METAANALYSIS

Impact of physical activity and sedentary behaviour on fall risks in older people: a systematic review and meta-analysis of observational studies

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Abstract The objective of this work was to summarise and evaluate the evidence showing that physical activity is a protector factor as regards falls in older people. Relevant studies were identified through a systematic search in the MEDLINE and Cochrane Library, under the keywords of accidental fall/numerical data and risk factors, and with the bibliographies of retrieved papers. The combined odds ratio (OR) [95% confidence interval] for physical activity was 0.75 [0.64, 0.88] with moderate heterogeneity ($I^2=33\%$). For fall injury, it was 0.59 [0.47, 0.74] and, for falls in general, it rose to 0.94 [0.76, 1.17] with nil heterogeneity. The combined OR for sedentary factors was 1.14 [1.10, 1.82] with moderate heterogeneity ($I^2=36\%$). Regular physical activity in daily life yields significant reduction in falls in older people, especially falls with injuries.

Keywords Ageing · Fall · Physical activity · Sedentary behaviour · Older people

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Introduction

A fall is defined as an event in which the participant unintentionally comes to rest on the ground or at a lower level [1]. Falls have become a major public health problem for industrialised countries with an ageing population [2, 3]. Several studies [4, 5] have estimated that one third of the population over 65 years and one half of people over 85 years of age experience one or more falls per year. Fall consequences may be traumatic, psychological, economic and/or social. Accidental falls are the first cause of accidental death in this age range [6], and when they do not result in death, they constitute one of the main causes of invalidity and are often synonymous with loss of autonomy and institutionalisation.

It is well-known that the aetiology of falling is multifactorial and those falls risk factors are quite numerous. Many studies [7–18] have attempted to determine the risk factors and their relative impact on actual falls. A combination of these risk factors has led to predicting the degree of risk of falls in older people. Among them, potential protective factors such as physical activity and detrimental factors such as sedentary behav-

iour recurrently appear. Therefore, prevention and reha-bilitation programmes should take these modifiable factors into consideration and thereby help to reduce the magnitude of fall risk.

Meta-analyses on drugs [19–23], muscle weakness [24], balance impairment [25], sociodemographic items [26] and fall risk in older persons have all been carried out. That said, the only meta-analysis performed on exercises aimed at preventing falls is quite recent and dealt only with randomised controlled trials (RCTs) [27]. The main conclusion was that an exercise programme can reduce fall rates in older people with a pooled estimate rate ratio (RR) of 0.83 [0.75, 0.91]. So far, no meta-analyses have been performed on sedentary behav-iour. Meta-analysis restricted to RCTs is usually preferred to meta-analysis of observational studies [28] because it provides the most accurate and non-biased results, the least likely to be contested by potential confounders [29]. Nevertheless, for practical and ethical reasons (e.g. imposed sedentary behav-iour), RCTs are generally not feasible and observational studies have been largely preferred. Follow-up studies of older people have been organised in which their living habits, including physical activity, have been documented. Despite the problems with observational studies, meta-analyses can help to draw out some generalisations and conclusions and are, therefore, necessary in order to compare their conclusions with those from meta-analysis of RCTs.

The purpose of this study is to synthesise the findings of published observational studies and to determine whether physical activity and sedentary behaviour can modify fall risks in persons over 60 years. The procedures consist of (1) performing a meta-analysis to estimate the degree of statistical association between physical activity and falls and between sedentary behaviour and falls and (2) exploring the sources of heterogeneity.

Methods

Literature search strategy

The original articles published from 1966 through 2007 in English and French were identified through a systematic search on the biomedical electronic base MEDLINE and the Cochrane Library. During this first step, the key words in the thesaurus were 'accidental fall/numerical data' and 'risk factors'. The second step consisted of a manual search for the articles cited within the previously identified publications.

Study inclusion criteria

Two readers independently selected and reviewed all the abstracts of articles derived from the electronic search.

- Study inclusion criteria:

  - Participants were aged 60 years and more, either living in their own homes, institutionalised or hospitalised;
  - 'Falls' were in daily life, including any fall, recurrent falls and injurious falls;
  - All the different types of studies, whether observa-tional or interventional, were taken into consideration.

- First step of exclusion criteria:

  - Participants were aged under 60 years;
  - Accidental falls in road accident, falls from ladders, scaffolding and cliffs;
  - Samples involving a cohort suffering from serious neuromuscular disease or specific disease (e.g. osteoporosis, Parkinson's disease, dementia);
  - Letters to the editor, commentaries, editorials and meta-analysis were not considered.

- Second step of exclusion criteria:

  - Excluding all studies not considering sedentary behaviour and physical activity;
  - Excluding interventional studies.

To avoid duplication of data when the same group of aged persons was investigated in several publications, only the study reporting the most recent data was retained. Disagreements on study inclusion were settled subsequent to discussion with a third party.

Data extraction and study characteristics

Each reader gathered information on half of the studies. Data from a quarter of them were independently extracted by each of the two readers in order to evaluate the degree of inter-reader concordance. Discordances were resolved by consensus. Few extraction mistakes (6.4%) were observed, and double extraction on all studies did not prove necessary.

The following data were gathered:

- Name of the first author
- Date and journal of publication, impact factor 2007 of the journal
- Schema of study: exposed or non-exposed cohort, case–control or cross-sectional
- Number of subjects
- Number of fallers
- For observational cohort studies: prospective or retrospective collection, consecutive series, random sampling
- For observational case–control studies: cases and controls derived from a comparably sourced popula-tion, matched or random sampling

– For cross-sectional studies: consecutive recruitment or random sampling

Demographics

Definition of the population included minimum and maximum age, mean and standard deviation.

Evaluation criteria

– Definition of the fall: an isolated incident, more than a single fall, duration and collection of the 'falling' event
– Definition of risk factors and categories among the following: iatrogenic, medical histories, extrinsic, physical and sociodemographic
– For quantitative variables:

  • Number of fallers with risk factor for falls
  • Number of fallers without risk factor for falls
  • Number of non-fallers with risk factor for falls
  • Number of non-fallers without risk factor for falls

– For qualitative variables:

  • Mean and standard deviation in the group of fallers
  • Mean and standard deviation in the group of non-fallers

– Order of data gathering on the risk factor(s) with regard to falls: risk factor for falls evaluated before a fall, at time of fall or after a fall

Methodological quality assessment

Two readers assessed the quality of each study included according to a validated scale [30] derived from the recommendations of Cook in 1992 [31]. This scale provides a level of proof in accordance with the methodology, study power, randomisation, population, data collection and biases. Level 1 of proof coding in #1 is synonymous with established scientific proof, level 2 coding in #2 denotes scientific assumption and levels 3 and 4 coding in #3 and #4 refer to a low degree of scientific proof.

Statistical analysis

The quantitative variables are expressed by the mean, standard deviation, median and extreme values. The qualitative variables are described in terms of the number of individuals and the corresponding percentages. The analyses were carried out with SAS software, version 9.1 (SAS Inc., Cary, NC, USA).

Two meta-analyses were completed, one on physical activity and one on sedentary behaviour. Outcomes were analysed using fixed-effect models. The degree of effect of physical activity and sedentary behaviour on falls risk was measured with the odds ratio (OR) with a 95% confidence interval (CI). Fixed-effect meta-analysis was conducted through the Mantel–Haenszel method [32].

Heterogeneities between studies' results were assessed with standard methods, in particular the chi-square test [33] and the I^2 statistic [34]. A value of I^2 <25% led to the conclusion that heterogeneity might be low, between 25% and 50% that it was moderate and 50% to 75% that it was high [34]. In case of moderate or high heterogeneity, estimation of level of proof was conducted. Sources of heterogeneity were also examined (samples, intervention, judgement criteria). Stratified analysis on these sources and sensitivity analysis in function of methodological quality were carried out. We also used Begg's funnel plots [35, 36] to detect possible publication bias.

All meta-analyses were conducted with Review Manager 5 (RevMan), version 5.0.14. We defined a statistical test with a p value lower than 0.05 as significant.
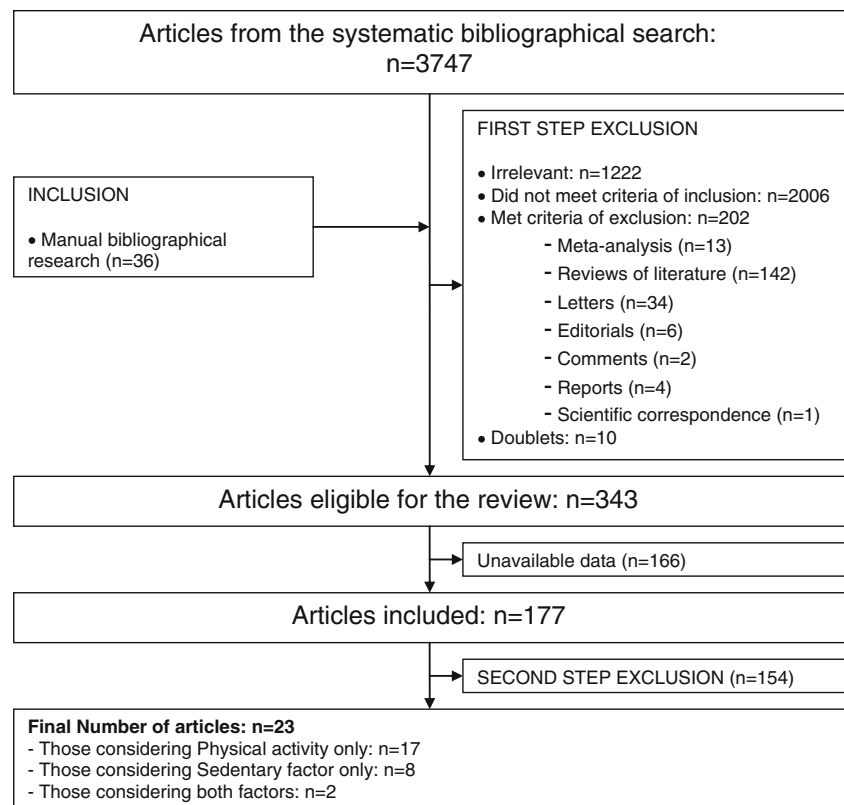
Results

Study selection

The computerised search allowed our team to identify 3,747 indexed articles published from 1966 through 2007 (Fig. 1). Two thousand and six did not meet the inclusion criteria, and 1,222 did not deal with risk factors for falls (e.g. consequences of the fall, prevention of falls). Thirteen meta-analyses, 142 overviews of the literature, 34 letters, 6 editorials, 2 commentaries, 4 reports, 1 scientific correspondence and 10 doublets were likewise eliminated from consideration, thereby leaving only 307 original articles. Using a manual search, 36 references were added. At the end of the initial selection step, only 343 studies had consequently been chosen for further consideration. Due to missing information (e.g. absence of number of fallers/non-fallers with or without risk factors, absence of standard deviation), the final analysis included only 177 articles. Among them, 17 studies presented data concerning physical activity (Table 1) and 8 pertained to sedentary behaviour (Table 2).

Study characteristics

Physical activity

The 17 studies concerning physical activity (Table 1) were published from 1988 to 2007. The median number of subjects was 387 (40–1,158). There were seven cross-sectional studies (41%), two case–control studies (12%) and eight cohort studies (47%), of which one was

Fig. 1 Flowchart of the studies involved in the meta-analysis

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│      Articles from the systematic bibliographical search: │
│                         n=3747                            │
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FIRST STEP EXCLUSION

- Irrelevant: n=1222
- Did not meet criteria of inclusion: n=2006
- Met criteria of exclusion: n=202
  - Meta-analysis (n=13)
  - Reviews of literature (n=142)
  - Letters (n=34)
  - Editorials (n=6)
  - Comments (n=2)
  - Reports (n=4)
  - Scientific correspondence (n=1)
- Doublets: n=10

INCLUSION

- Manual bibliographical research (n=36)

Articles eligible for the review: n=343

Unavailable data (n=166)

Articles included: n=177

SECOND STEP EXCLUSION (n=154)

Final Number of articles: n=23
- Those considering Physical activity only: n=17
- Those considering Sedentary factor only: n=8
- Those considering both factors: n=2

retrospective. Seven studies (41%) were at level 2, two studies (12%) were rated at level 3, while eight (47%) were of insufficient level of proof (#4). Fourteen studies included both men and women and 3 were limited to women.

Sedentary factors

The eight studies concerning sedentary factors (Table 2) were published from 1993 to 2006. The median number of subjects included was 541 [40–1,526]. The studies were all observational. Among them, there were four cross-sectional studies (50%), two case–control studies (25%) and only two cohort studies (25%). Two studies (25%) were at level 2, two studies (25%) were rated at level 3, while four (50%) were of insufficient level of proof (#4). Six studies included both men and women and two were limited to women.

Meta-analyses

Physical activity

Seventeen studies considered physical activity (Table 1); the OR was 0.71 [0.63, 0.80] with $I^2=29\%$ ($\chi^2=22.4$, $df=16$, $p=0.13$) (Table 3). A sensitivity analysis was performed in function of methodological quality (Fig. 2); only nine studies with good or moderate quality were kept.

The OR was 0.75 [0.64, 0.88] with $I^2=33\%$ ($\chi^2=11.91$, $df=8$, $p=0.16$).

Stratified analyses (Table 3) were performed to calculate the OR in function of fall type. For any falls [9, 37–42], the OR was 0.94 [0.76, 1.17] and, for traumatic falls [43, 44], 0.59 [0.47, 0.74]. Follow-up on falls was generally performed over 12 months; only one study collected falls during a period <12 months [43] and one did not indicate period length [44]. The OR for the minimum 12-month follow-up was 0.94 [0.76, 1.17]. Stratified analysis on mean population age revealed an OR of 1.05 [0.80, 1.38] for the mean age of 60 to 80 years [9, 37, 40, 42] and an OR of 0.68 [0.51, 0.91] for subjects with a mean age over 80 years [38, 39, 41, 44].

Heterogeneity was moderate (27% to 33%) and became nil subsequent to subgroup analyses. An evaluation of the sources of heterogeneity was performed and, whatever the stratified analyses were, two studies [43, 44] remained separated from the others on account of judgement criteria (fall injury) or length of follow-up (<12 months), either or both of which might have caused this moderate heterogeneity.

The asymmetric funnel plot (Fig. 3) suggests publication bias. An empty surface appears in the left part of the graphic, signifying that negative small studies were not included in our systematic study or were not published.

Logistic regression model analyses were completed in 11 studies [9, 37, 38, 40, 42–48]. Among them, three

Table 1 Description of articles included in the exercises meta-analysis in alphabetical order

First author–country	Year	Sample size (men/women)	Fallers, n (%)	Mean age±SD (min–max)	Judgement criteria Number	Length	Collection	Study quality (ANAES [30])	Definition of physical activity
Assantachai–Thailand [60]	2003	1,043 (371/672)	207 (19.8)	68.2±u.k. (60–u.k.)	1 fall and +	6 months	Patient interrogation	4	Exercise during the last year
Brauer–Australia [37]	2000	100 (0/100)	35 (35.0)	73±5 (65–86)	1 fall and +	6 months	Patient interrogation	2	Self reported activity level (>1 h/week)
Buatois–France [45]	2006	189 (108/81)	57 (30.2)	70±4 (66–74)	1 fall and +	16 months	Patient interrogation	4	Current physical activities
Chan–Singapore [61]	1997	401 (207/194)	69 (17.2)	68.8±u.k. (60–90)	1 fall and +	1 year	Patient interrogation	4	Exercise at least 3 times a week, with each session lasting at 20 min
Covinsky–USA [38]	2001	557 (187/370)	123 (22.1)	81.6±u.k. (65–u.k.)	1 fall and +	1 year	Patient interrogation	2	Aerobic activity ≥1 h/week: walking, swimming, golfing, running, aerobics, dancing and bicycling
Faulkner–USA [46]	2007	370 (106/264)	37 (10.0)	78±3 (74–85)	2 falls and +	1 year	Patient interrogation	4	Routine walking: walking for exercise; walking to work, store or church; or walking the dog in the previous week and at least 10 times in the previous 12 months
Herndon–USA [43]	1997	1,158 (292/866)	467 (40.3)	u.k.±u.k. (65–u.k.)	Min 1 traumatic fall	6 months	Patient interrogation	3	Current exercise three or more times weekly
Huang–Taiwan [47]	2004	405 (227/157)	202 (49.9)	78±u.k. (65–u.k.)	1 fall and +	1 year	Patient interrogation	4	Type of exercise: moderate range
Johnson–Canada [48]	2003	96 (17/79)	30 (31.3)	82.4±7 (65–98)	1 fall and +	4 months	Patient interrogation	4	Regular physical activity
Liu–Canada [39]	1995	100 (17/83)	59 (59.0)	83±6 (62–96)	1 fall and +	1 year	Notebook patient	2	Exercises greater than or equal to once weekly
Lord–Australia [62]	1993	704 (0/704)	239 (33.9)	74.6±u.k. (65–99)	1 fall and +	1 year	Patient interrogation	4	3+h planned exercise a week
Luukinen–Finland [40]	1996	788 (276/512)	88 (11.2)	76.1±5 (70–92)	2 falls and +	2 years	Patient interrogation	2	≥3 h/week of physical exercise
Maki–Canada [41]	1994	96 (40/56)	59 (61.5)	83±6 (62–96)	1 fall and +	1 year	Notebook patient	2	Exercise (20 min or more) more than once per week
Peel–Australia [44]	2006	387 (70/317)	126 (32.6)	82.6±7 (65–u.k.)	Min 1 traumatic fall	u.k.	Patient interrogation	3	Calculations of sufficient physical activity based on minutes per week spent walking, as well as doing moderate and/or vigorous activity in an average week in the last 6 months; sport involvement over the life stages was also recorded
Teno–USA [42]	1990	586 (191/395)	127 (21.7)	76.5±u.k. (65–99)	2 falls and +	1 year	Patient interrogation	2	To participate in sport activities
Tinetti–USA [9]	1988	336 (151/185)	118 (35.1)	78.5±5 (74–u.k.)	1 fall and +	1 year	Patient interrogation	2	Weekly walk for exercise+other physical exercise weekly
Toulotte–France [63]	2006	40 (0/40)	21 (52.5)	u.k.±u.k. (60–u.k.)	1 fall and +	2 years	Patient interrogation	4	Physical activities 2 h/week: walking

SD standard deviation, u.k. unknown

Table 2 Description of articles included in the sedentary factor meta-analysis in alphabetical order

First author–country	Year	Sample size (men/women)	Fallers, n (%)	Mean age±SD (min–max)	Judgement criteria (the fall)			Study quality (ANAES [30])	Definition of sedentary factor
					Number	Length	Collection		
Brassington–USA [58]	2000	1,526 (555/971)	284 (18.6)	u.k.±u.k. (65–99)	1 fall and +	1 year	Patient interrogation	4	Underactive
Isberner–USA [49]	1998	90 (33/57)	45 (50.0)	78.2±u.k. (63–99)	1 fall and +	7 months	Patient interrogation	3	Physically inactive
Ishizuka–Brazil [64]	2005	49 (8/41)	32 (65.3)	71.2±5 (60–u.k.)	1 fall and +	u.k.	Patient interrogation	4	Sedentary
Koepsell–USA [50]	2004	654 (212/442)	327 (50.0)	u.k.±u.k. (65–u.k.)	1 fall and +	2 years	Notebook patient	3	Physically active: not at all
Lord–Australia [62]	1993	704 (0/704)	239 (33.9)	74.6±u.k. (65–99)	1 fall and +	1 year	Patient interrogation	4	Any activity
Luukinen–Finland [40]	1996	788 (276/512)	88 (11.2)	76.1±5 (70–92)	2 falls and +	2 years	Patient interrogation	2	Essential daily activity only
Murray–Australia [65]	2005	40 (10/30)	20 (50.0)	78.2±u.k. (64–90)	1 fall and +	1 year	Patient interrogation	4	Not very physically active
Pajala–Finland [66]	2006	428 (0/428)	198 (46.3)	68.6±3 (63–76)	1 fall and +	1 year	Notebook patient	2	Sedentary

SD standard deviation, *u.k.* unknown

carried out regression analysis with the data chosen and did not include exercises [37, 46, 48]. Some considered all risk factors that were associated with falls in the univariate analysis, i.e. variables revealing significant differences between the groups (non-fallers versus fallers). But frequently, physical activity was not a significant variable in the first analyses [9, 38, 40, 42, 45] and was not included in the logistic regression model. Nevertheless, two studies revealed a significant difference in univariate

analysis and, therefore, considered exercises in their model [43, 44]; the adjusted OR obtained was 0.6 [0.4, 0.8] for Herndon et al. in 1997 and 0.49 [0.29, 0.83] for Peel et al. in 2006.

Sedentary factors

The OR, concerning sedentary factors and calculated with the results of the eight selected studies (Table 2), was 1.37

Table 3 Stratified analysis results

Study characteristics		Physical activity				Sedentary factor			
		$n_{Studies}$	$n_{Subjects}$	OR [95% CI]	I^2 (%)	$n_{Studies}$	$n_{Subjects}$	OR [95% CI]	I^2 (%)
All studies		17	7,343	0.71 [0.63, 0.80][a]	29	8	4,279	1.37 [1.14, 1.64][a]	66
Study quality	Good/moderate quality (1–3)	9	4,095	0.75 [0.64, 0.88][a]	33	4	1,960	1.14 [1.10, 1.82][a]	36
	Poor quality (4)	8	3,248	0.67 [0.56, 0.79][a]	27	4	2,319	1.32 [1.03, 1.70][a]	81
Good/moderate quality	Falls								
	Minimum 1 fall	7	2,557	0.94 [0.76, 1.17]	0	4	1,960	1.14 [1.10, 1.82][a]	36
	Minimum 1 traumatic fall	2	1,538	0.59 [0.47, 0.74][a]	0	0	0	na	na
	Follow-up								
	<12 months	1	1,151	0.61 [0.47, 0.78][a]	na	1	90	3.38 [1.29, 8.88][a]	na
	12 months and more	7	2,557	0.94 [0.76, 1.17]	0	3	1,870	1.32 [1.01, 1.72][a]	0
	u.k.	1	387	0.53 [0.32, 0.87][a]	na				
	Population								
	Institution	0	0	na	na	0	0	na	na
	Ambulatory	9	4,095	0.75 [0.64, 0.88][a]	33	4	1,960	1.14 [1.10, 1.82][a]	36
	Mean age								
	60–80 years	4	1,808	1.05 [0.80, 1.38]	0	3	1,306	1.50 [1.12, 2.01][a]	52
	>80 years	4	1,136	0.68 [0.51, 0.91][a]	0	0	0	na	na
	u.k.	1	1,151	0.61 [0.47, 0.78][a]	na	1	654	1.19 [0.71, 1.98]	na

na not applicable

[a] Significant

Study or Subgroup	Factor + Events	Total	Factor - Events	Total	Weight	Odds Ratio M-H, Fixed, 95% CI	Odds Ratio M-H, Fixed, 95% CI
1.1.1 Study quality 1-3							
Brauer 2000	29	80	6	20	0.9%	1.33 [0.46, 3.83]	
Covinsky 2001	80	416	37	141	6.7%	0.67 [0.43, 1.05]	
Herndon 1997	125	386	338	765	23.0%	0.61 [0.47, 0.78]	
Liu 1995	24	39	35	57	1.6%	1.01 [0.44, 2.32]	
Luukinen 1996	59	533	29	255	5.2%	0.97 [0.61, 1.55]	
Maki 1994	24	39	35	57	1.6%	1.01 [0.44, 2.32]	
Peel 2006	26	112	100	275	6.7%	0.53 [0.32, 0.87]	
Teno 1990	20	86	106	498	3.6%	1.12 [0.65, 1.93]	
Tinetti 1988	60	185	48	151	5.4%	1.03 [0.65, 1.63]	
Subtotal (95% CI)		**1876**		**2219**	**54.8%**	**0.75 [0.64, 0.88]**	
Total events	447		734				

Heterogeneity: Chi² = 11.91, df = 8 (P = 0.16); I² = 33%
Test for overall effect: Z = 3.61 (P = 0.0003)

1.1.2 Study quality 4							
Assantachai 2003	95	551	112	492	14.7%	0.71 [0.52, 0.96]	
Buatois 2006	39	135	18	54	2.7%	0.81 [0.41, 1.60]	
Chan 1997	24	179	45	222	5.2%	0.61 [0.35, 1.05]	
Faulkner 2007	8	171	29	199	3.8%	0.29 [0.13, 0.65]	
Huang 2004	30	68	172	337	4.9%	0.76 [0.45, 1.28]	
Johnson 2003	26	76	4	20	0.6%	2.08 [0.63, 6.86]	
Lord 1993	57	218	182	486	12.5%	0.59 [0.42, 0.84]	
Toulotte 2006	14	26	7	14	0.6%	1.17 [0.32, 4.28]	
Subtotal (95% CI)		**1424**		**1824**	**45.2%**	**0.67 [0.56, 0.79]**	
Total events	293		569				

Heterogeneity: Chi² = 9.57, df = 7 (P = 0.21); I² = 27%
Test for overall effect: Z = 4.49 (P < 0.00001)

Total (95% CI)		**3300**		**4043**	**100.0%**	**0.71 [0.63, 0.80]**	
Total events	740		1303				

Heterogeneity: Chi² = 22.40, df = 16 (P = 0.13); I² = 29%
Test for overall effect: Z = 5.68 (P < 0.00001)
Test for subgroup differences: Not applicable

Fig. 2 Forest plot of studies included in the physical activity meta-analysis (*n*=17 studies) in function of methodological quality

[1.14, 1.64] with I^2=66% (χ^2=20.57, *df*=7, *p*=0.004). Sensitivity analysis was carried out in order to separate good or moderate quality studies (#1–3) from poor quality studies (#4) (Fig. 4). The significant OR obtained were, respectively, 1.41 [1.10, 1.82] and 1.32 [1.03, 1.70] with I^2=36% (χ^2=4.72, *df*=3, *p*=0.19) and I^2=81% (χ^2=15.8, *df*=3, *p*=0.001).

Stratified analyses (Table 3) were also conducted in accordance with fall types. Fall collection was carried out during 12 months or more in three studies, and in one, it was <12 months [49]. The significant OR obtained for the follow-up of 12 months or more was 1.32 [1.01, 1.72]. No studies included populations living in institutions and none dealt with traumatic falls. The significant OR calculated with stratified analysis in function of mean age was 1.50 [1.12, 2.01] for a mean age between 60 and 80 years.

Heterogeneity was high prior to sensitivity analysis (66%), moderate (36%) for studies with good or moderate methodological quality and quite high (81%) for studies with poor methodological quality. After subgroup analyses, it diminished (0%) when length of follow-up was 12 months and more and increased (52%) when the mean age of population was 60 to 80 years.

As in our previous meta-analysis, the asymmetric funnel plot (Fig. 5) suggests publication bias. An empty surface appears in the left part of the graphic, meaning that negative small studies are not included in our systematic study or are not published.

When the authors completed logistic regression model [40] or multivariate analysis of fall risk [50], this factor was not considered or did not appear to be a significant risk factor for falls.

Discussion

This systematic review and meta-analysis indicates that physical activity constitutes a protector factor for falls in persons aged over 60 years. Physically active older adults are less at risk of falling (OR of 0.75 [95% CI of 0.64, 0.88]) than those who are physically inactive or sedentary (OR of 1.41 [95% CI of 1.10, 1.82]). These results were confirmed in stratified analysis, especially for fall injury, ambulatory people and people with a mean age over 80 years as regards meta-analysis of physical activity.

For physical activity, the main finding in our study is consistent with previous meta-analysis on RCTs [27],
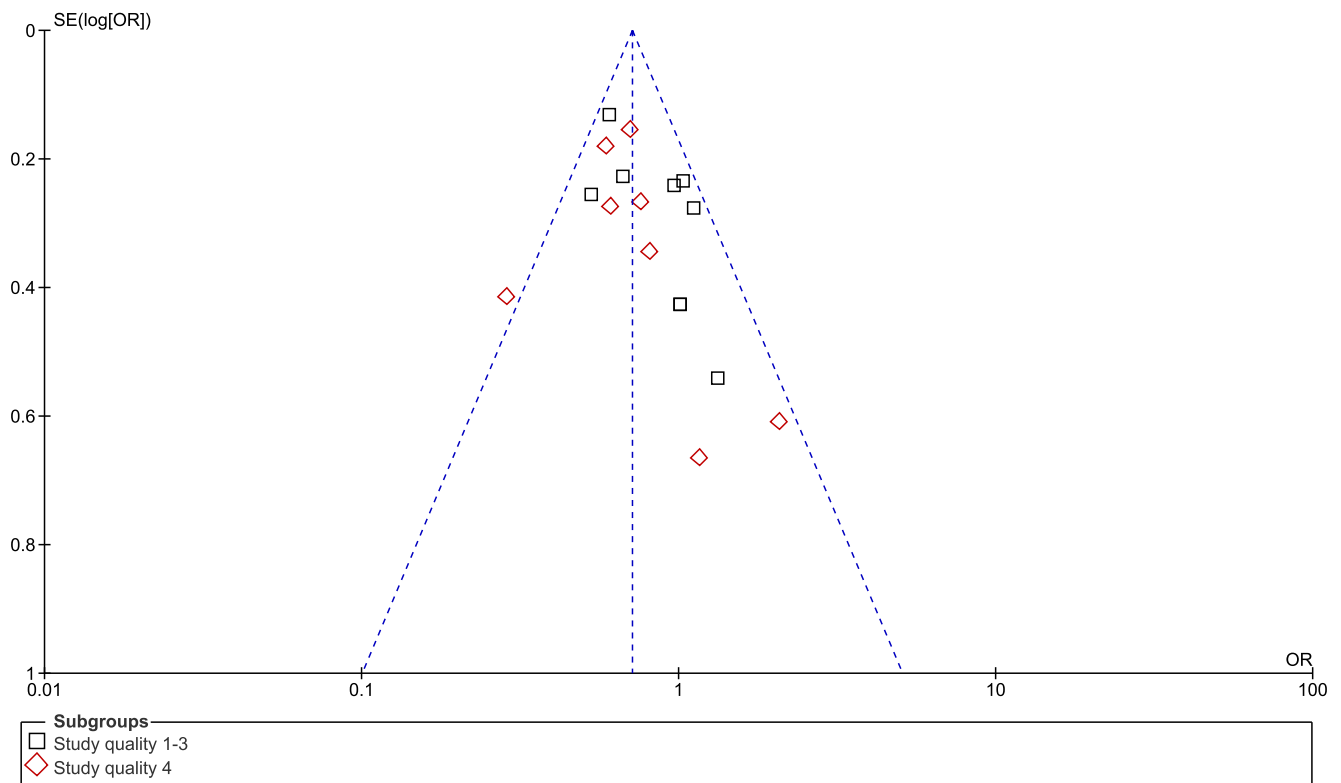
Fig. 3 Funnel plot of studies included in the physical activity meta-analysis (*n*=17 studies) in function of methodological quality

which provides strong evidence that exercise programmes can reduce fall rates in older people (RR of 0.83 [95% CI of 0.75, 0.91]). In previous meta-analysis, programmes including balance exercise were more effective in fall prevention than those including walking exercises. However,

this result is peculiar since falls occur also in dynamic balance.

Surprisingly, when excluding articles dealing only with injurious falls, physical activity did not have any significant preventive effect. Therefore, physical exercise may protect
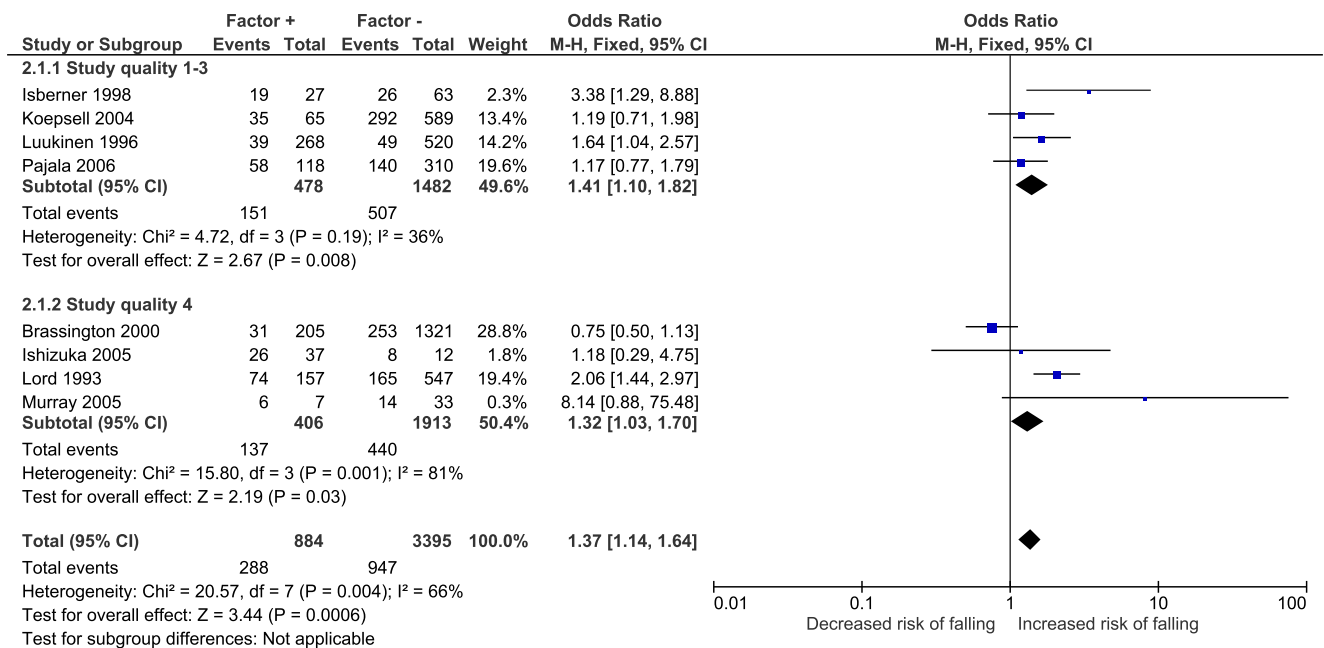
Fig. 4 Forest plot of studies included in the sedentary factor meta-analysis (*n*=8 studies) in function of methodological quality
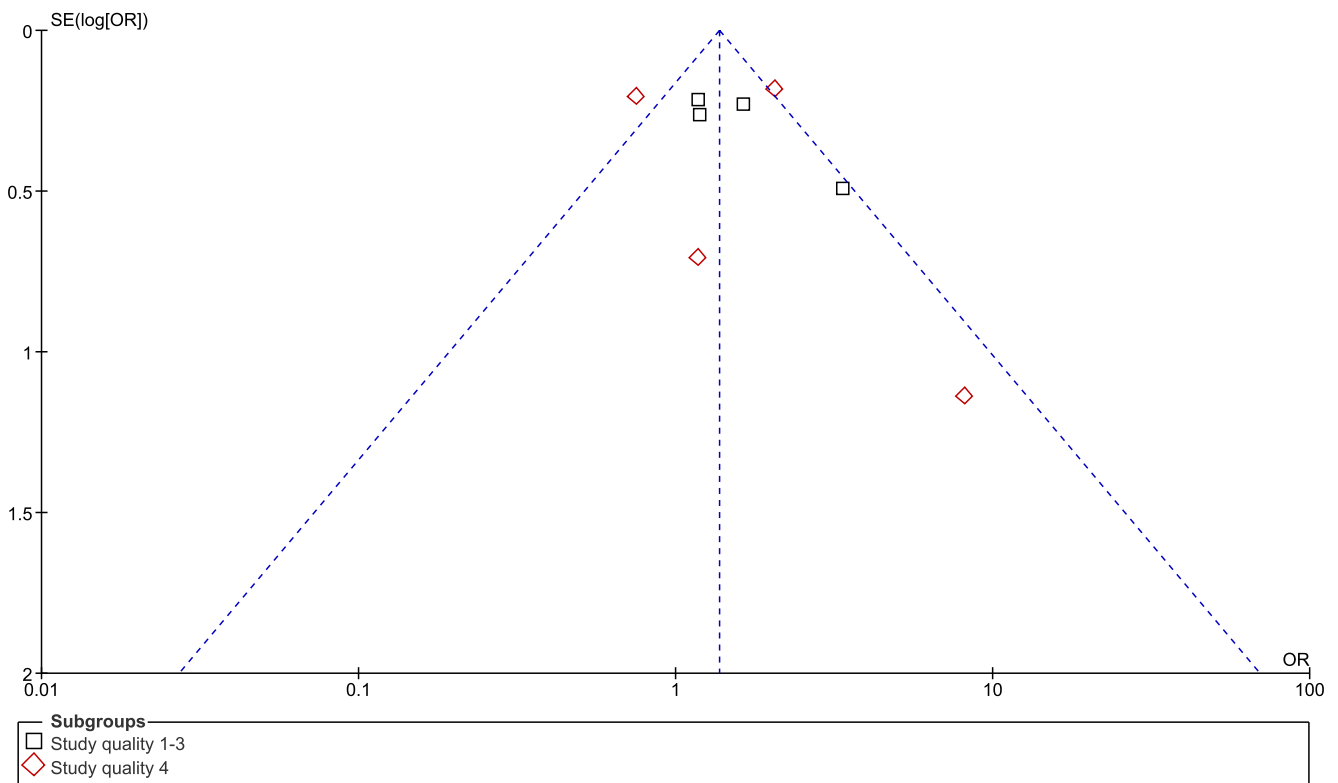
Fig. 5 Funnel plot of studies included in the sedentary factor meta-analysis (*n*=8 studies) in function of methodological quality

less as regards number of falls than as regards degree of injury entailed; it is possible that those who have lower physical activity might have lower muscle mass and thus are more susceptible to injury when falling occurs. Similarly, no significant reduction of the number of fallers was found when the follow-up was 12 months or more. It may be doubtful that older people practise exercises all year, maintaining a sufficient degree of intensity, frequency and duration. It is also possible that this meta-analysis of observational study fails to precisely estimate the impact of physical activity on falls.

It was convincingly demonstrated and highlighted that exercise load is a highly important variable [27, 51]. Exercise programmes would be more effective if they would be more intense, with a high frequency (twice weekly) and especially if the length of the programme would exceed 25 weeks. Such length should be considered as the minimal amount of time necessary for physiological adaptations in older people. In all the studies included in our meta-analysis, the amount of physical activity was only globally estimated through questionnaires and no precise indication of exercise load was reported. The quality of the exercise descriptions in term of intensity, duration and type are not precise enough to perform a proper analysis. It was not known whether the subjects regularly practised physical activities and for how long they engaged in regular physical activity. The length of involvement could possibly exceed

the 25 theoretical weeks and exercises actually performed in daily life (or not).

The finding that physical activity diminished the risk of falls in older people can be explained by changing or reducing other known risk factors. Exercises can heighten or maintain balance [52, 53], gait (e.g. walking speed [53], walking efficiency [54]), muscle strength [24] (e.g. ankle strengthening [53], physical strength [55]) and can also slow down physical deterioration in older people residing in nursing homes [53]. To develop an effective fall prevention or rehabilitation programme, it is essential to know the relative shares of the factors likely to prevent or reduce fall risks. In any event, physical activity is particularly low in older age groups but it can be of particular help in older people, and that is why sustained training has been highly recommended in fall prevention programmes [27, 55–57].

Sedentary behaviour has been reported to be a strong factor influencing the health of ageing subjects, and it is also likely to have an impact on the risk of falls. The OR for sedentary behaviour was not quite as high as we might have expected. Nevertheless, it is significant and as important as are other fall risk factors, such as drugs. The unadjusted OR estimated for nine medication classes [21] (i.e. antihypertensive agents, diuretics, β blockers, sedatives and hypnotics, neuroleptics and antipsychotics, antidepressants, benzodiazepines, narcotics, non-steroidal anti-inflammatory drugs) are all lower than 2, similar to our results concerning sedentary factors.

For muscle weakness [24], especially lower extremity, the OR seems to be somewhat higher (1.76 [1.31, 2.37]). This is also the case with balance impairment [25], for which overall fall risk was calculated at 1.98 [1.60, 2.46]. The last two factors appear to increase the risk of a fall to a greater degree than medication, and they may be limited by sustained physical training.

This meta-analysis has shown certain limitations. First, our methodology excluded numerous studies on account of unavailable data because we needed to calculate the ORs using the same method for all participants. Second, like in most meta-analyses, publication bias was such that unpublished studies were not sought after. Thirdly, the difference between sedentary behaviour and physical activity could be not clear. Therefore, we experienced in some cases great difficulties to decide where to include some of published works whether in the table for 'physical activity' (Table 1) or in the table related to 'sedentary behaviour' studies (Table 2). For instance, under studies including physical activity (Table 1), one study [46] considered physical activity as 'any walking, including walking the dog at least 10 times in the previous 12 months'. On the other hand, under limited activity (Table 2), we included one work [58] in which the subjects were 'underactive'. Those are the reasons why relatively few studies are included in these two meta-analyses, and they also explain a limited but real publication bias.

In conclusion, physical activity practised by older people would be an indicator of a lower risk of fall, especially as regards injurious fall. However, we could not draw any cause–effect relationship. It is possible that people who are healthier and do not tend to fall choose to do physical activity and not the opposite. However, our results are similar to those found in RCT studies and our sedentary behaviour study indicated that the latter had a negative impact close to that of the major classes of medicine used by older people. Given the high number of participants (7,343 for physical activity and 4,279 for sedentary behaviour), these results may be generalised to the entire population of elders, including men and women, whether they be living in an institution or in the community. To prevent falls, caregivers should support and motivate this category of subjects to regularly engage in practice physical exercises and follow recommendations of the American College of Sports Medicine [59].

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