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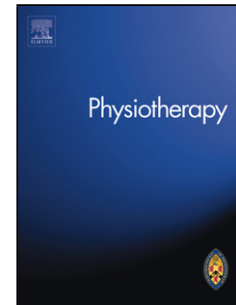
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Long-term follow-up of exercise interventions aimed at preventing falls in older people living in the community: a systematic review and meta-analysis

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Abstract

Background

Fall-related injuries are the leading cause of accident-related mortality for older adults, with 30% of those aged 65 years and over falling annually. Exercise is effective in reducing rate and risk of falls in community-dwelling adults; however, there is lack of evidence for the long-term effects of exercise.

Objectives

To assess the long-term effect of exercise interventions on preventing falls in community-dwelling older adults.

Data Sources

Searches were undertaken on MEDLINE, EMBASE, AMED, CINAHL, psycINFO, the Physiotherapy Evidence Database (PEDro) and The Cochrane Library from inception to April 2017.

Study selection

Randomised controlled trials (RCTs), cohort studies or secondary analyses of RCTs with long-term follow-up (>12 months) of exercise interventions involving community-dwelling older adults (65 and over) compared to a control group.

Data extraction/Data synthesis

Pairs of review authors independently extracted data. Review Manager (RevMan 5.1) was used for meta-analysis and data were extracted using rate ratio (RaR) and risk ratio (RR).

Results

Twenty-four studies (7818 participants) were included. The overall pooled estimate of the effect of exercise on rate of falling beyond 12-month follow-up was rate ratio (RaR) 0.79 (95% confidence interval (CI) 0.71 to 0.88) and risk of falling was risk ratio (RR) 0.83 (95% CI 0.76 to 0.92) Subgroup analyses revealed that there was no sustained effect on rate or risk of falling beyond two years post-intervention.

Conclusions

Falls prevention exercise programmes have sustained long-term effects on the number of people falling and the number of falls for up to two years after an exercise intervention.

Contribution of the paper:

- There is a shortage of data relating to the possible long-lasting effects of falls prevention exercise interventions for older adults.
- Previous systematic reviews have assessed the effect of falls prevention exercise programmes for up to 12-months; this review evaluates the sustained effect of falls prevention exercise programmes beyond a year.
- This review provides evidence of the long-term effect of certain falls prevention exercise interventions.

Key words: falls prevention, exercise, older adults, long-term effects

Systematic review registration number: CRD42017062461

Introduction

As the proportion of older people continues to increase, managing long-term health conditions, including the prevention of falls, remains a global public health challenge. Fall-related injuries are the leading cause of accident-related mortality and disability for older adults (1), with 30% of those aged 65 years and over falling at least once per year, and risk of falling increasing with age (2).

Falls have a multifactorial aetiology, associated with identifiable and some modifiable risk factors, including lack of physical activity, and commonly, disturbances of gait and balance and loss of lower limb strength (3). Appropriately designed exercise programmes have been established as an effective stand-alone intervention for reducing risk and rate of falls in community-dwelling older people (4).

The UK physical activity guidelines are due to be reviewed and updated in 2018, but current guidelines recommend that adults aged 65 and over should be undertaking at least 150 minutes of moderate intensity activity per week. This includes muscle strengthening on at least two days and for those at risk of falls, incorporating exercises for balance and coordination on at least two days each week (5). Best practice recommendations suggest that falls prevention exercise programmes should include moderate to high challenge balance exercises; must be of sufficient dose (2-hours per week for at least 6-months) and that ongoing exercise is essential (6).

As fall prevention interventions can take time to for benefits to accrue, the recommended follow-up period for fall prevention clinical trials is 12 months (7). Few community-based randomised controlled trials (RCTs) of exercise to prevent falls extend data collection beyond this time point (8, 9). This is highlighted in a recent systematic review of exercise to prevent falls in older adults, where the mean (SD) duration of follow-up was 51 (27) weeks (6). There is a shortage of follow-up data relating to the possible long-lasting effects of exercise in older adults, and uncertainty whether there

is ongoing maintenance of any accrued benefit from exercise and changes to health behaviours beyond the end of a trial intervention (8, 10). It is an important public health question to determine whether prevention interventions are effective and potentially cost-effective in the long-term.

Therefore, the aim of this systematic review and meta-analysis was to determine whether there was any evidence for the long-term effects of falls prevention exercise programmes on rate and risk of falling for community dwelling older people aged 65 years and over.

Methods

This systematic review was conducted in accordance with the PRISMA guidelines (11). The review protocol was prospectively registered on 11/04/2017: (CRD42017062461; https://www.crd.york.ac.uk/PROSPERO/display_record.asp?ID=CRD42017062461)

Selection Criteria

This review included any study examining the long-term effectiveness of exercise designed to reduce falls in older people. Eligible studies included RCTs, follow-up studies or secondary analyses of RCTs where follow-up was conducted 12-months or more from the date of participant recruitment or randomisation.

Participants: any study targeting community-dwelling (living in their own home, excluding long-term care) adults aged 65 years and over. Trials testing interventions designed to prevent falls in hospital, or targeted at people with specific medical conditions such as stroke, Parkinson's disease and multiple sclerosis were excluded.

Interventions: Studies were eligible if the exercise intervention was designed to prevent falls. Eligible comparisons included 'usual care', a 'placebo' control intervention or another falls prevention intervention not involving exercise e.g. vitamin D supplementation, environmental modifications. Studies testing single component exercise interventions i.e. walking, or interventions with multiple

exercise components i.e. a combination of two or more categories of exercise such as Tai Chi and walking were included. Multi-arm trials were included, but only those where one of the treatment arms was exercise alone (as opposed to exercise combined with other interventions such as medication or environmental reviews) with data reported separately compared to control.

Outcomes: The primary outcomes of interest were rate of falls and number of people falling. Studies that reported data on rate (incidence) of falls and/or number of participants sustaining at least one fall were included. Prospective data collection, using monthly calendars, postcards or diaries, is considered the gold standard for collecting data on falls (7, 12). However, RCTs often use postal questionnaires to capture falls data retrospectively by asking participants about previous falls over a specific period. Therefore, as per the Cochrane falls prevention reviews (4), we included both prospective and retrospective data collection methods.

Search strategy

Searches were undertaken on MEDLINE, EMBASE, AMED, CINAHL, psycINFO, the Physiotherapy Evidence Database (PEDro) and The Cochrane Library from the earliest record to April 2017. Studies published in the English language were included. Key search terms included relevant Medical Subject Headings (MeSH) and free text including falls, prevention, and exercise, physical activity, long-term and follow-up with modifications for each database as necessary. The search strategy is available in Appendix 1. In addition, reference lists of the included studies and other relevant texts were manually searched.

Data collection

Based on the selection criteria, titles and abstracts of identified studies were screened for possible inclusion (SF). Subsequently, full texts were assessed for potential inclusion. Pairs of review authors (SF and JB/KS) independently extracted data including the following study characteristics: study design, duration, and participant information, description of interventions, outcome measures and

reported data. Any discrepancies were resolved via discussion. Each exercise intervention was classified using the Prevention of Falls Network Europe (ProFaNE) taxonomy (13).

Assessment of risk of bias in included studies

The Cochrane Collaboration's tool for assessing risk of bias in randomised trials was used (14). The following domains for risk of bias were assessed by pairs of review authors (SF/JB and SF/KS) : random sequence generation (selection bias); allocation concealment (selection bias); blinding of participants (not possible to blind participants in trials of exercise interventions) and personnel (performance bias); blinding of outcome assessment (detection bias); incomplete outcome data (attrition bias); selective reporting (reporting bias) and any other bias (14). Differences were resolved by discussion.

Measures of treatment effect

Outcome data were categorised by follow-up time point as either falls occurring between 12-24 months or beyond 24 months after recruitment or randomisation.

Rate of falls is the total number of falls per unit of time of falls monitoring e.g. falls per person years (4). The rate ratio (RaR) compares the rate of falls between the intervention and control group within each study. The treatment effect of exercise on rate of falls is reported as an unadjusted incidence rate ratio (IRR) with 95% confidence interval (CI) if these were reported.

Where the RaR was not reported, this was calculated from the total number of falls divided by the length of time falls were monitored (person years) for participants contributing data. We calculated the standard error of the RaR using the formula given in the Cochrane Handbook for Systematic Reviews of Interventions (14). The analytical approach assumed that participants were followed-up for the maximum period unless otherwise reported. When calculating the RaR, we used an available case analysis i.e. included data from every participant for whom the outcome was obtained at follow-up out of the denominator randomised (14).

Number of people falling at least once (risk of falling) is a dichotomous outcome and, therefore, was analysed as a risk ratio. The risk ratio compares the number of people who fell once or more. We extracted or calculated relative risk (RR) and 95% CI if reported.

Where trials had multiple exercise intervention arms but one control group, the control group was apportioned appropriately to prevent double counting (14).

Data synthesis

The primary analysis was an overall synthesis of the effect of exercise versus control on falls occurring within both specified time points of interest. Subgroup analyses were planned, as pre-specified in the protocol, to investigate whether exercise modality (single versus multiple exercise component interventions) and duration of exercise interventions and follow-up impacted upon outcomes. Exercise modality was grouped using the ProFaNE categories.

Duration of exercise intervention was categorised as <6 months, 6-12 months and >12 months. Each subgroup analysis was considered by length of follow-up i.e. between 12-24 months or >24 months from recruitment or randomisation.

All forest plots were compiled using the generic inverse variance method in Review Manager (RevMan 5.1). A random effects model was used due to expected clinical and statistical heterogeneity amongst the interventions. The I^2 statistic was used for measuring heterogeneity. This statistic describes the percentage of variability in effect estimates that is due to heterogeneity rather than chance (14).

Results

Study Selection

Electronic searches generated 515 studies. After removal of duplicates and ineligible studies (Figure 1), 29 studies were potentially eligible for inclusion. Five trials were excluded on full review because

they did not follow up participants for longer than 12 months (n=1) or report rate of falls or number of people falling (n=4).

INSERT FIGURE 1

The systematic review includes 24 studies with 7818 participants. Of these, 16 were RCTs and eight were either cohort studies or secondary analyses of RCT data. Sample sizes ranged from 52 (15) to 1235 participants (16) with a median of 231 participants. Overall, 79% of the included participants were women; 11 trials (46%) included females only.

Four trials had two exercise groups for comparison with one control group (16-19). For these trials, the numbers of participants and falls in the control groups were apportioned appropriately. A total of 28 comparisons were undertaken.

Study Characteristics

Characteristics of the trials are summarised in Table 1. One USA trial (8) recruited participants aged 50-65 years but long-term follow-up was carried out ten years later, therefore, the mean age of the participants was 70.9 (SD 4.28) and 70.3 (SD 4.03) years in the intervention and control group, respectively. Another trial recruited adults aged 60 and older but mean age was 72 (SD 8.1) years (20). A sensitivity analysis was undertaken on the primary analysis and exclusion of these studies did not change the direction or magnitude of summary of effect. These two studies were therefore included in the final analyses. Nine studies used retrospective falls data collection methods rather than the gold standard prospective falls diary method (8, 9, 15, 16, 21-25). A post-hoc sensitivity analysis was undertaken to explore impact on falls rate; exclusion of these nine studies did not change the magnitude of the effect estimate, therefore, all studies were included in the meta-analysis.

INSERT TABLE 1

Interventions: Of the 24 included studies, 15 (63%) tested multiple exercise component interventions (10, 15, 21, 24-31) and nine (38%) tested a single exercise intervention (8, 9, 20, 22, 23, 32-35). Four of the studies compared two exercise interventions: two compared multiple exercise component interventions (16, 19), one compared a single component intervention and a multiple exercise component intervention (17) and finally, one tested a single intervention of different frequencies of Tai Chi (3D) (18).

All but four trials (8, 18, 20, 22) included gait, balance and functional training within the exercise intervention. These four studies investigated either single 3D interventions of Tai Chi or general physical activity i.e. walking.

The duration of exercise intervention varied from relatively short-term interventions of less than 6-months duration (range 12-20 weeks; n=7 studies) (18, 19, 23, 24, 26, 28, 33), those lasting between 6 and 12 months (n=9 studies) (9, 10, 15-17, 20, 32, 34, 35) and those testing exercise interventions of longer than 12-months duration (range 12-24 months; n=8 studies) (8, 21, 22, 25, 27, 29-31).

Duration of follow-up

The range of follow-up time points from recruitment or randomisation varied across the studies from 16-months to 10 years. Twenty-one (88%) studies followed participants up for between 12-24 months. Of these, seven trials (21, 22, 25, 27, 29-31) collected outcome data from participants immediately at the end of the exercise intervention at either 16, 18, or 24 months. Eight trials collected follow-up data 12-months after the intervention ended (10, 17, 18, 20, 23, 33-35). The remaining nine studies collected outcome data at 14 months (15, 26, 28), 16 months (32), 20 months (19), 37 months (9), 45 months (24) and 10 years (8) after delivery of the exercise intervention.

Outcomes

Rate of falls were clearly reported in 11 studies and was calculated using reported data for 12 studies. The remaining study did not include sufficient data to calculate falls rate but did report results on risk of falling. Data on risk of falling (number of people falling) were available for 18 studies.

Risk of bias within studies

Risk of bias for each study is shown in Figure 2. Based on the overall key risk of bias items, 13/24 (54%) studies were rated low risk of bias (three or more items judged at low risk). For individual risk of bias items, half (12/24) failed to adequately describe either sequence generation or allocation concealment. Almost all studies (23/24; 96%) were judged at high risk of performance bias, as it was not possible to blind participants and personnel delivering an exercise intervention. Four studies (17%) were at either high or unclear risk of detection bias and 11 studies (46%) had high or unclear risk of attrition bias because of losses over time.

INSERT FIGURE 2

Effects of Exercise on Rate and Risk of Falling

The overall pooled estimate of the RaR for the effect of exercise on fall rates beyond 12-month follow-up was 0.79 (95% CI 0.71 to 0.88; 6250 participants, 23 studies, Figure 3.1). A RaR value of 0.79 indicates that participants in the exercise interventions had a 21% lower rate of falls after one year compared to those receiving a control intervention. Based on the 95% CI, the range for this estimate was from 12% to 29%. (The 95% CI is the interval of values in which the true rate ratio is likely to lie with a probability of 95%). However, there was moderate to substantial statistical heterogeneity in the estimate of the effect of exercise ($I^2 = 60\%$).

INSERT FIGURE 3.1

The overall pooled estimate of the effect of exercise on risk of falling (RR) was 0.83 (95% CI 0.76 to 0.92; 4690 participants, 18 studies, 21 interventions, Figure 3.2) with evidence of moderate statistical heterogeneity ($I^2 = 55\%$). A value of 0.83 indicates that participants in the exercise interventions had a lower risk of sustaining at least one fall after one year compared to those participants receiving the control interventions. Those receiving exercise had a 17% lower risk of sustaining at least one fall after one year (relative risk reduction).

INSERT FIGURE 3.2

Exercise type: Multiple component exercise interventions versus control

Overall, in studies testing multiple exercise component interventions i.e. a combination of two or more categories of exercise, there was a 18% reduction in rate of falls beyond 12 months when compared to control interventions (RaR 0.82; 95% CI 0.74 to 0.91; 4323 participants, 14 studies, 15 interventions, $I^2 = 55%$, Table 2). There was also a reduction in the risk of falling (9%) beyond 12 months (RR 0.91, 95% CI 0.85 to 0.96; 2710 participants, 8 studies, 9 interventions; $I^2 = 0%$, Table 2).

INSERT TABLE 2*Single component exercise interventions versus control*

Similarly, single component exercise interventions reduced rate of falls (RaR 0.65, 95% CI 0.48 to 0.87; 1932 participants, 10 studies, 11 interventions, $I^2 = 67%$, Figure 4.3) and risk of falling in the longer-term (RR 0.74, 95% CI 0.60 to 0.90; 1980 participants, 11 studies, 12 interventions, $I^2 = 64%$, Figure 4.4).

Duration of exercise interventions

Studies testing exercise interventions of less than six months in duration suggested a 21% reduction on rate of falls beyond 12 months (RaR 0.79, 95% CI 0.72 to 0.87, 1575 participants, 6 studies, 8 interventions, $I^2 = 60%$, Table 2). There was no difference in the risk of falling between intervention and control (RR 0.89, 95% CI 0.77 to 1.03, 1334 participants, 5 studies, 6 interventions, $I^2 = 49%$, Table 2).

The studies testing exercise interventions of 6-12 months duration reduced rate of falls by 33% (RaR 0.67, 95% CI 0.56 to 0.80, 1732 participants, 9 studies, 11 interventions, $I^2 = 57%$, Table 2) and risk of falling by 36% beyond 12 months (RR 0.64, 95% CI 0.48 to 0.85, 1540 participants, 7 studies, 8 interventions, $I^2 = 67%$, Table 2). Similarly, the trials testing longer exercise interventions of >12 months in duration resulted in a reduction in rate and risk of falling (RaR 0.88, 95% CI 0.82 to 0.94, 8 studies, 2943 participants, $I^2 = 51%$, Table 2) and (RR 0.91, 95% CI 0.85 to 0.98, 1727 participants, 5 studies, $I^2 = 0%$, Table 2).

Duration of follow-up

Overall, the exercise interventions in studies whereby participants were followed-up for up to 24-months after randomisation showed a 21% reduction in rate of falls (RaR 0.79, 95% CI 0.70 to 0.88; 5929 participants, 20 studies, 24 interventions, $I^2 = 64\%$, Table 2) and 17% reduction in risk of falling (RR 0.83, 95% CI 0.75 to 0.93, 4442 participants, 16 studies, 19 interventions, $I^2 = 59\%$, Table 2). However, the three studies with follow-up beyond 24 months found no effect on rate (RaR 0.80, 95% CI 0.60 to 1.06; 321 participants, 3 studies, $I^2 = 0\%$, Table 2) or risk of falling (RR 0.79, 95% CI 0.61 to 1.03; 248 participants, 2 studies, $I^2 = 0\%$, Table 2).

Discussion

This systematic review of exercise interventions for falls prevention found evidence that exercise programmes have sustained benefits on falls reduction over time. This meta-analysis of 24 studies found that exercise interventions can reduce rate and risk of falling in community-dwelling older people beyond a year when compared to a control intervention. The overall long-term reduction in rate of falls was 21% (range 12% to 29%), based on 23 studies involving 6250 participants, and risk of falling was reduced by 17% (range 8% to 24%), (18 studies; 4690 participants).

Using the ProFaNE taxonomy classification, gait, balance and functional training exercises (13), are the most frequently used and considered the most effective type of exercises to include in a falls prevention programme (36). In this review, 20/24 (83%) of the studies included this category of exercise intervention. When incorporated in multiple exercise component interventions, gait, balance and functional training exercises reduced rate and risk of falling by 18% and 9%, respectively. When tested as single component interventions, gait, balance and functional training programmes (9, 32-35) were found to reduce rate of falls (55%) but not risk of falling. 3D (Tai Chi) interventions (18, 20) were the only single component interventions to significantly reduce risk of falling (16%). Single interventions of strength/resistance exercises and general physical activities i.e. walking, were not found to be effective in reducing rate or risk of falling.

These findings support the recommendations by Sherrington *et al.* (36) for the essential components to include in falls prevention exercise programmes. Gait, balance and functional training exercises (with an emphasis on balance exercises) are an essential element of either a single or multi-component falls prevention exercise intervention. This review suggests that this category of exercise also has long-term benefits on falls prevention.

This review found that the various falls prevention interventions being tested may have slightly different long-term effects, impacting on rate of falls and number of fallers differently, and therefore, this must be taken into account when designing interventions. The ProFANE expert group (7) recommend that falls prevention trials include rate and risk of falling as key outcomes, both of which were examined in this review. These outcomes are clinically important as every fall carries a risk of injury, therefore, interventions that reduce rate of falls have clinical and economic significance. From a public health perspective, delaying time to first fall by reducing risk of falling is also an important clinical outcome (4).

Our results support the recommendations by Sherrington *et al.* (6) regarding the essential components to include in falls prevention exercise programmes. Gait, balance and functional training exercises (with an emphasis on balance exercises) are an essential element of either a single or multiple exercise component falls prevention exercise intervention. Our review findings suggest that this type of exercise also has long-term benefits on falls prevention.

Similarly, our review findings concur with recommendations that falls prevention exercise interventions should be of at least six months duration (36). We found that exercise interventions delivered over a longer duration, lasting from six months to a year, reduced rate and risk of falling by a third. However, in a survey of 231 NHS falls prevention services, programme length varied in the 188 (81%) services providing an exercise intervention, ranging from programmes lasting two to 24 weeks, with a mean exercise programme length of only eight weeks (SD 3 weeks) (37). In our review,

the pooled results of shorter interventions such as those delivered in NHS settings (<6 months), did reduce rate of falls (21%) but were not found to reduce risk of falling.

Overall, the pooled results of the 21 exercise interventions in studies following up participants for up to 24 months had a 21% and 16% reduction on rate and risk of falling respectively. This is despite different durations of intervention and time to follow-up data collection. Only three studies followed up participants for more than two years (8, 9, 24). Of these, two studies followed participants up to four years and one to 10-years. When data were pooled, there was no evidence that these interventions had any long-term effect on falling. Individually, the studies did suggest an effect on rate and risk of falling long-term, as they found that those in the intervention arms experienced fewer falls beyond two years compared with those in the control arms, but these results were not statistically significant when pooled.

Study limitations

The findings of the review are limited by and should be interpreted with caution due to the moderate to substantial statistical and clinical heterogeneity of the included studies. There is a risk that the effects of exercise on rate and risk of falling may be overestimated because of methodological weaknesses in nearly half of the included studies.

Although the interventions were grouped using the ProFaNE taxonomy, the content of exercise programmes was diverse, and studies also varied widely in terms of mode and duration of delivery. It was not possible to evaluate finer level detail, such as extent of participant attendance, adherence or quality of prescribed exercise e.g. whether individually or group-delivered sessions.

There was variability in the methods used to collect outcome data to capture falls. Over half of studies used the gold standard prospective falls diaries/calendars but nine studies used retrospective self-report which rely upon memory recall of past events, possibly resulting in recall bias (12). However, the sensitivity analyses by data collection method did not change the direction or magnitude of estimate of effect.

The majority of the included participants were female (79%). Although women are more likely to fall compared to men, gender specific differences in falls risk do exist and this along with these other limitations must be taken into consideration when generalising the results to the wider population and in the design of falls prevention interventions (38).

Finally, the quantity of studies following-up trial participants beyond two years was limited, with only three studies collecting data in the longer term. There may be other broader health-related benefits from older adults undertaking exercise programmes, such as improvements in cardiovascular function or psychological health. Although long-term follow-up is rarely used as a primary outcome in the falls prevention field, the effectiveness, safety and the economics of falls prevention interventions could be judged more fully in light of the knowledge gained from longer term follow-up of clinical trials.

Conclusion

There is evidence that certain types of falls prevention exercise programmes have long-term effects on falling and these effects may be sustained up to two years after an exercise intervention. The impact of exercise interventions on falls appear to decline after two years, although few studies undertake follow-up beyond this timeframe. Future studies should consider performing long-term follow-up to fully understand the sustained health benefits from falls prevention interventions delivered to community-dwelling older adults.

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Conflict of interest: None declared

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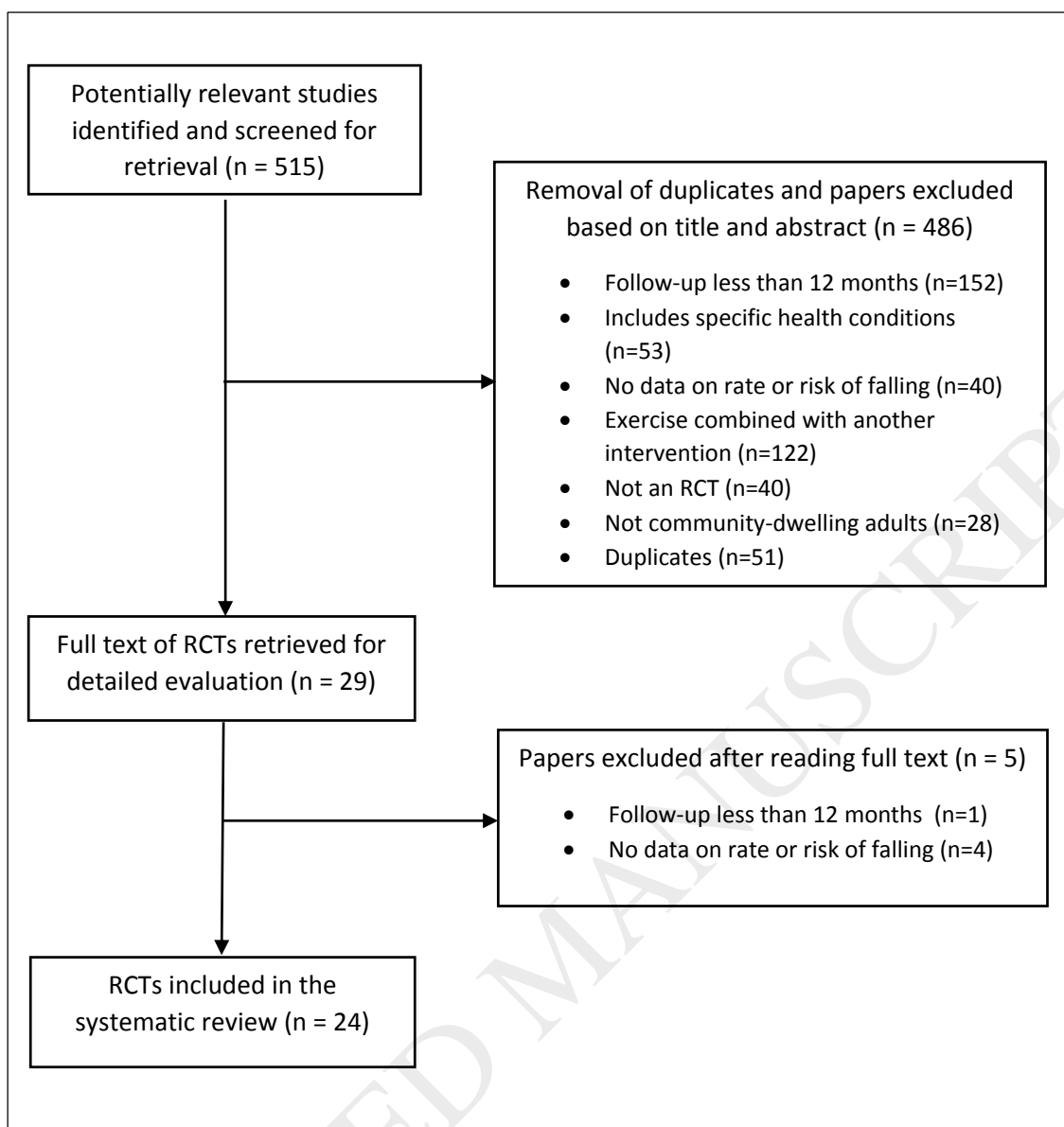


Figure 1. Flow diagram of search and study selection process

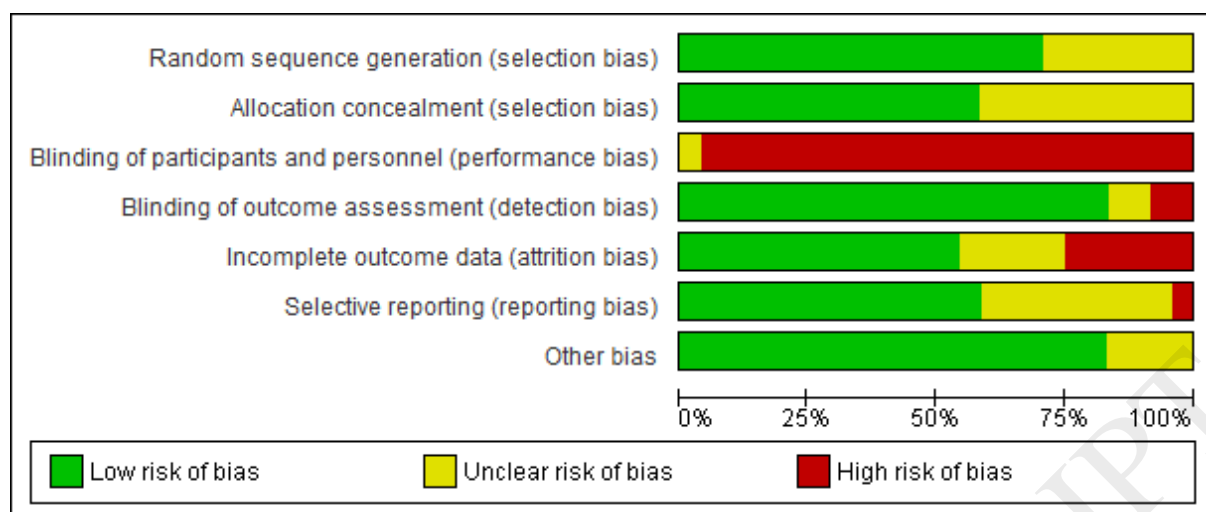


Figure 2. Risk of Bias Graph

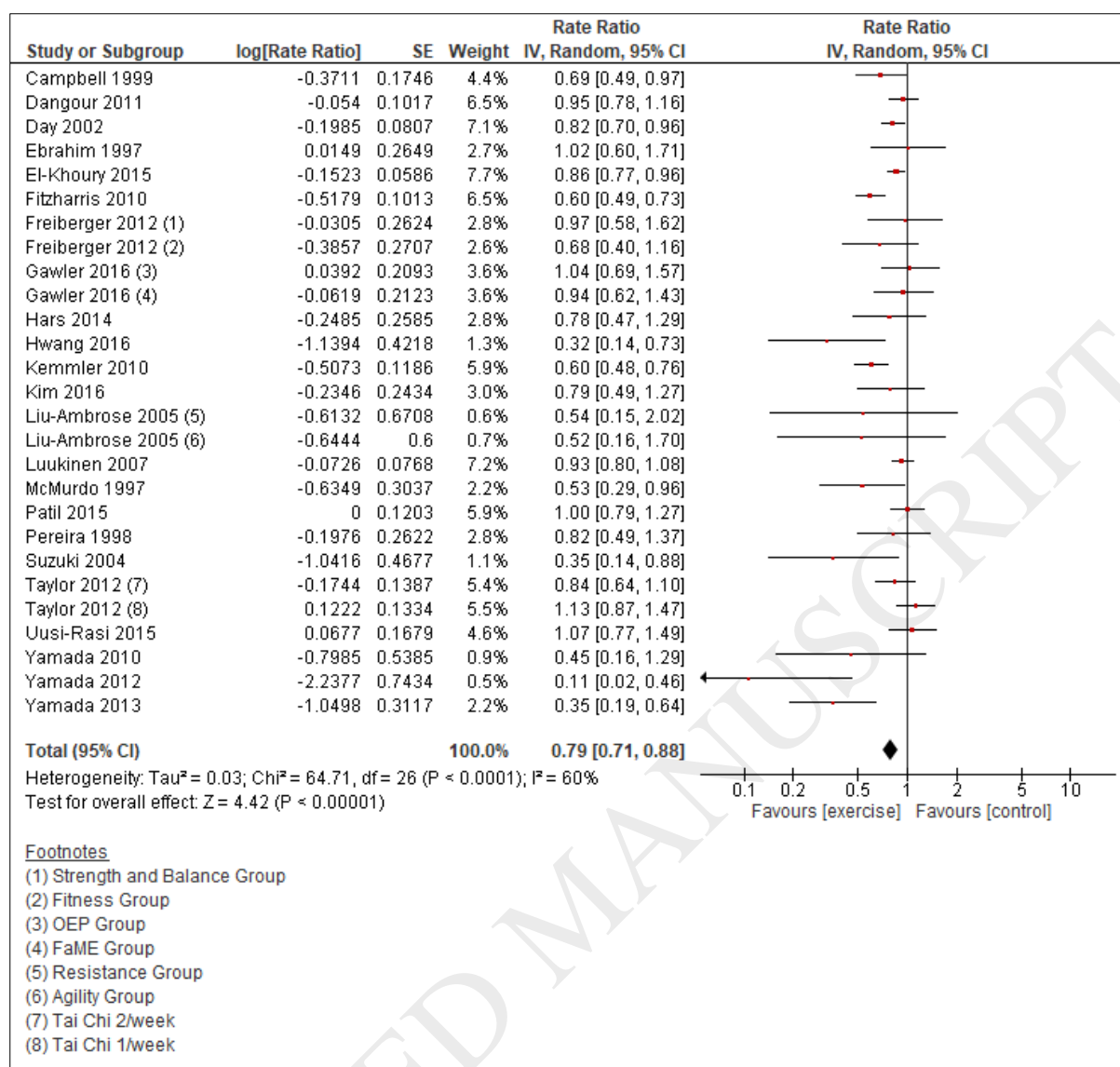


Figure 3.1 Exercise vs control, Outcome 1, Rate of falling

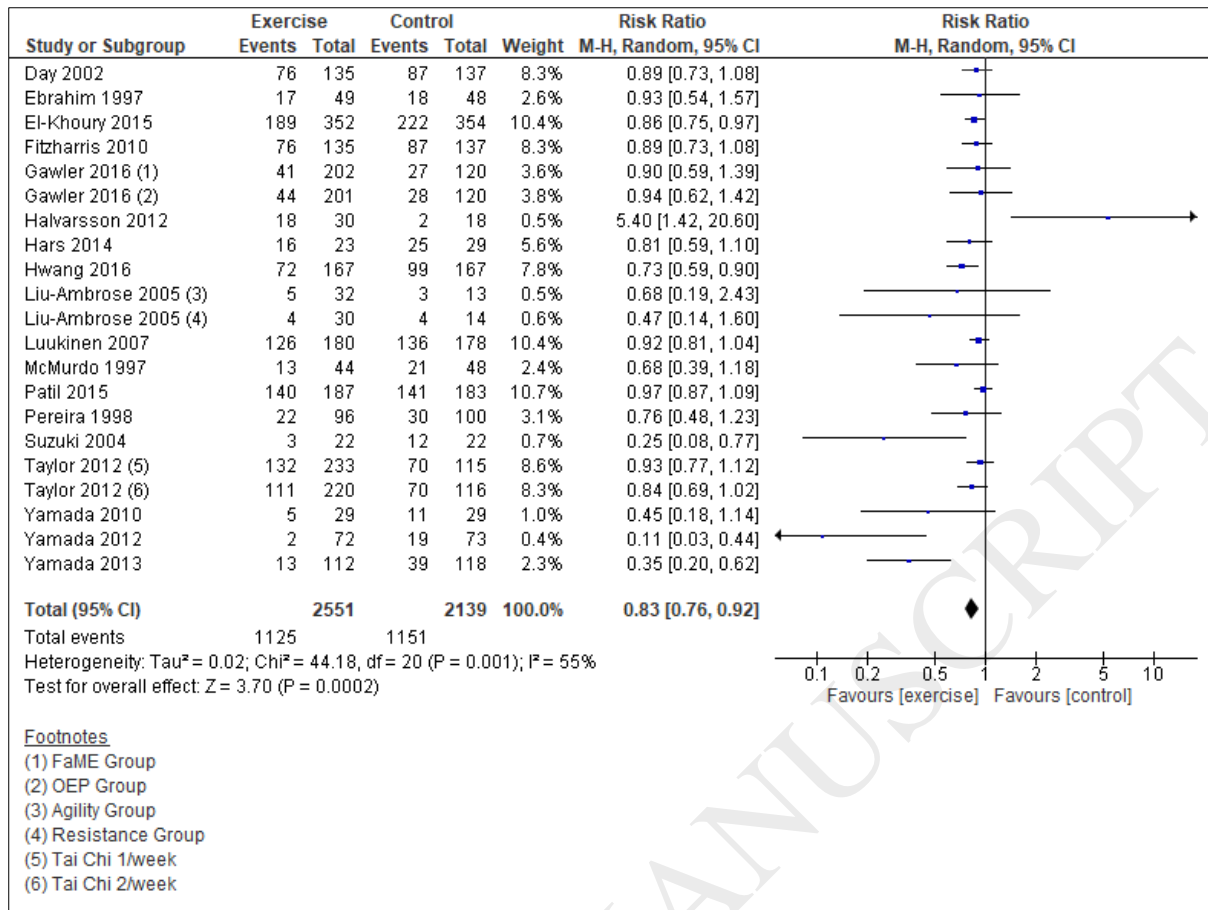


Figure 3.2 Exercise vs control, Outcome 2, Risk of falling

Table 1. Characteristics of included studies

Study & design	Sample size	Inclusion criteria	Mean age (SD or range)	Type of exercise intervention*	Duration of intervention (weeks)	Duration of follow-up (months)	Control Intervention	Falls outcome measures/ collection
Campbell 1999 (New Zealand) Follow-up of RCT (10)	233	Community dwelling women ≥ 80 years old who could move around their own homes independently and were not receiving physiotherapy.	83.9 (3.0)	Gait, balance and functional training; strength/ resistance	52	24	Social visits and telephone calls	Number of falls collected using 12 monthly prospective falls postcards
Dangour 2011 (Chile) Cluster RCT (21)	984	Community dwelling men and women aged 65-67.9 years old who could walk unaided, were not seeking advice for weight loss and had an MMSE >13	66.1 (1.0)	Gait, balance and functional training; strength/ resistance; 3D (dance)	2 years	24	No intervention.	Retrospective self-reported incidence of falls and fractures
Day 2002 (Australia) RCT (26)	272	Community dwelling men and women aged ≥ 70 years; living in their own home; could walk 10-20 metres.	76.1 (5.0)	Gait, balance and functional training; strength/ resistance; flexibility	15	18	No intervention	Number of falls collected using monthly prospective falls postcards. Number of fallers.
Ebrahim 1997 (UK) RCT (22)	165	Postmenopausal women who had sustained an upper arm fracture in the past two years.	66.4 (7.8) to 70.5 (11.0)	General physical activity	2 years	24	Placebo group – general advice and simple upper limb exercises	Retrospective self-reported number of falls.
El-Khoury 2015 (France) RCT (27)	706	Community dwelling women aged 75-85; with diminished balance or gait (taking ≥ 7 seconds to walk 6 metres or unable to do four consecutive tandem steps)	79.8 (2.8)	Gait, balance and functional training; strength/ resistance; flexibility	2 years	24	Information brochure	Number of falls and injurious falls collected using prospective monthly calendar postcards. Number of fallers Fear of falling
Fitzharris 2010 (Australia) Secondary analysis of RCT (28)	272	Community dwelling men and women aged ≥ 70 years; living in their own home; could walk 10-20 metres.	76.1 (5.0)	Gait, balance and functional training; strength/ resistance; flexibility	15	18	No intervention	Number of falls collected using monthly prospective falls postcards. Number of fallers.
Freiberger 2012 (Germany) RCT	216	Community dwelling men and women aged ≥ 70 years having fallen in the past 6	76.1 (4.1)	(2 exercise interventions - strength and balance group and fitness	16	24	No intervention	Number of falls and injurious falls collected using monthly fall calendars.

(19)		months or fear of falling.		group). Gait, balance and functional training; strength/resistance; endurance training				
Gawler 2016 (UK) Secondary analysis of RCT (16)	1235	Community dwelling men and women aged ≥ 65 years and physically able to attend group exercise.	72.4 (5.8)	(2 exercise interventions – FaME and OEP) Gait, balance and functional training; strength/resistance; flexibility; 3D (Tai Chi); general physical activity	24	24	Usual care	Retrospective self-reported number of falls and injurious falls during long-term follow-up period. Number of fallers.
Halvarsson 2012 (Sweden) Follow-up of RCT (23)	59	Community dwelling healthy men and women aged ≥ 65 years; fear of falling and/or at least one fall in previous 12 months	77 (67-93)	Gait, balance and functional training	12	15	No intervention	Retrospective self-reported number of falls. Number of fallers. Fear of falling.
Hars 2014 (Switzerland) Follow-up of RCT (9)	134	Community dwelling men and women aged ≥ 65 years; increased risk of falling based on self-report falls after the age of 65, balance assessment and frailty phenotype.	76 (6.6)	Gait, balance and functional training	45	48	Delayed intervention	Retrospective self-reported number of falls. Number of fallers.
Hwang 2016 (Taiwan) RCT (20)	456	Community dwelling men and women aged ≥ 60 years; received fall-related medical attention between Jan 2011 and Dec 2012; independently mobile.	72 (8.1)	3D (Tai Chi)	24	18	Lower extremity training	Number of falls collected using monthly prospective falls diaries. Number of fallers. Time to first fall
Kemmler 2010 (Germany) RCT (29)	246	Women; ≥ 65 years old.	68.9 (3.9)	Gait, balance and functional training; strength/resistance; flexibility; 3D (dance)	18 months	18	Wellness programme	Number of falls collected using monthly prospective falls calendars. Number of fallers and fallers with injuries.
Kim 2016 (Japan)	78	Community dwelling women aged over 75;	79.2 (2.8)	Gait, balance and functional training;	12	48	Health Education	Retrospective self-reported number of falls. Fractures

Follow-up of RCT (24)		diagnosed with sarcopenia.		strength/resistance				
Liu-Ambrose 2005 (Canada) Follow-up of RCT (17)	98	Women aged 75-85 with a diagnosis of osteoporosis or osteopenia	79.0 (3.0)	(2 exercise interventions - Resistance Training Group and Agility Training Group) Gait, balance and functional training; strength/resistance	25	18	Stretching (sham exercise)	Number of falls collected using monthly prospective falls calendars. Falls Risk.
Luukinen 2007 (Finland) RCT (25)	486	Adults aged 85 years and over with ≥ 1 risk factor for falling or ≥ 2 falls in past year	88.0 (3.0)	Gait, balance and functional training; general physical activity	16 months	16	Visit their physician without an intervention	Retrospective self-reported number of falls. Number of fallers.
McMurdo 1997 (UK) RCT (32)	118	Community dwelling postmenopausal women	64.5 (range 60-73)	Gait, balance and functional training	30	24	Calcium supplementation	Rate of falls (data collection method not reported). Number of fallers.
Patil 2015 (Finland) Secondary analysis of RCT (30)	409	Women aged 70-80; living at home independently; fallen at least once in previous 12 months	74.4 (2.9)	Gait, balance and functional training; strength/resistance	24 months	24	No exercise	Number of falls collected using monthly prospective falls diaries. Number of fallers. Fall related injuries.
Pereira 1998 (USA) Follow-up of RCT (8)	229	Postmenopausal women not taking HRT	70.9 (4.28)	General physical activity	2 years	10 years	No intervention	Retrospective self-reported number of falls.
Suzuki 2004 (Japan) RCT (15)	52	Community-dwelling women aged 73 to 90 years living in Koganei City and able to attend a Comprehensive Geriatric Assessment	77.68 (3.41)	Gait, balance and functional training; strength/resistance; flexibility; 3D (Tai Chi)	24	20	Advice pamphlet	Retrospective self-reported number of falls. Number of fallers
Taylor 2012 (New Zealand) RCT (18)	684	Aged 65+ (55 years if Maori or Pacific Islanders to account for ethnic disparities in health); at least one fall in the previous 12 months or considered to be at	74.5 (6.5)	(2 exercise interventions both Tai Chi but of different frequency i.e. once/week or twice/week) 3D (Tai Chi)	20	17	Low-level exercise	Number of falls collected using monthly prospective falls calendars. Number of fallers.

		risk of falling (FRAT).						
Uusi-Rasi 2015 (Finland) RCT (31)	205	Women aged 70 – 80 years; living at home independently; had fallen at least once in the previous year; no use of vitamin D and no contraindication to exercise.	74.4 (2.9)	Gait, balance and functional training; strength/resistance	24 months	24	Placebo without exercise	Number of falls collected using monthly prospective falls diaries. Number of fallers and injured fallers.
Yamada 2010 (Japan) Pilot RCT (33)	60	Community dwelling adults ≥65 years old; MMSE of 24 or greater; able to walk independently (or with a stick); excluding those with other comorbidities such as PD or stroke	79.5 (6.2)	Gait, balance and functional training	16	16	Walking exercise	Number of falls collected using monthly prospective falls diaries. Number of fallers.
Yamada 2012 (Japan) RCT (34)	157	Community dwelling adults ≥75 years old MMSE of 24 or greater; able to walk independently (or with a stick); excluding those with other comorbidities such as PD or stroke	85.8 (5.9)	Gait, balance and functional training	24	18	Simple course with obstacle negotiation	Number of falls collected using monthly prospective falls diaries. Number of fallers.
Yamada 2013 (Japan) RCT (35)	264	Community dwelling adults ≥65 years old MMSE of 24 or greater; able to walk independently (or with a stick); excluding those with other comorbidities such as PD or stroke	76.2 (8.5)	Gait, balance and functional training	24	18	Indoor walking programme	Number of falls collected using monthly prospective falls diaries. Number of fallers

*ProFaNE classification of exercise

Table 2. A summary of the effects of exercise on rate and risk of falling

Characteristic	No. of studies	Rate Ratios (95% Confidence Interval)	No. of studies	Risk Ratios (95% Confidence Interval)
Effect of exercise on:				
Rate of falls beyond 12 months	23	0.79 (0.71 to 0.88)		
Risk of falling beyond 12 months			18	0.83 (0.76 to 0.92)
Type of exercise				
<i>Multiple component exercise</i>	14	0.82 (0.74 to 0.91)	8	0.91 (0.85 to 0.96)
Gait/balance/functional training and strength/resistance exercises	4	0.99 (0.83 to 1.17)	1	0.99 (0.87 to 1.13)
Gait/balance/functional training and strength/resistance and flexibility exercises	3	0.76 (0.62 to 0.93)	3	0.87 (0.79 to 0.95)
Gait/balance/functional training and strength/resistance and flexibility and 3D exercises	3	0.65 (0.43 to 0.99)	2	0.53 (0.15 to 1.84)
Gait/balance/functional training and strength/resistance and 3D exercises	1	0.95 (0.78 to 1.16)		
Gait/balance/functional training and strength/resistance and endurance exercises	1	0.68 (0.40 to 1.16)		
Gait/balance/functional training and strength/resistance exercises and general physical activity	2	0.82 (0.63 to 1.06)	1	0.94 (0.62 to 1.42)
Gait/balance/functional training and general physical activity	1	0.93 (0.80 to 1.08)		
Gait/balance/functional training and 3D exercises and general physical activity	1	0.52 (0.16 to 1.70)	1	0.68 (0.19 to 2.43)
<i>Single component exercise</i>	10	0.65 (0.48 to 0.87)	11	0.74 (0.60 to 0.90)
Gait/balance/functional training	5	0.45 (0.28 to 0.74)	6	0.60 (0.33 to 1.12)
3D exercises	2	0.79 (0.50 to 1.25)	2	0.84 (0.73 to 0.96)
General physical activity	2	0.91 (0.63 to 1.31)	2	0.83 (0.58 to 1.18)
Strength/resistance exercises	1	0.54 (0.15 to 2.02)	1	0.47 (0.14 to 1.60)
Duration of exercise intervention				
<6-months	6	0.79 (0.72 to 0.87)	5	0.89 (0.77 to 1.03)
6-12 months	9	0.67 (0.56 to 0.80)	8	0.64 (0.49 to 0.83)
>12 months	8	0.88 (0.82 to 0.94)	5	0.91 (0.85 to 0.98)
Duration of follow-up				
12-24 months	20	0.79 (0.70 to 0.88)	16	0.83 (0.75 to 0.93)
>24 months	3	0.80 (0.60 to 1.06)	2	0.79 (0.61 to 1.03)