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Revisão

Use of accelerometry to measure physical activity in adults and the elderly

Actividade física em adultos e idosos avaliados por acelerometria

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ABSTRACT

OBJECTIVE: To review the use of accelerometry as an objective measure of physical activity in adults and elderly people.

METHODS: A systematic review of studies on the use of accelerometty as an objective measure to assess physical activity in adults were examined in PubMed Central, Web of Knowledge, EBSCO and Medline databases from March 29 to April 15, 2010. The following keywords were used: "accelerometry," "accelerometer," "physical activity," "PA," "patterns," "levels," "adults," "older adults," and "elderly," either alone or in combination using "AND" or "OR." The reference lists of the articles retrieved were examined to capture any other potentially relevant article. Of 899 studies initially identified, only 18 were fully reviewed, and their outcome measures abstracted and analyzed.

RESULTS: Eleven studies were conducted in North America (United States), five in Europe, one in Africa (Cameroon) and one in Australia. Very few enrolled older people, and only one study reported the season or time of year when data was collected. The articles selected had different methods, analyses, and results, which prevented comparison between studies.

CONCLUSIONS: There is a need to standardize study methods for data reporting to allow comparisons of results across studies and monitor changes in populations. These data can help design more adequate strategies for monitoring and promotion of physical activity.

DESCRIPTORS: Adult. Aged. Motor Activity. Physical Exertion. Acceleration. Techniques, Measures, Measurement Equipment. Review.

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RESUMO

OBJETIVO: Analisar o uso da acelerometria como medida objetiva da atividade física em adultos e idosos.

MÉTODOS: Revisão sistemática nas bases PubMed, Web of Knowledge, EBSCO e Medline, de 29 de março a 15 de abril de 2010. As palavras-chave utilizadas na busca foram: *"accelerometry", "accelerometer", "physical activity", "PA", "patterns", "levels", "adults", "older adults"* e *"elderly"*, isoladamente ou combinadas usando *"and"* ou *"or"*. As listas de referências dos artigos recuperados foram examinadas para captar artigos potenciais. Dos 899 estudos localizados, 18 foram revistos integralmente, com seus dados extraídos e analisados.

RESULTADOS: Onze estudos foram realizados nos Estados Unidos, cinco na Europa, um em Camarões e outro na Austrália. Poucos envolveram idosos, e apenas um referiu a estação ou período do ano em que decorreu a coleta de dados. Os métodos, análises e resultados divergiram entre os estudos, impossibilitando uma análise mais aprofundada.

CONCLUSÕES: Deve-se promover a padronização de procedimentos que permitam comparar resultados entre estudos e monitorizar alterações numa população. Esses dados contribuem para a adequação das estratégias de monitoramento e promoção da atividade física.

DESCRITORES: Adulto. Idoso. Atividade Motora. Esforço Físico. Aceleração. Técnicas, Medidas, Equipamentos de Medição. Revisão.

INTRODUCTION

Physical activity (PA) is important for the maintenance of good health throughout life.[18] Studies assessing PA in adults have mainly used self-reported methods, which are associated with several sources of errors and limitations.[21] The majority of studies using objective measures -more specifically accelerometry- aimed to validate PA questionnaires are cross-sectional or conducted in US populations and few provide information on a large sample of healthy elderly.[8,20] Only one systematic review addressed the level of agreement between subjectively and objectively assessed PA in adults.[26]

Other review studies have explored the use of accelerometers and other motion sensors to provide reliable information on mobility and objective measures of gait and balance, fall risk assessment,[5,23,30] and advantages of the use of these methods in mobility-related activities in individuals with chronic diseases[1] and older people.[9] There are no systematic reviews on accelerometry data in adults and elderly that describe the results as well as methods of analyses and reporting used.

This study aimed to review the use of accelerometry as an objective measure of PA in adults and elderly people.

METHODS

A systematic review was conducted through electronic searches on the PubMed Central, Web of Knowledge, EBSCO and Medline databases from March 29 to April 15, 2010.

The keywords "accelerometry," "accelerometer," "physical activity," "PA," "patterns," "levels," "adults," "older adults," and "elderly" were searched alone or in combination using "AND" or "OR." The reference lists of the studies retrieved were examined to capture any other potentially relevant articles.

The inclusion criteria were: a) publication prior to April 15, 2010; b) subjects aged 18 years and older; c) apparently healthy individuals; d) data collection using uniaxial accelerometers; e) English language; f) data reporting (mean and standard deviation of the accelerometer daily ct.min^{-1}; minutes spent at different levels of PA; total activity in counts per day); g) data collection for at least four days.

Studies were excluded if they: a) included exclusively children or adolescents (under 18 years); b) only included patients or individuals with conditions or disorders (e.g., diabetes, cardiovascular disease, chronic obstructive pulmonary disease, osteoarthritis, Parkinson's disease, and overweight); c) included no relevant data; d) were not conducted in humans; e) used accelerometers to measure drug effects on an individual's ability to perform certain tasks.

Studies in languages other than English were not included because of concerns about translation and interpretation. Validity studies, randomized control trials, clinical studies, systematic reviews, meta-analyses and other studies involving intervention programs were included when baseline or relevant data were available.

Studies using biaxial or triaxial accelerometers were excluded due to issues of validation and comparability of results. Also, the focus of our study was on the most commonly and widely used technology.

The Downs & Black checklist[11] was used to assess the methodological quality of studies. Items that were not relevant to the objectives of this study were removed from the original[11] checklist (27 items). The modified version consisted of 12 items from the original list (1-3, 5-7, 10-12, 18, 20 and 27; highest possible score: 12) and eight additional items to ensure the quality of the description of the accelerometry data collection methods. These items were scored if the investigators reported the following (highest possible score = 8):

1. A minimum of four days of data collection;
2. Specific hours of data collection (waking hours, sleep);
3. A minimum number of monitoring hours per day to be considered as a valid day of data collection;
4. The epoch used in data collection;
5. Use of an activity log along with the accelerometer;
6. Calibration method of the devices;
7. Software used to analyze crude data;
8. How the authors accounted for periods of rest, time when the accelerometer was not worn, and artifacts.

Two main evaluators reviewed the studies selected and any discrepancies were resolved by consensus.

Two assistant evaluators independently abstracted the data from each study. Study characteristics (year of publication, country of origin and study design), subject characteristics (mean age, age range and sex), accelerometer and assessment characteristics (make and model, days of data collection, cut-offs and analysis software) were described.

The outcomes of interest included time spent at activities of different levels and mean and total daily activity. Sample sizes, means and standard deviations for each outcome were extracted from each study.

Only nonpatient data were used for studies involving both patients and nonpatients. Redundant data were excluded when the authors published multiple articles based on the same data.

The variables studied were time spent on sedentary activities or physical inactivity, moderate PA and moderate-to-vigorous PA, daily mean counts and total counts per day. These variables were chosen because they represent the choices made by most researchers in their analyses and data reporting.

Most of the selected outcomes from the studies were presented as means and standard deviations. Data were not incorporated into the analyses when the results were not reported this way or if they were not presented at all or presented in a non-comparable manner (e.g., median).

Studies that collected 24-hour data could not be pooled for analysis because they derived from a sum of daily counts and, therefore, were non-comparable.

Age group or gender-specific data were considered whenever possible but few authors reported data from men and women separately. The overall results were used in the studies where data from different ethnicities or races were reported.

Ages were divided into two groups (mean age <60 and >60 years) because of inconsistencies of age group data reported in the studies. These groups were defined based on data stratification used in most studies. However, it was not possible to examine the effect of age on the majority of variables due to inconsistent data reporting.

RESULTS

The initial search identified 1,358 titles in the databases. We retrieved 899 papers as potentially relevant articles (Figure). After a review of the titles and abstracts there were selected 29 articles. A complete full-text reviews of these 29 articles showed that 11 did not meet the inclusion criteria. Reasons for study exclusion were: no relevant or comparable data (seven studies); no use of a uniaxial accelerometer (three studies); and redundant data (one study). No additional articles were identified by screening the reference lists. Thus, 18 studies were selected.

Eleven studies were conducted in the United States, five in European countries, one in Australia and one in Cameroon. All were published between 2000 and 2009 and most were of cross-sectional design (Table 1).

The articles evaluated a total of 19,848 subjects. The sample sizes ranged from 33 to 4,867 individuals.

The ages ranged from 18 to 70 years. Although the review focused on those aged 18 years and older, one study included subjects from the age of six. Data were stratified by age and only age groups older than 18 were analyzed. Six studies enrolled older people.

Most studies included both men and women, but two enrolled women only.

Most studies met eight or more criteria from the original Downs & Black checklist, suggesting good methodological quality. The item with greater proportion of low scores was the one concerning "subjects being representative of the entire population from which they were recruited".

A mean of 5.38 quality criteria items concerning the description of data collection methods were met by the studies reviewed. One study achieved the highest possible score and five did not meet at least half of the quality criteria.

All studies used the same accelerometer (ActiGraph 7164 or GT1M), worn at the waist, and data was collected for at least four days. The majority used data from seven consecutive days, except one that collected data for 14 days and another one that collected data for five to seven days.

One study reported using only the average from three days of monitoring when one of the days had more than 16 hours of consecutive zero readings. Participants from that study corresponded to 1.4% of the total sample.

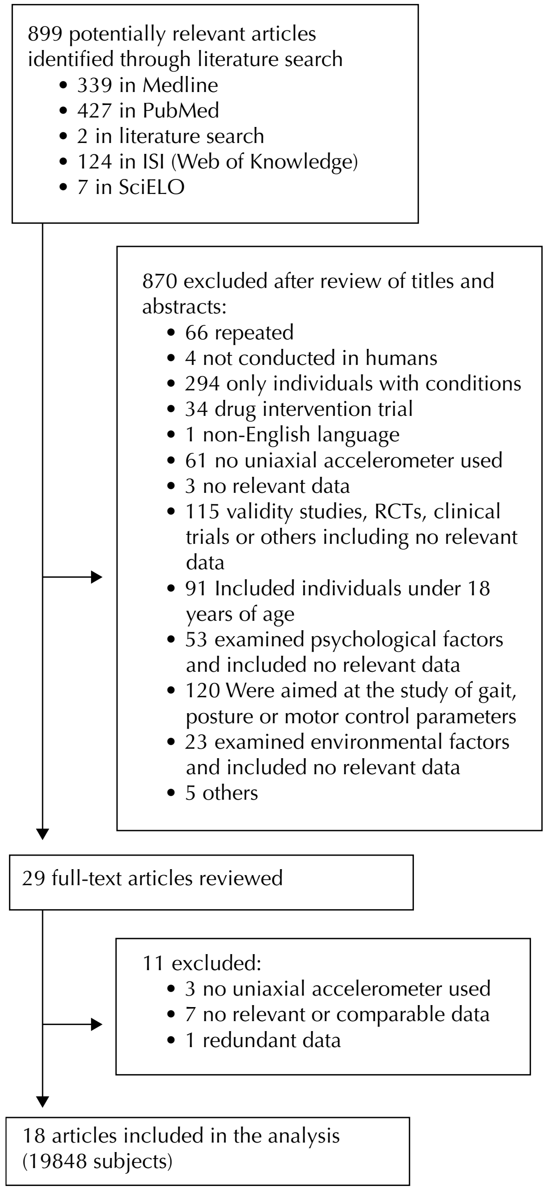
All studies asked their subjects to remove the equipment during bathing, swimming or skiing. Fourteen studies collected data during waking hours, three collected data throughout the day. The minimum number of monitoring hours per day ranged from eight to 12 hours (for studies collecting data during waking hours) and 22 hours (for one study that collected data for 24 hours per day). One study considered a valid minimum of six hours per day.

The subjects wore the device on average 11.2 hours per day. Three studies did not address the minimum hours of data collection.

Few studies reported other methodological issues as described above (nine studies).

Different cut-offs were chosen to define the thresholds of PA levels in $ct{\cdot}min^{-1}$. The majority (10 studies) used Freedson cut-offs or adjusted them to account for physical inactivity or sedentary activities[25] (Table 2).

The thresholds for inactivity or sedentary activities were variable: $<100\ ct{\cdot}min^{-1}$; $<200\ ct{\cdot}min^{-1}$; $<251\ ct{\cdot}min^{-1}$; $<260\ ct{\cdot}min^{-1}$; $<499\ ct{\cdot}min^{-1}$; $<500\ ct{\cdot}min^{-1}$. All studies defined thresholds for moderate PA, either alone or in combination with a level of vigorous PA, because this level of PA is associated with health benefits. The limits for this level of PA varied across studies. The most conservative estimate of moderate-to-vigorous PA was set at 2020 $ct{\cdot}min^{-1}$. Other studies defined lower limits, but they were close to this one (1952, 1999 and 2100 $ct{\cdot}min^{-1}$), except for two studies that adopted Swartz cutoffs[28] that establish lower limits for moderate PA starting at 574 $ct{\cdot}min^{-1}$.



RCT: Randomized controlled trial

Figure. Study flowchart. 2010.

The results were grouped according to similarities in data collection methods, units, and data reporting techniques. Data were also stratified by sex (male, female) and mean age (<60 and >60 years) (Table 3).

DISCUSSION

Systematic reviews have explored the use of accelerometers and other motion sensors to provide reliable information on mobility and objective measures of gait and balance, fall risk assessment,[5,23,30] and advantages

Table 1. Characteristics of the studies included in the review. 2000–2010.

Author, year	Country	N	Mean age or age range (years)	Days of data collection	Minimum days of valid monitoring	Hours of data collection	Minimum hours of valid monitoring	Epochs	Activity log	Calibration method	Software used	How to account for periods of resting, not wearing time, and other artifacts?	Quality score
Assah et al[2] (2009)	Cameroon	33 (men and women)	34.2 (SD 7.3)	7 days	N/a	24 hours a day	N/a	1-min	N/a	N/a	Excel and MAHUFFE	N/a	12
Coleman et al[3] (2008)	US	2199 (men and women)	45 (SD 11)	7 days		Waking hours	At least 10 hours per day	N/a	N/a	N/a	N/a	N/a	10
Cooper et al[4] (2000)	UK	108 (men and women)	38.6 (SD 9.3)	7 days	At least 4 full weekdays and one full weekend day of valid recording	Waking hours	At least 09 hours per day	1-min	N/a	N/a	N/a	N/a	15
Cust et al[6] (2008)	Australia	182	57.2	7 days	At least 4 days	Waking hours	At least 10 hours per day	1-min	N/a	N/a	N/a	Activity counts above 18000 were excluded. Consecutive strings of zero-count epoch lasting more than 20 minutes were assumed to be non-wear time	16
Davis et al[8] (2006)	UK, Italy and France	163 (men and women)	76.1 (SD 3.9)	7 days	At least 5 days	Waking hours	At least 10 hours per day	1-min	activity log	N/a	Caloric Bas software (CSA, Inc. 1999), Microsoft Acess 2000 macro	Unusually high and low counts and continuous data base with the same value were excluded	13
Davis & Fox[7] (2007)	US	31 (men and women)	43.6 (SD 12)	7 days	At least 4 days	24 hours a day	At least 10 hours per day	1-min	writen log	N/a	Microsoft Actisoft to analyze data	60 or more minutes of consecutive zeros were eliminated (considered not being worn)	13
Dinger & Behrens[10] (2006)	US	454 (men and women)	19.9 (SD 1.6)	7 days	At least 5 days	Waking hours	At least 12 hours per day	1-min	N/a	Manufacturer´s calibration of the device	N/a	N/a	15
French et al[12] (2007)	US	158 (men and women)	47.6 (SD 10.2)	4 days		Waking hours	N/a	N/a	N/a	N/a	SAS version 8.0	Days in which there were more than 16 hours of consecutive zero readings, were removed from the analysis.	11
Gerdhem et al[13] (2008)	Sweden	57 (women only)	80.1 (SD 0.1)	5-7 d	At least 5 days	Waking hours	At least 08 hours per day	1-min	7-d activity log	Calibration against standardized vertical movement	MATHLAB (MathWorks Inc., Natick, US)	Sequences of >10 min means "not being worn"	20

To be continued

Table 1 continuation

Author, year	Country	N	Mean age or age range (years)	Days of data collection	Minimum days of valid monitoring	Hours of data collection	Minimum hours of valid monitoring	Epochs	Activity log	Calibration method	Software used	How to account for periods of resting, not wearing time, and other artifacts?	Quality score
Hagströmmer et al[14] (2007)	Sweden	1114 (men and women)	45 (SD 15)	7 days	At least 4 days, of which one has to be a weekend day	Waking hours	At least 10 hours per day	1-min	N/a	N/a	Microsoft acess	20 or more minutes of consecutive zeros were eliminated. Accelerometer malfunction was identified as having counts greater than 20000 cpm	16
Harris et al[15] (2009)	UK	N= 1529, n=238 (men and women)	74	7 days	At least 5 days	Waking hours	N/a	5-sec	7-d activity log	N/a	Actigraph Actilife Monitoring System and MAHUFFE.exe available from www. mrc-epid.cam.ac.uk/)	N/a	15
Hawkins et al[16] (2009)	US	2688 (men and women)	18 to >60	7 days	At least 4 days	Waking hours	At least 10 hours per day	1-min	N/a	Manufacturer´s calibration of the device	N/a	60 or more minutes of consecutive zeros were eliminated (considered not being worn)	15
Janney et al[17] (2008)	US	3809 (men and women)	43 to 47	7 days	At least 4 days	Waking hours	At least 10 hours per day	1-min	N/a	N/a	N/a	60 or more minutes of consecutive zeros were eliminated (considered not being worn)	15
Jillcot et al[19] (2007)	US	199 (women only)	53.3 (SD 6.9)	7 days	At least 4 days	Waking hours	At least 06 hours per day. Average wearing time was 11.2 hours	1-min	N/a	N/a	ActiProcess data reduction program used to determine valid wearing time and to generate variables for use in subsequent analyses	20 or more minutes of consecutive zeros were eliminated	16
Johannsen et al[20] (2008)	US	206 (men and women)	20 to 101	14 days	At least 7 days	Accelerometer removed only during bathing (24 hours collecting data per day)	At least 22 hours per day	1-m	N/a	N/a	N/a	N/a	13
Mathews et al[24] (2002)	US	92 (men and women)	18 to 79	7 days	At least 7 days	Waking hours	At least 12 hours per day	1-m	N/a	Manufacturer´s calibration of the device	N/a	N/a	16
Strath et al[27] (2008)	US	3250 adults (men and women)	47.2 (SD 17.0)	7 days	At least 4 days	Waking hours	At least 10 hours per day	1-min	N/a	Standardized quality procedures	N/a	Blocks of >60 minutes zero counts was considered time not being worn	16
Troiano et al[29] (2008)	US	4867 (men and women)	6 to >70	7 days	At least 4 days	Waking hours	At least 10 hours per day	1-min	7-d activity log	Manufacturer´s calibration of the device	SAS and SUDAAN	N/a	15

Table 2. Cut-offs chosen by researchers (specific for ActiGraph). Intensities presented in counts per minute ($ct \cdot min^{-1}$). 2000-2010

Author, year	Sed/Inact ($ct \cdot min^{-1}$)	LPA ($ct \cdot min^{-1}$)	MPA ($ct \cdot min^{-1}$)	MVPA ($ct \cdot min^{-1}$)	VPA ($ct \cdot min^{-1}$)
Assah et al[2] (2009)	<100	101-1951		1952-5724	>5724
Coleman et al[3] (2008)				1952	
Cooper et al[4] (2000)		500-1952	1952 -5724		≥5725
Cust et al[6] (2008)	<100	<574	574-4944		>4945
Davis et al[8] (2006)	<200	200-1999		>1999	
Davis &Fox[7] (2007)		500-1952	1952-5724		≥5725
Dinger & Behrens[10] (2006)	<499	500-1951	1952-5724		≥5725
French et al[12] (2007)	1-251	251-2100		>2100	
Gerdhem et al[13] (2008)	<500	500-1952		>1952	
Hagströmmer et al[14] (2007)	<100			1952 to 5724	≥5725
Harris et al[15] (2009)	<200	200-1999	2000-3999		≥4000
Hawkins et al[16] (2009)	<260	260-1951		> or equal 1952	
Janney et al[17] (2008)	<260	260-1951		> or equal 1952	
Jillcot et al[19] (2007)			574 -4944		≥ to 4945
Johannsen et al[20] (2008)		<574		Moderate activity: 575 -4945	High activity: 4946 to 9317
Mathews et al[24] (2002)		<500	Moderate 1 = 500 to 1951 - nonambulatory activities	Moderate 2 = 1952 to 5724 -ambulatory activities	>5724
Strath et al[27] (2008)				>760	
Troiano et al[29] (2008)			2020		5999

Sed/Inact: sedentary/physical inactivity; LPA: leisure-time physical activity; MPA: moderate physical activity; MVPA: moderate-to-vigorous physical activity; VPA: vigorous physical activity.

of the use of these methods in the mobility-related activities in individuals with chronic diseases[1] and older people.[9] The present study summarizes published results and methods from studies that used accelerometry to describe PA in adults and elderly people.

Most research studies were conducted in North America (11 studies). Three were part of the well-known National Health and Nutrition Examination Survey (NHANES) 2003–2004 where accelerometers were included in a large-scale study for the first time.[16,27,29] Five studies reported data from European countries (2,971 individuals of a total sample of 19,848). These findings suggest that, in addition to information on the elderly, there is a need for studies with populations with characteristics different from the US population.

All were cross-sectional studies. One study[6] reported the time of year when data was collected and its data analysis included that season. Season of the year has been identified as a potential factor affecting active behavior[22] and PA in the elderly, and depending on the season there is a need to repeat data collection or collect data for longer periods.

This review study tried to select a homogeneous group of studies by establishing detailed and complete inclusion criteria. Even after careful selection of studies, there was a diversity of methods, analyses, and results, and the goal of describing PA results was not fully accomplished.

Units, data reporting techniques, and sample stratification varied widely across the studies, making comparisons between studies or subgroups difficult and preventing any additional conclusions. The most reported variable outcome was daily average $ct \cdot min^{-1}$, and all other variables could only be grouped into very limited subgroups of no more than three studies. Most studies did not include older people, and most did not report separately the results of men and women, even when both were included in the samples.

A meta-analysis would allow to summarizing the results from studies with different sample sizes and reliabilities and provide a quantitative review of the literature. However, given the nature of our data and the goals of this study, we found that summarizing the effects across all subgroups was inadequate.

Notwithstanding, new insights have been added to a previous review that used accelerometry data in adults but could not differentiate calibration cut-offs or data collection methods of different study protocols.[26]

Table 3. Summary of time spent at different levels of activity, activities in counts per minute ($ct \cdot min^{-1}$), daily average ($ct \cdot min \cdot d^{-1}$) and total counts per day ($ct \cdot d^{-1}$). 2002-2010.

Author, year	Subgroup (years)	Mean ($ct \cdot min^{-1}$)	SD ($ct \cdot min^{-1}$)	n
Inactivity				
Dinger & Behrens[10] (2006)	Fem <60	793.4	72.7	245
	Male < 60	778.6	84.8	209
Hagströmmer et al[14] (2007)	Fem	468	90	614
	Male	451	82	500
	Both	459	86	1114
	Both <60 a	465	87	92
	Both <60 b	459	90	441
	Both <60 c	460	84	459
	Both >60	451	79	122
Mathews et al[24] (2002)	Fem <60	747.9	66	50
	Male <60	739.8	66	42
Mild activity				
Dinger & Behrens[10] (2006)	Fem <60	112.2	32.9	245
	Male <60	118.8	37	209
French et al[12] (2007)	Both <60 a	255.5	13.1	28
	Both <60 b	248.8	11.3	36
	Both <60 c	220	6.7	94
MVPA				
Davis et al[8] (2006)	Fem <60	38.4	18.4	23
	Fem >60	16.7	12.1	93
	Male <60	40.4	19.2	22
	Male >60	23.8	20	70
Strath et al[27] (2008)	Fem	78	40.4	1594
	Male	102,7	53.1	1678
Mathews et al[24] (2002)	Fem <60	27.6	23.7	50
	Male <60	32.6	25.2	42
Coleman et al[3] (2008)	Both <60 a	33	24	1578
	Both <60 b	27	21	183
	Both <60 c	35	24	429
Daily mean activity ($ct \cdot min \cdot d^{-1}$)				
Davis et al[8] (2006)	Fem <60	370	81.1	23
	Male <60	236.1	84.4	93
	Fem >60	404.3	134	22
	Male >60	255.1	103.4	70
Dinger & Behrens[10] (2006)	Fem <60	360.3	106.1	245
	Male <60	402.6	113.4	209
Hagströmmer et al[14] (2007)	Fem	385	152	614
	Male	370	131	500
Troiano et al[29] (2007)	Male <60 a	423.6	12.6	212
	Male <60 b	444.2	13.4	217
	Male <60 c	386.5	11.3	259
	Male <60 d	338.2	11.3	204
	Male >60 a	256.7	8.8	269
	Male >60 b	188.9	5.4	355

To be continued

Table 3 continuation

Author, year	Subgroup (years)	Mean ($ct \cdot min^{-1}$)	SD ($ct \cdot min^{-1}$)	n
Troiano et al[29] (2007)	Fem <60 a	327.2	6.9	219
	Fem <60 b	333.6	8.6	240
	Fem <60 c	311.4	8.1	258
	Fem <60 d	271.6	7.8	219
	Fem >60 a	251.2	6.8	287
	Fem >60 b	169.8	3	349
Mathews et al[24] (2002)	Fem <60	300	131.7	50
	Male <60	330	141.7	42
Total activity ($ct \cdot d^{-1}$)				
Dinger & Behrens[10] (2006)	Fem <60	344804.1	110619.5	245
	Male <60	383787.2	112001.3	209
Harris et al[15] (2009)	Fem >60	220031	116764	110
	Male >60	232518	126583	124
Mathews et al[24] (2002)	Fem <60	270188.9	119648.1	50
	Male <60	303359.1	138275	42

Fem: female; MPA: moderate physical activity; a, b, c, d: subgroups

Although we conducted an extensive search of the databases, we may have missed other studies. The inclusion criteria of English-language studies, selected search databases, and exclusion of grey literature may also have affected the number of studies selected for analysis.

This review shows there is scarce research studies in adults especially elderly and suggests directions for further studies, such as the development of studies in countries other than the US, use of longitudinal designs and accounting for the season or time of year.

There is a need to standardize data collection methods and units for data reporting to allow comparisons of results across studies and monitor changes in populations. These data can help design more adequate strategies for monitoring and promotion of PA.

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