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Oladi, Sana, Uiga, Liis ORCID logoORCID: <https://orcid.org/0000-0002-5371-9428>, Hebert-Losier, Kim and Masters, Rich (2022) Testing the efficacy of a motor analogy designed to promote safe landing by older adults who fall accidentally: a study protocol for a randomised control study. *BMJ Open*, 12 (8). 060144-060144. ISSN 2044-6055

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Version: Published Version

Publisher: BMJ Journals

DOI: <https://doi.org/10.1136/bmjopen-2021-060144>

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BMJ Open Testing the efficacy of a motor analogy designed to promote safe landing by older adults who fall accidentally: a study protocol for a randomised control study

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To cite: Oladi S, Uiga L, Hebert-Losier K, *et al*. Testing the efficacy of a motor analogy designed to promote safe landing by older adults who fall accidentally: a study protocol for a randomised control study. *BMJ Open* 2022;**12**:e060144. doi:10.1136/bmjopen-2021-060144

► Prepublication history for this paper is available online. To view these files, please visit the journal online (<http://dx.doi.org/10.1136/bmjopen-2021-060144>).

Received 13 December 2021
Accepted 02 May 2022



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ABSTRACT

Introduction Falling is associated with adverse effects on the health of older people. The majority of research into falls among older people has focused on prevention, with less attention to 'how to fall safely'. Previous research suggests that motor analogies can be used to promote safe landing by young adults; however, the efficacy of this technique for older people remains unknown. This study aims to determine whether a motor analogy is useful for promoting safe falling in the older adult population.

Methods and analysis The study adopts a randomised, controlled, single-blinded study design. People 65 years and older will be randomly allocated to a control condition or a motor analogy condition. They will receive a nudge in a forward, backward or sideways direction (randomised order), which will initiate a fall. The nudge will occur at variable (randomised) time points, so participants will not be aware of when they will fall. Participants in the motor analogy condition will be instructed to 'land like a feather', whereas participants in the control condition will be instructed to 'land safely'. The primary outcome parameters are maximum impact force (normalised by mass) applied to different body segments during impact and fracture risk ratio of wrists and hips. A two-way multivariate analysis of variance will be conducted to examine differences between the motor analogy and control conditions as a function of the different variables.

Ethics and dissemination The University of Waikato Human Research Ethics Committee (Health 2021#45) has granted ethical approval. Outcomes will be disseminated through publication in peer-reviewed journals and presentations at conferences.

Trial registration Australian New Zealand Clinical Trials Registry ACTRN12621001189819. Registered on 6 September 2021.

INTRODUCTION

Accidental falls can adversely affect the health of older people and are second only to traffic incidents as the most common cause of death.¹ Millions of older adults fall each year. Not only are falls associated with high personal costs, such as reduced well-being,

STRENGTHS AND LIMITATIONS OF THIS STUDY

- ⇒ Single-blinded randomised controlled trial (the research assistant and participants are blinded to the conditions, but not the lead investigator).
- ⇒ Investigates a promising novel method for reducing fall-related injuries in older adults.
- ⇒ The proposed method can be easily implemented alongside fall prevention programmes or into health services attended by older adults.
- ⇒ One limitation of this study is that frail older adults who do not pass the Physical Activity Readiness Questionnaire are excluded from the study.

but also healthcare sectors are heavily burdened.^{2,3} For instance, every year in New Zealand 18% of the total cost of injury is due to falls.⁴ The government estimates that by the year 2025 fall-related injuries will cost the country around US\$418 million annually.⁵ Researchers and healthcare professionals have investigated various interventions to reduce the occurrence of falls; nevertheless, it is estimated that around 30%–60% of older adults fall unexpectedly annually.⁶ The complex nature of falls, combined with intrinsic (eg, impaired balance, reduced cognitive status, poor vision, etc) and extrinsic (eg, slippery floors, loose rugs, poor lighting, etc) risk factors, increases the difficulty of establishing effective fall prevention interventions.⁷

In a systematic review and meta-analysis of multifactorial fall prevention programmes, Hopewell *et al* (2020) found that prevention programmes may reduce fall rates, but have little to no effect on other fall-related consequences, such as fractures, hospital admission or medical attention and health-related quality of life.⁸ To address the multidimensional nature of falls and to mitigate their negative effects on health, complementary



approaches are needed to accompany fall prevention interventions. Consistent with this position, a small number of researchers have proposed that fall-related injuries can be reduced by learning ‘how to land safely’ when a fall occurs.^{9 10} A systematic review by Moon and Sosnoff¹⁰ revealed that only 13 studies have investigated safe landing techniques, and that most of the studies (12 out of 13) tested young adults rather than older adults. Landing techniques varied according to the direction of fall. For instance, to land safely from sideways falls, participants were instructed to use the martial arts technique of roll and slap.^{11–14} Different techniques were instructed for forward (eg, ‘land with a slightly flexed elbow angle’)¹⁵ and backward (eg, ‘bend the hips and knees’) falls.¹⁶

Older adults generally learn more slowly than younger adults and fail to reach similar levels of expertise,^{17–19} so their capacity to learn a different assortment of safe landing techniques that can be used appropriately when falling is questionable. For example, age-related declines in the ability to store and manage information (via working memory)^{19 20} make comprehension of explicit instructions (eg, how to land safely) more challenging during learning. Additionally, older adults generally display impaired reaction times,^{21 22} which increases the difficulty associated with selecting and executing the appropriate technique during a fall. It takes approximately 0.3s to recover balance when falling from standing height, with impact occurring after approximately 0.7s if recovery is not possible,²³ so there is minimal opportunity between the balance recovery phase and impact with the ground (ie, 0.4s) for older people to explicitly choose (and use) an appropriate safe landing technique.

Consequently, an approach to landing safely is required that involves less explicit information about technique and can be processed more quickly (ie, less resource demanding). Motor analogies may achieve this goal. Analogies leverage a concept that is already well known by the learner in order to convey the complex structure of the motor skill.^{24 25} Motor analogies are often used to teach movement skills to novices by comparing the movements with a similar, well-known concept, such as, ‘imagine you are putting a cookie in a cookie jar on a high shelf’ (for a basketball free-throw)²⁶ or ‘strike the ball while bringing the bat up the hypotenuse of a triangle’ (for a table tennis topspin forehand).²⁴ Such analogies are thought to promote implicit motor learning, which seeks to minimise accrual of conscious knowledge of the underlying rules governing the mechanics of movements.^{25 27} Implicit motor learning has been shown to impose fewer demands on cognitive resources than explicit motor learning^{27–29} and, importantly, has been shown to result in better learning by older adults.^{30 31}

Motor analogies have been shown to be beneficial for skill learning in the older adult population, resulting in preserved skill level over time and robust performance under dual-task conditions.³¹ They have also been used in rehabilitation settings to improve dynamic balance³² and walking by patients with Parkinson disease³³ and stroke.³⁴

These advantages have been attributed to the simplicity of retrieving analogies from memory³⁵ and the role they play in rapidly deploying attention during movement.³⁶ The potential for analogies to depute for explicit instructions, facilitate development of mental representations in long-term memory,³⁷ reduce the demands associated with processing information (ie, lower reliance on working memory)^{28 37–39} and hasten processing time²⁵ makes them a compelling choice for learning safe landing strategies.

Masters *et al.*,⁴⁰ sought to develop a simple motor analogy that promotes safe landing in the event of a fall. They conducted focus group discussions with older fallers, physiotherapists, occupational therapists, martial artists, gymnasts, dancers, parkour enthusiasts and health and safety experts. Analysis of the focus group transcripts revealed three common themes that were used to describe safe landing: ‘soft’, ‘silent’ and ‘slow’. Based on these themes, two motor analogies with the potential to promote soft, slow, silent landing were identified: *land like a snowflake* or *land like a feather*. In a previous experiment, we found that instructions to ‘land like a snowflake’ caused young adults to land more safely than control instructions (‘land on the ground’) when self-initiating falls.⁴¹ In a second experiment, we found that instructions to ‘land like a feather’ caused young adults to land more safely than control instructions (‘land safely’) when falling unexpectedly.⁴² To evaluate the quality of the landings, we attached inertial measurement units (IMUs) to different body segments of participants and extracted measures that we used to calculate impact force and wrist fracture risk ratio. Participants allocated to the motor analogy condition landed with less force and were less likely to fracture a wrist (ie, lower wrist fracture ratio) than participants allocated to the control condition, regardless of fall direction (forward, backward, sideways). These results suggest that participants allocated to the motor analogy condition were better able to adapt their movements to land safely.

One of the main limitations of these studies was that the motor analogies were tested in a young population; it is yet to be seen whether motor analogies can be used to promote safer landing by older people. It is well-known that ageing is associated with progressive loss of functional capacity.⁴³ For instance, older people often show a decline in functional balance,⁴⁴ ability to learn skills⁴⁵ and motor planning.⁴⁶ Hence, to account for individual differences in balance status in the proposed study, the primary researcher (a physiotherapist) will administer a short version of the Balance Evaluation Systems Test (Mini-BESTest), which is a clinical balance tool used for identifying balance dysfunction.⁴⁷ Participants will also complete an Activities-specific Balance Confidence (ABC) scale, which is a valid and reliable self-estimation tool for assessing the balance status of older adults with respect to falling.^{48 49} Furthermore, the Movement Specific Reinvestment Scale (MSRS)⁵⁰ will be administered to gain insight into individual differences in movement planning; the propensity that older people have for movement specific

reinvestment has been linked to a need for more time to ‘plan’ future movements.⁵¹ Alongside the biomechanical variables used for assessing safe landing, the assessment of functional balance (Mini-BESTest, ABC scale) and propensity for reinvestment (MSRS) will provide valuable information to understand the effectiveness of our motor analogy with respect to older adults.

The goal of this research is to determine whether older people land more safely (ie, with less risk of injury) when they are encouraged to use a motor analogy, ‘land like a feather’, if they fall. Based on our previous experiments, we hypothesise that:

1. Maximum acceleration (impact force normalised by mass) of various body segments (upper arms, wrists, hands, hips, thighs and legs) will be significantly lower across all fall directions (forward, backward, sideways) in the motor analogy condition compared with the control condition.
2. Fracture risk ratio (ratio of force at impact divided by the load necessary to cause a fracture) of the hips and wrists will be significantly lower in the motor analogy condition compared with the control condition.

METHOD

Study design

This study is a randomised, controlled, single-blinded study for participants aged 65 years and older. After assessment of cognition, functional balance and physical activity readiness, participants will be randomly allocated to a motor analogy condition or a control condition. The start and end date for data collection are anticipated to fall between 1 January 2023 and 30 December 2023.

Population

The study population will be older adults without leg and/or foot amputation who are able to stand and ambulate without walking aids. Participants will be required to have the ability to stand without help for 1 min and to walk without a walking aid for 6 m. Furthermore, all participants should be able to communicate in English, with no psychiatric or neurological impairments that prohibit participation. To screen for dementia, a score above 3 on the Mini-Cog test will be required. The Mini-Cog test has been validated for dementia screening (a score between 1 and 3 is considered ‘possibly impaired’, and a score above 3 is considered ‘probably normal’).⁵² To screen for physical activity limitations, the researcher will administer a Physical Activity Readiness Questionnaire (PARQ⁺). The PARQ⁺ offers safe screening of older adults prior to engaging in exercise or physical activity.^{53 54} Participants who answer ‘yes’ to two or more of the PARQ⁺ questions (ie, require a doctor consultation for physical activity) will be excluded.

Randomisation procedure and blinding

Randomisation procedure

All participants who fulfil the inclusion criteria will be randomly assigned to either the motor analogy condition

or the control condition using a random generator computer programme. The randomisation procedure (and outcome) will only be available to the lead investigator, who will not share this information with the participants or the research assistant.

Blinding

The research assistant who will be delivering the nudge that causes the participant to fall onto the padded surface will be blind to whether the participant has been allocated to the motor analogy condition or the control condition. Participants will not be informed about the experimental condition to which they have been assigned (motor analogy or control). Participants will also be blind to the direction in which they will be nudged (forward/backward/sideways).

Measurements and instrumentation

A 2D video camera (Canon, 25 frames per second) and Delsys Trigno (Delsys, Natick, Massachusetts, USA) IMUs will be used for data collection. The video camera will be positioned 3 m from the left side of participants on a tripod (height 1.3 m). The researcher will place IMU sensors on 15 different body segments. Acceleration data from the IMU sensors will be recorded at a frequency of 148.15 Hz using EMGworks Acquisition software (V.4.5.4). A hand-held dynamometer (MyoMeter, M550; range: 0–50 kg) will be used to record the force applied when nudging participants to initiate each fall.

Procedure

Eligible participants will be invited to the human performance science lab at the University of Waikato for a data collection session that will last around 70–80 min. **Figure 1** provides a flow diagram to illustrate the stages of data collection. Each consecutive component of the diagram is

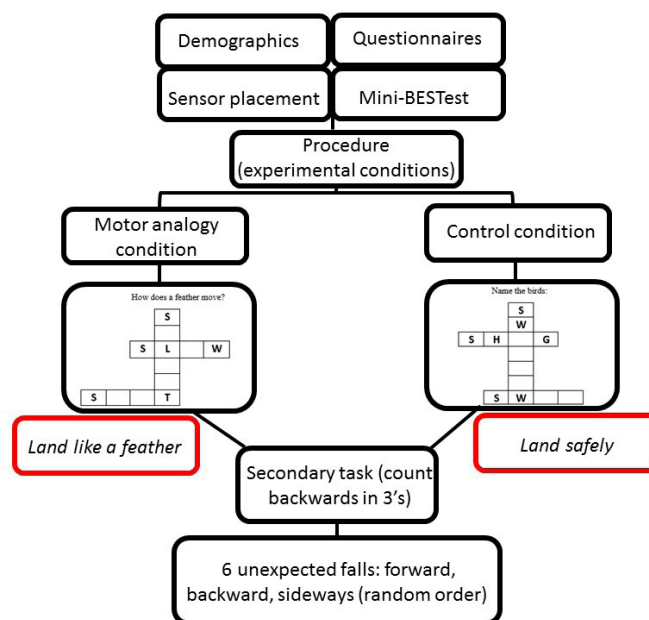


Figure 1 Flow diagram of the data collection session.

described in the subsequent section (eg, Demographics, Questionnaires, Sensor placement etc).

Demographics

At the beginning of the data collection session, demographic information will be collected: age, gender, height (cm), mass (kg), history of fall, walking aids and educational level. To establish history of falls, the following questions will be asked: Have you fallen? If so, how many times in the past year? Have you experienced a near fall? If so, how many times in the past year? Have you visited a hospital, family doctor or another healthcare professional because of a fall in the past year?

Questionnaires

Two psychometric questionnaires will be administered:

1. Activities-specific Balance Confidence (ABC) scale: this 16-item scale assesses confidence in ability to maintain balance during a range of indoor and outdoor functional activities (eg, 'How confident are you that you will not lose your balance or become unsteady when you walk around the house?'). The items of the scale are rated from 0% (lowest level of confidence) to 100% (highest level of confidence). This scale is a valid and reliable tool for measuring balance confidence in older adults.⁵⁵
2. Movement Specific Reinvestment Scale (MSRS): this scale comprises 10 items divided into two subscales. The Conscious Motor Processing subscale measures propensity to consciously control movements (eg, 'I try to think about my movements when I carry them out'). The Movement Self-consciousness subscale measures propensity to monitor 'style' of movement (eg, 'I am self-conscious about the way I look when I am moving'). The items are rated on a 6-point Likert scale from strongly disagree (1) to strongly agree (6). Thus, cumulative scores range from 10 to 60, with higher scores reflecting higher propensity for movement-specific reinvestment. The MSRS has been shown to have high internal consistency and test-retest reliability.⁵⁶

Sensor placement

Fifteen IMU sensors will be attached over the following body segments using double-sided tape: head, chest (aligned with the sternum), lower back (aligned with L3), upper arms (dorsal), wrists (dorsal), hands (dorsal), hips (greater trochanter), thighs (lateral) and lower legs (lateral). **Figure 2** demonstrates the placement of the IMU sensors on the participants.

Mini-BESTest

The researcher will administer a short version of the Mini-BESTest, which is a standardised clinical balance tool used to assess functional balance.^{57–60} This test has a maximum score of 28 points, with higher scores indicating better balance.

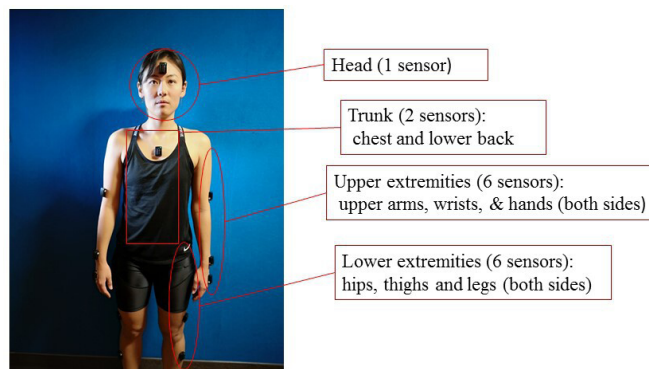


Figure 2 Positioning of inertial measurement units on different body segments.

Crossword puzzle

Participants in the motor analogy condition will be required to complete a three-word crossword puzzle designed to prime them about how feathers land on the ground: soft, slow, silent (**figure 3A**). Participants in the control condition will be asked to complete a similar crossword puzzle that uses names of birds as neutral primes: swallow, shag and swan (**figure 3B**). Crossword puzzles have been used in research to activate concepts/primes.⁶¹

Experimental conditions

Participants in the motor analogy condition will be instructed to 'land like a feather', whereas participants in the control condition will be instructed to 'land safely'. They will stand on a surface-level platform (27 cm × 32 cm) facing a fully padded landing area. A research assistant will apply a gentle impulse (nudge) to the left shoulder of participants, who will be instructed to fall in the direction in which the nudge is applied. If the nudge does not yield a fall the trial will not be repeated (the subsequent trial in the sequence will be initiated). The nudge will be applied in a forward, backward or sideways direction. Order of fall direction will be randomised using a random order generator. The research assistant will be blinded to condition (motor analogy/control) and each nudge will be applied using a hand-held dynamometer. The load cell will be placed on the participant's shoulder and the research assistant will apply a nudge via the surface of the dynamometer. The integral of the force with respect to time will be calculated (ie, impulse). The impulse required to initiate each fall will be recorded and used as a covariate in the statistical analysis to control for potential differences in nudge force. To reduce the likelihood that participants will anticipate the nudge, they will be required to count backwards in 3's during each trial (a concurrent secondary task). Nudges will occur at variable time points during counting. To familiarise participants with the experimental procedure, one practice trial will be conducted. The direction of the fall during the practice trial (forward, backward, sideways) will be randomised across participants. Afterwards, the experimental procedure will be repeated twice (with a different

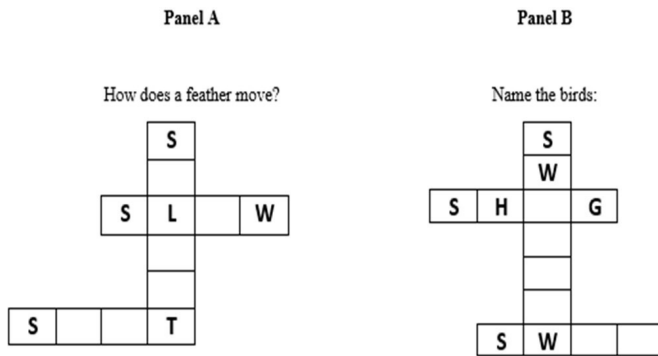


Figure 3 Crossword puzzles for priming participants. (A) soft, slow, silent and (B) swallow, shag, swan.

order of falls on each occasion). Hence, each participant will fall six times during the experimental procedure.

Prior experience of activities, such as dancing, gymnastics, sports (eg, rugby, surfing, parkour, etc), martial arts (eg, tai-Chi, judo, taekwondo, etc) may affect participants' landing strategies. Thus, after data collection, the experimenter will record information regarding participants' experience of these activities (eg, type of activity, years of participation, level of ability, type of fall strategy learnt, etc). This information will be used to support interpretation of the findings of our study.

Public involvement statement

Initially, people with an interest in falling (eg, older adults, healthcare professionals, physiotherapists, fall experts, etc) were consulted about safe landing via focus groups. Key themes were used to design motor analogies with potential to facilitate safe landing in the event of a fall. After testing the efficacy of the motor analogies using young adults, we consulted with fall prevention leaders in New Zealand about testing the analogies in older adults. We also engaged with the community through fall prevention classes and retirement homes, with a goal to determine the level of interest that older adults have in safe landing, and to take their feedback into account when designing the proposed study. We plan to disseminate our findings among fall prevention leaders and interested older adults who have provided us with their contact information.

Primary outcome

The acceleration data recorded by the IMUs will be exported in excel format and processed using Matlab (R2017b, MathWorks, Natic, USA). Start of fall (Start) and end of fall (End) will be extracted from a one-dimensional signal magnitude acceleration vector (SMV) of the lower back unit. [Figure 4](#) displays exemplar data from a backward fall.

To determine the beginning and end of a fall, a threshold will be calculated using a 100 ms moving window applied to the SMV data. Subsequently, the relative standard deviation (RSD) of the windows will be calculated. The generated RSDs will be averaged and used as a threshold for identifying the start and the end of the fall for each

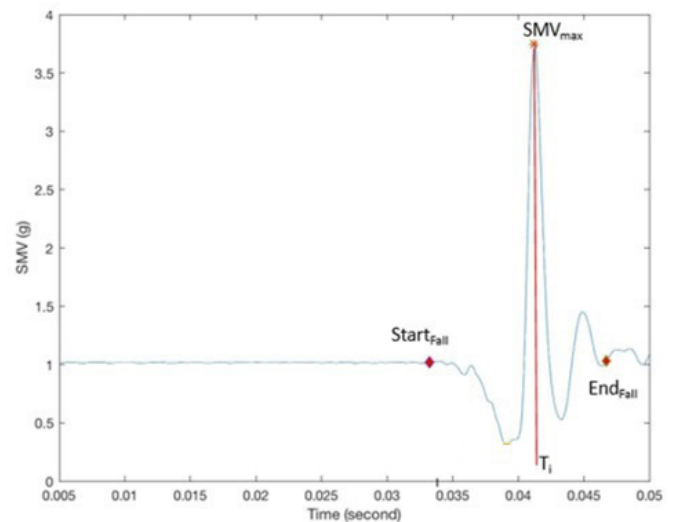


Figure 4 SMVs of the lower back inertial measurement unit during a backward fall. Start of fall (StartFall), time of impact (T_i) and end of fall (EndFall) are displayed. SMVs, signal magnitude vectors.

trial. RSD has previously been used to compute thresholds for identifying cancer cells,⁶² optic-nerve signals⁶³ and in various human motion dynamics studies.⁶⁴ The start of the fall will be defined as the trench before the SMV reaches its maximum value (SMV_{max})^{65 66} outlined by the SMV crossing the threshold. The end of the fall will be defined as the SMV crossing the threshold after it reaches its maximum value (SMV_{max}). The start and end of fall identification method will be verified using the video recordings. Maximum acceleration (SMV_{max} g) will be extracted from all 15 IMUs.

The fracture risk of different body parts depends on the severity of the impact and the capacity of the bones to resist the impact.⁶⁷ Therefore, fracture risk ratio will be defined as the ratio of force at impact divided by the load necessary to cause a fracture.^{68 69} To calculate the force applied to the wrists and hips, the SMV of the wrist units at time of impact will be multiplied by the scaling factors for the forearm and femoral head mass (%mass) provided by Dumas *et al*,⁷⁰ and then multiplied by 9.807 (convert g to m/s^2).² Finally, the force applied to the participant's wrist and hip IMUs will be divided by the load required to fracture the radius bone and femur head based on cadaveric studies.⁷¹ This measurement does not include the direction of force applied to the wrist and hips; hence, it is an estimation of the fracture risk ratio.

Sample size

Sample size estimation was conducted using a customisable statistical spreadsheet (xSampleSize.xlsx, www.sportsci.org). Sample size requirements were calculated from standard two-tailed hypothesis equations using 80% power ($\beta=0.20$), a 5% significance level ($\alpha=0.05$), and critical values of the f distribution for multivariate analysis of variance. Data from our previous research with young adults (smallest difference= $0.22 m/s^2$; within-subject

SD=0.28 m/s²; between-subject SD=0.32 m/s²) were used, with maximum acceleration (impact force normalised by mass) as our primary outcome. The calculations resulted in a minimum group size of 32 participants per condition. To account for 20% attrition rate, this study aims to recruit 38 participants per condition.

Data integrity and analysis

The lead investigator will monitor data integrity by regularly examining data files for omissions and errors. The demographics, questionnaire scores and outcome measures will be used to compare the conditions (motor analogy vs control). The means and SD of variables will be calculated and differences between the conditions will be examined using IBM SPSS Statistics V.25 (IBM SPSS Statistics Software). A two-way between-groups multivariate analysis of variance will be conducted to explore the effect of condition (motor analogy, control) and fall direction (forward, backward, sideways) on the following variables of interest: fracture risk ratios of hips, fracture risk ratios of wrists and SMV_{max} (g) of the 15 IMUs located on the body segments displayed in figure 2. Significant main effects and interactions will be further scrutinised using analysis of variance of variables separately. To control for the multiplicity problem caused by conducting multiple statistical tests, the Benjamini-Hochberg (B-H) method will be used to control the alpha level using successive modified Bonferroni corrections.⁷² All participants will be included in the analyses and will be given an anonymous participation ID to protect confidentiality. Only study investigators will have access to the raw data. All datasets used or analysed during this study will be available from the corresponding author on reasonable request.

Ethics and dissemination

The University of Waikato Human Research Ethics Committee (Health 2021#45) approved the study protocol. The results of the trial will be submitted to international peer-reviewed journals and presented at conferences.

DISCUSSION

Falls can cause significant health problems for older adults and can result in frailty, immobility, and decline in functional ability. The use of motor analogies to promote safe(r) landing is a promising approach that has potential to reduce the severity of injuries that occur during accidental falls. In this paper, we described the methodology for a randomised controlled single-blinded study that investigates the efficacy of using a motor analogy to promote safer landing by older adults.

The project requires work with older people; hence, extreme caution is required to ensure the safety of our participants. One of the conditions of participation in this study is that participants can walk without assistance for at least 6 m (twice the length of the 3-metre walk test in the Min-BESTest) in a controlled laboratory

environment. Older people who cannot walk for 6 m without assistance, or stand without a walking aid for at least 1 min, will be excluded from the study. Thus, the exclusion criterion requires the participants to be comfortable when walking and standing independently. Additionally, we will administer the PARQ⁺ and participants who answer 'yes' to two or more of the questions will be excluded. The PARQ⁺ is sensitive to underlying conditions, such as osteoporosis, cardiovascular problems, respiratory disease, previous surgery, arthritis, chronic conditions, high blood pressure, back problems, stroke and so on. Therefore, if a participant is not in a healthy physical condition, they will not participate. This approach therefore excludes frail older adults from our participant pool, which is necessary due to the risk of injury associated with our fall intervention.

In studies that examine older people, criteria often are designed to exclude those with cognitive impairments. However, previous studies have reported that motor learning interventions can be effective for people with cognitive and/or communicative impairments.⁷³ In this study, we therefore attempt to include a sample that is more representative of older adults. A mini cognition test (Mini-Cog) will be administered to assess the likelihood of dementia. A score between 1 and 3 is considered 'possibly impaired', and a score above 3 is considered 'probably normal'.⁵² Only participants who score below the cut-off point of 3 will be excluded; hence, this will provide us an opportunity to assess the effect of motor analogies on older adults within different ranges of cognition, which is consistent with our ultimate goal to develop a simple solution for safe landing that is applicable to the widest possible audience.

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Contributors The idea and rationale that underpins the work was generated by RSWM. SO is a PhD student who is supervised by RSWM (Chief Supervisor), LU (Secondary Supervisor), and KH-L (Secondary Supervisor). SO wrote the manuscript with support from RSWM, LU and KH-L. All of the authors have advised on study design and methodology, and will contribute to analysis, interpretation and dissemination of the findings.

Funding This work is part of a programme of research led by RSWM, which is supported by a charitable donation from Freemason's New Zealand. Award/grant number N/A.

Competing interests None declared.

Patient and public involvement Patients and/or the public were involved in the design, or conduct, or reporting or dissemination plans of this research. Refer to the Methods section for further details.

Patient consent for publication Obtained.

Provenance and peer review Not commissioned; externally peer reviewed.

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