

Effective Exercise for the Prevention of Falls: A Systematic Review and Meta-Analysis

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OBJECTIVES: To determine the effects of exercise on falls prevention in older people and establish whether particular trial characteristics or components of exercise programs are associated with larger reductions in falls.

DESIGN: Systematic review with meta-analysis. Randomized controlled trials that compared fall rates in older people who undertook exercise programs with fall rates in those who did not exercise were included.

SETTING: Older people.

PARTICIPANTS: General community and residential care.

MEASUREMENTS: Fall rates.

RESULTS: The pooled estimate of the effect of exercise was that it reduced the rate of falling by 17% (44 trials with 9,603 participants, rate ratio (RR) = 0.83, 95% confidence interval (CI) = 0.75–0.91, $P < .001$, $I^2 = 62%$). The greatest relative effects of exercise on fall rates (RR = 0.58, 95% CI = 0.48–0.69, 68% of between-study variability explained) were seen in programs that included a combination of a higher total dose of exercise (> 50 hours over the trial period) and challenging balance exercises (exercises conducted while standing in which people aimed to stand with their feet closer together or on one leg, minimize use of their hands to assist, and practice controlled movements of the center of mass) and did not include a walking program.

CONCLUSION: Exercise can prevent falls in older people. Greater relative effects are seen in programs that include exercises that challenge balance, use a higher dose of exercise, and do not include a walking program. Service providers can use these findings to design and implement exercise programs for falls prevention. *J Am Geriatr Soc* 56:2234–2243, 2008.

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The development and implementation of effective and cost-efficient strategies to prevent falls in older people is an urgent global health challenge. In developed countries, life expectancy for people aged 65 years old is approximately 17 years for men and 21 years for women. At least one-third of people aged 65 and older fall at least once annually,¹ and falls account for more than half of the injury-related hospitalizations for older people.² Fall rates in the general older population are reported to be 1.2 falls per person year.³

Falls in older people are not purely random events but can be predicted by assessing a number of risk factors.^{4,5} Some of these risk factors (e.g., reduced muscle strength and impaired balance and gait) can be modified using exercise, whereas others (e.g., poor vision, psychoactive medication use) require different intervention approaches. Exercise can be used as a stand-alone falls prevention intervention or as a component of a multifaceted program. Multifaceted interventions can prevent falls in the general community, in those at greater risk of falls, and in residential care facilities.^{4,6}

Many trials have sought to establish the specific effect of exercise on fall rates, but a large proportion of these trials have been underpowered. The best way to interpret these trials may be to pool their data in a meta-analysis, but trials of the effects of exercise on fall rates vary in their quality, have been conducted on a range of populations, and employ exercise programs that differ greatly in their aims and content. Meta-analysis should therefore involve exploration of whether these factors “explain” (are associated with) estimates of the effect of exercise programs.^{7,8}

A Cochrane review of fall prevention strategies⁶ conducted separate meta-analyses on different forms of exercise and concluded that some exercise programs can prevent falls in community dwellers (e.g., home exercise program of balance and strength training, a Tai Chi group program) but

that others are unlikely to be beneficial (brisk walking in women with an upper limb fracture in the previous 2 years) or require further investigation (untargeted group-based exercise interventions and individual lower-limb strength training). A limitation to this approach is that it combines programs that may be different (e.g., group programs that are of low and high intensity) and separates programs that share key features (e.g., balance training).

This study sought to establish the effect of exercise on fall rates, with a major aim of explaining between-trial variability. Meta-regression methods were used to investigate whether particular features of study populations, exercise programs, and study design were associated with the size of estimates of effects of exercise on fall rates.

METHODS

Data Sources and Searches

A literature search was conducted in May 2007. OVID was used to search MEDLINE, EMBASE, and CINAHL. Search filters developed by the Scottish Intercollegiate Guidelines Network (SIGN; <http://www.sign.ac.uk/methodology/filters.html>) to identify randomized trials were combined with a strategy to identify studies of the effects of exercise (available from the authors on request) and search terms from the relevant Cochrane review⁶ (to identify studies of falls prevention). The search was supplemented with searches of PubMed, the Physiotherapy Evidence Database (<http://www.pedro.fhs.usyd.edu.au>), SafetyLit (<http://www.safetylit.org/archive.htm>), and Prevention of Falls Network Europe (ProFaNE; <http://www.profane.eu.org/>). The reference list of the Cochrane review⁶ and other reviews and the updated search results provided by the trial search coordinator of the Cochrane Bone, Joint and Muscle Trauma Group were also checked.

Study Selection

Published randomized trials conducted in older people in which the primary intervention being evaluated was exercise and the outcome was number of falls, number of fallers, or rate of falls were reviewed. Trials were ineligible if non-exercise interventions were a major (>25% of time) component of the intervention being evaluated.

To determine eligibility of identified trial reports, two investigators (CS, RDH) independently scanned titles and abstracts. If it was clear that the control group received exercise or the intervention program involved substantial (>25% of time) additional nonexercise interventions, the study was excluded. The full articles were obtained for the remaining titles. Differences of opinion of the two investigators about study eligibility were resolved by discussion.

Data Extraction and Quality Assessment

Two of the authors (CS and SRL or JCTC) extracted data on study characteristics and estimates of effect of exercise from each study. Differences were resolved by discussion with a third investigator (SRL or JCTC).

The quality of study design was assessed by noting whether allocation to groups was concealed and analysis was according to intention to treat.⁹

The studies were described in terms of population (dwelling situation and risk status), presence and intensity of different exercise program components (addressing strength, balance, endurance, flexibility, and walking), broad aspects of the exercise program (amount of supervision, progression of exercises, modifying in type or intensity of exercise, adherence to program and overall dose of exercise), and study design (concealed allocation to groups and intention-to-treat analysis). Criteria for coding are summarized in Table 1. The majority of characteristics were coded on 3- to 5-point scales, but all were dichotomized a priori for the analysis. For several variables, analyses were conducted using two different cutpoints for dichotomization. The cutpoint that explained the most variability was used and is reported in the tables.

Five of the trials had two exercise groups and one control group. For these trials, estimates of the effects of each exercise intervention were obtained. To avoid “double counting” of control subjects from these trials, the total falls and subject numbers in the control group were allocated in proportion to the participant numbers in each intervention group. There were thus 49 comparisons in the meta-analysis.

Estimates of the effect of exercise were extracted from each trial. Where possible, estimates of incidence rate ratios (IRRs) from negative binomial regression models (6 studies), person-time analyses (1 study), or hazard ratios from proportional hazards models that allowed for multiple falls per person (6 trials) were used. Alternatively, data on the total number of falls ($n = 20$) or number of falls per person ($n = 6$) and exposure times (person-years of follow-up using actual follow-up times and number of participants providing data where reported) were used to calculate IRRs. Three trials reported only the incidence proportions of fallers in intervention and control groups, and two trials reported only the hazard ratios for time to first fall. For these trials, the ratio of incidence proportions or the hazard ratio was used as an estimate of the IRR. Where possible, unadjusted falls rates and longer follow-up times were used (e.g., in an article such as¹⁰, which presented 6- and 12-month falls data, the 12-month data were used).

Four of the trials were cluster-randomized. Two of these accounted for the effect of clustering. For the other two, the variance of estimates for clustering was adjusted by assuming an intracluster correlation of 0.01.^{11,12}

Data Synthesis and Analysis

A random-effects meta-analysis was conducted. Comprehensive Meta-Analysis software (Version 2, Biostat, Englewood NJ) was used to calculate a pooled IRR. Statistical heterogeneity was quantified with the I^2 and Q statistics. Publication bias was assessed using Egger's test. The pooled effect was also calculated in STATA (Stata Corp., College Station, TX) using the “metan” command.¹⁴ Influence was assessed in STATA using the “metaninf” command.¹⁴

Sensitivity analyses were conducted to assess the effect of excluding the trials for which only risk ratios or hazard ratios were available and excluding the cluster randomized trials.

Table 1. Summary of Included Trials (n = 44) and Comparisons (n = 49) Showing Control Group Fall Rate over Follow-Up Period, Sample Size, Length of Follow-Up, Estimate of Effect of Intervention, and Number and Percentage of Trials with Each Population, Program, or Study Quality Descriptor

First Author, Year, and Intervention Type	Control Group Falls/Person-Year or % Who Fell During Follow-Up Period	Data Extracted	Sample Size at Randomization	Follow-Up (Months)	Estimate of Fall Rate Ratio (95% CI)	High-Support Residential Care ^a	Population at Greater Risk ^b	Average Age 75 and Older	Moderate-to High-Intensity Strength Training ^c	High-Challenge Balance Training ^d	Moderate-to High-Intensity Endurance Training ^e	Stretching Program ^f	Walking Program ^g	Moderately to Highly Supervised Exercise ^h	Exercises Progressed Weekly or More	Exercises Modified in Type or Intensity	Good Adherence ^k	50+ Total Hours of Exercise ^l	Concealed Allocation to Groups ^m	Intention to Treat Analysis ⁿ
Barnett, 2003 ³⁰	0.97	IRR	163	12	0.60 (0.36-0.99)	N	Y	Y	Y	Y	Y	Y	Y	Y	N	N	Y	Y	Y	Y
Bunout, 2005 ³¹	0.18	F/PY	298	12	1.22 (0.70-2.14)	N	N	Y	Y	N	Y	N	Y	Y	Y	Y	Y	Y	N	N
Buchner, 1997 ³²	0.81	Rate Ratio	105	25	0.61 (0.39-0.93)	N	Y	Y	Y	N	Y	N	N	Y	Y	Y	Y	Y	N	Y
Campbell, 1997 ³³	1.34	HR-4	233	12	0.68 (0.52-0.90)	N	Y	Y	Y	Y	Y	N	Y	N	N	Y	N	Y	Y	Y
Campbell, 1999 ³⁴	0.97	HR-M	93	10	0.87 (0.36-2.09)	N	Y	N	Y	Y	Y	N	Y	N	N	Y	Y	Y	Y	Y
Campbell, 2005 ³⁵	1.13	IRR	391	12	1.15 (0.82-1.61)	N	Y	Y	Y	Y	Y	N	Y	N	N	Y	N	Y	Y	Y
Carter, 2002 ³⁶	0.52	F/PY	93	5	0.88 (0.32-2.41)	N	N	N	N	N	N	Y	N	N	N	Y	Y	N	N	N
Cerny, 1998 ³⁷	0.46	F/PY	28	6	0.87 (0.17-4.29)	N	N	Y	Y	Y	Y	Y	Y	N	N	N	N	Y	N	N
Day, 2002 ³⁸	64%	HR-M	1090	18	0.82 (0.70-0.97)	N	N	Y	N	N	N	N	N	N	N	N	N	Y	N	Y
Ebrahim, 1997 ³⁹	0.55	F/PY	165	24	1.29 (0.90-1.83)	N	Y	N	N	N	Y	N	Y	N	N	Y	Y	Y	Y	N
Faber, 2006 ⁴⁰	2.50	FR	278	12	1.32 (1.03-1.69)	N	Y	Y	N	Y	N	N	Y	Y	N	Y	Y	N	N	N
"Functional walking"																				
Tai Chi					0.96 (0.76-1.22)	N	Y	Y	Y	Y	N	Y	Y	Y	N	Y	Y	N	N	N
Green, 2002 ⁴¹	31%	Risk ratio	170	9	1.34 (0.87-2.07)	N	Y	N	N	Y	N	Y	Y	Y	N	Y	Y	N	Y	Y
Hauer, 2001 ⁴²	60%	Risk ratio	57	6	0.75 (0.46-1.25)	N	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	N	Y
Korpelainen, 2006 ⁴³	0.53	F/PY	160	30	0.79 (0.59-1.05)	N	N	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Latham, 2003 ⁴⁴	2.7	F/PY	243	6	1.08 (0.87-1.35)	N	Y	Y	N	N	N	Y	N	N	Y	Y	Y	N	Y	Y
Li, 2005 ¹⁰	0.76	F/PY	256	12	0.45 (0.33-0.62)	N	N	Y	Y	Y	N	N	N	N	N	N	Y	Y	N	Y
Lin, 2007 ⁴⁵	0.88 ^l	FR	150	6	0.67 (0.32-1.41)	N	Y	Y	Y	Y	N	Y	Y	N	Y	Y	N	N	N	N
Lord, 1995 ⁴⁶	0.63	F/PY	197	12	0.85 (0.57-1.27)	N	N	N	Y	Y	Y	Y	Y	N	N	N	Y	Y	N	N
Lord, 2003 ⁴⁷	0.85	IRR (c)	551	12	0.78 (0.62-0.99)	N	Y	Y	Y	Y	Y	Y	Y	N	N	N	N	Y	N	Y
Liu-Ambrose, 2004 ⁴⁸	0.65	F/PY	104	6	1.8 (0.67-4.85)	N	N	Y	N	N	N	N	N	Y	Y	Y	Y	N	N	Y
Agility					1.03 (0.36-2.98)	N	N	Y	Y	Y	Y	N	N	Y	N	N	Y	N	N	Y
Luukinen, 2007 ⁴⁹	1.23	HR-M	486	16	0.93 (0.80-1.09)	N	Y	Y	N	N	N	N	Y	N	N	Y	N	Y	N	Y
McMurdo, 1997 ⁵⁰	0.32	F/PY	118	24	0.53 (0.28-0.98)	N	N	N	N	N	N	N	N	N	N	N	Y	Y	N	N
Madureira, 2007 ⁵¹	0.90	FR	66	12	0.48 (0.25-0.93)	N	N	N	Y	Y	N	Y	Y	N	N	N	Y	Y	N	N
Means, 2005 ⁵²	1.18	FR	338	6	0.41 (0.21-0.77)	N	N	N	Y	Y	Y	Y	Y	Y	Y	Y	Y	N	N	N
Morgan, 2004 ⁵³	31%	HR	294	12	1.05 (0.66-1.68)	N	Y	Y	Y	Y	N	N	N	Y	Y	Y	Y	N	N	Y
Mulrow, 1994 ⁵⁴	2.05	F/PY	194	4	1.26 (0.90-1.76)	Y	Y	Y	N	N	N	N	Y	Y	Y	Y	Y	N	Y	N
Nowalk, 2001 ⁵⁵ strength/endurance	75%	Risk ratio	112	24	0.96 (0.63-1.46)	N	Y	Y	Y	N	Y	N	Y	N	N	Y	Y	N	N	N
Tai Chi					0.77 (0.46-1.28)	N	Y	Y	N	N	N	N	N	N	N	N	N	N	N	N
Protas, 2005 ⁵⁶	37.6	F/PY	18	0.5	0.62 (0.26-1.48)	N	Y	N	Y	Y	Y	N	Y	Y	N	Y	Y	N	N	Y
Reinsch, 1992 ⁵⁷	40%	HR (c)	230	12	1.24 (0.77-1.98)	N	N	N	N	N	N	N	N	N	N	N	N	Y	N	N
Resnick, 2002 ⁵⁸	0.56	FR	20	6	0.71 (0.04-11.58)	N	Y	Y	N	N	Y	N	Y	Y	N	Y	Y	N	N	N
Robertson, 2001 ⁵⁹	1.01	IRR	240	12	0.54 (0.32-0.91)	N	Y	Y	Y	Y	Y	N	Y	N	N	Y	Y	Y	Y	Y

(Continued)

Table 1. (Contd.)

First Author, Year, and Program Type, If Two Intervention Groups	Control Group Falls/Who Fell During Follow-Up Period	Data Extracted	Sample Size at Randomization	Follow-Up (Months)	Estimate of Fall Rate Ratio (95% CI)	High-Support Residential Care ^a	Population at Greater Risk ^b	Average Age 75 and Older	Moderate-to High-Intensity Strength Training ^c	High-Challenge Balance Training ^d	Moderate-to High-Intensity Endurance Training ^e	Stretching Program ^f	Walking Program ^g	Moderately to Highly Supervised Exercise ^h	Exercises Progressed Weekly or More ⁱ	Exercises Modified in Type or Intensity ^j	Good Adherence ^k	50+ Total Hours of Exercise	Concealed Allocation to Groups ^m	Intention to Treat Analysis ⁿ
Rubenstein, 2000 ⁶⁰	2.25	F/PY	59	3	0.90 (0.42-1.91)	N	Y	Y	Y	N	Y	N	Y	Y	N	Y	Y	Y	Y	N
Sakamoto, 2006 ⁶¹	1.14	F/PY	553	6	0.82 (0.64-1.04)	Y	Y	Y	N	N	N	N	N	Y	N	N	Y	N	N	N
Schoenfelder, 2000 ⁶²	3.43	F/PY	16	6	3.06 (1.61-5.82)	Y	Y	Y	Y	N	N	N	Y	Y	N	N	Y	N	N	N
Schnelle, 2003 ⁶³	0.69	F/PY	190	8	0.62 (0.38-0.98)	Y	Y	Y	N	N	N	N	Y	Y	Y	Y	Y	Y	N	N
Sihonen, 2004 ⁶⁴	1.57	F/PY	27	12	0.38 (0.17-0.87)	Y	Y	Y	N	Y	N	N	Y	Y	Y	Y	Y	Y	Y	N
Skelton, 2005 ²¹	3.21	IRR	100	20	0.69 (0.50-0.96)	N	Y	N	N	Y	Y	Y	N	Y	Y	Y	Y	Y	N	Y
Steinberg, 2000 ⁶⁵	0.85	FR (CI)	252	17	0.90 (0.79-1.03)	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N
Suzuki, 2004 ⁶⁶	0.46	F/PY	52	20	0.35 (0.14-0.90)	N	N	Y	Y	Y	N	N	N	N	N	N	N	N	N	N
Toulotte, 2003 ⁶⁷	1.95	F/PY	20	4	0.08 (0.00-1.37)	Y	Y	Y	N	Y	N	N	Y	N	N	N	Y	N	N	Y
Vouklatos, 2007 ⁶⁸	0.74 ^l	IRR	702	6	0.67 (0.46-0.97)	N	N	N	N	Y	N	N	N	N	N	N	Y	N	N	Y
Wolf, 1996 ⁶⁹	3.18	HR-M	200	20	0.51 (0.36-0.73)	N	N	Y	N	Y	N	N	N	N	N	N	Y	Y	N	N
Tai Chi																				
Balance					0.98 (0.71-1.34)	N	N	Y	N	N	N	N	N	Y	Y	Y	Y	N	N	N
Wolf, 2003 ⁷⁰	60%	HR-M (CI)	311	11	0.75 (0.52-1.08)	N	Y	Y	N	Y	N	N	N	N	N	N	Y	Y	N	N
Woo, 2007 ²²	0.52	F/PY	180	12	0.49 (0.24-0.99)	N	N	N	N	Y	N	N	N	N	N	N	Y	Y	Y	N
Tai Chi																				
Strength					0.78 (0.41-1.48)	N	N	N	Y	N	N	N	N	N	N	N	Y	Y	Y	N
Total, n (%)						6 (12)	29 (59)	32 (65)	19 (39)	25 (51)	20 (41)	12 (24)	27 (55)	23 (47)	14 (29)	28 (57)	41 (84)	25 (51)	16 (33)	22 (45)

^a Mainly high-support care facility (nursing home) residents.
^b The presence of a particular falls risk factor was used as inclusion criteria to the study, or the entire population was known to be at greater risk (e.g., aged care facility residents, aged ≥ 75 , impaired strength or balance, previous falls).
^c Moderate intensity (40-60% of the one repetition maximum (1RM); i.e., a weight so heavy that it can only be lifted once) or high intensity (>60% 1RM).
^d Moderately challenging = two of the following criteria or highly challenging = all three criteria: movement of the center of mass, narrowing of the base of support, and minimizing upper limb support.
^e Moderate intensity = 40% to 60% of maximum heart rate, some increase in breathing or heart rate, or perceived exertion of 11 to 14 on the Borg scale; high intensity = >60% of maximum heart rate or heart rate reserve, large increase in breathing or heart rate (conversation is difficult or broken), or perceived exertion of ≥ 15 on the Borg scale.
^f Short- or long-duration stretches were specifically mentioned.
^g Walking program or practice was specifically mentioned.
^h 10 or fewer participants per instructor.
ⁱ Most exercises progressed at least weekly.
^j Type or intensity of most exercises was designed for each individual based on an assessment.
^k $\geq 75\%$ participants attended 50% or more sessions or > 50% attendance rate.
^l ≥ 50 hours of exercise with instructor plus prescribed home exercise over study period.
^{m,n} Coded using PEDro rating scale⁷¹ <http://www.pedro.fhs.usyd.edu.au>.
ⁱ Additional data provided by the author.
 IRR = incidence rate ratios from analysis with negative binomial models from trial reports; F/PY = Falls per person-year (by group) were used to calculate rate ratio; rate ratio = rate ratio from trial reports; FR = fall rates (by group) were used to calculate rate ratios; HR = hazard ratio from Cox models or survival analyses considering time to first fall in trial reports; HR-M = hazard ratio from extensions to Cox models that allow for multiple events from trial reports; HR-4 = hazard ratio from extensions to Cox models that allow for up to four events from trial reports; Risk ratio = risk ratio was calculated from the proportion of fallers in each group; CI = cluster randomized trials; N = no; Y = yes.

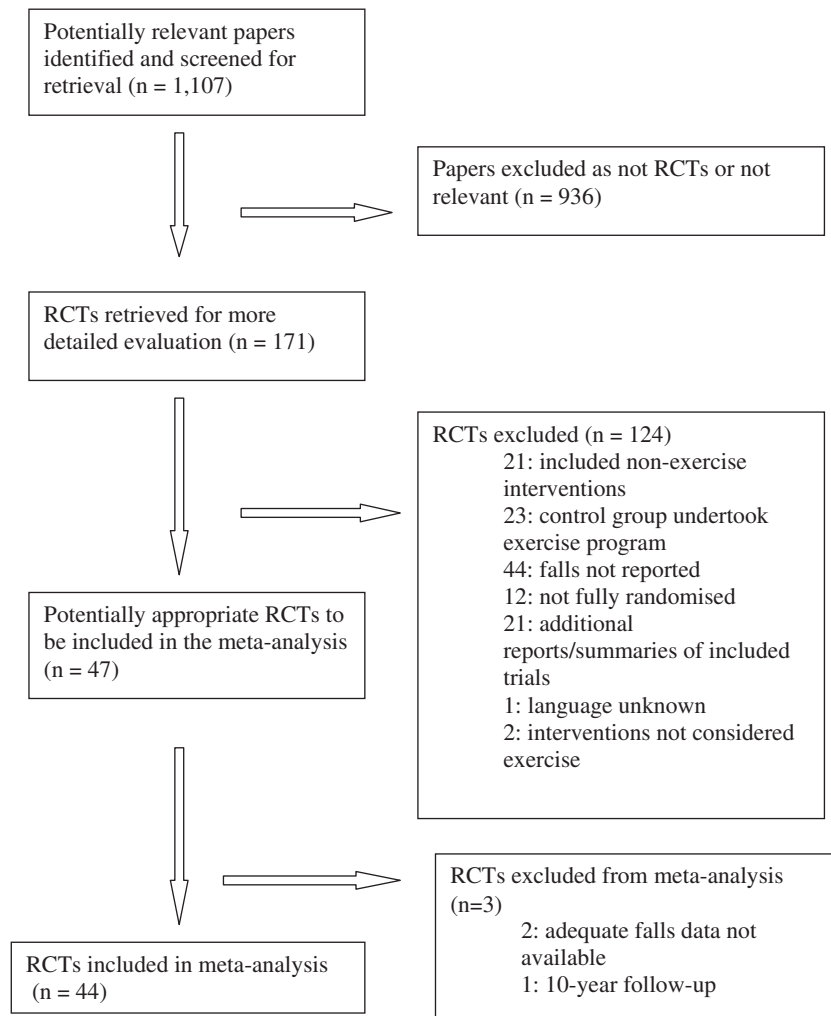


Figure 1. QUOROM statement¹⁶ flow diagram.

Heterogeneity was investigated with random effects meta-regression using the “metareg” command in STATA.¹⁴ Univariate meta-regressions were conducted to assess the associations between each study characteristic and estimates of the effect of exercise. The five strongest predictors were then entered into a multivariate model, and a backwards elimination approach was used to remove those that did not contribute significantly to the model.¹⁵ The best model was identified by examining the proportion of overall between-trial variability explained by each model (as assessed using the τ^2 statistic). Subsequent models were then assessed to determine whether other combinations of the five variables that explained the most variance in the univariate analyses could account for similar variability in exercise effect. The exponentiated coefficients of the meta-regression models were the “ratio of rate ratios,” which estimate of the effect of each variable or combination of variables on the effect of exercise on fall rates. The “lincom” command in STATA was used to assess the effect of specific combinations of variables from the multivariate models on the pooled effect of exercise on fall rates.

To assess the extent of correlation between variables, phi coefficients were calculated for each pair of variables in the models using SPSS (SPSS, Inc., Chicago, IL). Pairs of

variables were not included in the same models if they had phi correlation coefficients greater than 0.6.

RESULTS

Trial Flow and Study Characteristics

Searching yielded 171 trials, of which 47 were potentially appropriate for inclusion in the meta-analysis (Figure 1).¹⁶ Two trials were then excluded, because they did not report sufficient data to estimate effects of exercise on falls, and one trial was excluded because it presented only 10-year follow-up data. Five trials had two intervention groups, so the 44 included trials yielded 49 estimates of the effects of exercise. The included trials involved a total of 9,603 participants. Characteristics of the trials are summarized in Table 1. The majority of trials were conducted in older people living in the general community; six trials were conducted in residents of high care residential facilities (nursing homes). Twenty-nine trials included only participants who could be defined as being at greater risk of falls. Most of the exercise programs ($n = 23$) evaluated in the trials were conducted under supervision, with fewer than 10 participants per instructor. In most of the programs, the intensity or type of exercise was tailored to the individual ($n = 28$).

Effects of Exercise on Fall Rates

The pooled estimate of the incidence rate ratio (the effect of exercise on fall rates) was 0.83 (95% confidence interval (CI) = 0.75–0.91, $P < .001$). There was a moderate to high level of heterogeneity in estimates of the effects of exercise ($I^2 = 62\%$, $Q = 125.5$, degrees of freedom (df) = 48, $P < .001$; Figure 2). No study exerted excessive influence, because omission of any single study had little effect on the pooled estimate (the 95% CIs remained between 0.74 and 0.92). There was no conclusive evidence of small sample bias (Egger’s Test of the Intercept $B0 = -0.675$, 95% CI = $-4.10-0.06$, $t = 1.544$, $df = 47$, $P = .13$, and the funnel plot of standard error and log rate ratio was quite symmetrical). Sensitivity analysis revealed similar effects when the meta-analysis was conducted without the five trials for which only proportion of fallers or time to first fall were available (pooled RR = 0.80, 95% CI = 0.73–0.89, 43 comparisons) and when the four cluster randomized trials were omitted (pooled RR = 0.82, 95% CI = 0.73–0.91, 44 comparisons).

Trial-Level Determinants of Effects of Exercise

The proportion of between-study variability in effect sizes (effects of exercise on fall rates) explained by each of the study

and program characteristics is shown in Table 2. The total dose of exercise (22%, dichotomized as ≤ 50 hours over the trial period) and the presence of highly challenging balance training in exercise programs (19%) explained the most variability. The presence of either of these features in the exercise programs tested in the included trials was associated with a greater reduction in fall rates (ratio of rate ratios = 0.80, 95% CI = 0.65–0.99, $P = .04$ for dose; ratio of rate ratios = 0.76, 95% CI = 0.62–0.93, $P = .009$ for balance training).

There was an indication of a lesser effect of exercise on fall rates in the trials that were conducted in higher-risk populations; this variable explained 12% of between-study variability ($P = .09$). To explore this finding, a post hoc analysis was undertaken using the control rate of falls during the follow-up period dichotomized at 1 (close to the median) and 2 falls per person-year. In the 41 comparisons for which these data were available, there was a lesser effect of exercise on falls in the trials in which the control groups had an average fall rate of 2 or more per person-year (ratio of rate ratios = 1.36, 95% CI = 1.05–1.77, $P = .02$, 17% between-study variability explained).

A meta-regression model with three variables explained 68% of the between-study variability of the effect

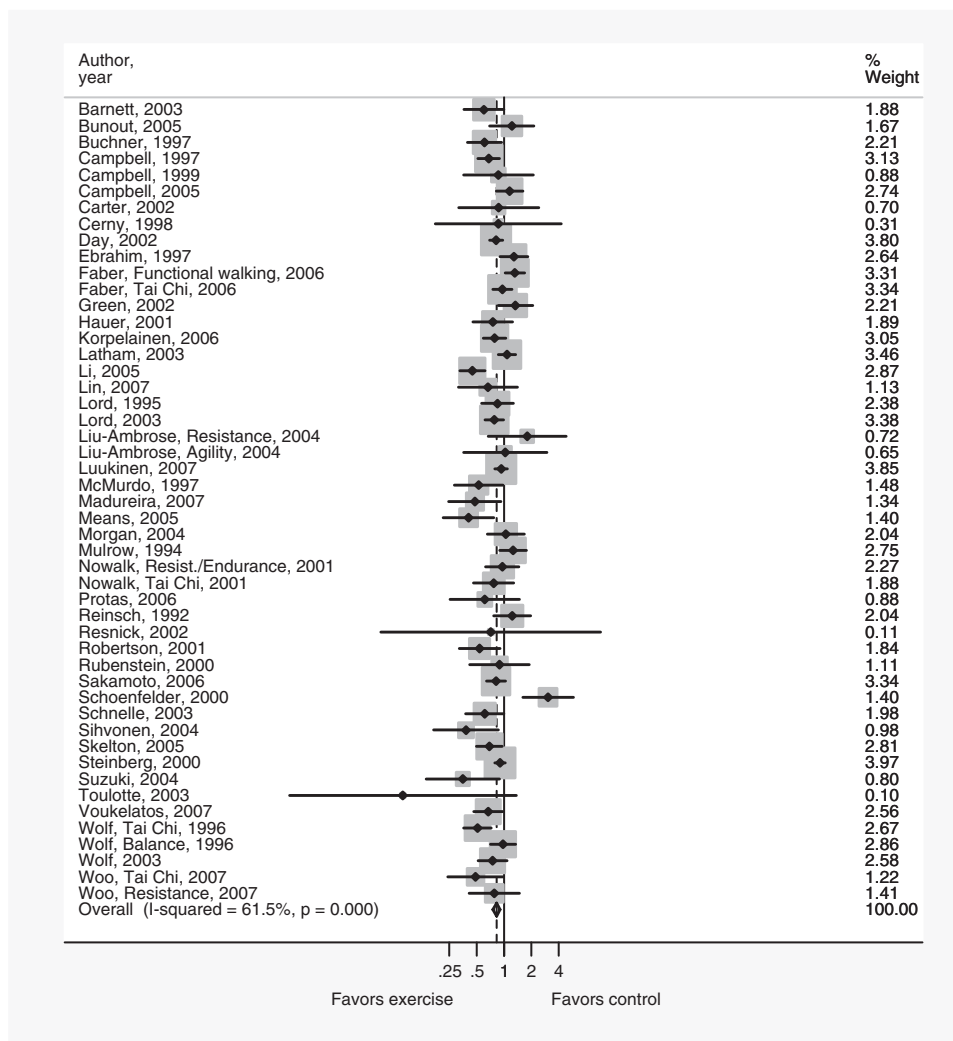


Figure 2. Forest plot from the meta-analysis of exercise on fall rates showing estimates of effect of exercise on falls with 95% confidence intervals and relative weight for each trial.

Table 2. Trial-Level Determinants of Effects of Exercise: Univariate and Multivariate Associations

Characteristic	Comparisons with This Feature, n	Ratio of Rate Ratios (95% Confidence Interval)*	P-Value	Variance Explained, % [†]
Study population				
Mainly care facility residents	13	1.17 (0.92–1.49)	.19	4
Mainly high-support care facility residents	6	1.16 (0.81–1.65)	.41	0
Study population at high risk	29	1.21 (0.97–1.50)	.09	12
Average age ≥ 75	32	1.05 (0.83–1.33)	.66	0
Control group fall rate > 2 per person per year during follow-up period (p1)	10	1.36 (1.05–1.77)	.02	17
Type and intensity of exercise				
Moderate- or high-intensity strength training	19	1.09 (0.87–1.36)	.47	0
High-intensity strength training	5	1.16 (0.81–1.67)	.40	0
Moderate- or high-challenge balance training	34	0.75 (0.60–0.94)	.01	14
High-challenge balance training	25	0.76(0.62–0.93)	.009	19
Moderate- or high-intensity endurance training	20	0.94 (0.75–1.18)	.58	0
Stretching program	12	0.89 (0.69–1.15)	.37	0
Walking program (any)	27	1.19 (0.96–1.46)	.11	9
Longer walking program (≥ 20 minutes)	8	1.07 (0.79–1.45)	.67	0
Exercise program features				
Supervised exercise	41	0.89 (0.68–1.17)	.40	0
Moderately to highly supervised exercise (10 or fewer participants per instructor)	23	1.16 (0.93–1.44)	.18	3
Progressive (monthly or more)	32	1.12 (0.89–1.40)	.34	0
More progressive (weekly or more)	14	1.01 (0.79–1.28)	.96	0
Intensity or type modified (most exercises)	28	1.21 (0.98–1.49)	.08	15
Good adherence	41	0.97 (0.73–1.27)	.80	0
Dose with instructor ≥ 30 hours	25	0.95 (0.77–1.19)	.67	0
Dose of prescribed home program ≥ 30 hours	12	0.84 (0.66–1.07)	.15	2
Total (instructor and home program) dose ≥ 50 hours over trial	25	0.80 (0.65–0.99)	.04	22
Total dose ≥ 8 hours per month (p2)	19	1.04 (0.83–1.30)	.72	0
Total length of exercise program ≥ 12 months (p2)	20	0.98 (0.78–1.22)	.83	0
Study design features				
Concealed allocation to groups	16	1.05 (0.83–1.32)	.69	0
Intention to treat analysis	22	0.91 (0.73–1.12)	.36	3
Multivariate (adjusted)				68
High-challenge balance training	25	0.79 (0.66–0.95)	.01	
Total dose ≥ 50 hours	25	0.80 (0.67–0.96)	.02	
Walking program (any)	27	1.32 (1.11–1.58)	.003	

*The “ratio of rate ratios” is the estimate of the effect of each variable or combination of variables on the effect of exercise on fall rates.

[†]The proportion of between-trial variability (as assessed using the τ^2 statistic) of the model with no covariates that is explained by model with these variable(s) included.

(p1) post hoc analyses undertaken to explore importance of not being at high risk. This analysis includes only the 41 trials for which control fall rate data were available. The percentage variance explained was calculated from the variance in a meta-analysis with these 41 trials only.

(p2) post hoc analyses undertaken to explore importance of total dose.

of exercise on fall rates. In this model, each of the predictor variables (exercise program descriptors) was independently and significantly ($P < .05$) associated with the effect of exercise on falls (Table 2). The regression model was used to obtain adjusted estimates of the effects of exercise on fall rates in studies with and without each of the three predictive characteristics (Table 3). The greatest effects of exercise on falls (RR = 0.58, 95% CI = 0.48–0.69) were obtained from programs that challenged balance to a high extent, included a higher total dose of exercise, and did not include a walking program.

A sensitivity analysis found that excluding the six comparisons from studies undertaken in nursing homes had little effect on the results. The same three variables were retained in the model, and the model explained 65% of intertrial variability.

Models were also developed in which the other two variables that explained more than 10% of between-study variability in univariate analyses (a high-risk population and a tailored exercise program) replaced the variable regarding the inclusion of walking in an exercise program, but these models explained less than 50% of between-study variability.

Table 3. Adjusted Effects of Exercise on Falls

Program	High Balance Challenge	Mod-Low Balance Challenge
	Adjusted Pooled Rate Ratios (95% Confidence Interval)	
High dose and walking	0.76 (0.66–0.88)	0.96 (0.80–1.16)
High dose, no walking	0.58 (0.48–0.69)	0.73 (0.60–0.88)
Low dose and walking	0.95 (0.78–1.16)	1.20 (1.00–1.44)
Low dose, no walking	0.72 (0.60–0.87)	0.91 (0.79–1.05)

The adjusted pooled rate ratios estimate the effects of exercise on fall rates in trials with different combinations of exercise program components.

DISCUSSION

This systematic review provides strong evidence that exercise programs can reduce fall rates in older people. The overall reduction of 17% based on 44 trials involving 9,603 participants provides confidence that these findings are robust and generalizable to a broad section of older people. Furthermore, the meta-regression analysis model revealed that three factors (balance training, exercise dose, and the absence of a walking program) are associated with the efficacy of exercise programs.

The inclusion of balance training in exercise programs appears to be important. This finding is consistent with the Frailty and Injuries: Cooperative Studies of Intervention Techniques prospective meta-analysis of individual participant data from eight trials, which found a pooled estimate of a 17% lower falls risk from exercise programs that included balance training but not from other forms of exercise.¹⁷

Inclusion of balance training may help to explain why several intervention strategies that appear to be different are similarly effective in substantially reducing fall rates. For example, effective programs, such as Tai Chi¹⁰ conducted in a group setting and the home-based Otago Exercise Programme,¹⁸ primarily include balance training. These trials also show that, with appropriate prescription and supervision, exercise that challenges balance can be administered safely. For example, it has been demonstrated that the Otago Exercise Programme is feasible and safe for older people to undertake at home and produced a 35% reduction in falls and falls-related injury.¹⁸

Total exercise dose also explained a significant and independent amount of variability with regard to the effectiveness of the exercise trials. This finding is consistent with trials of stroke rehabilitation, which have found better outcomes with more-intense exercise.¹⁹ The measure of exercise dose combined frequency of exercise on a weekly basis with program length, and this measure proved to be superior in discriminating between less-effective and more-effective trials than weekly exercise frequency or program length when analyzed separately. Although programs varied markedly with regard to these factors, the criterion for a minimal effective exercise dose would equate to a twice-weekly program running over 25 weeks. This finding has important implications for service delivery, because many programs are offered for shorter periods than this, typically for 10 weeks. Strategies for achieving long-term exercise participation could include combining supervised group exercise with interspersed or follow-on home exercise programs.

Exercise programs that did not include walking reduced fall rates more than exercise programs that involved walking. One explanation might be that participants are exposed to greater risk of falls while walking, although the published trials do not indicate that many falls occurred when participants were undertaking the prescribed walking programs. An alternative explanation is that time spent walking takes the place of time spent undertaking balance training (the most effective exercise) in time-limited programs. Falls are not the only important outcome for exercise trials in older people, and other studies have shown that walking programs have health benefits including improved fitness, weight loss, and lower blood pressure.²⁰ For these reasons, walking programs could be included in exercise programs for older people, but if fall prevention is the primary aim, walking programs should be included only if they are in addition to a balance training program of adequate intensity and duration. Ideally, there should also be some assessment of whether a walking program will unduly increase the risk of falls for individual participants. Further research into the relationship between walking programs and falls is required.

There is an indication that lesser relative reductions in fall rates were seen in studies of exercise that included people at a high risk of falls. This provides support for a population-based approach to falls prevention with appropriate exercise. However the absolute effects of exercise may be greater in high-risk populations, such as nursing home residents or those with previous falls. For example, one trial²¹ found a 31% difference between fall rates in the intervention and control groups in a sample of multiple fallers in which the control group fall rate was 3.2 falls per person-year. This equates to the prevention of 1 fall per person-year. A trial in a lower-risk population in which the control group rate was 0.52 falls per person-year²² found a 51% between-group difference, which represented the prevention of 0.27 falls per person-year. It could also be argued that the consequences of falls (e.g., fracture rates, hospital admissions, and moves to institutional care) may also be more significant in higher-risk populations. For these reasons, exercise for falls prevention should be undertaken in populations at high risk and in the general older community.

The studies that were conducted in high-risk populations were more likely to include walking programs ($\phi = 0.42$, $P = .003$) and modified exercise ($\phi = 0.46$, $P < .001$). No two of these three variables simultaneously made an independent contribution to the models. Thus it is possible that risk status confounds the effect of walking and modifying of exercise on falls.⁹

Although poorer muscle strength is a risk factor for falls,²³ the presence of moderate- or high-intensity strength training was not found to be associated with a greater effect of exercise on falls. This finding is more definitive than previous meta-analysis findings. One previous study⁷ found some indication of an effect of strength training on the proportion of fallers (pooled adjusted risk ratio from 9 studies was 0.82, 95% CI = 0.48–1.41) but not on the rate of falls (pooled adjusted incidence RR from 14 studies was 1.04, 95% CI = 0.76–1.42), and another¹⁷ found the pooled effect of resistance training on falls to be 0.96 ($P = .59$). It is likely that impaired balance is a stronger risk

factor for falls than poor muscle strength and that this finding is in keeping with previous findings that strength training increases strength but has less-clear effects on balance abilities.^{24,25} Nevertheless, the relationship between strength and falls may be nonlinear. This may mirror the nonlinear relationship between strength and gait speed²⁶ (i.e., once a person has sufficient strength to avoid falling, further strength training may not be of additional benefit). Like walking programs, strength training is likely to provide many older people with other health benefits,^{25,27} but it does not seem to be the optimal intervention for falls prevention.

This systematic review had certain limitations. First, because a meta-regression of trial-level characteristics was used, some caution is warranted when interpreting the findings.²⁸ The analysis permits inference only about the effects of trial-level characteristics (e.g., whether the trial included high-risk participants or average exercise dose) on trial-level estimates of effects of exercise. Inferences cannot be made about the effects of the characteristics of individuals (e.g., presence of risk factors in individual participants) or of participant-specific features of the intervention (e.g., the dose of exercise given to an individual) on the effects of exercise on falls risk in individual participants.²⁹ Despite multivariate adjustment, there is the possibility that the conclusions are subject to confounding by unmeasured variables or by failure to adjust completely for measured variables. There is also a possibility that the coding of program content does not reflect the real nature of the program, because the coding was based on the short descriptions of often-complex programs in the published articles. Nonetheless, the findings are consistent with the little that is known about optimal exercise protocols from analyses at the level of individual participants.¹⁷

In conclusion, this analysis confirms that exercise can reduce fall rates in older people and identifies the important components of effective exercise intervention strategies. It confirms the importance of balance training in falls prevention and the need for exercise to be sustained over time. Service providers can use these findings to design and implement exercise programs for preventing falls.

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