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SYSTEMATIC REVIEW

Critical features of multifactorial interventions for effective falls reduction in residential aged care: a systematic review, intervention component analysis and qualitative comparative analysis

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Abstract

Background: Multifactorial fall prevention trials providing interventions based on individual risk factors have variable success in aged care facilities. To determine configurations of trial features that reduce falls, intervention component analysis (ICA) and qualitative comparative analysis (QCA) were undertaken.
Methods: Randomised controlled trials (RCTs) from a Cochrane Collaboration review (Cameron, 2018) with meta-analysis data, plus trials identified in a systematic search update to December 2021 were included. Meta-analyses were updated. A theory developed through ICA of English publications of trialist's perspectives was assessed through QCA and a subgroup meta-analysis.
Results: Pooled effectiveness of multifactorial interventions indicated a falls rate ratio of 0.85 (95% confidence interval, CI, 0.65–1.10; $I^2 = 85\%$; 11 trials). All tested interventions targeted both environmental and personal risk factors by including assessment of environmental hazards, a medical or medication review and exercise intervention. ICA emphasised the importance of co-design involving facility staff and managers and tailored intervention delivery to resident's intrinsic factors for successful outcomes. QCA of facility engagement plus tailored delivery was consistent with greater reduction in falls, supported by high consistency (0.91) and coverage (0.85). An associated subgroup meta-analysis demonstrated strong falls reduction without heterogeneity (rate ratio 0.61, 95%CI 0.54–0.69, $I^2 = 0\%$; 7 trials).
Conclusion: Multifactorial falls prevention interventions should engage aged care staff and managers to implement strategies which include tailored intervention delivery according to each resident's intrinsic factors. Such approaches are consistently associated with a successful reduction in falls, as demonstrated by QCA and subgroup meta-analyses. Co-design approaches may also enhance intervention success.

Keywords: fall prevention, aged care, multifactorial, facility engagement, systematic review, older people

Key Points

- Multifactorial interventions for all residents in care facilities can reduce fall rates, but trial findings are inconsistent.
- Effective and ineffective multifactorial programs include an assessment of environmental hazards and personal risk factors.
- Facility engagement and tailored intervention delivery are consistently associated with effective fall prevention programs.

Introduction

Multifactorial falls prevention interventions are commonly applied and recommended [1, 2]. This approach provides various intervention features based on individual resident risk assessment [1, 3]. Whilst the evidence for this approach to prevention falls in the community is more convincing [4], it is uncertain whether these interventions reduce the rate of falls in residential aged care [5]. The meta-analysis of multifactorial prevention trials demonstrated reduction in rate of falls by 15% (rate ratio of 0.85), however, the 95% confidence interval (CI) of 0.65 to 1.10, included the possibility of increased falls [5]. Additionally, heterogeneity was high (I^2 = 85%) and not explained by predefined subgroup analyses for level of care or cognition [5].

Both effective and non-effective trials had the same features (i.e. medical review, exercise, environmental modification, and assistive aids) suggesting that the difference between these trials lies in the nuances of interactions between features and their delivery [6]. Therefore, approaches such as a network meta-analysis which assumes that features interact in an additive manner were not suitable [6, 7]. Where many trial and implementation features exist but the interaction is unclear, the combination of intervention component analysis (ICA) and qualitative comparative analysis (QCA) is ideal [8]. ICA uses inductive thematic analysis methods to develop a qualitative theory on the features and interactions that drive effectiveness from the trialists' perspectives. QCA can then be used to systematically determine if the features and interactions identified are necessary and/or sufficient to trigger the outcome [9]. Using the ICA derived theory to inform the QCA avoids data dredging [8, 10, 11]. This approach is suited to small sets of trials with high heterogeneity and intervention complexity [6, 9, 12]. ICA and QCA approaches have been applied to systematic reviews exploring complex public health interventions [9, 10, 12–14].

This study aims to determine 'What are the features of effective multifactorial falls prevention interventions for residents in aged care facilities?' by (i) utilising ICA to inform a theory of which intervention features are associated with a reduction in falls, (ii) examine the consistency of the theory with the fall outcomes by utilising QCA and (iii) determine if features from the theory explain the heterogeneity through subgroup meta-analysis.

Methods

Study selection

Randomised controlled trials (RCTs) of multifactorial interventions in residential aged care settings (care facilities or nursing homes), reporting falls outcomes of rate or risk of falls or risk of fractures suitable for meta-analysis from the Cochrane Collaboration review [5] and a search update of Cochrane Central Register of Controlled Trials (CENTRAL) from August 2017 to March 2021 MEDLINE (August 2017 to December 2021), and Embase and Cumulative Index to Nursing and Allied Health Literature (CINAHL) Plus from January 2017 to December 2021 were included. All records were screened for inclusion independently by two authors. The updated search was imported into Endnote ×9 (Clarivate Analytics, PA, USA) for duplicate removal prior to Covidence (Veritas Health Innovation, Melbourne Australia) screening and data extraction. Interventions classified in the Cochrane review as 'multiple' interventions which provided the same intervention components to all participants were excluded [3, 5]. Any discrepancies were resolved by discussion or involvement of a third author.

Data extraction, risk of bias and subgroup analysis

For new trials, two authors independently extracted data using the form previously used in the 2018 Cochrane Collaboration review [5] and conducted risk of bias based on the Cochrane Collaboration risk of bias tool using Covidence. Study characteristics and meta-analysis falls data from any new trial identified was added to the data from trials previously included [5].

Meta-analyses were conducted using the generic inverse variance method according to the methods reported using RevMan Web as described in the Cochrane Collaboration 2018 review [5]. The overall effect was either reported as rate of falls, risk of falls or risk of fractures [5]. Rate of falls (i.e. the total number of falls per unit of person time that falls was monitored during or after the intervention) was reported as a rate ratio (RaR) and 95% confidence interval (CI). Risk of falls (i.e. the number of fallers during or after the intervention) was reported as risk ratio (RR) and 95%CI. Risk of fracture (i.e. the number of participants sustaining a fracture during or after the intervention) was reported as risk ratio (RR) and 95%CI.

Mean age and standard deviation of the total sample was calculated by a reviewer using an online calculator [15], as necessary. Findings from ICA/QCA on trial features consistent with effective falls reduction informed a subgroup meta-analysis on falls data.

Intervention component analysis

Included research papers published in English and associated trial records were imported into NVivo 12 (QSR International Pty Ltd, Release 1.6.1) for inductive line-by-line coding [16]. First, intervention features were coded using intervention descriptions in the methods section of trial reports. Intervention features relating to the inclusion criteria (i.e. all residents etc.), intervention components (e.g. assistive aids, exercise etc.) and features prominent in the field (e.g. resident education) were all coded. Second, trialists' perspectives of trial features that prevent falls in aged care were coded by inductive thematic analysis of their reflections reported in discussion and conclusions sections.

The primary trial report was first coded, followed by reading all associated papers (e.g. the protocol, or editorial; Table 1) to code additional information. Initial coding was conducted by one author, with a random sample checked by a second author for agreement. The remaining process followed the reflexive thematic analysis methods of Braun and Clarke [17]. One author grouped similar initial codes and considered relationships between codes from different studies to determine key themes expressed by trialists. Grouping and relationships of codes were checked by a second author to establish agreement of the themes. Key trialists perceptions were designated as themes while more specific views with fewer supporting codes were designated as subthemes. Themes and subthemes were discussed amongst all authors including experts in falls prevention and residential aged care research to consider logic and commonality of thoughts.

Two authors used standard definitions derived from the ICA to independently code the trial features. The presence or absence of some trial features were coded as 'crisp' data, i.e. as a binary with a '0' to denote the absence of a particular feature or a '1' to denote its presence. Other trial features were coded as 'fuzzy' data, i.e. on a scale to capture differences in partial presence (e.g. 0, 0.25, 0.75, 1).

Effectiveness of falls outcomes from the trials were also coded as fuzzy based on the meta-analyses data on a scale representing the following categories. Statistically effective (meta-analysis point estimate of effect $\leq$0.8, 95%CI $<$1) was coded as 1, clinically effective (point estimate $\leq$0.8, regardless of 95%CI) was coded as 0.75, no effect (point estimate $>$0.8 and $<$ 1.2) was coded as 0.25 and data that indicates increases falls (point estimates $\geq$1.2, regardless of 95%CI) was coded as 0 [5]. Rate of falls data was preferentially used to risk of falls when multiple falls outcomes were available as rate data appears more sensitive to change [5, 19].

ICA themes and subthemes based on trialists' perspectives were prioritised for testing in the QCA. Where the presence of certain features was not clear from published records, trialists were contacted for additional information. An assumption based on the published text was made when attempts resulted in no response.

Qualitative comparative analysis

The data table of the coded features and effectiveness was screened to determine the features corresponding to the ICA findings that were suitable for representing a theory that could be tested in QCA in R Project (version 4.1.2) [18]. A feature was not suitable for QCA if (i) it was present amongst all trials, or (ii) only present in one or two trials. Themes from the ICA were considered in preference to subthemes and other features as the theory for QCA testing. A data table of suitable features was imported for analysis.

Theories were examined for consistency through 'truth tables' which considered the configurations of features present amongst trials in relation to effectiveness. Truth tables produced inclusion scores representing the proportion of trials with a particular combination of features that was associated with effectiveness. Higher scores closer to 1 indicated that a greater proportion of trials were represented by the configuration were effective, a score of 1 indicates that all trials with the configuration were effective. Boolean minimisation was used to determine if a theory explaining most, or all, the included trials from the truth table could be further simplified into essential features. Minimised solutions were assessed for consistency, and coverage, with higher coverage scores closer to 1 indicating that the solution explains more trials.

Following identification of the best theory to explain most trials, any logical remainders present were examined. A logical remainder is a configuration of features that are not present amongst the trials. Assumptions about logical remainders can be used to simplify the solution further. When present, logical remainders were incorporated to create an intermediate solution, considering the presence of contradictory simplifying assumptions. The theory was also tested to examine its association with the negated outcome, given that in QCA, causality is not assumed to be symmetrical. Detailed description of the specific steps within the QCA has previously been published [12].

Results

Eleven RCTs from the 2018 Cochrane Collaboration Review [5] and one new RCT were eligible for inclusion, from 2,893 records screened from the search update (Appendix 1, Figure S1 and Table S1). Eleven included trials had rate of falls meta-analysis data [20–30] and one had only risk of falls data [31]. Trials provided a range of multifactorial interventions (Table 1). Multifactorial interventions were either initiated from a baseline risk assessment tool [23–26, 28–30], multidisciplinary team assessment [21, 22, 31], nurse practitioner assessment [27] or resident self-selection [20].

With the addition of one new study, the pooled rate of falls remained inconclusive (RaR = 0.85, 95%CI 0.65–1.10; I^2 = 85%; 11 studies; n = 4,781) (Appendix 1, Figure S2a and S2b). Risk of falls and fracture also remained inconclusive (Appendix 1, Figures S3a, S3b, S4a and S4b). Risk of bias remained mostly high for attrition bias but mostly low for other sources of bias examined (Appendix 1, Figures S2a, S2b, S3a and S3b). As all studies had high risk of performance and detection bias, these biases were not drivers of the inconclusive findings observed.

One RCT included in the 2018 Cochrane Collaboration Review was excluded from ICA and QCA due to no English

Table 1. Study characteristics

Author, year (primary paper and related records)	Study design	Country	Randomised N	Age mean (SD) or Median (range)	Female (%)	Intervention	Control	Falls Outcomes	Intervention duration	Post-intervention follow-up duration
Becker 2003 [20] Becker 2000 [32] Rapp 2008 [33]	Cluster RCT	Germany	Total: 981 I: 509 C: 472	Total: 84.0 (7.2)[a] I: 83.5 (7.5) C: 84.3 (6.9)	79	Residents choose to participate in any combination of personal interventions for any length of time. Choosing none would mean that they still receive environmental interventions including environmental modification and modified nursing care resulting from staff training on risk factors and prevention measures, audit and monthly feedback on falls and injuries. All residents provided written information on falls prevention with personal falls prevention consultation by nurse or exercise instructor offered to all residents, not chair or bed bound.	Usual care, no specific activities.	Rate of falls Risk of falls Risk of fracture	12 months	None
Dyer 2004 [21] Dyer 2003 [34]	Cluster RCT	United Kingdom	Total: 196 I: 102 C: 94	Total: 87.3 (6.9)[a] I: 87.4 (6.9) C: 87.2 (6.9)	78	Baseline assessment by PT, nurse, and OT where exercise, environmental modifications, optician, and podiatry referral to interventions based on these. Also, medical review by geriatrician at baseline sent to GP for GP to implement. Staff were invited to education day at the end of the exercise program provided by researchers.	Usual care, complete falls record only.	Rate of falls Risk of falls	12–14 weeks	12 months
Jensen 2002 [22] Jensen 2003 [35]	Cluster RCT	Sweden	Total: 402 I: 194 C: 208	Total: 83 (65–100) I: 83 (65–97) C: 84 (65–100)	72	Supervised exercise, medication review, environmental modifications, supplying and repairing aids, hip protectors. Staff education, post fall problem solving conferences and staff guidance. Employed 8 extra PTs during intervention and 3 during follow up.	Usual care, roles of staff per usual.	Rate of falls Risk of falls Risk of fracture	11 weeks	34 weeks
Kerse 2004 [23] Kerse 2021 [36]	Cluster RCT	New Zealand	Total: 617 I: 346 C: 271	Total: 83.2 (10.6) I: 83.0 (8.9) C: 83.6(12.5)	72	Falls coordinator appointed in from existing staff to carry out fall-risk assessment tool for all residents and coordinate recommendations and care plan with other health professionals. Wall logo for those at high risk as coloured dots with falls prevention strategies. Falls coordinators trained by research staff and supported with visits and phone calls as needed for 6 months.	Usual care.	Rate of falls Risk of falls	6 months	12 months.
Logan 2021 [24] Kerse 2021 [36] Allen 2021 [37] Robinson 2018 [38] Robinson 2020 [39] Sims 2019 [40]	Cluster RCT	United Kingdom	Total: 1657 I: 775 C: 882	Total: 85.0 (9.3) I: 86.0 (8.6) C: 84.2 (9.7)	68	GtACH risk assessment with every resident to produce a written action plan within 4 weeks of staff training by falls specialists and re-assessment expected every 3 to 6 months. Care home staff trained in small 1-hour sessions using case studies and role play which repeated sessions offered to reach all staff including managers with a member of care home staff allocated as falls champion responsible for training new staff and embedding the programme.	Usual care.	Rate of falls Risk of falls Risk of fracture	90 days	270 days after intervention

(*Continued*)

Table 1. Continued

Author, year (primary paper and related records)	Study design	Country	Randomised N	Age mean (SD) or Median (range)	Female (%)	Intervention	Control	Falls Outcomes	Intervention duration	Post-intervention follow-up duration
McMurdo 2000 [25]	Cluster RCT	United Kingdom	Total: 133 I: 77 C:56	Total: 84.0 (6.8) I: 84.9 (6.7) C:83.7 (6.7)	81	Falls risk assessment at baseline and 6 months including medical review (blood pressure check, medication review and visual acuity check) and 6-month exercise program. Recommendations sent to GP and referral to optometrists if indicated.	Reminiscence therapy including quizzes, music, and archive material.	Rate of falls Risk of falls Risk of fracture	6 months	6 months
Neyens 2009 [26] Neyens 2007 [41]	Cluster RCT	The Netherlands	Total: 518 I: 249 C: 269	Total: 82.7 (7.7)[a] I: 82.1 (7.7) C: 83.3 (7.7)	68	General medical assessment by medical staff (at start of trial, on admission, if change in medical condition). Assessment with fall risk evaluation tool by multidisciplinary team at start of trial, on admission, after a fall, at request of ward staff, 2 times per year for all residents. Determines where medication review, exercise and/or providing assistive and protective aids or removal of environmental hazards are required. Fortnightly staff meeting discussion each assessed resident.	Usual care, no insight on fall prevention programme.	Rate of falls	12 months	None
Rubenstein 1990 [27]	RCT	United States of America	Total: 160 I: 79 C: 81	Total: 87.4 (0.9)[a] I: 86.8(0.6) C: 87.9 (0.7)	85	Comprehensive post fall assessment within 7 days of fall by nurse (including physical examination, visual screening, pulse, blood pressure, footwear and foot problem assessment, gait and balance assessment, laboratory tests, ECG, 24 hr Holter and environmental assessment for hazards) where recommendations are sent to resident's primary care physician.	Usual care—no assessment.	Rate of falls Risk of falls	One-time occurrence.	24 months
Shaw 2003 [31]	RCT	United Kingdom	Total: 308 I: 150 C: 158	Mean, 95%CI Total: 84 (71–97) I: 84 (71–97) C: 84 (71–97)	80	Multidisciplinary (PT, Medical with Psychogeriatric as required, cardiovascular review and OT) assessment to identify and intervention to manage risk factors (including 3-month exercise program. Repeat PT and OT therapy assessment and cardiovascular test if abnormal at 3 months.	Same assessment but without intervention and with usual care.	Rate of falls Risk of falls Risk of fracture	3 months (Or 6 months)	12 months
Walker 2015 [28] Robertson 2010 [42] Robertson 2012 [43]	Cluster RCT	United Kingdom	Total: 52 I: 25 C: 27	Total: 83(14) I: 84 (14.8) C: 82 (13.4)	67	Use of the Guide to Action Care Home tool (a checklist of falls risk factors with suggested actions) in addition to standard care. Tool takes staff 15 to 20 minutes to complete and can lead to intervention that take 2 hours on average to complete. Facility staff training provided on multiple occasions with goal of training all staff through sessions, manual and ongoing support.	Usual care with standard care, no training or manual.	Rate of falls	Once	6 months
Whitney 2017 [29]	Cluster RCT crossover	United Kingdom	Total: 191 I: 103 C: 88	Total: 83.5 (8.8) I: 84.6(5.6) C:84.1 (7.7)	69	Falls risk assessment to direct interventions including medical, environmental modification, equipment modification, cognitive and behavioural treatment, family guidance, level of mobility restrictions and supervision.	Usual care by treating team	Rate of falls Risk of falls Risk of fracture	Once	6 months
Salvà 2016 [30][b]	Cluster RCT	Spain	Total: 330 I: 193 C:137	Total: 84.4 I: 84.2 (6.8) C: 84.5 (6.6)	72	Mini Falls Assessment Instrument to address risk factors for gait and balance impairment, cognitive impairment, polypharmacy, assistance with ADLs, lower limb pain, urinary incontinence, weakness, symptomatic heart disease, fear of falling, neuroleptics/psychotropic drugs, problems in feet, dizziness, visual impairment, and depressive symptoms.	Usual care with falls risk assessment without intervention actions	Rate of falls Risk of falls Risk of fracture	12 months	None

Abbreviations: ADLs: activities of daily living, C: control, ECG: electrocardiogram, I: intervention, hr: hours, GP: general practitioner, GtACH: Guide to Action in Care Homes, PT: physiotherapist, OT: occupational therapist, RCT: randomised controlled trial, SD: standard deviation, 95%CI: 95% confidence interval. [a]Reviewer calculated. [b] Included in updated meta-analysis as well as subgroup analysis from results of ICA and QCA but could not be used for ICA and QCA as published in Spanish.

full text [30]. Studies in ICA and QCA represent 91 trialists from studies conducted in five countries enrolling 5,215 residents in aged care facilities who were predominately females aged in their 80s (Table 1). Four trials were coded as statistically effective, three trials as clinically effective, two trials as having no effect and two trials as increased falls (Appendix 1 and Table S2).

Intervention component analysis

Twenty-four published records associated with the 11 included studies were available for thematic analysis (Table 1). Trialists' described the residential aged care setting as a complex environment for research and multifactorial interventions. The success of the intervention was described as dependent not only on impacting the risks for falls but also navigating the influence of the staff and institution on the resident [20, 24, 40]. From the trialists' perspectives the key themes driving trial effectiveness were (i) intervention co-design and (ii) tailored intervention delivery for resident's intrinsic factors (Table 2).

Intervention co-design

The concept of intervention co-design with managers was mentioned amongst trialists as a method to address implementation factors perceived to affect trial effectiveness. Co-design was described as engaging managers to support staff with necessary training and mutual decision making about the intervention protocol. Manager engagement in these areas was perceived as a facilitator of staff uptake and staff intervention adherence [21, 29].

Specifically, staff who were actively adhering to the intervention were perceived as crucial to implementation in situations where often facility staff conducted the risk assessment that initiated components of the multifactorial intervention. Trialists' described staff engagement in the intervention, to be associated with altered attitudes and understanding of falls as well as upskilling staff [22, 23].

Two trials also described the importance of ensuring residents were actively participating in the intervention which was encouraged through education. However, only one included trial included resident education as an intervention feature [20]. Whereas in falls prevention trials in hospitals, patient education on falls was an important implementation factor [44].

Tailoring intervention delivery to resident's intrinsic factors

As multifactorial interventions include a combination of intervention features, determined by each resident's risk factors, trialists' indicated that they could not determine which intervention feature was effective alone or in sub-combinations. Trialists' perceived enabling staff to tailor the intervention to individual residents based on intrinsic personal factors, when conducting the risk factor assessment was important to ensure the environmental and personal intrinsic risks targeted, could be modified to improve the resident's ability to safely mobilise. Specifically, residents with cognitive impairments and falls history were perceived to respond to intervention features differently and have a different risk profile than those without and therefore impact intervention effectiveness differently. Overall, a more tailored and considered approach to residents with a higher risk of falls is suggested during intervention delivery.

Trialists suggested that an intervention approach appropriate for people with cognitive impairment considered (i) providing a tailored separate intervention for learning-based intervention components or (ii) considering whether the modification of the risk factor can be reasonably achieved to a degree likely to reduce falls from the resident undergoing the intervention. A tailored separate intervention was described to potentially include extra supervision, support, and additional time to allow intervention effects to be observed. To ensure appropriate risk factor selection, if a risk factor cannot by appropriately modified, trialist suggest focusing on interventions associated with alternate more modifiable risk factors.

Environmental (non-individual) factors that were targeted considered a combination of (i) repairing institutional hazards based on an occupational therapist's assessment, (ii) improving monitoring through the provision of bed and chair sensors and/or (iii) repairing or providing personal aids for safe mobility such as walking aids, footwear, vision correction through assessment and use of hip protectors. Personal risk factors included medical management through medication review alone or combined with tailored supervised strength and balance exercise, nutrition support strategies, vitamin D supplementation or socialisation considerations. As all trials addressed both environmental and personal risk factors, including both are key for effective multifactorial intervention risk assessment.

Theory for QCA

Intervention features from ICA themes (i.e. co-design, tailored intervention delivery), subthemes and other features were collated for coding (Appendix Table S2). As co-design was only present in one trial and therefore could not be tested, facility engagement was coded as the feature representing the sub-theme with most evidence (Table 2). Therefore, the main theory-derived features arising from the ICA as possible driver/s of the variation in effectiveness amongst trials that could be examined in QCA were facility engagement and tailored intervention delivery (Appendix Table S3).

Qualitative comparative analysis

The truth table analysis indicated that the presence of both facility engagement and tailoring intervention delivery was consistent with effective falls prevention in the included trials with a high inclusion score (0.92) and consistency score (0.91; Table 3). The presence of these two features explained trial effectiveness in all included trials, supported

Table 2. ICA trial authors' perspectives of features of multifactorial trials associated with intervention effectiveness in residential aged care

Theme	Subtheme	Effectiveness	Informal evidence
Intervention co-design with managers and staff (102 codes from 11 studies)	Facility engagement on the intervention (72 codes from 10 studies)	Present or mostly present in 6 out 7 effective trials. Not present in 2 no effect trials and 1 trial that increased falls.	"To enhance protocol adherence in a definitive study, we suggest that care home managers are asked to agree at the outset when and to whom the training will be provided, that refresher sessions are scheduled in advance and that protocols for inclusion of Guide to Action Care Home in care home records are agreed." [28]
	Engaging staff through managers and provide staff necessary education, training, and refreshers. (30 codes from 7 studies)	Present or mostly present in 6 out 7 effective trials. Not present in 2 no effect trials and 1 trial that increased falls.	"Complex interventions in care homes require; readiness for involvement including support from managers, a tailored approach to each home and work to be planned jointly with an emphasis on building relationships between visiting healthcare professionals and care home staff. . .. . .a greater focus on these may have improved the engagement of staff with this programme." [29] ". . .. . .more-active engagement of management may have increased adherence and affected the overall result." [23]
Tailoring intervention delivery to resident's intrinsic factors (21 codes from 11 studies)	Tailoring multifactorial intervention approach to intrinsic factors to sufficiently modifiable risk factors considering cognitive capacity and falls history (14 codes from 7 studies)	Present or mostly present in 7 out of 7 effective trials. Not present in 1 trial that increased falls. Partially present in 1 trial with no effect.	"Personal characteristics such as cognitive and physical function or emotional status vary considerable between residents of nursing homes, and it is plausible that different groups of residents are susceptible to preventive measures in a different way. Thus, the composition of the study population may influence the effectiveness of a fall prevention program. Therefore, it seems reasonable to develop subgroup-specific interventions to improve the overall effectiveness of fall prevention program in institutional settings." [33] "The intervention was not adequately tailored to address risk factors" [29]
	Address both environmental and personal risk factors for enhancing safe mobility (12 codes from 11 studies)	Present in all included trials.	"The intervention program comprised strategies that targeted both general and resident specific risk factors for falling" [22]

Table 3. Qualitative comparative analysis: Truth Table of facility engagement & tailored intervention delivery

C	Facility engagement	Tailoring intervention delivery	Outcome	Number of studies	Sufficiency Inclusion Score	Proportional reduction in inconsistency	Cases	Supports Theory
1	Not engaged[a]	Partially[b]	Ineffective	1	0.56	0.20	Shaw *et al.* [31]	Yes
2	Not well attempted[b]	Mostly[c]	Ineffective	2	0.58	0.38	Kerse *et al.* [23], Rubenstein *et al.* [27]	Yes
3	Mostly[c]	No[a]	Ineffective	1	0.50	0.20	Whitney *et al.* [29]	Yes
4	Mostly engaged[c] or engaged[d]	Mostly[c] or Tailored[d]	Reduced falls	7	0.92	0.91	**Becker *et al.* [20], Dyer *et al.* [21], Jensen *et al.* [22], Logan *et al.* [24], McMurdo *et al.* [25], Whitney *et al.* [29], Walker *et al.* [28]**	Yes

Abbreviations: C: configuration Coded in QCA as [a] 0, [b] 0.25, [c] 0.75, [d] 1, Inclusion cut-off = 0.85 **Effective case,** non-effective case.

by a high coverage score (0.85) and negation did not offer a better solution (Appendix 1, Table S4), providing support for the theory tested. Table 3 demonstrates all possible combinations of the two features explored and no logical remainders.

Subgroup analysis of theory components

Subgroup meta-analyses indicated that trials that undertook facility engagement and tailoring intervention delivery significantly reduced that rate of falls and risk of falling, with no between trial statistical heterogeneity (rate ratio 0.61, 95%CI 0.54–0.69, 7 trials, $I^2 = 0\%$, Figure 1; risk ratio 0.76, 95%CI 0.66–0.89; 5 trials, $I^2 = 0\%$, Appendix 1, Figure S5). The absence of one or both features was associated with residual heterogeneity in the remaining trials (pooled rate ratio 1.16, 95%CI 0.86–1.56, three trials, $I^2 = 63\%$, Figure 1; risk ratio 0.97, 95%CI 0.86–1.10; four trials, $I^2 = 13\%$, Appendix 1, Figure S5). The risk of fracture was not significantly reduced in either subgroup (Appendix 1, Figure S6).

Discussion

This study has demonstrated that trials of multifactorial interventions that consistently lead to a reduction in falls assessed each resident's environmental and personal risk factors to engage facility staff and tailor intervention delivery to the resident's intrinsic factors. Whilst other approaches may also lead to effectiveness, this approach consistently explains the outcomes for all effective and ineffective trials included in this systematic review.

This finding of facility engagement, co-design and tailored intervention delivery as important features in multifactorial interventions in residential aged care to reduce falls is consistent with other research in the field. A previous systematic review has recommended that multifactorial interventions target not only the resident but also facility staff and organisational policy, acknowledging individual staff members, staff communication and knowledge and skills as contributing factors to fall prevention success [45]. Engaged staff, in this industry where there is traditionally a high staff turnover, are acknowledged to be associated with patient safety, improved quality of care and job retention due to satisfaction [46, 47]. The reduction in falls rates observed with facility engagement may therefore be related to the positive influence of staff when they have adequate knowledge, awareness, and intrinsic motivation. The finding that tailoring the intervention delivery to resident's intrinsic factors is an important driver further emphasises the implementation gap between providing an individual falls risk assessment on both personal and environmental factors and ensuring that the delivery of interventions is appropriate for the resident. A realist evaluation of an included successful large multifactorial trial which incorporated facility engagement and tailored intervention delivery approaches has suggested that strong engagement with the facility on the local context and challenges should shape implementation [24, 48]. Tailoring intervention delivers and involving stakeholders has also recently been identified as important strategies for multifactorial interventions in the community [49]. The strong support for this theory of drivers of successful trials through the subgroup meta-analysis and high consistency scores in the QCA presented here indicates that multifactorial interventions in residential aged care should be widely implemented following this approach with ongoing evaluation using an established translational framework such as RE-AIM [50].

While environmental risks were extensively assessed in all included trials, when reported, adherence to environmental recommendations was low (20 to 45%) [27, 29, 51]. Reported adherence to interventions addressing personal risk factors was also inconsistent but slightly higher with variations from low to mostly adherent (21 to 76%) [20, 27, 29, 52]. Therefore, in further implementation and evaluation of multifactorial interventions in this setting with tailored intervention delivery, detailed reporting of all intervention features that are recommended, following risk assessment and the adherence to each feature could support future analysis.

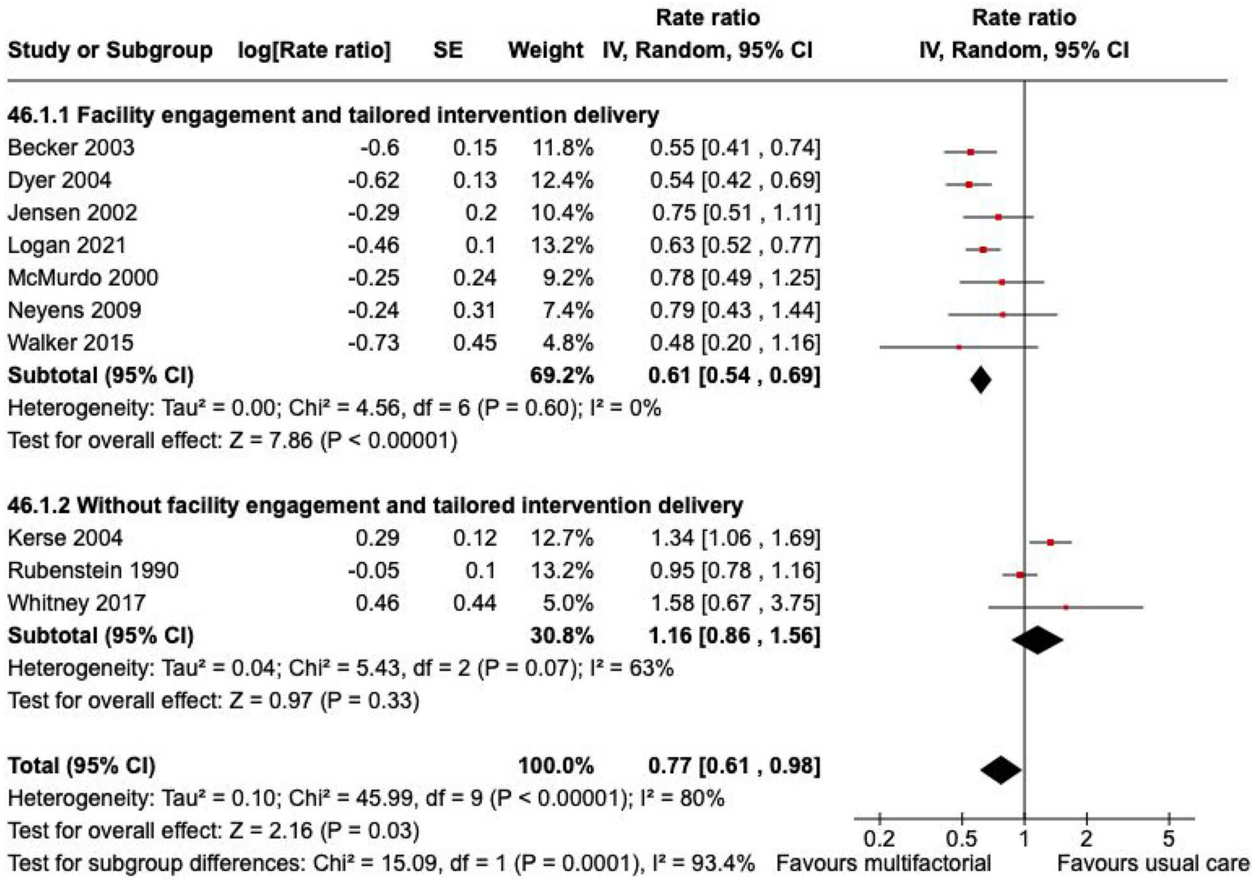

Figure 1. Presence or absence of facility engagement and tailoring intervention delivery on rate of falls

There are some limitations to the current analysis. One trial published in Spanish included in the Cochrane review was excluded from ICA/QCA analysis [30]. In this trial, the abstract and trial protocol suggests that tailored intervention delivery was unlikely, but it is unclear whether the facility was engaged. Therefore, it is likely that this ineffective trial is also consistent with the ICA/QCA theory proposed. There was also some subjectivity in the QCA coding of one trial for facility engagement where two authors could only use the published records to independently code facility engagement due to no response from trialist to attempts at requesting additional information. All coding for trial features requires some degree of subjectivity, but independent coding by two authors minimises the potential for bias.

Although existing trials had variable quality, the high consistency scores from the QCA as well as the lack of heterogeneity and statistical significance of the pooled effect size in the subgroup analyses (Figure 1) provides strong support for the validity of this theory of features driving multifactorial trial effectiveness. Thus, it is unlikely that the addition of a small number of new trials, even with differing outcomes, would lead to rejection of this proposed theory, although other additional pathways and explanations may also exist [53].

Conclusion

To reduce rate of falls consistently and successfully, multifactorial interventions in residential aged care should engage the facility in intervention development, implementation, and staff training for multifactorial risk assessment to promote staff adherence. It is also necessary to support staff to tailor the intervention to the residents' intrinsic factors, such as cognitive ability. Testing of trials incorporating these features with QCA showed consistency with falls prevention outcomes. A subgroup meta-analysis of trials with these features demonstrated a significant reduction in falls without heterogeneity. Multifactorial fall prevention trials in residential aged care should continue to individually assess risk factors all residents and offer environment hazard assessment, medical review, assistive aids and exercise intervention. Implementation of this approach for successful multifactorial falls prevention should be undertaken in aged care facilities widely, with ongoing evaluation utilising appropriate translational frameworks.

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