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ACADEMIC LITERATURE REVIEW

Physical activity assessment and health outcomes in old age: how valid are dose–response relationships in epidemiologic studies?

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Abstract In this systematic review the validity of the dose–response relationships between physical activity (PA) and energy expenditure (EE) on defined health outcomes (cardio- and cerebrovascular morbidity and mortality, cancer) for the elderly is questioned. Medline, Cochrane, and EMBASE databases were reviewed for epidemiological longitudinal studies in populations aged 60+ for the years 1985–2007. Although most of the 18 identified studies generally demonstrated an inverse dose–response relationship between PA and EE level with morbidity and mortality, the range of dose–responses was remarkably broad. The nature of the dose–response relationship remained unclear. PA questionnaires - even those constructed for the elderly - do not cover the extremely diverse aspects of age-specific PA behavior and modes of muscular activity. Only non-age-specific tables had been used to estimate the EE in the elderly. Direct measurements of EE were limited. The results have implications for the interpretation of the dose–response relationships between PA and EE on defined health outcomes in old age.

Keywords Physical activity · Energy expenditure · Dose–response relationship · Epidemiologic studies · Old age

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Introduction

Increasing epidemiology literature reports an inverse dose–response relationship between low- and/or moderate-intensity physical activity (PA) and energy expenditure (EE) on disease-specific morbidity and mortality in adult populations. Epidemiologic studies of PA and health rely on the appropriateness and accuracy of the methods used to measure the PA and EE. Directly measured PA by accelerometer [34] and EE by the doubly labeled water technique (DLW) [32] are currently the objective methods of choice [30]. However, these techniques are generally too expensive to use in population-based studies. Therefore, self-reporting questionnaires are most frequently the method to assess PA. From measurements of PA frequency, intensity, and duration, the EE is estimated by using tables for the given physical activity [1, 2].

The aim of this review is to examine the validity of the dose–response relationships between PA and EE on health-related outcomes as reported for older populations in epidemiologic studies. From a geriatric point of view, the authors raise at least three concerns about the methods used to measure the PA and EE:

Firstly, the PA behavior of elderly people is different from that of younger adults. Depending on different determinants of PA behavior (e.g. physiological, psychological, social, and environmental), which may vary with age, older people may prefer: light or moderate instead of intense PA [4, 7]; habitual activity instead of sport activity; short irregular bursts of PA instead of regular, daily, or weekly session.

Secondly, questionnaires may not assess PA in older adults with the same accuracy as in younger adults. Accuracy of recalled information in the elderly may be affected by the irregularity and/or complexity of their PA habits. Older people who are consistently either regularly active or sedentary may be able to remember their activity habits precisely. On the contrary, people with PA patterns that fluctuate within days, weeks, or even months are less likely to remember accurately [4, 7]. Additionally, in recalling PA the elderly with declining cognition and memory may bias self-reported information on previous PA, particularly over long periods of time [12]. Finally, the underlying questionnaires are deficient in covering the entire spectrum of all the physical activities undertaken and the manner in which they are performed in the elderly.

Thirdly, although EE measurements such as kcal/h or kcal/week, and METs have been used with older populations in health outcome studies, they may not have been designed or validated for that purpose. The same PA may be performed with a substantially lower level of EE in the elderly compared to younger adults. Consequently, existing reference tables of estimated EE that are based on PA information from populations with a wide spectrum in age [1, 2] may not reliably estimate the true EE of PA in old age.

These concerns prompted us to take a closer look at population-based observational studies which evaluate the dose–response of PA and selected health-related outcomes among populations aged 60+. Particularly, we scrutinized the age-specific PA assessment and EE determination, and look for potential limitations to evaluating and interpreting the dose–response relationships.

Material and methods

Studies of interest

The comprehensive literature search was selectively restricted to studies published in English between January 1, 1985 and May 31, 2007. The types of studies considered were longitudinal observational (cohort studies, panel studies) and population-based case-control studies. Randomized controlled trials were excluded because they are usually restricted to (1) a relatively small sample size and (2) have too narrow sample characteristics compared to population-based studies. Our search was limited to studies which used primary health outcomes of morbidity and mortality for cardio- and cerebrovascular disease, cancer, and all-cause mortality. Participants had to be over 60 and living in community dwellings. Techniques to measure PA and EE applicable in everyday life were considered. Excluded were studies using laboratory procedures to measure EE (e.g. room calorimetry). Also excluded were studies which assessed PA by two levels only - when the one reference level was defined as “physical inactivity” or EE “<500 kcal/week” (equal to no physical activity).

Search strategy

Search strategy, identification and selection of studies are shown in Fig. 1.

We searched Medline, Cochrane, and EMBASE databases. The following key words (single MESH) and text words in categories (a to d), were combined to identify all articles that evaluated dose–response relationships for selected health outcomes

(a) The elderly population
(b) Physical activity and/or energy expenditure
(c) Exercise, leisure activity, leisure time physical activity, recreational activity, housework
(d) Physical activity questionnaire, physical activity recall questionnaire, physical activity survey, physical activity record, physical activity diary, DLW, accelerometer, pedometer, and motion sensor

Additionally, the names of PA questionnaires specifically designed for older populations (e.g. Questionnaire d`Activite Physique Saint Etienne (QAPSE) [5]; Zutphen Physical Activity Questionnaire (Zutphen) [11] were entered into the electronic search system. Meta-analyses and systematic reviews were hand-checked to find additional studies. Again, these studies were screened for further appropriate references. A non-statistical descriptive approach was chosen to present the quality of the methods used in assessing PA behavior and EE in the elderly.

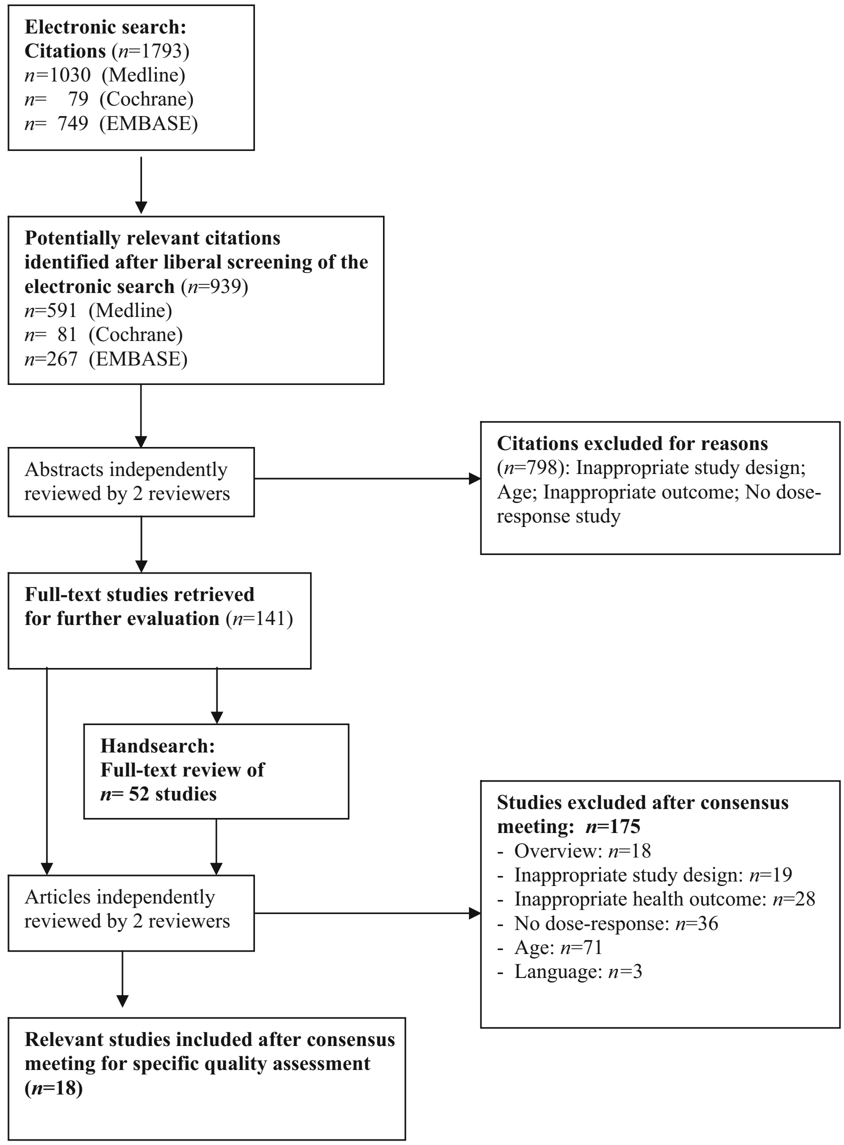
Identification of relevant studies

The authors identified a total of 193 potentially relevant studies (141 publications from the electronic search and 52 from the manual search), but 175 studies did not meet the above inclusion criteria so were excluded. The remaining 18 studies were all prospective cohort studies. In these studies 31,660 individuals were included. Median year of publication was 1998. The follow-up period ranged from 6 months [19] to 30 years [6] with an average of 8.1 years.

Results and discussion

The health outcomes assessed were all-cause mortality (n=10); mortality from specific causes, cardiovascular, stroke, cancer (n=3); mortality from coronary heart disease (n=1); risk of coronary heart disease (n=1); and prevalence of cardiovascular risk factors (n=3). Sixteen of the 18 cohort studies provided data on an inverse dose–response relationship between PA and health outcomes as assessed. When low and/or moderate PA and EE levels were compared to high levels, there was a wide range of increase in mortality risk,

Fig. 1 Search strategy, and identification and selection of studies



between 37% and 113% with an average of 75% [3, 18, 27, 29]. When comparing high PA level and low and/or moderate PA levels the mortality risk was reduced by a large range of 29–60% with an average of 50% [7, 8, 15, 21, 25, 35]. Looking at high versus moderate/low PA level, in men the average risk of mortality was also reduced for cardiovascular disease by 30% [7], and by 57% [3], while no significant effect was reported for cancer mortality [16]. Cardiovascular morbidity on average was more than double with low compared to high PA level [17]. Prevalence of coronary risk factors and PA level were either significantly associated [6, 35] or were not [19]. In only ten studies the health effect of PA and EE was adjusted for comorbidity, and in eight studies adjusted for age (Table 1, column 6). Overall, the wide range of results regarding the dose–response relationship is clearly evident. Additionally, the nature of the dose–response relationship remains unclear. This may be due to various methodological reasons.

In the 18 studies, questionnaires were given to assess PA. Additionally in five of the studies, EE was estimated (Table 1, columns 4 and 5) using published tables [1, 2]. In a single study the DLW method, accompanied with a questionnaire, was used [25]. Objective techniques such as accelerometer and pedometer use to determine EE for a defined PA had not been performed at all.

These reviews clearly showed that the methods used to assess PA behavior and pattern and EE varied enormously. None of the methods applied were entirely appropriate and sensitive enough to describe and measure both the PA behavior common among older populations and the EE of the PA as demonstrated in the following.

Quality of the physical activity questionnaires

Among the 18 cohort studies, four PA questionnaires designed for older populations were administered: the QAPSE [5]; the Zutphen [11]; the Nottingham Questionnaire of Activity and Aging (NottQAA) [27], and the Elderly Nutrition and Health Survey Taiwan (ENHSTai) [21] (Table 1, column 3). However, only three of them have been validated among older populations [5, 11, 21]. These questionnaires have been applied in six of the 18 cohort studies (Table 1, column 3). Only two instruments (QAPSE and Zutphen) demonstrated an excellent relationship using the DLW method [5, 11] when tested in older people, indicating a strong direct validity which makes them appropriate for assessing PA and estimating EE in the elderly. Two questionnaires were designed with younger and older populations in mind (the modified Paffenbarger Physical Activity Questionnaire (modPPAQ), the Minnesota Leisure Time Physical Activity Questionnaire (modMLTPAQ)) and were applied in a modified version [15, 20]. Specific PA questionnaires for women - who represent the largest proportion of the elderly population - have not yet been developed.

For three questionnaires in the cohort studies (the modPPAQ; the QAPSE; the modMLTPAQ; Table 1, column 3) evidence for higher validity in measuring intensive PA rather than moderate or low-intensity PA has been reported [9]. It is not surprising that in many cohort studies the applied questionnaires focus on PA of moderate to vigorous intensity - which may be engaged in by only a small and highly select proportion of the older population - and ignore low-intensity PA. Because moderate and low PA was more prevalent among older people than vigorous PA [4, 6] the validity of measurements from the cohort studies, applied to the older population, in general may be limited.

Modes of physical activity assessed

The types of PA determined in the questionnaires varied greatly. Most studies assessed leisure time PA and sports as well as stair climbing and walking (Table 1, column 4). While structured walking (e.g. brisk and regular) was included, unstructured walking (e.g. being around on one's feet) as an essential dimension of PA in older age [26] was not considered in any single study. The self-reports of walking distance and speed of older people - which are more likely to differ from younger persons - have not yet been proven to be accurate and reliable.

Although domestic activities were shown to be a major source of PA in older people [22], only three studies (15%) used instruments which explicitly asked for PA performed as housekeeping and home activities, (e.g. indoor and outdoor domestic home chores, grocery shopping, carrying, lifting, pushing objects, and unaccounted leisure time activities) [e.g. 27] (Table 1, column 4) which are especially relevant for older people. Lawler et al. (2002) reported that over two-thirds of the 60–79-year-old women assessed were at the recommended levels when domestic activities were included in the broad spectrum of PA.

Dimensions of physical activity change with age

Among the cohort studies, follow-up periods were up to 30 years (Table 1, column 2). Although age itself has little impact on interindividual differences in response to regular PA [10, 24], in the PA questionnaires applied to the aging population over a long follow-up period the dimensions of the PA which changes with advancing age and health has to be considered [7, 13]. The Zutphen elderly study demonstrated that over a 10-year follow-up period the total time spent on PA in men aged 65–84 decreased by 33% to 28 min/day. Time spent on cycling and gardening decreased from both an age and period effect. Time spent on walking remained stable, but its relative contribution to total time spent on PA increased with aging [7]. Among the questionnaires used, only the Zutphen [6] covered a broad spectrum of PA common in the elderly over a wide age range, yet did not involve domestic PA [6, 33, 35].

Physical activity versus energy expenditure

It is still unknown whether the EE measurements are sensitive or specific enough to accurately assess the age-specific features of PA. The highly valid DLW method applied only in one study [25] does provide EE on a PA over a certain time period. Yet, it does not provide detailed information on intensity, duration, and modes of the PA. Therefore, extrapolating EE from practice is difficult. In all other studies EE was calculated by MET scores for each activity from tables [1, 2]. In these tables, reference values on EE are expressed as a ratio of working to resting metabolic rate.

However, tables have not been established by EE measurements explicitly obtained from older populations. In the elderly the total EE was shown to vary widely with body weight and activity behavior, while the resting metabolic rate was lower than in younger individuals [31, 36]. Thus, the validity of the working metabolic rate in older people estimated from tables may be compromised, and the actual dose–response relationship cannot be concluded (Table 1, columns 5 and 6).

Summary of results

This systematic review shows a general inverse dose–response relationship between PA and EE on defined health

Table 1 Prospective cohort studies in the elderly: population characteristics, methods of assessing physical activity and energy expenditure, and dose–response relationships

1 **Primary author**	2 **Study design, population and health outcome**	3 **Questionnaire Type and source**	4 **Physical activity described**	5 **Operationalizing of PA and EE**	6 **Additional notes**
Kaplan 1987	17-year follow-up. 4,174 F and M. Age 60–94 years. Mortality risk	Questionnaire Alameda Country Study (SA)	LTPA (e.g. walking, gardening, fishing), sport, exercise. Index (often, sometimes, never)	Low vs. high	Negative response based on low LTPA index. Co-M
Lee 1990	8-year follow-up. 508 W and M aged ≥60 years. Risk of all cause mortality	10-item scale on PA (I)	LTPA, performed during past 2 weeks (1976, 1980, 1984)	Total scale score from sum of all items	Dose–response: No. Co-M;
Rakowski 1992	4-year follow-up. 3,679 F, 2,222 M aged ≥70 year. Risk of all cause mortality	Longitudinal Study of Aging Questionnaire (I)	Baseline LTPA: Questions: "How often do you walk a mile or more at a time?" "Are physically more active, less active or the same active as other persons?"	Walking 1 mile: Never; <1; 2–3; ≥4 days/week	Dose–response: yes, based on ≥4 days/week. Co-M; A
Bijnen 1996	30-year follow-up. 1,402 M aged 60–90 year. Prevalence of cardiovascular risk factors	Questionnaire of the Zutphen Elderly Study (I)	Walking, cycling (previous week). Hobbies, gardening in summer/winter. Odd job and sports (min/week)	Total PA level (min/week). Intensity level: 3-point ordinal scale: moderate PA (2–4 kcal/kg/h); heavy PA (≥4 kcal/kg/h). Walking, cycling ≥20 min ≥3 times weekly at intensity 60% max ex. performance	Questionnaire -Designed for older populations -Validated among the elderly (age 70–89) -Direct validity: DLW r=0.61 -Reliability r=0.98. Dose–response: yes, based on both total and heavy PA, and for cycling (only for some risk factors)
La Croix 1996	4.2-year follow-up. 1,645 F and M aged ≥65 year. Mortality risk from CHD	Questionnaire adapted from Minnesota Leisure Time Physical Activity Questionnaire (SA)	5 categories of walking: for exercise, work, errands, pleasure, hiking (h/week)	Hours walked per week <1; 1–4; >4 h/week	Questionnaire -Designed for younger and older populations -Validated among elderly (mean age 73) -Direct validity: DLW r=0.23 Dose–response: yes, based on walking >4 h/week. Co-M

Table 1 (continued)

1 **Primary author**	2 **Study design, population and health outcome**	3 **Questionnaire Type and source**	4 **Physical activity described**	5 **Operationalizing of PA and EE**	6 **Additional notes**
Morgan 1997	10-year follow-up. 1,042 individuals aged ≥65 year. Mortality risk	Questionnaire of the Nottingham Longitudinal Study of Activity and Aging (I)	Walking. Indoor activities incl. housework (min/week)	Tertile grouping of PA level: High activity (1st); intermediate activity (2nd); low activity (3rd)	Questionnaire -Designed for older populations -Reliability $\alpha \geq 0.7$. Dose–response: yes, inversely related to activity level. Co-M; A
Bath 1998	12-year follow-up. 1,042 individuals aged ≥65 year. Risk of all cause and disease specific mortality	Questionnaire of Nottingham Longitudinal Study of Activity and Ageing (I)	Outdoor PA; indoor productive PA incl. housework; walking; shopping; leisure activities; strength a/o joint flexibility activity (min/week)	Tertiles of PA: Light, moderate vigorous. Walking: <10 vs. ≥10 min/day	Questionnaire -Designed for older populations -Reliability $\alpha \geq 0.7$ Dose–response inversely related to tertiles of PA. A
Bjinen 1998	10-year follow-up. 802 M aged 64–84 year. Risk of all cause and cardiovascular mortality	Questionnaire of the Zutphen Elderly Study (SA)	Walking, cycling, hobbies, odd jobs, sport, gardening, (min/week). 1985 and 1995	Total PA score (min/week) converted in tertiles	Questionnaire -Designed for older populations -Validated among the elderly (mean age 74) -Direct validity: DLW r=0.61 -Reliability r=0.93. Inverse dose–response relationship across tertiles. Co-M
Fried 1998	5-year follow-up. 658 F and 5,201 M aged ≥65 year. (range 65–101 year at baseline). Mortality risk	Questionnaire from Cardiovascular Health Study (I)	Moderate and vigorous LTPA (estimated kcal/week)	5-point ordinal scale: from <67.5 to >1,890 kcal/week	Inverse dose–response relationship across tertiles.
Hakim 1998	12-year follow-up. 707 M aged 61–81 year. Risk of all cause mortality and mortality from CHD and cancer	Questionnaire adapted to Framingham Heart Study (I)	Daily distance walked (miles/day) at baseline	3-point ordinal scale for walking distance per day (miles/day): 0.0–0.9; 1.0–2.0, and 2.1–8.0	Framingham Questionnaire -Validated among men aged 45–64 -Direct validity (MET) r=0.63 and r=0.55 -Reliability r=0.30–0.59 Dose–response inversely related to miles/day. A

Table 1 (continued)

1 **Primary author**	2 **Study design, population and health outcome**	3 **Questionnaire Type and source**	4 **Physical activity described**	5 **Operationalizing of PA and EE**	6 **Additional notes**
Bijnen 1999	5-year follow-up. 472 M, aged 70–79 year. Mortality risk	Questionnaire of the Zutphen Elderly Study (SA)	Walking, cycling, hobbies, odd jobs, sports, gardening (min week^{-1}). LTPA: EE estimation for walking, stair climbing, sports/ recreation. 1985 und 1995.	Total PA score (min/week) converted in tertiles. Intensity: "heavy" (≥ 4 kcal/kg/h) vs. "non-heavy" (<4 kcal/kg/h)	Questionnaire -Designed for older populations -Validated among the elderly (age 70–89; mean age 74) -Direct validity: DLW r=0.61 -Reliability r=0.93. Dose–response: yes, based on 2nd and 3rd tertiles of total PA; no, based on intensity. Co-M; A
Hakim 1999	2–4 year follow-up. 2,678 M, aged 71–93 year. Risk of CHD	Questionnaire adapted to Framingham Heart Study (I)	Walking (miles per day) (baseline)	3-point ordinal scale for Miles/day (<0.25 vs. >1.5; 0.25–1.5 vs. >1.5; <0.25 vs. 0.25–1.5)	Framingham Questionnaire -Validated among men aged 45–64 -Direct validity (MET) r=0.63 and r=0.55 -Reliability r=0.30–0.59. Dose–response: yes, based on higher miles/day each. A
Kostka 1999	0.5-year follow-up. 21 F and 17 M, aged 65–84 year. Change of risk factors (blood lipids and lipoproteins)	Questionnaire d`Activité Physique Saint Etienne (I)	Sports, gardening, housework, walking corresponding to intensity ≥ 3 METS	Mean habitual daily EE (kJ/day)	Questionnaire -Designed for older populations -Validated among the elderly (mean age 71) -Direct validity: DLW r=0.32 -Reliability: low/moderate -Responsiveness: low. Dose–response: no relationship referring MHDEE for 6 months
Stessman 2000	6-year follow-up. 456 subjects aged ≥70 year. Mortality risk	Jerusalem 70-year Old-Longitudinal Study Questionnaire adapted from Gothenburg population study of 70-year olds (I)	LTPA (walking, sport)	-No activity (walking <4 h/week) -Moderate PA (walking around 4 h/week) -Sports (sport activity at least 2 times per week. -Regular PA (walking ≥1 h/day)	Questionnaire designed for older populations. Dose response: yes, based on moderate and regular PA

Table 1 (continued)

1 Primary author	2 Study design, population and health outcome	3 Questionnaire Type and source	4 Physical activity described	5 Operationalizing of PA and EE	6 Additional notes
Van Dam 2002	5-year follow-up 424 M, age 69–89 year, mean 75 year. Prevalence of glucose tolerance	Questionnaire of the Zutphen Elderly Study (SA)	Walking, cycling time hobbies, odd jobs, sport, gardening (min/week). 1985 and 1990	Duration of moderate PA (≥4 kcal/kg/h): none; > 0–29; 30–59; ≥60 min/day) Cycling, walking, gardening: none; >0–19; 20 (min/day)	Questionnaire -Designed for older populations -Validated among the elderly (mean age 74) -Direct validity: DLW r=0.61 -Re-test reliability r=0.93. Dose–response: yes, based on moderate PA ≥30 min/day and cycling >19 min/day. A
Gregg 2003	12.5-year follow-up. 9,518 F, aged >65 year. Risk of all cause mortality	Modified Paffenbarger PA Questionnaire (SA)	Stairs climbed, blocks walked, sports, recreation. EE (kcal/week) (baseline, after 5.7 years and 12.5 years)	Quintile for kcal week^{-1} for -Total PA: <163 (1st) to ≥1,907 (5th); -Walking: <70 (1st) to ≥898 (5th)	Paffenbarger PA Questionnaire -Designed for older and younger populations -Validated among older people -Direct validity: DLW r=0.39 -Reliability: low -Responsiveness: low. Inverse dose–response based across kcal/week for all-cause and CVD Co-M
Lan 2006	2 years follow-up. 2,113 F and M age ≥65 years. Mortality risk	Questionnaire Elderly Nutrition and Health Survey (I)	13 activities (e.g. walking, race walking, Chinese-style exercise, sports, weight lifting, indoor exercises (baseline). Estimation of EE (kcal/week)	5-point ordinal indices on total amount of EE: from sedentary and <500 to ≥2,000 (kcal/week)	Questionnaire -Designed for older populations -Validated among older people (age 65–≥80) -Internal consistency α=0.88 -Repeated measures kappa 0.41–0.46. Dose–response: yes, based on based (kcal/week), with benefit >1,000 kcal/week). Co-M

Table 1 (continued)

1 **Primary author**	2 **Study design, population and health outcome**	3 **Questionnaire Type and source**	4 **Physical activity described**	5 **Operationalizing of PA and EE**	6 **Additional notes**
Manini 2006	Population-based study of EE over 2 weeks. 6.15-year follow-up. 302 community-dwelling F (aged 70–82). Risk of all cause mortality	DLW and unspecified questionnaire (I)	Free-living activities. Measured EE.	Tertiles for kcal/day: <521 (low) 521–770 (medium) >770 (high)	DLW: validity and repeatability: high. Dose–response relation based on highest tertile

Abbreviations: *A* adjusted for age, *Co-M* adjusted for co-morbidities and/or perceived health, *CHD* coronary heart disease, *DLW* doubly labeled water, *EE* caloric energy expenditure, *F* female, *I* interview-administered, *kcal* kilocalorie, *kJ* kilojoules, *LTPA* leisure time physical activity, *M* male, *MET* metabolic equivalent, *MHDEE* mean habitual daily energy expenditure, *PA* physical activity, *SA* self-administered

outcomes among older persons, with a wide range of dose–responses. The reviewed cohort studies suggested that none of the methods applied were entirely appropriate and sensitive enough to describe and measure both the PA behavior and related EE in the older population. Important methodological limitations were: a restricted use of available PA questionnaires specifically developed for and validated for the older population. The PA questionnaires used lacked appropriateness for age-specific features of PA. Although two instruments constructed for older populations are valid for assessing PA and reliable for estimating EE they do not cover the extremely diverse aspects of age-specific PA behavior and modes of muscular activity typical for the elderly. Only limited direct measurements of EE for PA in older adults had been undertaken. For the estimation of EE only non-age-specific tables had been used. These methodological deficiencies may limit the validity and interpretation of the dose–response relationships as reported in the epidemiologic studies reviewed.

Study limitations Facing these findings, the problem of a potential publication bias must be kept in mind. A literature review is highly selective in nature and may omit studies that have obtained what have been called “negative” results, which may not have reached publication.

Dose–response data leave us uncertain as to whether long-term observation, e.g. for 20 years, of PA and health outcomes confers different benefit when compared to short-term observation. To clarify and extend this issue, methodological advances in PA assessment are needed, i.e. additional observations on changes in PA over different time periods as they relate to health outcomes.

Implications for future research

To adequately assess health-relevant PA and EE for older populations in epidemiologic studies, questionnaires and methods should be designed which are more sensitive to the unstructured and complex PA common among the elderly [28]. To be most accurate, the sampling interval, the PA and EE units used, should be sensitive to both brief periods of activity and low-intensity activity. In order to allow meaningful dose–response interpretation there is a need for clearly defined and standardization, of the PA undertaken and EE units used for assessment in the elderly. Such age-specific measurements could also serve for the development of tables on EE appropriate for older people. Finally, it is suggested that epidemiological studies on health-enhancing PA and EE need to be reconsidered for appropriateness in the older population. The results of the dose–response relationship need to be interpreted with new findings and evidence.

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