What Works to Prevent Falls in Community-Dwelling Older Adults? Umbrella Review of Meta-analyses of Randomized Controlled Trials

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Background. Preventing falls is an international priority. There is a need to synthesize the highest-quality falls prevention evidence in one place for clinicians.

Purpose. The aim of this study was to conduct an umbrella review of meta-analyses of randomized controlled trials (RCTs) of falls prevention interventions in community-dwelling older adults.

Data Sources. The MEDLINE, EMBASE, CINAHL, AMED, BNI, PsycINFO, Cochrane Library, PubMed, and PEDro databases were searched.

Study Selection. Meta-analyses with one pooled analysis containing ≥3 RCTs that investigated any intervention to prevent falls in community-dwelling older adults aged ≥60 years were eligible. Sixteen meta-analyses, representing 47 pooled analyses, were included.

Data Extraction. Two authors independently extracted data.

Data Synthesis. Data were narratively synthesized. The methodological quality of the meta-analyses was moderate. Three meta-analyses defined a fall, and 3 reported adverse events (although minor). There is consistent evidence that exercise reduces falls (including the rate, risk, and odds of falling), with 13/14 pooled analyses (93%) from 7 meta-analyses demonstrating a significant reduction. The methodological quality of meta-analyses investigating exercise were medium/high, and effect sizes ranged from 0.87 (relative risk 95% confidence interval=0.81, 0.94; number of studies=18; number of participants=3,568) to 0.39 (rate ratio 95% confidence interval=0.23, 0.66; number of meta-analyses=6). There is consistent evidence that multifactorial interventions reduce falls (5/6, 83% reported significant reduction). There is conflicting evidence regarding the influence of vitamin D supplementation (7/12, 58.3% reported significant reduction).

Limitations. Meta-analyses often used different methods of analysis, and reporting of key characteristics (eg, participants, heterogeneity, publication bias) was often lacking. There may be some overlap among included meta-analyses.

Conclusions. There is consistent evidence that exercise and individually tailored multifactorial interventions are effective in reducing falls in community-dwelling older adults.

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Falls represent a substantial threat to the aging global population's quality of life and remain a leading cause of morbidity and mortality.[1–3] Falls are common and affect around 30% of those aged over 65 years of age living in the community, and the risk increases with age.[2,4,5] The financial costs of falls also are profound. For instance, after accounting for inflation, the direct cost of health care provision following a fall in the United States was estimated at $30 billion in 2010.[6] Not surprisingly, numerous national and international guidelines have been developed that seek to prevent falls.[1,7,8]

A diverse range of interventions have been developed and tested through robust randomized controlled trials (RCTs) and subsequently summarized in systematic reviews and meta-analyses. Conclusions based on systematic reviews of RCTs are considered the top of the hierarchy of evidence.[9] Although there are some criticisms of systematic reviews as an entity (eg, prone to bias in original studies, publication bias, and may miss landmark well-powered primary studies[10]), a well-conducted systematic review does have the ability to make robust, generalizable conclusions over and above those from a single study. In addition, meta-analyses have the potential to provide the closest effect size of an intervention.[11] Although meta-analyses based on systematic reviews are considered the "gold standard," there is increasing recognition that even a perfect meta-analysis with perfect data can provide only a partial overview of the interventions available to clinicians.[12] This finding is particularly true in complex interventions such as falls prevention, where many different options are available to clinicians. With this realization, the popularity of umbrella reviews, or systematic reviews of systematic reviews, has increased to provide clinicians, policy makers, and researchers with the highest-quality information in one place regarding any particular intervention.

Concerning the prevention of falls, a range of interventions has been considered with systematic reviews and meta-analyses, including single interventions such as exercise[13] and vitamin D supplementation[14] or more complex multifactorial interventions.[4] Physical therapists have an integral role in the prevention of falls, and it is essential they have knowledge of the highest-quality evidence of interventions that reduce falls. Because of this proliferation in high-quality falls prevention research, we sought to conduct a comprehensive umbrella review of all systematic reviews containing meta-analyses of RCTs on the prevention of falls in community-dwelling older adults.

Method

This umbrella review followed a predetermined published protocol (PROSPERO registration: CRD42014010715).

Eligibility Criteria

Meta-analyses of RCTs that investigated any intervention that sought to reduce falls in community-dwelling older adults were included. More specifically, meta-analyses had to meet the following criteria:

Population. The study population comprised community-dwelling older adults (ie, living in the community and not in a long-term care facility, with a mean age of ≥60 years). We did not include studies conducted in hospitals or long-term care facilities. We excluded reviews in specialist populations (eg, stroke, Parkinson disease).

Interventions. Any intervention that sought to prevent falls was included.

Outcome measures. Our primary outcome measure was the effect of interventions on the rate of falls or the number of fallers. In this study, a fall was defined as "an unexpected event in which the participants come to rest on the ground, floor, or lower level."[15(p1619)] We considered any type of falls, including recurrent (2 or more falls over the study period) and injurious falls.

We did not place any language restriction upon our searches. If we encountered manuscripts published in languages other than English, German, French, or Spanish, we planned to contact the authors to acquire the data of interest. Meta-analyses not informed by a systematic review were excluded. Meta-analyses must contain at least one pooled analysis with ≥3 RCTs. Because some meta-analyses conducted multiple subgroup and sensitivity analyses, we report the primary analysis (effect size) for each intervention they investigated. If we encountered meta-analyses that were updates from previous reviews (eg, updated Cochrane review), we included only the most recent meta-analysis. If we encountered reviews on similar topics with different methods of analysis, inclusion criteria, and results, we included both reviews (decided by 3 authors). Meta-analyses including some controlled trials were included if ≥80% of the included studies within the pooled analysis were RCTs.

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- eAppendix: Articles Excluded From Community-Dwelling Umbrella Review: Reasons for Exclusion

Search Procedure

Two independent authors (B.S., S.B.) conducted a systematic search of the MEDLINE, EMBASE, CINAHL, AMED, BNI, PsycINFO, Cochrane Library, PubMed, and PEDro databases from inception to August 2014. A third author (M.D.D.) was available as a mediator. The key words used in the searches were "falls" or "fall*" or "recurrent falls" or "injurious fall" or "fall prevention" AND "randomised control trial" or "RCT" or "systematic review" or "meta-analysis" AND "older adult" or "elderly" or "age" AND "intervention" AND "exercise" AND "vitamin D supplementation" and "multifactorial." The reference lists of all potentially eligible articles were reviewed.

Data Extraction and Synthesis

Two authors (B.S., S.B.) independently extracted data, and a third reviewer (M.D.D.) was available. Data extracted included: first author, year of publication, country, setting, aim, search strategy, eligibility criteria, type of fall investigating, falls definition used, details of falls intervention, number of studies and number of participants, participant demographics, main results (effect size with 95% confidence intervals [95% CIs]), adverse events, heterogeneity, publication bias, and conclusions. In the literature, a range of statistical methods has been used to assess the effect of interventions on falls, including rate ratios (RaR=rate of falls), risk ratios/relative risk (RR=number of people who have fallen/risk of falls), and odds ratios (OR=odds of having a fall during the trial). The RaR provides a summary of the rate of falls between the intervention and control groups.[4] The RR, on the other hand, compares the number of people who have fallen between the intervention and control groups,[4] and the OR is the ratio of the odds of a fall happening in each group.[16] Collectively, we refer to the effect of the interventions on falls. However, when we refer to individual meta-analyses, we refer to the actual measurement used in each study. Where possible, we extracted data on heterogeneity from each pooled analysis and, in accordance with the Cochrane collaboration, report the I^2 statistic, which refers to the percentage of total variation across studies that is due to heterogeneity rather than chance.[16,17] Low, moderate, and high I^2 values of 25%, 50%, and 75%, respectively, are commonly accepted.[17] Due to the heterogeneity in the populations, interventions, and other key characteristics, the results are presented in a narrative synthesis.[12]

Methodological Quality Assessment

Two authors (B.S., S.B.) independently completed the Assessment of Multiple Systematic Reviews (AMSTAR).[18] A third reviewer (M.D.D.) was available. The AMSTAR is a reliable and valid way to assess the methodological quality of systematic reviews and meta-analyses.[19] The AMSTAR tool consists of 11 items that are rated as "met," "unclear," or "unmet," and scores are given ranging from 0 (low quality) to 11 (highest quality).[18,19] The AMSTAR scores are graded as high (8–11), medium (4–7), or low (0–3) quality.[18–20]

Results

Description of Search Results

Using the search strategy, 112 full texts were considered, and 96 articles were excluded (see eAppendix, available at ptjournal.apta.org, for list of excluded articles). Within the final sample, 16 separate meta-analyses reporting 47 pooled analyses were represented.[4,14,21–34] Full details of the search results are presented in the Figure.

Description of Included Meta-analyses

Details of the included meta-analyses are summarized in Table 1. In brief, the meta-analyses included between 3 and 22[23] individual RCTs and between 348[23] (education and exercise analysis, number of studies=3) and 27,522[21] participants across the pooled analyses. Only 3 meta-analyses provided a definition for a fall.[4,24,26] Three meta-analyses provided details of adverse events of the RCT interventions,[4,24,29] which were all minor. Overall, the quality of the meta-analyses was medium to high. Specifically, 8 meta-analyses were graded as high quality,[4,14,22,24–26,29,32] 7 were graded as medium quality,[21,23,27,28,30,31,33] and 1 was considered as low quality[34] (see Tab. 1 for AMSTAR scores).

Single Interventions

Exercise. Seven meta-analyses investigated a range of exercise interventions,[4,23,24,27,29,30,34] and from these meta-analyses, 13 out of 14 pooled analyses demonstrated that exercise significantly reduced falls (including the rate and risk of falling). Exercise was responsible for reductions in falls, ranging from a 13% reduced risk[29] (RR=0.87; 95% CI=0.81, 0.94); number of trials=18; number of participants=3,568) and a 61% reduction in the rate of falls[24] (RaR=0.39; 95% CI=0.23, 0.66; number of trials=6) and rate of falls causing fracture (number of trials=6). Only one study[34] demonstrated a nonsignificant reduction in falls, although it was rated as low quality. Overall, the methodological quality of exercise MAs was moderate to high.

Guo et al[23] pooled 22 studies (number of participants=4,912) investigating a range of exercise interventions and found that exercise significantly reduced the odds of falling (OR=0.78; 95% CI=0.65, 0.93). El-Khoury et al[24] found that exercise

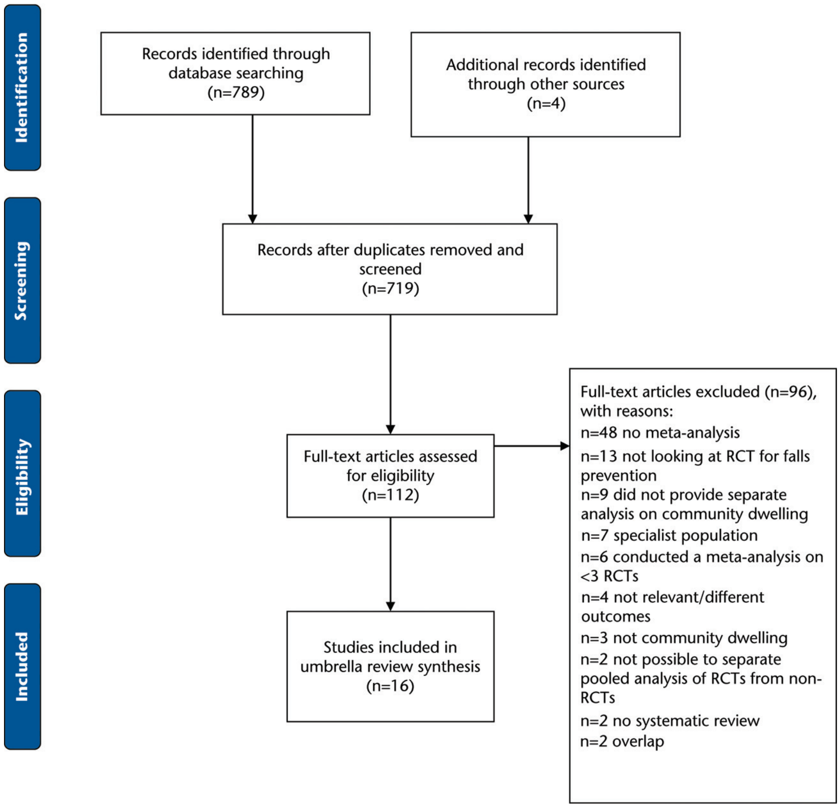

Figure.
Flow diagram of search strategy. RCT=randomized controlled trial.

significantly reduced the rate of injurious falls (RaR=0.63; 95% CI=0.51, 0.77; number of trials=10; I^2=50%), the rate of falls resulting in medical care (RaR=0.70; 95% CI=0.54, 0.92; number of trials=8; I^2=20%), the rate of falls causing serious injury (RaR=0.57; 95% CI=0.36, 0.90; number of trials=7; I^2=46%), and the rate of falls causing a fracture (RaR=0.39; 95% CI=0.23, 0.66; number of trials=6; I^2=0%). Petridou et al[27] reported that exercise significantly reduced risk of falls (RR=0.67; 95% CI=0.52, 0.85). Gillespie et al[4] demonstrated that exercise reduced the rate of falls regardless of whether it was conducted in a group setting (RaR=0.71; 95% CI=0.63, 0.82; number of trials=16; number of participants=3,622; I^2=48%) or at home (RaR=0.68; 95% CI=0.58, 0.80; number of trials=7; number of participants=951; I^2=0%). They also established that exercise focused on gait, balance, or functional training reduces the rate of falls (RaR=0.72; 95% CI=0.55, 0.94; number of trials=4; number of participants=519; I^2=0), whereas tai chi, although significant, was borderline and heterogeneous (RaR=0.72; 95% CI=0.52, 1.00; number of trials=5; number of participants=1,563; I^2=72%). Michael et al[29] reported that physical therapy–based exercises resulted in a reduction in risk of falls (RR=0.87; 95% CI=0.81, 0.94; number of trials=18; number of participants=3,986; I^2=4%). Thomas et al[30] reported the Otago exercise program significantly reduced the rate of falls across 6 studies involving 1,466 people (RaR=0.68; 95% CI=0.56, 0.79; I^2=0%).

In conclusion, there is consistent evidence (93% or 13/14 pooled analyses) to support the effectiveness of exercise as a single intervention to prevent falls (including the risk, odds, and rate of falls). This finding is primarily based on medium-high quality evidence.

Vitamin D supplementation. Seven meta-analyses investigated the influence of vitamin D supplementation on falls,[4,14,21,23,26,29,33] and from 12 pooled analyses, 7 established that vitamin D supplementation significantly reduced falls. The effect size ranged from a 22% reduced odds of falling when vitamin D supplementation was combined with calcium[23] (OR=0.78; 95% CI=0.63, 0.98; number of trials=6; number of participants=4,326) to a 12% reduced risk of falls without calcium[26] (RR=0.88; 95% CI=0.81, 0.96; number of trials=10; number of participants=12,701).

Guo et al[23] pooled 11 RCTs (6 with vitamin D supplementation and calcium and 5 with vitamin D supplementation alone) and found there was no significant effect on the odds of falling. In a subgroup analysis, the authors established that vitamin D supplementation when combined with calcium reduced the odds of falling (OR=0.78; 95% CI=0.63, 0.98) but vitamin D supplementation alone did not (OR=1.02; 95% CI=0.82, 1.28). Kalyani et al[26] pooled 10 studies and reported that vitamin D supplementation significantly reduced the risk of falls (RR=0.88; 95% CI=0.81, 0.96; number of participants=12,701; I^2=34%). Gillespie et al[4] pooled the data from 7 RCTs (number of participants=9,324) and reported that vitamin D supplementation had no significant effect on falls rate (RaR=1.00; 95% CI=0.90, 1.11; I^2=69%). Murad et al[14] and Michael et al[29] pooled the data on RCTs of vitamin D supplementation with and without calcium and found that the risk and odds of falls were respectively reduced (Michael et al[29]: RR=0.83; 95% CI=0.77, 0.89; number of trials=9; number of participants=5,809; I^2=3%; Murad et al[14]: OR=0.80; 95% CI=0.69, 0.93; number of trials=16; number of participants=unclear). Bolland et al[21] reported that vitamin D supplementation had no significant effect on the risk of falls (RR=0.96; 95% CI=0.90, 1.02; number of trials=14; number of participants=27,522); this finding remained true in subgroup analyses for vitamin D supplementation alone (RR=0.96; 95% CI=0.88, 1.04; number of trials=11; number of participants=20,861) and when combined with calcium (RR=0.93; 95% CI=0.85, 1.02; number of trials=5; number of participants=9,336).

In summary, there is conflicting evidence (58.3% or 7/12 pooled analyses) regarding the effectiveness of vitamin D supplementation to reduce falls (including the rate, odds, and risk), although the influence of vitamin D supplementation appears more effective when combined with calcium.

Environmental interventions. In total, 3 meta-analyses considered environmental interventions to reduce falls, and 7 different pooled analyses were available.[4,23,31] All 3 meta-analyses reported one analysis that demonstrated environmental interventions reduced falls; overall, 4 out of the 7 pooled analyses demonstrated a statistically significant reduction in falls.

Guo et al[23] reported in the pooled environmental and assistive technology analysis that the odds of falling were not significantly reduced (OR=0.83; 95% CI=0.68, 1.01; number of trials=13; number of participants=6,353). However, when they conducted a subgroup analysis of these results, they demonstrated that home visit and modification did significantly reduce the odds of falling (OR=0.75; 95% CI=0.56, 0.99; number of trials=7; number of participants=3,531), whereas assessment and modification alone did not (OR=1.11; 95% CI=0.83, 1.48; number of trials=3; number of participants=1,956). In their Cochrane review, Gillespie et al[4] demonstrated that home safety and modification reduces the rate of falls (RaR=0.81; 95% CI=0.68, 0.97; number of trials=6; number of participants=4,208; I^2=64%). They then demonstrated that home safety interventions were significantly effective when delivered by an occupational therapist (RaR=0.69; 95% CI=0.55, 0.86; number of trials=4; number of participants=1,443) but not when delivered by a non-occupational therapist (RaR=0.91; 95% CI=0.75, 1.11; number of trials=4; number of participants=3,075; I^2=42%). Finally, Clemson et al[31] conducted a review focusing solely on environmental interventions and found that interventions that adapted and modified the environment resulted in a reduction in the risk of falls (RR=0.79; 95% CI=0.65, 0.97; number of trials=6; number of participants=3,298; I^2=69%).

Overall, there is conflicting evidence (57%, 4/7 pooled analysis) to suggest that environmental interventions may reduce falls in community-dwelling older adults. This finding was based on moderate-quality meta-analyses.

Surgery. Two meta-analyses[4,23] reported a pooled analysis investigating the influence of surgery on falls. Gillespie et al[4] pooled data from 3 RCTs investigating cardiac pacing surgery and found that it significantly reduced the rate of falls in older adults with carotid sinus hypersensitivity, a condition that causes sudden changes in heart rate and blood pressure (RaR=0.73; 95% CI=0.57, 0.93; number of participants=349; I^2=51%). Guo et al[23] pooled 2 studies investigating cardiac pacing and 1 study investigating cataract surgery and found there was a nonsignificant reduction in the odds of falling (OR=0.87; 95% CI=0.45, 1.66; number of participants=704). Overall, there is limited evidence to suggest that surgical interventions can reduce falls.

Other Single Interventions

Guo et al[23] reported that education did not significantly reduce the odds of falling (OR=0.75; 95% CI=0.51, 1.10; number of trials=4; number of participants=810). Campbell and Robertson[28] pooled a range of single interventions and reported a statistical reduction in the rate of falls (RaR=0.77; 95% CI=0.67, 0.89;

number of trials=10; number of participants=unclear).

Multifactorial Interventions

Six meta-analyses investigated the efficacy of individually tailored multifactorial interventions.[4,25,27–29,34] Of these meta-analyses, 5 reported that falls were significantly reduced,[4,25,27,28,34] and 1 showed a nonsignificant trend toward reducing falls.[29] Multifactorial falls preventions reduced falls by between 10%[25,27] and 35%,[34] although the study by Weatherall et al[34] scored low (2) on the AMSTAR tool.

Choi and Hector[25] pooled 12 RCTs (number of participants=unclear) and found that multifactorial interventions reduced the risk of falls (RR=0.90; 95% CI=0.85, 0.96; Q=1.757; P=.185), which is comparable to the effect found in the meta-analysis by Petridou et al[27] (RR=0.90; 95% CI=0.82, 1.00; number of trials=5; number of participants=1,952; Q=6.9; P=.1). Gillespie et al[4] pooled data from 19 RCTs investigating multifactorial interventions and found that the rate of falls was significantly reduced (RaR=0.76; 95% CI=0.67, 0.86; number of participants=9,503; I^2=85%). Campbell and Robertson[28] pooled data from 6 RCTs and established that the rate of falls was reduced (RaR=0.78; 95% CI=0.68, 0.89; number of participants=unclear; I^2=38%).

Overall, there is consistent evidence (83%, 5/6 pooled analyses) that multifactorial interventions reduce falls (including the rate and risk of falling) in community-dwelling older adults. This finding was based on moderate- to high-quality meta-analyses.

Other Combined and Multicomponent Interventions

Goodwin et al[22] pooled the data from 15 RCTs investigating "multicomponent" interventions, where the interventions were not individually tailored. They found that multicomponent interventions significantly reduced the risk of falls (RR=0.86; 95% CI=0.80, 0.92; number of participants=unclear; I^2=0%). Another meta-analysis[32] pooled data from 4 nurse-led RCTs and found that the intervention had no significant effect on the odds of falling (OR=0.51; 95% CI=0.19, 1.36; number of participants=1,392; I^2=89%).

Overall, there is limited evidence from one meta-analysis that multicomponent interventions reduce falls, and there is no evidence that nurse-led interventions reduce falls. Summaries of the interventions are presented in Table 2.

Discussion

Within this umbrella review, we have demonstrated that there is consistent moderate- to high-quality evidence (13/14 pooled analyses or 6/7 meta-analyses) that exercise can significantly reduce falls (including the rate, risk, and odds of falling). There is conflicting evidence that environmental and vitamin D supplementation interventions can reduce falls. There is evidence from moderate- and high-quality meta-analyses that multifactorial interventions can reduce falls among older adults (5/6 pooled analyses reported significant reduction). Surprisingly, there is a dearth of information on the harms from fall prevention interventions reported in the meta-analyses included in our umbrella review. However, in those meta-analyses that did report such information, the reported harms were all relatively minor, and this dearth of information may be a reflection of the lack of reporting in the original studies.

The results of this review support the notion that exercise should be provided to community-dwelling older adults to prevent falls. Our findings echo those of individual meta-analyses[13] showing strong evidence that exercise is effective in preventing falls (albeit pooled analyses across mixed settings). The exact type (eg, balance, strengthening, tai chi), duration, frequency, and setting of such interventions do show some variations in the effect of the results, but describing these variations in greater detail is beyond the scope of this review. Still, with regard to the optimal nature of exercise, a balanced program including endurance, balance, and strength exercises could be recommended.[35] Perhaps the most robust included meta-analysis investigating exercise was the Cochrane review by Gillespie et al.[4] All 4 pooled analyses that we included demonstrated a similar significant reduction in falls, regardless of whether it was in a group (RaR=0.71), was at home (RaR=0.68), involved balance training (RaR=0.72), or was tai chi-based (RaR=0.72). In an innovative review, El-Khoury et al[24] found that exercise had profound effects on reducing a range of different types of injurious falls (including fractures); thus, exercise has an integral role in the management of falls in the community. Overall, about half of the pooled analyses investigating exercise (5/11 pooled analyses) had low to moderate heterogeneity (I^2<50% or nonsignificant Cochran Q). Therefore, together with the moderate- and high-quality nature of these meta-analyses, we can be confident that exercise helps to prevent falls.

Ultimately, outside evidence on the frequency, intensity, and type (FIT) principles, the patients' preference also should be considered, as it can influence adherence to exercise programs. In addition, some older adults may have specific physical comorbidities (eg, musculoskeletal pain[3]), meaning that they may need a physical therapist to provide an assessment and deliver appropriate adaptive interventions. Specifically, the effectiveness of physical therapy–based exercise interventions was established in the US Preventive Services Task Force meta-analysis.[29] The results of the current umbrella review affirm the central role of physical therapists in the prevention of falls in community-dwelling older adults. When one considers that exercise has a range of wider health benefits, such as comparable effects of medication interventions on preventing mortality,[36] the standout benefits of exercise on falls prevention are encouraging. We recommend, therefore, that all older people at risk for falling or known to fall should be encouraged to exercise, and for those who are particularly high risk and have a range of limitations, physical therapists should oversee this process.

The evidence regarding vitamin D supplementation is conflicting, although this intervention does appear more promising when combined with calcium supplementation. In their recent sequential meta-analysis, Bolland et al[21] demonstrated that vitamin D supplementation did not reduce falls or alter the relative risk by 15% or more. They recently compared the results of their meta-analysis[21] and an earlier one,[14] which arrived at opposite conclusions, and stated that the different conclusions were due to methodological differences and different statistical approaches.[37] Other groups have criticized these findings because of the inclusion of low-quality RCTs and the importance of appropriate doses.[38,39] Although even small effects of vitamin D supplementation could still result in public health recommendations because of overall low serum levels in older adults, little adverse effects, and low price, calcium has to be considered separately. Calcium supplementation has been associated with an increased risk of cardiovascular events,[40] and in a recent review by the same group, the authors concluded that any benefit of calcium supplements on preventing fracture is outweighed by increased cardiovascular events.[41] So far, weighing current evidence and balancing risks (few) and benefits (fair) beyond the outcome falls (in the preceding sentences, we discuss the wider implications of vitamin D; here, we are saying vitamin D may have other benefits outside of falls prevention), we support current recommendations of most guidelines: sufficient vitamin D supplementation of at least 1,000 IE daily or serum 25-hydroxy-vitamin D supplementation concentrations of 30 ng/mL (75 nmol/L) and higher, especially with respect to frail older adults and those with very low vitamin D supplementation levels.[42]

Regarding environmental falls prevention strategies, the interventions were generally not well defined and appear heterogeneous, although they may be effective in reducing falls, particularly when conducted by an occupational therapist.[4] Multifactorial interventions, in which particular risk factors are identified and then interventions are individually tailored, have become popular in the medical literature and clinical practice. The results from our umbrella review support the use of this approach, although delivering multifactorial interventions and identifying individual risk factors can be time-consuming. Therefore, the finding from the recent meta-analysis that multicomponent interventions (in which the intervention is not specifically tailored to the individual) also can reduce falls is of great interest.[22] This finding again seems to account particularly for programs where exercise is part of the intervention. However, effect sizes do not differ very much from those that build on exercise alone.

Limitations and Strengths

Our umbrella review has a number of strengths. We conducted a comprehensive search, including only the highest-quality evidence (meta-analyses of RCTs), and condensed this evidence in one place to make it readily accessible for physical therapists and other clinicians. The overall methodological quality of the included meta-analyses was moderate. Although this is the first umbrella review, a number of limitations should be acknowledged, which are largely reflected by limitations in the original studies. First, not all of the studies assessed heterogeneity, and as shown in Table 1, only studies of 10 meta-analyses reported a heterogeneity statistic. Often, the studies analyzed the effect of the intervention using different summary measures (eg, RaR, RR, OR), making it more challenging for the reader to interpret. Second, the meta-analyses often did not publish specific details regarding the included studies. Thus, it was not always possible to determine clinical homogeneity. Third, several meta-analyses may have included similar studies in their analyses. Also, it is unclear if the lack of adverse events reported in the included meta-analyses is due to the absence of these in the original studies. In addition, relying upon systematic reviews may mean that landmark primary studies are not highlighted. Finally, we could not include several reviews that investigated falls prevention interventions with meta-analysis in mixed settings that did not provide subgroup analysis for community-dwelling older adults.

Nevertheless, allowing for these caveats, our umbrella review is the first such review and provides key evidence to position physical therapists to be well equipped to manage falls in community-dwelling older adults. In essence, the available evidence suggests that exercise interventions are the most consistently effective and robust interventions to tackle falls in older adults, and it could be hypothesized that exercise also largely accounts for the effect seen in multifactorial/multicomponent programs. However, future research should investigate the frequency, intensity, and type of intervention and setting and test their effectiveness in clinical practice. Very few meta-analyses reported on the harms associated with falls prevention interventions—an important outcome that was likely limited by the primary studies. Regardless, policies are often made based on systematic reviews of interventions. Therefore, it is important that authors of studies of interventions adequately report any harmful side effects and clearly define their outcome measures in advance.

In conclusion, we found consistent evidence to suggest that exercise is associated with a reduction in the rate, risk, and odds of falling (including falls resulting in injury), thus affirming physical therapists' central position to lead in international efforts to prevent falls. There also is consistent evidence regarding the effectiveness of multifactorial interventions.

All authors designed the study, which was prospectively registered, and helped acquire the data. Mr Stubbs and Dr Denkinger wrote the manuscript. Dr Brefka provided input. All authors approved the final version.

PROSPERO registration: http://www.crd.york.ac.uk/PROSPERO/display_record.asp?ID=CRD42014010715.

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Table 1.
Summary and Results of Included Studies[a]

Study	Country	Intervention	RCTs Included (n=Number of Participants)	Participants' Details	Define a Fall?	Main Results (95% CI)	Heterogeneity	Adverse Events	AMSTAR	Conclusion
Bolland et al,[21] 2014	New Zealand	Vitamin D with or without calcium	14 (n=27,522)	Mean age=67–81 y in RCTs, 24%–100% female participants in RCTs	No	RR=0.96 (0.90, 1.02)	NR	NR	5	Vitamin D supplementation with or without calcium does not reduce the risk of falling in community-dwelling older adults
		Vitamin D without calcium	11 (n=20,861)			RR=0.96 (0.88, 1.04)	NR			
		Vitamin D with calcium	5 (n=9,336)			RR=0.93 (0.85, 1.02)	NR			
Goodwin et al,[22] 2014	United Kingdom	Multicomponent interventions (2 or more interventions not individually tailored)	15 (n=?, 5,034 in total)	Mean age=69–86.4 y, 38%–100% female	No	**RR=0.86 (0.80, 0.92)**	I^2=0%	NR	9	Multicomponent interventions not specifically tailored to an individual's risk factors reduce the number of fallers and rate of falls
						RaR=0.78 (0.71, 0.85)	I^2=20%			
Gou et al,[23] 2014	Taiwan	Exercise vs control:	22 (n=4,912)	Older adults without cognitive impairment Mean age=64.5–89.0 y	No	**OR=0.78 (0.65, 0.93)**	NR	NR	4	Exercise reduces falls in older adults
		Non tai chi exercise	20 (n=4,150)			**OR=0.78 (0.64, 0.95)**				
		Nutritional supplement:	11 (n=9,750)			OR=0.89 (0.75, 1.04)				Vitamin D supplementation with calcium reduces falls, but vitamin D alone does not

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Table 1.
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Study	Country	Intervention	RCTs Included (n=Number of Participants)	Participants' Details	Define a Fall?	Main Results (95% CI)	Heterogeneity	Adverse Events	AMSTAR	Conclusion
		Vitamin D alone	5 (n=5,424)			OR=1.02 (0.82, 1.28)				
		Vitamin D + calcium	6 (n=4,326)			**OR=0.78 (0.63, 0.98)**				
		Environment/assistive technology:	13 (n=6,353)			OR=0.83 (0.68, 1.01)				
		Home visit and modification	7 (n=3,531)			**OR=0.75 (0.56, 0.99)**				Home visits and modification reduce falls
		Assess and modification	3 (n=1,956)			OR=1.11 (0.83, 1.48)				
		Education intervention:	4 (n=810)			OR=0.75 (0.51, 1.10)				Education alone or when combined with exercise has no effect on falls
		Education and exercise	3 (n=348)			OR=1.16 (0.40, 3.32)				
		Surgery (2× cataract and 1× cardiac pacing)	3 (n=704)			OR=0.87 (0.45, 1.66)				Surgery does not reduce falls
El-Khoury et al,[24] 2013	France	Exercise	17 (n=4,305)	Mean age=76.7 y, 77% female	Yes	**RaR for injurious falls=0.63 (0.51, 0.77, number of trials=10)**	Injurious falls I^2=50%	Yes, 6 RCTs reported, a total of 8 participants had minor injuries No major adverse events	9	Exercise significantly reduces all types of injurious falls, including falls requiring medical care or resulting in severe injury or fractures
						RaR for falls requiring medical care=0.70 (0.54, 0.92, number of trials=8)	Falls requiring medical care I^2=20%			
						RaR for serious injury=0.57 (0.36, 0.90, number of trials=7)	Serious injury I^2=46%			

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Table 1.
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Study	Country	Intervention	RCTs Included (n=Number of Participants)	Participants' Details	Define a Fall?	Main Results (95% CI)	Heterogeneity	Adverse Events	AMSTAR	Conclusion
						RaR for falls causing fracture=0.39 (0.23, 0.66, number of trials=6)	Falls causing fracture I^2=0%			
Choi and Hector,[25] 2012	United States	Multifactorial interventions (n=15) or single interventions (n=2)	12/17 community dwelling (n=?, total=5,501)	NR	No	**Multifactorial interventions, community only RR=0.90 (0.85, 0.96, N=12)**	Q=1.757, P=.185	NR	8	Multifactorial interventions reduce falls
Kalyani et al,[26] 2010	United States	Vitamin D supplementation	10 (n=12,701)	Age range= 71–92 y	Yes	**RR=0.88 (0.81, 0.96)**	I^2=34%	NR	9	Vitamin D therapy reduces falls in community-dwelling older adults younger than 80 y regardless if a fall was defined or not
			5 (n=1,504)			**RR=0.79 (0.69, 0.92)** for participants <80 years of age who defined a fall	I^2=29%			
Petridou et al,[27] 2009	Greece	Exercise and multifactorial interventions:	10 (n=2,549)	All ≥65 years of age	No	**RR=0.67 (0.52, 0.85)**	Q=51.4 (P<.001)	NR	5	Exercise and multifactorial interventions both reduce falls
		Exercise only	5 (n=597)			**RR=0.45 (0.29, 0.71)**	Q=18.5 (P<.001)			
		Multifactorial interventions only	5 (n=1,952)			**RR=0.90 (0.82, 1.00)**	Q=6.9 (P=.14)			

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Table 1.
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Study	Country	Intervention	RCTs Included (n=Number of Participants)	Participants' Details	Define a Fall?	Main Results (95% CI)	Heterogeneity	Adverse Events	AMSTAR	Conclusion
Gillespie et al,[4] 2012	United Kingdom	**Exercise single interventions:**		70% female All ≥60 years of age	Yes			Yes Resistance, 2 trials reported musculoskeletal injuries	10	Exercise as a single intervention reduces falls (including multiple components and balance)
		Group exercise: multiple categories vs control	16 (n=3,622)			**RaR=0.71 (0.63, 0.82)**	I^2=48%			
		Home-based exercises containing multiple components vs control	7 (n=951)			**RaR=0.68, (0.58, 0.80)**	I^2=0%			
		Tai chi	5 (n=1,563)			**RaR=0.72 (0.52, 1.00)**	I^2=72%			Tai chi has marginal effect on falls
		Gait, balance, or functional training	4 (n=519)			**RaR=0.72 (0.55, 0.94)**	I^2=0%	Minor adverse events Vitamin D		
		Vitamin D:	7 (n=9,324)			RaR=1.00 (0.90, 1.11)	I^2=69%			Vitamin D does not reduce falls
		Surgery: cardiac pacing	3 (n=349)							Fitting cardiac pacing device reduces falls
		Environment:				**RaR=0.73 (0.57, 0.93)**	I^2=51%			Environmental interventions and modifications reduce falls when delivered by an OT to individuals at high risk of falling
		Home safety and modification	6 (n=4,208)			**RaR=0.81 (0.68, 0.97)**	I^2=64%			Home safety and modification are effective in reducing falls
		Home safety by OT	4 (n=1,443)			**RaR=0.69 (0.55, 0.86)**	I^2=58%			

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Table 1.
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Study	Country	Intervention	RCTs Included (n=Number of Participants)	Participants' Details	Define a Fall?	Main Results (95% CI)	Heterogeneity	Adverse Events	AMSTAR	Conclusion
		Home safety not by OT	4 (n=3,075)			RaR=0.91 (0.75, 1.11)				
		Multifactorial interventions	19 (n=9,503)			**RaR=0.76 (0.67, 0.86)**				Multifactorial interventions reduce falls
Campbell and Robertson,[28] 2007	New Zealand	Multifactorial interventions	14 (n=5,968)	67% female All >65 years of age	No	**RaR=0.78 (0.68,0.89, number of trials=6)**	I^2=38%	NR	7	Both multifactorial and single interventions reduce falls and are equally effective
		Single intervention				**RaR=0.77 (0.67, 0.89, number of trials=10)**	I^2=54%			
Michael et al,[29] 2010	United States	Multifactorial interventions	19 (n=7,099)	All studies included people >65 years of age	No	RR=0.94 (0.87, 1.02)	I^2=73%	5/19 reported harms, all minor	8	Physical therapy/ exercise and vitamin D significantly reduces falls, but it is unclear if multifactorial assessment and interventions reduce falls
		Exercise/ physical therapy	18 (n=3,568)			**RR=0.87 (0.81, 0.94)**	I^2=4%	No evidence of increased falls in physical therapy studies		
		Vitamin D (with or without calcium)	9 (n=5,809)			**RR=0.83 (0.77, 0.89)**	I^2=3%	No evidence vitamin D increases falls, no reported harms		

(Continued)

Table 1.
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Study	Country	Intervention	RCTs Included (n=Number of Participants)	Participants' Details	Define a Fall?	Main Results (95% CI)	Heterogeneity	Adverse Events	AMSTAR	Conclusion
Thomas et al,[30] 2010	Australia	Otago exercise program	6 (n=1,466), 1 study was CCT	Mean age=81.6 y	No	**RaR=0.68 (0.56, 0.79)**	I^2=0%	4 studies reported minor adverse events	7	The Otago exercise program significantly reduces falls
Murad et al,[14] 2011	United States	Vitamin D	16 (n=?, overall sample)	Mean age=76 y, 78% female	No	**OR=0.80 (0.69, 0.93)**	NR	NR	8	Vitamin D combined with calcium reduces falls and number of fallers among community-dwelling older adults
Clemson et al,[31] 2008	Australia	Environmental interventions (adaptations and modifications to environment)	6 (n=3,298)	Mean age=79.6 y	No	**RR=0.79 (0.65, 0.97)**	I^2=69%	NR	7	Focused home assessment interventions reduce falls, particularly in high risk groups
Tappenden et al,[32] 2012	United Kingdom	Nurse-based health promotion interventions	4 (n=1,392)	Age range=71.9–83 y	No	OR=0.51 (0.19, 1.36)	I^2=89%	NR	8	Nurse-based health promotion interventions do not appear to significantly reduce falls
Jackson et al,[33] 2007	United Kingdom	Vitamin D	3 (n=784)	>60 years of age	No	RR=0.92 (0.75, 1.12)	I^2=44%	NR	6	Vitamin D does not reduce falls
Weatherall,[34] 2004	New Zealand	Exercise	5 (n=860)	NR	No	OR=0.79 (0.58, 1.08)	NR	NR	2	Exercise does not significantly reduce falls, but multifactorial interventions do
		Multifactorial interventions	11 (n=3,350)			**OR=0.65 (0.52, 0.81)**				Note: very low-quality meta-analysis

[a] NR=not reported, OR=odds ratio, CI=confidence interval, AMSTAR=Assessment of Multiple Systematic Reviews, RR=risk ratio (number of people who fall) or relative risk, RaR=rate ratio (fall rate), ?=unclear how many participants were included in the analysis, OT=occupational therapist, CCT=controlled clinical trial. Bolded results are statistically significant.

Table 2.
Overview of Findings of the Meta-Analyses (MAs) Included in the Umbrella Review

Intervention	Number of MAs	Number of Pooled Analyses	Number of MAs (Number of Pooled Analyses)			% of Overall Effect (Pooled)[a]	Comment
			Reduces Falls	Increases Falls	Nonsignificant Effect		
Single interventions							
Exercise	7	14	6 (13)[4,23,24,27,29,30]	0	1 (1)[34]	+93% (13/14)	There is consistent evidence that exercise significantly reduces falls (rate, risk, and odds), including those that cause injury. Only one MA of low methodological quality demonstrated a nonsignificant reduction in falls.
Vitamin D	7	12	5 (7)[14,21,23,26,29]	0	3 (5)[4,23,33]	+58.3% (7/12)	There is conflicting evidence that vitamin D supplementation prevents falls. Best evidence exists for combination with calcium.
Environmental	3	7	3 (4)[4,23,31]	0	2 (3)[4,23]	+57% (4/7)	There is conflicting evidence that environmental interventions can reduce falls. Home assessment and modification are effective, particularly when delivered by an occupational therapist.
Surgery	2	2	1 (1)[4]	0	1 (1)[23]	Limited	There is limited and inconsistent evidence that surgery reduces falls, although one MA suggests that cardiac pacing surgery does reduce falls.
Education	1	1	0	0	1 (1)[23]	No evidence	1 MA demonstrated that education does not reduce falls
Single interventions combined	1	1	1 (1)[28]	0	0	Limited	1 MA pooled various single interventions and did not differentiate the type of intervention but found it reduced falls
Multifactorial, combined, and multicomponent interventions							
Individually tailored multifactorial interventions	6	6	5 (5)[4,25,27,28,34]	0	1 (1)[29]	+83% (5/6)	5 out of 6 MAs demonstrated that multifactorial interventions reduce falls, whereas 1 MA showed a trend toward reduction of falls. One MA demonstrating positive results had low methodological quality.
Nurse-led falls prevention	1	1	0	0	1 (1)[32]	No evidence	One MA found that nurse-led combined interventions do not reduce falls
Education and exercise combined	1	1	0	0	1 (1)[23]	No evidence	Education and exercise had no significant effect on falls
Multicomponent interventions (not individually tailored)	1	2	1 (2)[22]	0	0	Limited	One MA established that multicomponent interventions not tailored to the individual reduce falls

[a] Overall effect=number of supporting associations versus overall number (pooled), limited=only 1 MA investigating an intervention.

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