailty: variability and estimation of energy requirements. J Am Geriatr Soc. 2012;60(9):1695–700. https://doi.org/10.1111/j.1532-5415.2012.04101.x.
60. Starling RD. Energy expenditure and aging: effects of physical activity. Int J Sport Nutr Exerc Metab. 2001;11(Suppl):S208–17. https://doi.org/10.1123/ijsnem.11.s1.s208.
61. Garcia-Garcia FJ, Avila GG, Alfaro-Acha A, Andres MA, Aparicio ME, et al. The prevalence of frailty syndrome in an older population from Spain The Toledo Study for Healthy Aging. J Nutr Health Aging. 2011;15(10):852–6. https://doi.org/10.1007/s12603-011-0075-8.
62. Steffl M, Bohannon RW, Sontakova L, Tufano JJ, Shiells K, Holmerova I. Relationship between sarcopenia and physical activity in older people: a systematic review and meta-analysis. Clin Interv Aging. 2017;12:835–45. https://doi.org/10.2147/cia.S132940.
63. Smith L, Tully M, Jacob L, Blackburn N, Adlakha D, Caserotti P, et al. The association between sedentary behavior and sarcopenia among adults aged ≥65 years in low- and middle-income countries. Int J Environ Res Public Health. 2020. https://doi.org/10.3390/ijerph17051708.
64. Cartee GD, Hepple RT, Bamman MM, Zierath JR. Exercise promotes healthy aging of skeletal muscle. Cell Metab. 2016;23(6):1034–47. https://doi.org/10.1016/j.cmet.2016.05.007.
65. Gallagher D, Allen A, Wang Z, Heymsfield SB, Krasnow N. Smaller organ tissue mass in the elderly fails to explain lower

resting metabolic rate. Ann N Y Acad Sci. 2000;904:449–55. https://doi.org/10.1111/j.1749-6632.2000.tb06499.x.
66. Delsoglio M, Achamrah N, Berger MM, Pichard C. Indirect calorimetry in clinical practice. J Clin Med. 2019;8(9):1387. https://doi.org/10.3390/jcm8091387.
67. Pedrianes-Martin PB, Perez-Valera M, Morales-Alamo D, Martin-Rincon M, Perez-Suarez I, Serrano-Sanchez JA, et al. Resting metabolic rate is increased in hypertensive patients with overweight or obesity: potential mechanisms. Scand J Med Sci Sports. 2021;31(7):1461–70. https://doi.org/10.1111/sms.13955.
68. Bielinski R, Schutz Y, Jéquier E. Energy metabolism during the postexercise recovery in man. Am J Clin Nutr. 1985;42(1):69–82. https://doi.org/10.1093/ajcn/42.1.69.
69. Belza A, Frandsen E, Kondrup J. Body fat loss achieved by stimulation of thermogenesis by a combination of bioactive food ingredients: a placebo-controlled, double-blind 8-week intervention in obese subjects. Int J Obes. 2007;31(1):121–30. https://doi.org/10.1038/sj.ijo.0803351.
70. Collins LC, Walker J, Stamford BA. Smoking multiple high- versus low-nicotine cigarettes: Impact on resting energy expenditure. Metabolism. 1996;45(8):923–6. https://doi.org/10.1016/S0026-0495(96)90256-5.
71. Kashiwazaki H, Dejima Y, Suzuki T. Influence of upper and lower thermoneutral room temperatures (20 degrees C and 25 degrees C) on fasting and post-prandial resting metabolism under different outdoor temperatures. Eur J Clin Nutr. 1990;44(5):405–13.
72. Ooijen AMJC-V, Westerterp KR, Wouters L, Schoffelen PFM, van Steenhoven AA, van Lichtenbelt WDM. Heat production and body temperature during cooling and rewarming in overweight and lean men. Obesity. 2006;14(11):1914–20. https://doi.org/10.1038/oby.2006.223.
73. Taguri E, Tanaka S, Ohkawara K, Ishikawa-Takata K, Hikihara Y, Miyake R, et al. Validity of physical activity indices for adjusting energy expenditure for body size: do the indices depend on body size? J Physiol Anthropol. 2010;29(3):109–17. https://doi.org/10.2114/jpa2.29.109.
74. Sujatha T, Shatrugna V, Venkataramana Y, Begum N. Energy expenditure on household, childcare and occupational activities of women from urban poor households. Br J Nutr. 2000;83(5):497–503. https://doi.org/10.1017/s0007114500000635.
75. Sanchez-Delgado G, Alcantara JMA, Ortiz-Alvarez L, Xu H, Martinez-Tellez B, Labayen I, et al. Reliability of resting metabolic rate measurements in young adults: Impact of methods for data analysis. Clin Nutr. 2018;37(5):1618–24. https://doi.org/10.1016/j.clnu.2017.07.026.
76. Ainsworth BE, Haskell WL, Leon AS, Jacobs DR Jr, Montoye HJ, Sallis JF, et al. Compendium of physical activities: classification of energy costs of human physical activities. Med Sci Sports Exerc. 1993;25(1):71–80. https://doi.org/10.1249/00005768-199301000-00011.
77. Ainsworth BE, Haskell WL, Whitt MC, Irwin ML, Swartz AM, Strath SJ, et al. Compendium of physical activities: an update of activity codes and MET intensities. Med Sci Sports Exerc. 2000;32(9 Suppl):S498-504. https://doi.org/10.1097/00005768-200009001-00009.
78. Kozey SL, Lyden K, Howe CA, Staudenmayer JW, Freedson PS. Accelerometer output and MET values of common physical activities. Med Sci Sports Exerc. 2010;42(9):1776–84. https://doi.org/10.1249/MSS.0b013e3181d479f2.
79. Westerterp KR. Physical activity assessment with accelerometers. Int J Obes Relat Metab Disord. 1999;23(Suppl 3):S45–9. https://doi.org/10.1038/sj.ijo.0800883.
80. Migueles JH, Cadenas-Sanchez C, Ekelund U, Delisle Nyström C, Mora-Gonzalez J, Löf M, et al. Accelerometer data collection and processing criteria to assess physical activity and other outcomes: a systematic review and practical considerations. Sports Med. 2017;47(9):1821–45. https://doi.org/10.1007/s40279-017-0716-0.
81. Copeland JL, Esliger DW. Accelerometer assessment of physical activity in active, healthy older adults. J Aging Phys Act. 2009;17(1):17–30. https://doi.org/10.1123/japa.17.1.17.
82. Freedson PS, Melanson E, Sirard J. Calibration of the computer science and applications, Inc accelerometer. Med Sci Sports Exerc. 1998;30(5):777–81. https://doi.org/10.1097/00005768-199805000-00021.