BMJ Open

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Journal:	*BMJ Open*
Manuscript ID	bmjopen-2021-060144
Article Type:	Protocol
Date Submitted by the Author:	13-Dec-2021

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Keywords:	GERIATRIC MEDICINE, PUBLIC HEALTH, REHABILITATION MEDICINE, COMPLEMENTARY MEDICINE

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TITLE PAGE

Title

Testing the efficacy of a motor analogy designed to promote safe landing by older adults who fall accidentally: A randomized control study

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Word count

3878 words (excluding title page, abstract, references, figures and tables)

Protocol version

Original

TESTING THE EFFICACY OF A MOTOR ANALOGY DESIGNED TO PROMOTE SAFE LANDING BY OLDER ADULTS WHO FALL ACCIDENTALLY: PROTOCOL FOR A RANDOMIZED CONTROL STUDY

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 randomized, 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 an unexpected nudge in a forward, backward, or sideways direction (randomised order), which will initiate a fall (i.e., a simulation of an unexpected 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 2-way MANOVA 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.

Keywords: Older adults; Falls; Safe landing; Motor analogy

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 programs 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 (PARQ+) are excluded from the study.

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, but also health care 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 $418 million dollars annually.[5] Researchers and health care 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 (e.g., impaired balance, reduced cognitive status, poor vision, etc.) and extrinsic (e.g., 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 programs, Hopewell et al. (2020) found that prevention programs 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 Sosnoff [10] revealed that only thirteen 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 (e.g., "land with a slightly flexed elbow angle")[15] and backward (e.g., "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 (e.g., 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 0.3 seconds to recover balance when falling from standing height, with impact occurring after approximately 0.7 seconds if recovery is not possible,[23] so there is minimal opportunity between the balance recovery phase and impact with the ground

(i.e., 0.4 seconds) 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 (i.e., 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.[27 28] Implicit motor learning has been shown to impose fewer demands on cognitive resources than explicit motor learning[27 29 30] and, importantly, has been shown to result in better learning by older adults.[31 32]

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.[32] They have also been used in rehabilitation settings to improve dynamic balance[33] and walking by Parkinson[34] and stroke[35] patients. These advantages have been attributed to the simplicity of retrieving analogies from memory[36] and the role they play in rapidly deploying attention during movement.[37] The potential for analogies to depute for explicit instructions, facilitate development of mental representations in long term memory,[38] reduce the demands associated with processing information (i.e., lower reliance on working memory)[29 39-41] and hasten processing time[28] makes them a compelling choice for learning safe landing strategies.

Masters et al.[42] 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', 'slow'. Based on these themes, two motor analogies with 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.[43] 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.[44] To evaluate the quality of the landings, we attached inertial measurement units (IMU) to different body segments of participants and extracted measures that we used to calculated 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 (i.e., 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.[45] For instance, older people often show a decline in functional balance,[46] ability to learn skills,[47] and motor planning.[48] 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.[49] 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.[50 51] Furthermore, the Movement Specific Reinvestment Scale (MSRS)[52] 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.[53] 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 (i.e., 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:

- 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 to the control condition
- 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 to the control condition

METHOD

Study design

This study is a randomized, controlled, single-blinded study for participants aged 65 years and older. The University of Waikato Human Research Ethics Committee (Health 2021#45) approved the study protocol. After assessment of cognition, functional balance, and physical activity readiness, participants will be randomly allocated to a motor analogy condition or a control condition.

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 minute and to walk without a walking aid for 6 meters. 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 to 3 is considered "possibly impaired", and a score above 3 is considered "probably normal").[54] 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.[55 56] Participants who answer 'yes' to 2 or more of the PARQ$^+$ questions (i.e., 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 program. The randomization 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 Inc., Natrick, MA) inertial measurement units (IMU) will be used for data collection. The video camera will be positioned 3 meters from the left side of participants on a tripod (height 1.3 meters). 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 (Version 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 minutes. Figure 1 provides a flow diagram to illustrate the stages of data collection. Each consecutive component of the diagram is described in the subsequent section (e.g., 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.

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 (e.g., “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.[57]

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 (e.g., "I try to think about my movements when I carry them out"). The Movement Self-consciousness subscale measures propensity to monitor "style" of movement (e.g., "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.[58]

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), 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 Balance Evaluation Systems Test (Mini-BESTest), which is a standardized clinical balance tool used to assess functional balance.[59-62] This test has a maximum score of 28 points, with higher scores indicating better balance.

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 3, Panel A). Participants in the control condition will be asked to complete a similar crossword puzzle that uses names of birds as neutral primes: swallow, shag, swan (Figure 3, Panel B).

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 (27cm x 32cm) 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. The nudge will be applied in a forward, backward, or sideways direction. Order of fall direction will be randomized 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 force 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. The experimental procedure will be repeated twice (with a different order of falls on each occasion). Hence, each participant will fall six times during the experimental procedure.

Public involvement Statement

Initially, people with an interest in falling (e.g., older adults, health care 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 NZ 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 Inc., 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 trial. RSD has previously been used to compute thresholds for identifying cancer cells,[63] optic-nerve signals,[64] and in various human motion dynamics studies.[65] The start of the fall will be defined as the trench before the SMV reaches its maximum value (SMV_{max})[66 67] 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.[68] Therefore, fracture risk ratio will be defined as the ratio of force at impact divided by the load necessary to cause a fracture.[69 70] 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.,[71] and then multiplied by 9.807 (convert g to m/s^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.[72]

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 an 80% power ($\beta = 0.20$), and 5% significance level ($\alpha = 0.05$). We used data from our previous research with young adults (smallest difference=0.22 m/s^2; within subject SD= 0.28 m/s^2; between subject SD=0.32 m/s^2) for the calculations, 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 25 (IBM SPSS Statistics Software). A two-way between-groups multivariate analysis of variance (MANOVA) will be conducted to explore the effect of condition (motor analogy, control) and fall direction (forward, backward, sideways) on the following variables of interest: 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 (ANOVA) 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.[73] 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 upon reasonable request.

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 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 randomized 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 meters (twice the length of the 3-meter walk test in the Min-BESTest) in a controlled laboratory environment. Older people who cannot walk for 6 meters without assistance, or stand without a walking aid for at least one minute, 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 2 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, etc. 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.[74] 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 to 3 is considered "possibly impaired", and a score above 3 is considered "probably normal".[54] 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.

AUTHORS' CONTRIBUTIONS The idea and rationale that underpins the work was generated by R.S.W.M.; S.O. is a PhD student who is supervised by R.S.W.M. (Chief Supervisor), L.U. (Secondary Supervisor), and K. H-L. (Secondary Supervisor); S.O. wrote the manuscript with support from R.S.W.M., L.U., and K. H-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 R.S.W.M., which is supported by a charitable donation from Freemason's New Zealand.

AWARD/GRANT NUMBER N/A

COMPETING INTERESTS None declared

PROTOCOL AMENDMENTS Any change to the protocol will be communicated with the University of Waikato Human Research Ethics Committee (Health) and the Australian New Zealand Clinical Trials Registry (ANZCTR).

FIGURE CAPTIONS:

Figure 1: Flow diagram of the data collection session.

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

Figure 3: Crossword puzzles for priming participants. Panel A: soft, slow, silent. Panel B: swallow, shag, swan.

Figure 4: Signal magnitude vector (SMV) of the lower back inertial measurement unit during an unexpected backward fall. Start of fall (StartFall), time of impact (Ti) and end of fall (EndFall) are displayed.

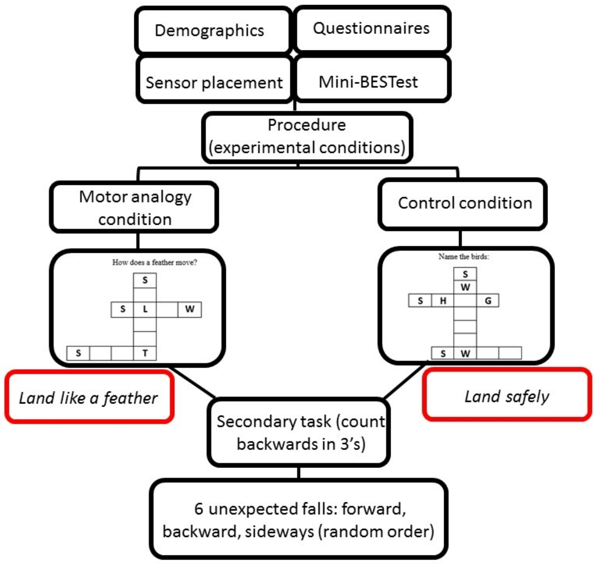
REFERENCES:

1. Chou L-W, Chang K-M, Wei Y-C, et al. Empirical mode decomposition-derived entropy features are beneficial to distinguish elderly people with a falling history on a force plate signal. *Entropy* 2021;23(4):472.
2. Arnold CM, Dal Bello-Haas VPM, Farthing JP, et al. Falls and wrist fracture: Relationship to women's functional status after age 50. *Canadian Journal on Aging/La Revue canadienne du vieillissement* 2016;35(3):361-71.
3. Greenberg M, Jacoby J, Barraco RD, et al. Analysis of Falls Efficacy Scale and vulnerable elders survey as predictors of falls. *Cureus* 2021;13(4)
4. Deverall E, Kvizhinadze G, Pega F, et al. Exercise programmes to prevent falls among older adults: modelling health gain, cost-utility and equity impacts. *Injury Prevention* 2019;25(4):258-63.
5. Barry M, Kaye N. ACC invests $30m to reduce falls and fractures for older New Zealanders: The official website of the New Zealand Government; 2016 [Available from: https://www.beehive.govt.nz/release/acc-invests-30m-reduce-falls-and-fractures-older-new-zealanders accessed September 29th 2021.
6. Rubenstein LZ. Falls in older people: epidemiology, risk factors and strategies for prevention. *Age and Ageing* 2006;35(suppl_2):ii37-ii41.
7. Ambrose AF, Paul G, Hausdorff JM. Risk factors for falls among older adults: a review of the literature. *Maturitas* 2013;75(1):51-61.
8. Hopewell S, Copsey B, Nicolson P, et al. Multifactorial interventions for preventing falls in older people living in the community: a systematic review and meta-analysis of 41 trials and almost 20 000 participants. *British Journal of Sports Medicine* 2020;54(22):1340-50.
9. Hsieh KL, Sosnoff JJ. A motor learning approach to reducing fall-related injuries. *Journal of Motor Behavior* 2020:1-5.
10. Moon Y, Sosnoff J. Safe landing strategies during a fall: systematic review and meta-analysis. *Archives of Physical Medicine and Rehabilitation* 2017;98(4):783-94.
11. Groen BE, Smulders E, De Kam D, et al. Martial arts fall training to prevent hip fractures in the elderly. *Osteoporosis International* 2010;21(2):215-21.
12. Groen BE, Weerdesteyn V, Duysens J. Martial arts fall techniques decrease the impact forces at the hip during sideways falling. *Journal of Biomechanics* 2007;40(2):458-62.
13. Groen BE, Weerdesteyn V, Duysens J. The relation between hip impact velocity and hip impact force differs between sideways fall techniques. *Journal of Electromyography and Kinesiology* 2008;18(2):228-34.
14. Weerdesteyn V, Groen BE, Van Swigchem R, et al. Martial arts fall techniques reduce hip impact forces in naive subjects after a brief period of training. *Journal of Electromyography and Kinesiology* 2008;18(2):235-42.
15. Lo J, McCabe GN, DeGoede KM, et al. On reducing hand impact force in forward falls: results of a brief intervention in young males. *Clinical Biomechanics* 2003;18(8):730-36.
16. Tan J-S, Eng JJ, Robinovitch SN, et al. Wrist impact velocities are smaller in forward falls than backward falls from standing. *Journal of Biomechanics* 2006;39(10):1804-11.

17. McNay EC, Willingham DB. Deficit in learning of a motor skill requiring strategy, but not of perceptuomotor recalibration, with aging. *Learning & Memory* 1998;4(5):411-20.
18. Serbruyns L, Gooijers J, Caeyenberghs K, et al. Bimanual motor deficits in older adults predicted by diffusion tensor imaging metrics of corpus callosum subregions. *Brain Structure & Function* 2015;220(1):273-90.
19. Voelcker-Rehage C. Motor-skill learning in older adults—a review of studies on age-related differences. *European Review of Aging and Physical Activity* 2008;5(1):5-16.
20. Light LL, Anderson PA. Working-memory capacity, age, and memory for discourse. *Journal of Gerontology* 1985;40(6):737-47.
21. Hultsch DF, MacDonald SWS, Dixon RA. Variability in reaction time performance of younger and older adults. *The Journals of Gerontology Series B: Psychological Sciences and Social Sciences* 2002;57(2):P101-P15.
22. Mendelson DN, Redfern MS, Nebes RD, et al. Inhibitory processes relate differently to balance/reaction time dual tasks in young and older adults. *Aging, Neuropsychology, and Cognition* 2009;17(1):1-18.
23. Le Goic M, Wang D, Vidal C, et al. An initial passive phase that limits the time to recover and emphasizes the role of proprioceptive information. *Frontiers in Neurology* 2018;9:986.
24. Liao C-M, Masters RSW. Analogy learning: A means to implicit motor learning. *Journal of Sports Sciences* 2001;19(5):307-19.
25. Masters RS. Theoretical Aspects of Implicit Learning in Sport. *International Journal of Sport Psychology* 2000
26. Lam WK, Maxwell JP, Masters RSW. Analogy versus explicit learning of a modified basketball shooting task: Performance and kinematic outcomes. *Journal of Sports Sciences* 2009;27(2):179-91.
27. Masters RSW. Knowledge, knerves and know-how: The role of explicit versus implicit knowledge in the breakdown of a complex motor skill under pressure. *British Journal of Psychology* 1992;83(3):343-58.
28. Masters RSW. Theoretical aspects of implicit learning in sport. *International Journal of Sport Psychology* 2000:530-40.
29. Masters RSW, van Duijn T, Uiga L. Advances in implicit motor learning. In: Hodges NJ, Williams MA, eds. Skill acquisition in sport: research, theory and practice. Third ed. UK: Routledge 2020:p.75-95.
30. Steenbergen B, Van Der Kamp J, Verneau M, et al. Implicit and explicit learning: applications from basic research to sports for individuals with impaired movement dynamics. *Disability and Rehabilitation* 2010;32(18):1509-16.
31. Chauvel G, Maquestiaux F, Hartley AA, et al. Age effects shrink when motor learning is predominantly supported by nondeclarative, automatic memory processes: Evidence from golf putting. *Quarterly Journal of Experimental Psychology* 2012;65(1):25-38.
32. Tse ACY, Wong TWL, Masters RSW. Examining motor learning in older adults using analogy instruction. *Psychology of Sport and Exercise* 2017;28:78-84.
33. Kim S-M, Qu F, Lam W-K. Analogy and explicit motor learning in dynamic balance: Posturography and performance analyses. *European Journal of Sport Science* 2021;21(8):1129-39.
34. Jie L-J, Goodwin V, Kleynen M, et al. Analogy learning in Parkinson's disease: a proof-of-concept study. *International Journal of Therapy and Rehabilitation* 2016;23(3):123-30.
35. Kleynen M, Wilson MR, Jie L-J, et al. Exploring the utility of analogies in motor learning after stroke: a feasibility study. *International Journal of Rehabilitation Research* 2014;37(3):277-80.
36. Donnelly CM, McDaniel MA. Use of analogy in learning scientific concepts. *Journal of Experimental Psychology: Learning, Memory, and Cognition* 1993;19(4):975.
37. Koedijker JM, Poolton JM, Maxwell JP, et al. Attention and time constraints in perceptual-motor learning and performance: Instruction, analogy, and skill level. *Consciousness and Cognition* 2011;20(2):245-56.
38. Meier C, Frank C, Grben B, et al. Verbal instructions and motor learning: How analogy and explicit instructions influence the development of mental representations and tennis serve performance. *Frontiers in Psychology* 2020;11:2.

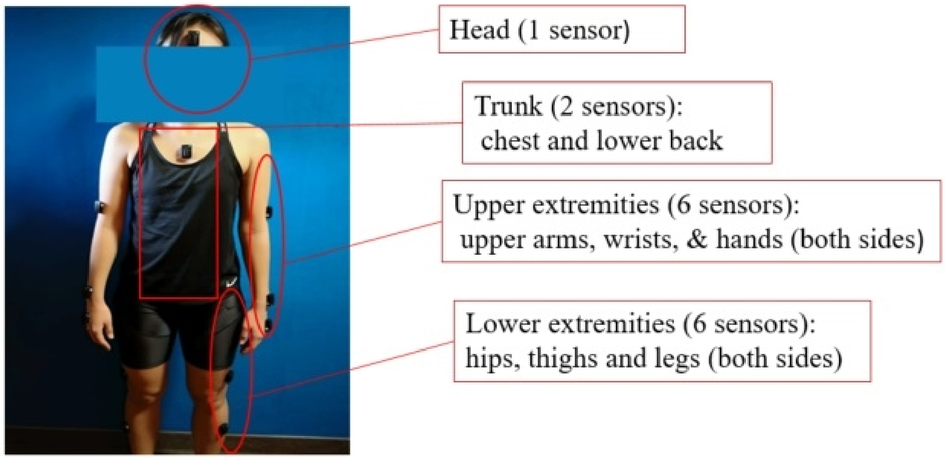
39. Masters RSW, Liao C. Chunking as a characteristic of implicit motor learning. European Congress of Sport Psychology, 2003.
40. Meier C, Frank C, Gröben B, et al. Verbal Instructions and Motor Learning: How Analogy and Explicit Instructions Influence the Development of Mental Representations and Tennis Serve Performance. *Frontiers in Psychology* 2020;11:2-2.
41. Poolton JM, Masters RSW. Chunking/Dechunking. *Encyclopedia of Sport and Exercise Psychology* 2014:129-30.
42. Masters RSW, Barbour K, Hébert-Losier K, et al. Promoting safer landing by older adults who fall unexpectedly. *The Journal of Sport and Exercise Science* 2018;2:31.
43. Oladi S, Uiga L, Hébert-Losier K, et al. Using inertial measurement units to determine the potential efficacy of a motor analogy for improving landing from self-initiated falls. *The Journal of Sport and Exercise Science* 2019;3:32.
44. Oladi S, Uiga L, Hébert-Losier K, et al. Using a motor analogy to promote safe-landing from unexpected fall. *The Journal of Sport and Exercise Science* 2020;4:30.
45. Sampaio A, Marques-Aleixo I, Seabra A, et al. Physical fitness in institutionalized older adults with dementia: association with cognition, functional capacity and quality of life. *Aging Clinical and Experimental Research* 2020:1-10.
46. Alexander NB. Postural control in older adults. *Journal of the American Geriatrics Society* 1994;42(1):93-108.
47. Raz N, Williamson A, Gunning-Dixon F, et al. Neuroanatomical and cognitive correlates of adult age differences in acquisition of a perceptual-motor skill. *Microscopy Research and Technique* 2000;51(1):85-93.
48. Wang S, Williams J, Wilmut K. Constraints on motor planning across the life span: Physical, cognitive, and motor factors. *Psychology and Aging* 2020;35(3):421.
49. Horak FB, Wrisley DM, Frank J. The balance evaluation systems test (BESTest) to differentiate balance deficits. *Physical Therapy* 2009;89(5):484-98.
50. Myers AM, Fletcher PC, Myers AH, et al. Discriminative and evaluative properties of the activities-specific balance confidence (ABC) scale. *The Journals of Gerontology Series A: Biological Sciences and Medical Sciences* 1998;53(4):M287-M94.
51. Powell LE, Myers AM. The activities-specific balance confidence (ABC) scale. *The Journals of Gerontology Series A: Biological Sciences and Medical Sciences* 1995;50(1):M28-M34.
52. Masters RSW, Eves FF, Maxwell JP. Development of a movement specific reinvestment scale. International Society of Sport Psychology (ISSP) World Congress: International Society of Sport Psychology (ISSP), 2005.
53. Uiga L, Capio CM, Ryu D, et al. The role of movement-specific reinvestment in visuomotor control of walking by older adults. *The Journals of Gerontology: Series B* 2020;75(2):282-92.
54. Borson S, Scanlan JM, Chen P, et al. The Mini-Cog as a screen for dementia: validation in a population-based sample. *Journal of the American Geriatrics Society* 2003;51(10):1451-54.
55. Cardinal BJ, Cardinal MK. Preparticipation physical activity screening within a racially diverse, older adult sample: comparison of the original and Revised Physical Activity Readiness Questionnaires. *Research Quarterly for Exercise and Sport* 2000;71(3):302-07.
56. Cardinal BJ, Esters J, Cardinal MK. Evaluation of the revised physical activity readiness questionnaire in older adults. *Medicine and Science in Sports and Exercise* 1996;28(4):468-72.
57. Schepens S, Goldberg A, Wallace M. The short version of the Activities-specific Balance Confidence (ABC) scale: Its validity, reliability, and relationship to balance impairment and falls in older adults. *Archives of Gerontology and Geriatrics* 2009;51(1):9-12.
58. Malhotra N, Poolton JM, Wilson MR, et al. Examining movement-specific reinvestment and performance in demanding contexts. *Journal of Sport and Exercise Psychology* 2015;37(3):327-38.
59. Marques A, Almeida S, Carvalho J, et al. Reliability, Validity, and Ability to Identify Fall Status of the Balance Evaluation Systems Test, Mini–Balance Evaluation Systems Test, and Brief–Balance Evaluation Systems Test in Older People Living in the Community. *Archives of Physical Medicine and Rehabilitation* 2016;97(12):2166-73.
60. O'Hoski S, Sibley KM, Brooks D, et al. Construct validity of the BESTest, mini-BESTest and briefBESTest in adults aged 50 years and older. *Gait & Posture* 2015;42(3):301-05.

61. Padgett PK, Jacobs JV, Kasser SL. Is the BESTest at its best? A suggested brief version based on interrater reliability, validity, internal consistency, and theoretical construct. *Physical Therapy* 2012;92(9):1197-207.
62. Sibley KM, Beauchamp MK, Van Ooteghem K, et al. Using the systems framework for postural control to analyze the components of balance evaluated in standardized balance measures: a scoping review. *Archives of Physical Medicine and Rehabilitation* 2015;96(1):122-32.
63. Ericson MB, Sandberg C, Gudmundson F, et al. Fluorescence contrast and threshold limit: implications for photodynamic diagnosis of basal cell carcinoma. *Journal of Photochemistry and Photobiology B: Biology* 2003;69(2):121-27.
64. Hay GA, Chesters MS. Signal-transfer functions in threshold and suprathreshold vision. *Journal of The Optical Society of America* 1972;62(8):990-98.
65. Venture G, Ayusawa K, Nakamura Y. A numerical method for choosing motions with optimal excitation properties for identification of biped dynamics-an application to human. IEEE International Conference on Robotics and Automation: IEEE, 2009:1226-31.
66. Degen T, Jaeckel H, Rufer M, et al. SPEEDY: a fall detector in a wrist watch. Seventh IEEE International Symposium on Wearable Computers: ISWC, 2003:184-87.
67. Kangas M, Vikman I, Nyberg L, et al. Comparison of real-life accidental falls in older people with experimental falls in middle-aged test subjects. *Gait & Posture* 2012;35(3):500-05.
68. Groen BE, Weerdesteyn V, Duysens J. The relation between hip impact velocity and hip impact force differs between sideways fall techniques. *Journal of Biomechanics* 2006(39):88.
69. DeGoede KM, Ashton-Miller JA, Schultz AB. Fall-related upper body injuries in the older adult: a review of the biomechanical issues. *Journal of Biomechanics* 2003;36(7):1043-53.
70. Melton 3rd LJ, Cummings SR. Heterogeneity of age-related fractures: implications for epidemiology. *Bone and Mineral* 1987;2(4):321-31.
71. Dumas R, Cheze L, Verriest JP. Adjustments to McConville et al. and Young et al. body segment inertial parameters. *Journal of Biomechanics* 2007;40(3):543-53.
72. Augat P, Reeb H, Claes LE. Prediction of fracture load at different skeletal sites by geometric properties of the cortical shell. *Journal of Bone and Mineral Research* 1996;11(9):1356-63.
73. Benjamini Y, Hochberg Y. Controlling the false discovery rate: a practical and powerful approach to multiple testing. *Journal of the Royal Statistical Society: Series B (Methodological)* 1995;57(1):289-300.
74. Jie L-J, Kleynen M, Meijer K, et al. The effects of implicit and explicit motor learning in gait rehabilitation of people after stroke: protocol for a randomized controlled trial. *JMIR Research Protocols* 2018;7(5):142.



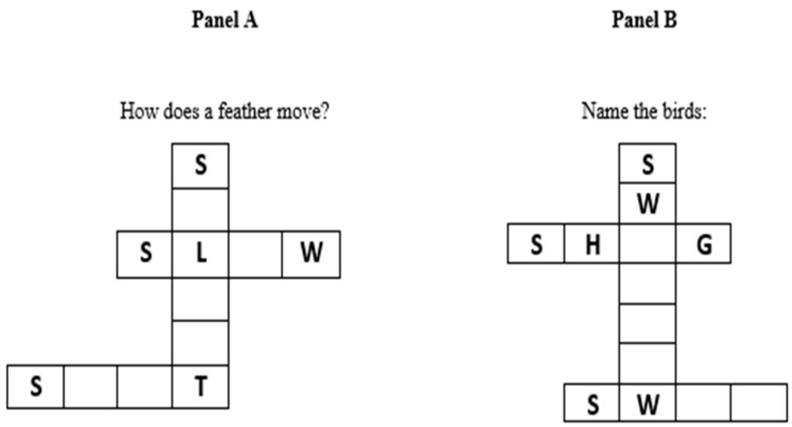
Flow diagram of the data collection session.

338x190mm (96 x 96 DPI)



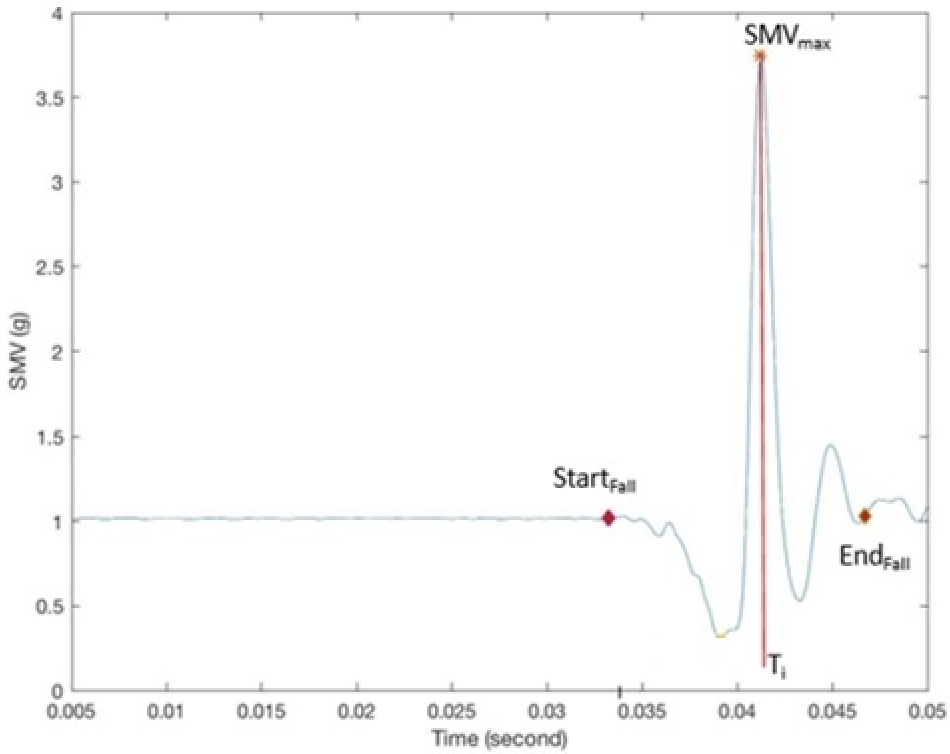
Positioning of inertial measurement units on different body segments

173x92mm (96 x 96 DPI)



Crossword puzzles for priming participants. Panel A: soft, slow, silent. Panel B: swallow, shag, swan.

338x190mm (96 x 96 DPI)



Signal magnitude vector (SMV) of the lower back inertial measurement unit during an unexpected backward fall. Start of fall (StartFall), time of impact (Ti) and end of fall (EndFall) are displayed.

127x100mm (96 x 96 DPI)

Section/item	Item #	Description	Page #
		Administrative information	
Title	1	Descriptive title identifying the study design, population, interventions, and, if applicable, trial acronym	2
Trial registration	2a	Trial identifier and registry name. If not yet registered, name of intended registry	3
	2b	All items from the World Health Organization Trial Registration Data Set	NA
Protocol version	3	Date and version identifier	1
Funding	4	Sources and types of financial, material, and other support	15
Roles and responsibilities	5a	Names, affiliations, and roles of protocol contributors	1; 15
	5b	Name and contact information for the trial sponsor	NA
	5c	Role of study sponsor and funders, if any, in study design; collection, management, analysis, and interpretation of data; writing of the report; and the decision to submit the report for publication, including whether they will have ultimate authority over any of these activities	15
	5d	Composition, roles, and responsibilities of the coordinating centre, steering committee, endpoint adjudication committee, data management team, and other individuals or groups overseeing the trial, if applicable (see Item 21a for data monitoring committee)	NA
		Introduction	
Background and rationale	6a	Description of research question and justification for undertaking the trial, including summary of relevant studies (published and unpublished) examining benefits and harms for each intervention	3-7
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		Methods: Participants, interventions, and outcomes	
Study setting	9	Description of study settings (eg, community clinic, academic hospital) and list of countries where data will be collected. Reference to where list of study sites can be obtained	9-11
Eligibility criteria	10	Inclusion and exclusion criteria for participants. If applicable, eligibility criteria for study centres and individuals who will perform the interventions (eg, surgeons, psychotherapists)	8

Interventions	11a	Interventions for each group with sufficient detail to allow replication, including how and when they will be administered	11
	11b	Criteria for discontinuing or modifying allocated interventions for a given trial participant (eg, drug dose change in response to harms, participant request, or improving/worsening disease)	NA
	11c	Strategies to improve adherence to intervention protocols, and any procedures for monitoring adherence (eg, drug tablet return, laboratory tests)	NA
	11d	Relevant concomitant care and interventions that are permitted or prohibited during the trial	NA
Outcomes	12	Primary, secondary, and other outcomes, including the specific measurement variable (eg, systolic blood pressure), analysis metric (eg, change from baseline, final value, time to event), method of aggregation (eg, median, proportion), and time point for each outcome. Explanation of the clinical relevance of chosen efficacy and harm outcomes is strongly recommended	12-13
Participant timeline	13	Time schedule of enrolment, interventions (including any run-ins and washouts), assessments, and visits for participants. A schematic diagram is highly recommended (see fig 1)	9
Sample size	14	Estimated number of participants needed to achieve study objectives and how it was determined, including clinical and statistical assumptions supporting any sample size calculations	13
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Methods: Assignment of interventions (for controlled trials)			
Allocation:			
Sequence generation	16a	Method of generating the allocation sequence (eg, computer-generated random numbers) and list of any factors for stratification. To reduce predictability of a random sequence, details of any planned restriction (eg, blocking) should be provided in a separate document that is unavailable to those who enrol participants or assign interventions	8
Allocation concealment mechanism	16b	Mechanism of implementing the allocation sequence (eg, central telephone; sequentially numbered, opaque, sealed envelopes), describing any steps to conceal the sequence until interventions are assigned	8
Implementation	16c	Who will generate the allocation sequence, who will enrol participants, and who will assign participants to interventions	8
Blinding (masking)	17a	Who will be blinded after assignment to interventions (eg, trial participants, care providers, outcome assessors, data analysts) and how	8-9

	17b	If blinded, circumstances under which unblinding is permissible and procedure for revealing a participant's allocated intervention during the trial	NA
Methods: Data collection, management, and analysis			
Data collection methods	18a	Plans for assessment and collection of outcome, baseline, and other trial data, including any related processes to promote data quality (eg, duplicate measurements, training of assessors) and a description of study instruments (eg, questionnaires, laboratory tests) along with their reliability and validity, if known. Reference to where data collection forms can be found, if not in the protocol	9-10
	18b	Plans to promote participant retention and complete follow-up, including list of any outcome data to be collected for participants who discontinue or deviate from intervention protocols	NA
Data management	19	Plans for data entry, coding, security, and storage, including any related processes to promote data quality (eg, double data entry; range checks for data values). Reference to where details of data management procedures can be found, if not in the protocol	13
Statistical methods	20a	Statistical methods for analysing primary and secondary outcomes. Reference to where other details of the statistical analysis plan can be found, if not in the protocol	13
	20b	Methods for any additional analyses (eg, subgroup and adjusted analyses)	NA
	20c	Definition of analysis population relating to protocol non-adherence (eg, as randomised analysis), and any statistical methods to handle missing data (eg, multiple imputation)	13
Methods: Monitoring			
Data monitoring	21a	Composition of data monitoring committee (DMC); summary of its role and reporting structure; statement of whether it is independent from the sponsor and competing interests; and reference to where further details about its charter can be found, if not in the protocol. Alternatively, an explanation of why a DMC is not needed	13
	21b	Description of any interim analyses and stopping guidelines, including who will have access to these interim results and make the final decision to terminate the trial	NA
Harms	22	Plans for collecting, assessing, reporting, and managing solicited and spontaneously reported adverse events and other unintended effects of trial interventions or trial conduct	NA
Auditing	23	Frequency and procedures for auditing trial conduct, if any, and whether the process will be independent from investigators and the sponsor	NA

Ethics and dissemination			
Research ethics approval	24	Plans for seeking research ethics committee/institutional review board (REC/IRB) approval	2
Protocol amendments	25	Plans for communicating important protocol modifications (eg, changes to eligibility criteria, outcomes, analyses) to relevant parties (eg, investigators, REC/IRBs, trial participants, trial registries, journals, regulators)	15
Consent or assent	26a	Who will obtain informed consent or assent from potential trial participants or authorised surrogates, and how (see Item 32)	Lead investiga tor ; 11
	26b	Additional consent provisions for collection and use of participant data and biological specimens in ancillary studies, if applicable	NA
Confidentiality	27	How personal information about potential and enrolled participants will be collected, shared, and maintained in order to protect confidentiality before, during, and after the trial	13
Declaration of interests	28	Financial and other competing interests for principal investigators for the overall trial and each study site	19
Access to data	29	Statement of who will have access to the final trial dataset, and disclosure of contractual agreements that limit such access for investigators	13
Ancillary and post-trial care	30	Provisions, if any, for ancillary and post-trial care and for compensation to those who suffer harm from trial participation	NA
Dissemination policy	31a	Plans for investigators and sponsor to communicate trial results to participants, healthcare professionals, the public, and other relevant groups (eg, via publication, reporting in results databases, or other data sharing arrangements), including any publication restrictions	11
	31b	Authorship eligibility guidelines and any intended use of professional writers	NA
	31c	Plans, if any, for granting public access to the full protocol, participant-level dataset, and statistical code	NA
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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 randomized control study

Journal:	*BMJ Open*
Manuscript ID	bmjopen-2021-060144.R1
Article Type:	Protocol
Date Submitted by the Author:	17-Mar-2022
Complete List of Authors:	Oladi, Sana; University of Waikato, Te Huataki Waiora School of Health, Division of Health, Engineering, Computing & Science Uiga, Liis; Manchester Metropolitan University, Department of Sport and Exercise Sciences Hebert-Losier, Kim; University of Waikato, Te Huataki Waiora School of Health, Division of Health, Engineering, Computing & Science Masters, Rich; University of Waikato, Te Huataki Waiora School of Health, Division of Health, Engineering, Computing & Science
Primary Subject Heading:	Geriatric medicine
Secondary Subject Heading:	Geriatric medicine, Public health, Rehabilitation medicine
Keywords:	GERIATRIC MEDICINE, PUBLIC HEALTH, REHABILITATION MEDICINE, COMPLEMENTARY MEDICINE

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TITLE PAGE

Title

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

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Word count

3878 words (excluding title page, abstract, references, figures and tables)

Protocol version

Original

TESTING THE EFFICACY OF A MOTOR ANALOGY DESIGNED TO PROMOTE SAFE LANDING BY OLDER ADULTS WHO FALL ACCIDENTALLY: A STUDY PROTOCOL FOR A RANDOMIZED CONTROL STUDY

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 randomized, 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 2-way MANOVA 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.

Keywords: Older adults; Falls; Safe landing; Motor analogy

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 programs 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 (PARQ+) are excluded from the study.

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, but also health care 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 $418 million dollars annually.[5] Researchers and health care 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 (e.g., impaired balance, reduced cognitive status, poor vision, etc.) and extrinsic (e.g., 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 programs, Hopewell et al. (2020) found that prevention programs 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 Sosnoff [10] revealed that only thirteen 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 (e.g., "land with a slightly flexed elbow angle")[15] and backward (e.g., "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 (e.g., 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 0.3 seconds to recover balance when falling from standing height, with impact occurring after approximately 0.7 seconds if recovery is not possible[23], so there is minimal opportunity between the balance recovery phase and impact with the ground

(i.e., 0.4 seconds) 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 (i.e., 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.[27 28] Implicit motor learning has been shown to impose fewer demands on cognitive resources than explicit motor learning[27 29 30] and, importantly, has been shown to result in better learning by older adults.[31 32]

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.[32] They have also been used in rehabilitation settings to improve dynamic balance[33] and walking by Parkinson[34] and stroke[35] patients. These advantages have been attributed to the simplicity of retrieving analogies from memory[36] and the role they play in rapidly deploying attention during movement.[37] The potential for analogies to depute for explicit instructions, facilitate development of mental representations in long term memory[38], reduce the demands associated with processing information (i.e., lower reliance on working memory)[29 39-41] and hasten processing time[28] makes them a compelling choice for learning safe landing strategies.

Masters et al.[42], 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', 'slow'. Based on these themes, two motor analogies with 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.[43] 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.[44] To evaluate the quality of the landings, we attached inertial measurement units (IMU) to different body segments of participants and extracted measures that we used to calculated 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 (i.e., 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.[45] For instance, older people often show a decline in functional balance[46], ability to learn skills[47], and motor planning.[48] 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.[49] 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.[50 51] Furthermore, the Movement Specific Reinvestment Scale (MSRS)[52] 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.[53] 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 (i.e., 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:

- 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 to the control condition
- 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 to the control condition

METHOD

Study design

This study is a randomized, 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 01/07/2022 and 30/12/2022.

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 minute and to walk without a walking aid for 6 meters. 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 to 3 is considered "possibly impaired", and a score above 3 is considered "probably normal").[54] 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.[55 56] Participants who answer 'yes' to 2 or more of the PARQ$^+$ questions (i.e., 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 program. The randomization 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^{TM} (Delsys Inc., Natrick, MA) inertial measurement units (IMU) will be used for data collection. The video camera will be positioned 3 meters from the left side of participants on a tripod (height 1.3 meters). 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 (Version 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 minutes. Figure 1 provides a flow diagram to illustrate the stages of data collection. Each consecutive component of the diagram is described in the subsequent section (e.g., 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.

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 (e.g., “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.[57]

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 (e.g., "I try to think about my movements when I carry them out"). The Movement Self-consciousness subscale measures propensity to monitor "style" of movement (e.g., "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.[58]

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), 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 Balance Evaluation Systems Test (Mini-BESTest), which is a standardized clinical balance tool used to assess functional balance.[59-62] This test has a maximum score of 28 points, with higher scores indicating better balance.

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 3, Panel A). Participants in the control condition will be asked to complete a similar crossword puzzle that uses names of birds as neutral primes: swallow, shag, swan (Figure 3, Panel B).

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 (27cm x 32cm) 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 randomized 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 (i.e., 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 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 (e.g., rugby, surfing, parkour, etc.), martial arts (e.g., taï-Chi, judo, taekwondo, etc.) may affect participants' landing strategies. Thus, after data collection, the experimenter will record information regarding participants' experience of these activities (e.g., type of activity, years of participation, level of ability, type of fall strategy learned 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 (e.g., older adults, health care 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 Inc., 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 trial. RSD has previously been used to compute thresholds for identifying cancer cells[63], optic-nerve signals[64], and in various human motion dynamics studies.[65] The start of the fall will be defined as the trench before the SMV reaches its maximum value (SMV_{max})[66 67] 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.[68] Therefore, fracture risk ratio will be defined as the ratio of force at impact divided by the load necessary to cause a fracture.[69 70] 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.[71], and then multiplied by 9.807 (convert g to m/s^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.[72] 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 an 80% power ($\beta = 0.20$), and 5% significance level ($\alpha = 0.05$). We used data from our previous research with young adults (smallest difference=0.22 m/s^2; within subject SD= 0.28 m/s^2; between subject SD=0.32 m/s^2) for the calculations, 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 25 (IBM SPSS Statistics Software). A two-way between-groups multivariate analysis of variance (MANOVA) will be conducted to explore the effect of condition (motor analogy, control) and fall direction (forward, backward, sideways) on the following variables of interest: 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 (ANOVA) 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.[73] 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 upon 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 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 randomized 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 meters (twice the length of the 3-meter walk test in the Min-BESTest) in a controlled laboratory environment. Older people who cannot walk for 6 meters without assistance, or stand without a walking aid for at least one minute, 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 2 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, etc. 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.[74] 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 to 3 is considered "possibly impaired", and a score above 3 is considered "probably normal".[54] 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.

AUTHORS' CONTRIBUTIONS The idea and rationale that underpins the work was generated by R.S.W.M.; S.O. is a PhD student who is supervised by R.S.W.M. (Chief Supervisor), L.U. (Secondary Supervisor), and K. H-L. (Secondary Supervisor); S.O. wrote the manuscript with support from R.S.W.M., L.U., and K. H-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 R.S.W.M., which is supported by a charitable donation from Freemason's New Zealand.

AWARD/GRANT NUMBER N/A

COMPETING INTERESTS None declared

PROTOCOL AMENDMENTS Any change to the protocol will be communicated with the University of Waikato Human Research Ethics Committee (Health) and the Australian New Zealand Clinical Trials Registry (ANZCTR).

FIGURE CAPTIONS:

Figure 1: Flow diagram of the data collection session.

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

Figure 3: Crossword puzzles for priming participants. Panel A: soft, slow, silent. Panel B: swallow, shag, swan.

Figure 4: Signal magnitude vector (SMV) of the lower back inertial measurement unit during a backward fall. Start of fall (StartFall), time of impact (Ti) and end of fall (EndFall) are displayed.

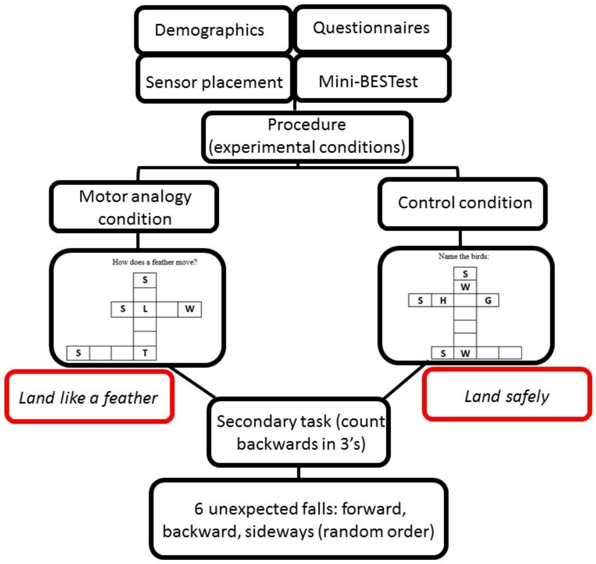
REFERENCES:

1. Chou L-W, Chang K-M, Wei Y-C, et al. Empirical mode decomposition-derived entropy features are beneficial to distinguish elderly people with a falling history on a force plate signal. *Entropy* 2021;23(4):472.
2. Arnold CM, Dal Bello-Haas VPM, Farthing JP, et al. Falls and wrist fracture: Relationship to women's functional status after age 50. *Canadian Journal on Aging/La Revue canadienne du vieillissement* 2016;35(3):361-71.
3. Greenberg M, Jacoby J, Barraco RD, et al. Analysis of Falls Efficacy Scale and vulnerable elders survey as predictors of falls. *Cureus* 2021;13(4)
4. Deverall E, Kvizhinadze G, Pega F, et al. Exercise programmes to prevent falls among older adults: modelling health gain, cost-utility and equity impacts. *Injury Prevention* 2019;25(4):258-63.
5. Barry M, Kaye N. ACC invests $30m to reduce falls and fractures for older New Zealanders: The official website of the New Zealand Government; 2016 [Available from: https://www.beehive.govt.nz/release/acc-invests-30m-reduce-falls-and-fractures-older-new-zealanders accessed September 29th 2021.
6. Rubenstein LZ. Falls in older people: epidemiology, risk factors and strategies for prevention. *Age and Ageing* 2006;35(suppl_2):ii37-ii41.
7. Ambrose AF, Paul G, Hausdorff JM. Risk factors for falls among older adults: a review of the literature. *Maturitas* 2013;75(1):51-61.
8. Hopewell S, Copsey B, Nicolson P, et al. Multifactorial interventions for preventing falls in older people living in the community: a systematic review and meta-analysis of 41 trials and almost 20 000 participants. *British Journal of Sports Medicine* 2020;54(22):1340-50.
9. Hsieh KL, Sosnoff JJ. A motor learning approach to reducing fall-related injuries. *Journal of Motor Behavior* 2020:1-5.
10. Moon Y, Sosnoff J. Safe landing strategies during a fall: systematic review and meta-analysis. *Archives of Physical Medicine and Rehabilitation* 2017;98(4):783-94.
11. Groen BE, Smulders E, De Kam D, et al. Martial arts fall training to prevent hip fractures in the elderly. *Osteoporosis International* 2010;21(2):215-21.
12. Groen BE, Weerdesteyn V, Duysens J. Martial arts fall techniques decrease the impact forces at the hip during sideways falling. *Journal of Biomechanics* 2007;40(2):458-62.
13. Groen BE, Weerdesteyn V, Duysens J. The relation between hip impact velocity and hip impact force differs between sideways fall techniques. *Journal of Electromyography and Kinesiology* 2008;18(2):228-34.
14. Weerdesteyn V, Groen BE, Van Swigchem R, et al. Martial arts fall techniques reduce hip impact forces in naive subjects after a brief period of training. *Journal of Electromyography and Kinesiology* 2008;18(2):235-42.
15. Lo J, McCabe GN, DeGoede KM, et al. On reducing hand impact force in forward falls: results of a brief intervention in young males. *Clinical Biomechanics* 2003;18(8):730-36.
16. Tan J-S, Eng JJ, Robinovitch SN, et al. Wrist impact velocities are smaller in forward falls than backward falls from standing. *Journal of Biomechanics* 2006;39(10):1804-11.
17. McNay EC, Willingham DB. Deficit in learning of a motor skill requiring strategy, but not of perceptuomotor recalibration, with aging. *Learning & Memory* 1998;4(5):411-20.
18. Serbruyns L, Gooijers J, Caeyenberghs K, et al. Bimanual motor deficits in older adults predicted by diffusion tensor imaging metrics of corpus callosum subregions. *Brain Structure & Function* 2015;220(1):273-90.
19. Voelcker-Rehage C. Motor-skill learning in older adults—a review of studies on age-related differences. *European Review of Aging and Physical Activity* 2008;5(1):5-16.
20. Light LL, Anderson PA. Working-memory capacity, age, and memory for discourse. *Journal of Gerontology* 1985;40(6):737-47.
21. Hultsch DF, MacDonald SWS, Dixon RA. Variability in reaction time performance of younger and older adults. *The Journals of Gerontology Series B: Psychological Sciences and Social Sciences* 2002;57(2):P101-P15.
22. Mendelson DN, Redfern MS, Nebes RD, et al. Inhibitory processes relate differently to balance/reaction time dual tasks in young and older adults. *Aging, Neuropsychology, and Cognition* 2009;17(1):1-18.

23. Le Goic M, Wang D, Vidal C, et al. An initial passive phase that limits the time to recover and emphasizes the role of proprioceptive information. *Frontiers in Neurology* 2018;9:986.
24. Liao C-M, Masters RSW. Analogy learning: A means to implicit motor learning. *Journal of Sports Sciences* 2001;19(5):307-19.
25. Masters RS. Theoretical Aspects of Implicit Learning in Sport. *International Journal of Sport Psychology* 2000
26. Lam WK, Maxwell JP, Masters RSW. Analogy versus explicit learning of a modified basketball shooting task: Performance and kinematic outcomes. *Journal of Sports Sciences* 2009;27(2):179-91.
27. Masters RSW. Knowledge, knerves and know-how: The role of explicit versus implicit knowledge in the breakdown of a complex motor skill under pressure. *British Journal of Psychology* 1992;83(3):343-58.
28. Masters RSW. Theoretical aspects of implicit learning in sport. *International Journal of Sport Psychology* 2000:530-40.
29. Masters RSW, van Duijn T, Uiga L. Advances in implicit motor learning. In: Hodges NJ, Williams MA, eds. Skill acquisition in sport: research, theory and practice. Third ed. UK: Routledge 2020:p.75-95.
30. Steenbergen B, Van Der Kamp J, Verneau M, et al. Implicit and explicit learning: applications from basic research to sports for individuals with impaired movement dynamics. *Disability and Rehabilitation* 2010;32(18):1509-16.
31. Chauvel G, Maquestiaux F, Hartley AA, et al. Age effects shrink when motor learning is predominantly supported by nondeclarative, automatic memory processes: Evidence from golf putting. *Quarterly Journal of Experimental Psychology* 2012;65(1):25-38.
32. Tse ACY, Wong TWL, Masters RSW. Examining motor learning in older adults using analogy instruction. *Psychology of Sport and Exercise* 2017;28:78-84.
33. Kim S-M, Qu F, Lam W-K. Analogy and explicit motor learning in dynamic balance: Posturography and performance analyses. *European Journal of Sport Science* 2021;21(8):1129-39.
34. Jie L-J, Goodwin V, Kleynen M, et al. Analogy learning in Parkinson's disease: a proof-of-concept study. *International Journal of Therapy and Rehabilitation* 2016;23(3):123-30.
35. Kleynen M, Wilson MR, Jie L-J, et al. Exploring the utility of analogies in motor learning after stroke: a feasibility study. *International Journal of Rehabilitation Research* 2014;37(3):277-80.
36. Donnelly CM, McDaniel MA. Use of analogy in learning scientific concepts. *Journal of Experimental Psychology: Learning, Memory, and Cognition* 1993;19(4):975.
37. Koedijker JM, Poolton JM, Maxwell JP, et al. Attention and time constraints in perceptual-motor learning and performance: Instruction, analogy, and skill level. *Consciousness and Cognition* 2011;20(2):245-56.
38. Meier C, Frank C, Grben B, et al. Verbal instructions and motor learning: How analogy and explicit instructions influence the development of mental representations and tennis serve performance. *Frontiers in Psychology* 2020;11:2.
39. Masters RSW, Liao C. Chunking as a characteristic of implicit motor learning. European Congress of Sport Psychology, 2003.
40. Meier C, Frank C, Gröben B, et al. Verbal Instructions and Motor Learning: How Analogy and Explicit Instructions Influence the Development of Mental Representations and Tennis Serve Performance. *Frontiers in Psychology* 2020;11:2-2.
41. Poolton JM, Masters RSW. Chunking/Dechunking. *Encyclopedia of Sport and Exercise Psychology* 2014:129-30.
42. Masters RSW, Barbour K, Hébert-Losier K, et al. Promoting safer landing by older adults who fall unexpectedly. *The Journal of Sport and Exercise Science* 2018;2:31.
43. Oladi S, Uiga L, Hébert-Losier K, et al. Using inertial measurement units to determine the potential efficacy of a motor analogy for improving landing from self-initiated falls. *The Journal of Sport and Exercise Science* 2019;3:32.
44. Oladi S, Uiga L, Hébert-Losier K, et al. Using a motor analogy to promote safe-landing from unexpected fall. *The Journal of Sport and Exercise Science* 2020;4:30.

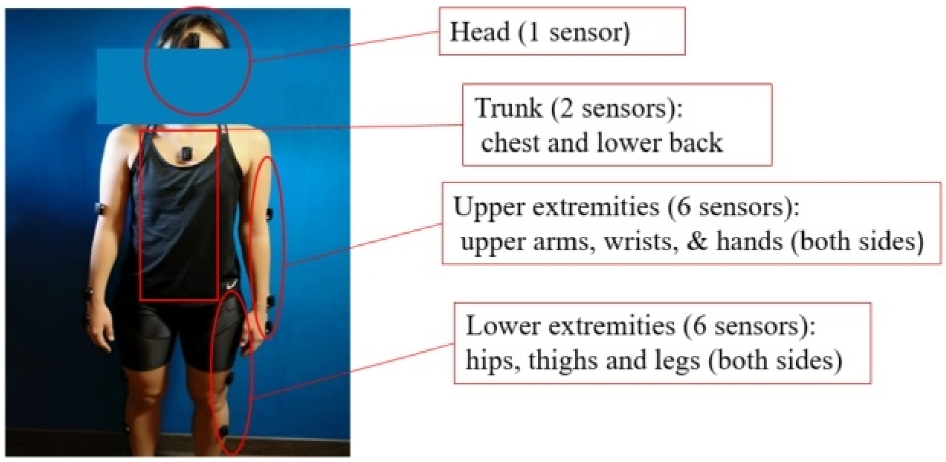
45. Sampaio A, Marques-Aleixo I, Seabra A, et al. Physical fitness in institutionalized older adults with dementia: association with cognition, functional capacity and quality of life. *Aging Clinical and Experimental Research* 2020:1-10.
46. Alexander NB. Postural control in older adults. *Journal of the American Geriatrics Society* 1994;42(1):93-108.
47. Raz N, Williamson A, Gunning-Dixon F, et al. Neuroanatomical and cognitive correlates of adult age differences in acquisition of a perceptual-motor skill. *Microscopy Research and Technique* 2000;51(1):85-93.
48. Wang S, Williams J, Wilmut K. Constraints on motor planning across the life span: Physical, cognitive, and motor factors. *Psychology and Aging* 2020;35(3):421.
49. Horak FB, Wrisley DM, Frank J. The balance evaluation systems test (BESTest) to differentiate balance deficits. *Physical Therapy* 2009;89(5):484-98.
50. Myers AM, Fletcher PC, Myers AH, et al. Discriminative and evaluative properties of the activities-specific balance confidence (ABC) scale. *The Journals of Gerontology Series A: Biological Sciences and Medical Sciences* 1998;53(4):M287-M94.
51. Powell LE, Myers AM. The activities-specific balance confidence (ABC) scale. *The Journals of Gerontology Series A: Biological Sciences and Medical Sciences* 1995;50(1):M28-M34.
52. Masters RSW, Eves FF, Maxwell JP. Development of a movement specific reinvestment scale. International Society of Sport Psychology (ISSP) World Congress: International Society of Sport Psychology (ISSP), 2005.
53. Uiga L, Capio CM, Ryu D, et al. The role of movement-specific reinvestment in visuomotor control of walking by older adults. *The Journals of Gerontology: Series B* 2020;75(2):282-92.
54. Borson S, Scanlan JM, Chen P, et al. The Mini-Cog as a screen for dementia: validation in a population-based sample. *Journal of the American Geriatrics Society* 2003;51(10):1451-54.
55. Cardinal BJ, Cardinal MK. Preparticipation physical activity screening within a racially diverse, older adult sample: comparison of the original and Revised Physical Activity Readiness Questionnaires. *Research Quarterly for Exercise and Sport* 2000;71(3):302-07.
56. Cardinal BJ, Esters J, Cardinal MK. Evaluation of the revised physical activity readiness questionnaire in older adults. *Medicine and Science in Sports and Exercise* 1996;28(4):468-72.
57. Schepens S, Goldberg A, Wallace M. The short version of the Activities-specific Balance Confidence (ABC) scale: Its validity, reliability, and relationship to balance impairment and falls in older adults. *Archives of Gerontology and Geriatrics* 2009;51(1):9-12.
58. Malhotra N, Poolton JM, Wilson MR, et al. Examining movement-specific reinvestment and performance in demanding contexts. *Journal of Sport and Exercise Psychology* 2015;37(3):327-38.
59. Marques A, Almeida S, Carvalho J, et al. Reliability, Validity, and Ability to Identify Fall Status of the Balance Evaluation Systems Test, Mini–Balance Evaluation Systems Test, and Brief–Balance Evaluation Systems Test in Older People Living in the Community. *Archives of Physical Medicine and Rehabilitation* 2016;97(12):2166-73.
60. O'Hoski S, Sibley KM, Brooks D, et al. Construct validity of the BESTest, mini-BESTest and briefBESTest in adults aged 50 years and older. *Gait & Posture* 2015;42(3):301-05.
61. Padgett PK, Jacobs JV, Kasser SL. Is the BESTest at its best? A suggested brief version based on interrater reliability, validity, internal consistency, and theoretical construct. *Physical Therapy* 2012;92(9):1197-207.
62. Sibley KM, Beauchamp MK, Van Ooteghem K, et al. Using the systems framework for postural control to analyze the components of balance evaluated in standardized balance measures: a scoping review. *Archives of Physical Medicine and Rehabilitation* 2015;96(1):122-32.
63. Ericson MB, Sandberg C, Gudmundson F, et al. Fluorescence contrast and threshold limit: implications for photodynamic diagnosis of basal cell carcinoma. *Journal of Photochemistry and Photobiology B: Biology* 2003;69(2):121-27.
64. Hay GA, Chesters MS. Signal-transfer functions in threshold and suprathreshold vision. *Journal of The Optical Society of America* 1972;62(8):990-98.
65. Venture G, Ayusawa K, Nakamura Y. A numerical method for choosing motions with optimal excitation properties for identification of biped dynamics-an application to human. IEEE International Conference on Robotics and Automation: IEEE, 2009:1226-31.

66. Degen T, Jaeckel H, Rufer M, et al. SPEEDY: a fall detector in a wrist watch. Seventh IEEE International Symposium on Wearable Computers: ISWC, 2003:184-87.
67. Kangas M, Vikman I, Nyberg L, et al. Comparison of real-life accidental falls in older people with experimental falls in middle-aged test subjects. *Gait & Posture* 2012;35(3):500-05.
68. Groen BE, Weerdesteyn V, Duysens J. The relation between hip impact velocity and hip impact force differs between sideways fall techniques. *Journal of Biomechanics* 2006(39):88.
69. DeGoede KM, Ashton-Miller JA, Schultz AB. Fall-related upper body injuries in the older adult: a review of the biomechanical issues. *Journal of Biomechanics* 2003;36(7):1043-53.
70. Melton 3rd LJ, Cummings SR. Heterogeneity of age-related fractures: implications for epidemiology. *Bone and Mineral* 1987;2(4):321-31.
71. Dumas R, Cheze L, Verriest JP. Adjustments to McConville et al. and Young et al. body segment inertial parameters. *Journal of Biomechanics* 2007;40(3):543-53.
72. Augat P, Reeb H, Claes LE. Prediction of fracture load at different skeletal sites by geometric properties of the cortical shell. *Journal of Bone and Mineral Research* 1996;11(9):1356-63.
73. Benjamini Y, Hochberg Y. Controlling the false discovery rate: a practical and powerful approach to multiple testing. *Journal of the Royal Statistical Society: Series B (Methodological)* 1995;57(1):289-300.
74. Jie L-J, Kleynen M, Meijer K, et al. The effects of implicit and explicit motor learning in gait rehabilitation of people after stroke: protocol for a randomized controlled trial. *JMIR Research Protocols* 2018;7(5):142.



Flow diagram of the data collection session.

338x190mm (96 x 96 DPI)



Positioning of inertial measurement units on different body segments

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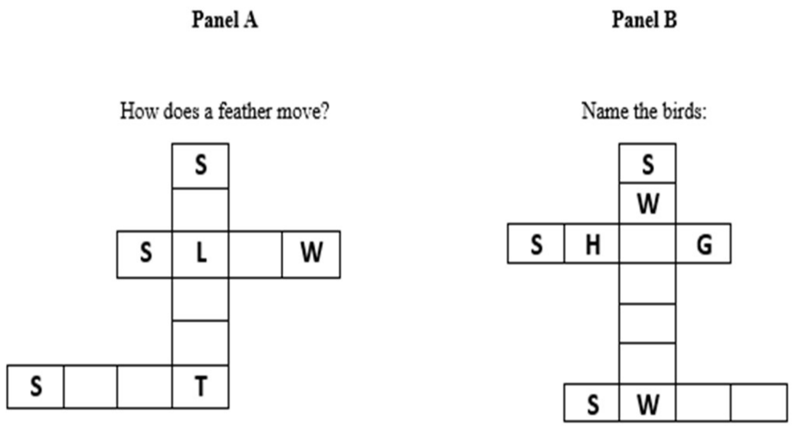
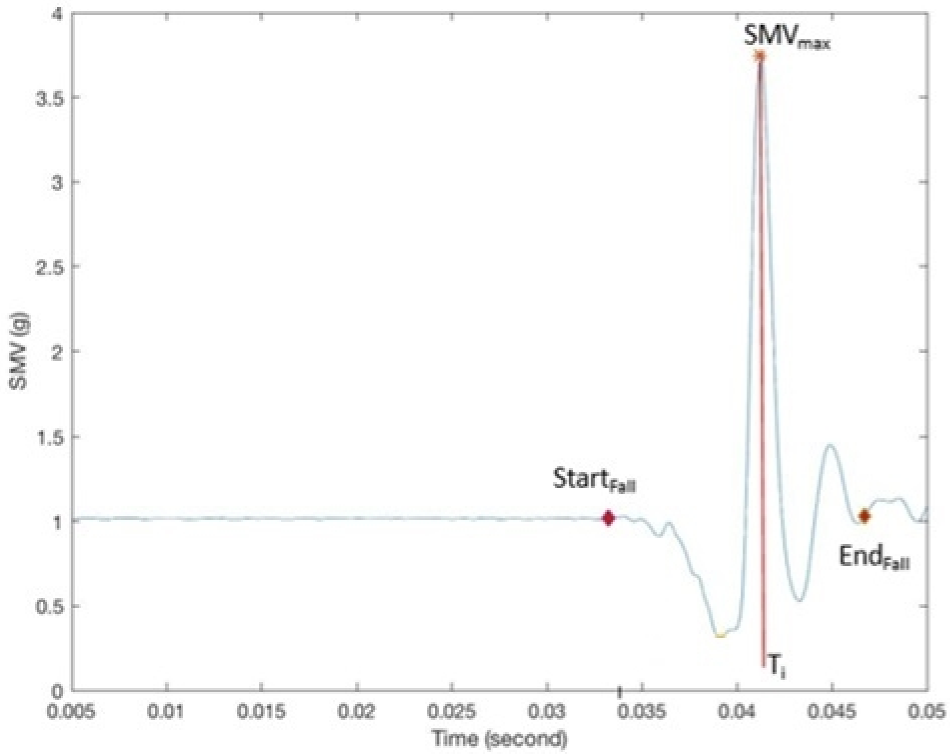


Crossword puzzles for priming participants. Panel A: soft, slow, silent. Panel B: swallow, shag, swan.

338x190mm (96 x 96 DPI)



Signal magnitude vector (SMV) of the lower back inertial measurement unit during an unexpected backward fall. Start of fall (StartFall), time of impact (Ti) and end of fall (EndFall) are displayed.

127x100mm (96 x 96 DPI)

Section/item	Item #	Description	Page #
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	2b	All items from the World Health Organization Trial Registration Data Set	NA
Protocol version	3	Date and version identifier	1
Funding	4	Sources and types of financial, material, and other support	15
Roles and responsibilities	5a	Names, affiliations, and roles of protocol contributors	1; 15
	5b	Name and contact information for the trial sponsor	NA
	5c	Role of study sponsor and funders, if any, in study design; collection, management, analysis, and interpretation of data; writing of the report; and the decision to submit the report for publication, including whether they will have ultimate authority over any of these activities	15
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	11d	Relevant concomitant care and interventions that are permitted or prohibited during the trial	NA
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Allocation concealment mechanism	16b	Mechanism of implementing the allocation sequence (eg, central telephone; sequentially numbered, opaque, sealed envelopes), describing any steps to conceal the sequence until interventions are assigned	8
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	18b	Plans to promote participant retention and complete follow-up, including list of any outcome data to be collected for participants who discontinue or deviate from intervention protocols	NA
Data management	19	Plans for data entry, coding, security, and storage, including any related processes to promote data quality (eg, double data entry; range checks for data values). Reference to where details of data management procedures can be found, if not in the protocol	13
Statistical methods	20a	Statistical methods for analysing primary and secondary outcomes. Reference to where other details of the statistical analysis plan can be found, if not in the protocol	13
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	20c	Definition of analysis population relating to protocol non-adherence (eg, as randomised analysis), and any statistical methods to handle missing data (eg, multiple imputation)	13
Methods: Monitoring			
Data monitoring	21a	Composition of data monitoring committee (DMC); summary of its role and reporting structure; statement of whether it is independent from the sponsor and competing interests; and reference to where further details about its charter can be found, if not in the protocol. Alternatively, an explanation of why a DMC is not needed	13
	21b	Description of any interim analyses and stopping guidelines, including who will have access to these interim results and make the final decision to terminate the trial	NA
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Auditing	23	Frequency and procedures for auditing trial conduct, if any, and whether the process will be independent from investigators and the sponsor	NA

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	26b	Additional consent provisions for collection and use of participant data and biological specimens in ancillary studies, if applicable	NA
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Access to data	29	Statement of who will have access to the final trial dataset, and disclosure of contractual agreements that limit such access for investigators	13
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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 randomized control study

Journal:	*BMJ Open*
Manuscript ID	bmjopen-2021-060144.R2
Article Type:	Protocol
Date Submitted by the Author:	22-Apr-2022
Complete List of Authors:	Oladi, Sana; University of Waikato, Te Huataki Waiora School of Health, Division of Health, Engineering, Computing & Science Uiga, Liis; Manchester Metropolitan University, Department of Sport and Exercise Sciences, Faculty of Science & Engineering Hebert-Losier, Kim; University of Waikato, Te Huataki Waiora School of Health, Division of Health, Engineering, Computing & Science Masters, Rich; University of Waikato, Te Huataki Waiora School of Health, Division of Health, Engineering, Computing & Science
Primary Subject Heading:	Geriatric medicine
Secondary Subject Heading:	Geriatric medicine, Public health, Rehabilitation medicine
Keywords:	GERIATRIC MEDICINE, PUBLIC HEALTH, REHABILITATION MEDICINE, COMPLEMENTARY MEDICINE

TITLE PAGE

Title

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

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Word count

3878 words (excluding title page, abstract, references, figures and tables)

Protocol version

Original

TESTING THE EFFICACY OF A MOTOR ANALOGY DESIGNED TO PROMOTE SAFE LANDING BY OLDER ADULTS WHO FALL ACCIDENTALLY: A STUDY PROTOCOL FOR A RANDOMIZED CONTROL

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 randomized, 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 2-way MANOVA 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.

Keywords: Older adults; Falls; Safe landing; Motor analogy

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 programs 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 (PARQ+) are excluded from the study.

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, but also health care 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 $418 million dollars annually.[5] Researchers and health care 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 (e.g., impaired balance, reduced cognitive status, poor vision, etc.) and extrinsic (e.g., 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 programs, Hopewell et al. (2020) found that prevention programs 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 Sosnoff [10] revealed that only thirteen 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 (e.g., "land with a slightly flexed elbow angle")[15] and backward (e.g., "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 (e.g., 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 0.3 seconds to recover balance when falling from standing height, with impact occurring after approximately 0.7 seconds if recovery is not possible[23], so there is minimal opportunity between the balance recovery phase and impact with the ground

(i.e., 0.4 seconds) 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 (i.e., 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.[27 28] Implicit motor learning has been shown to impose fewer demands on cognitive resources than explicit motor learning[27 29 30] and, importantly, has been shown to result in better learning by older adults.[31 32]

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.[32] They have also been used in rehabilitation settings to improve dynamic balance[33] and walking by Parkinson[34] and stroke[35] patients. These advantages have been attributed to the simplicity of retrieving analogies from memory[36] and the role they play in rapidly deploying attention during movement.[37] The potential for analogies to depute for explicit instructions, facilitate development of mental representations in long term memory[38], reduce the demands associated with processing information (i.e., lower reliance on working memory)[29 39-41] and hasten processing time[28] makes them a compelling choice for learning safe landing strategies.

Masters et al.[42], 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’, ‘slow’. Based on these themes, two motor analogies with 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.[43] 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.[44] To evaluate the quality of the landings, we attached inertial measurement units (IMU) to different body segments of participants and extracted measures that we used to calculated 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 (i.e., 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.[45] For instance, older people often show a decline in functional balance[46], ability to learn skills[47], and motor planning.[48] 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.[49] 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.[50 51] Furthermore, the Movement Specific Reinvestment Scale (MSRS)[52] 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.[53] 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 (i.e., 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:

- 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 to the control condition
- 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 to the control condition

METHOD

Study design

This study is a randomized, 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 01/07/2022 and 30/12/2022.

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 minute and to walk without a walking aid for 6 meters. 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 to 3 is considered "possibly impaired", and a score above 3 is considered "probably normal").[54] 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.[55 56] Participants who answer 'yes' to 2 or more of the $PARQ^+$ questions (i.e., 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 program. The randomization 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 Inc., Natrick, MA) inertial measurement units (IMU) will be used for data collection. The video camera will be positioned 3 meters from the left side of participants on a tripod (height 1.3 meters). 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 (Version 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 minutes. Figure 1 provides a flow diagram to illustrate the stages of data collection. Each consecutive component of the diagram is described in the subsequent section (e.g., 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. For the history of fall the following questions will be asked: Have you fallen and 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 (e.g., "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.[57]

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 (e.g., "I try to think about my movements when I carry them out"). The Movement Self-consciousness subscale measures propensity to monitor "style" of movement (e.g., "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.[58]

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), 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 Balance Evaluation Systems Test (Mini-BESTest), which is a standardized clinical balance tool used to assess functional balance.[59-62] This test has a maximum score of 28 points, with higher scores indicating better balance.

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 3, Panel A). Participants in the control condition will be asked to complete a similar crossword puzzle that uses names of birds as neutral primes: swallow, shag, swan (Figure 3, Panel B). Crossword puzzles have been used in research to activate concepts/primes.[63]

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 (27cm x 32cm) 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 randomized 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 (i.e., 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 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 (e.g., rugby, surfing, parkour, etc.), martial arts (e.g., taï-Chi, judo, taekwondo, etc.) may affect participants' landing strategies. Thus, after data collection, the experimenter will record information regarding participants' experience of these activities (e.g., type of activity, years of participation, level of ability, type of fall strategy learned 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 (e.g., older adults, health care 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 Inc., 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 trial. RSD has previously been used to compute thresholds for identifying cancer cells[64], optic-nerve signals[65], and in various human motion dynamics studies.[66] The start of the fall will be defined as the trench before the SMV reaches its maximum value (SMV_{max})[67 68] 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.[69] Therefore, fracture risk ratio will be defined as the ratio of force at impact divided by the load necessary to cause a fracture.[70 71] 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.[72], and then multiplied by 9.807 (convert g to m/s^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.[73] 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 an 80% power ($\beta = 0.20$), and 5% significance level ($\alpha = 0.05$),critical values of the f distribution (for Multivariate analysis of variance), and data from our previous research with young adults (smallest difference=0.22 m/s^2; within subject SD= 0.28 m/s^2; between subject SD=0.32 m/s^2) were used for the calculation, 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 25 (IBM SPSS Statistics Software). A two-way between-groups multivariate analysis of variance (MANOVA) 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 (ANOVA) 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.[74] 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 upon 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 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 randomized 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 meters (twice the length of the 3-meter walk test in the Min-BESTest) in a controlled laboratory environment. Older people who cannot walk for 6 meters without assistance, or stand without a walking aid for at least one minute, 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 2 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, etc. 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.[75] 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 to 3 is considered "possibly impaired", and a score above 3 is considered "probably normal".[54] 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.

AUTHORS' CONTRIBUTIONS The idea and rationale that underpins the work was generated by R.S.W.M.; S.O. is a PhD student who is supervised by R.S.W.M. (Chief Supervisor), L.U. (Secondary Supervisor), and K. H-L. (Secondary Supervisor); S.O. wrote the manuscript with support from R.S.W.M., L.U., and K. H-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 R.S.W.M., which is supported by a charitable donation from Freemason's New Zealand.

AWARD/GRANT NUMBER N/A

COMPETING INTERESTS None declared

PROTOCOL AMENDMENTS Any change to the protocol will be communicated with the University of Waikato Human Research Ethics Committee (Health) and the Australian New Zealand Clinical Trials Registry (ANZCTR).

FIGURE CAPTIONS:

Figure 1: Flow diagram of the data collection session.

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

Figure 3: Crossword puzzles for priming participants. Panel A: soft, slow, silent. Panel B: swallow, shag, swan.

Figure 4: Signal magnitude vector (SMV) of the lower back inertial measurement unit during a backward fall. Start of fall (StartFall), time of impact (Ti) and end of fall (EndFall) are displayed.

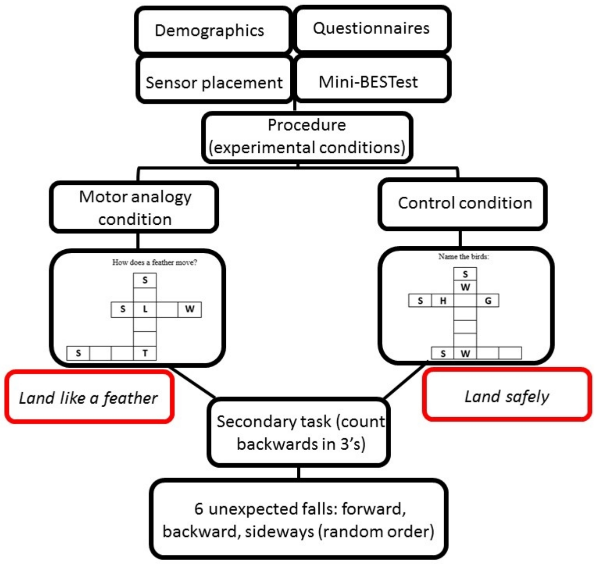
REFERENCES:

1. Chou L-W, Chang K-M, Wei Y-C, et al. Empirical mode decomposition-derived entropy features are beneficial to distinguish elderly people with a falling history on a force plate signal. *Entropy* 2021;23(4):472.
2. Arnold CM, Dal Bello-Haas VPM, Farthing JP, et al. Falls and wrist fracture: Relationship to women's functional status after age 50. *Canadian Journal on Aging/La Revue canadienne du vieillissement* 2016;35(3):361-71.
3. Greenberg M, Jacoby J, Barraco RD, et al. Analysis of Falls Efficacy Scale and vulnerable elders survey as predictors of falls. *Cureus* 2021;13(4)
4. Deverall E, Kvizhinadze G, Pega F, et al. Exercise programmes to prevent falls among older adults: modelling health gain, cost-utility and equity impacts. *Injury Prevention* 2019;25(4):258-63.
5. Barry M, Kaye N. ACC invests $30m to reduce falls and fractures for older New Zealanders: The official website of the New Zealand Government; 2016 [Available from: https://www.beehive.govt.nz/release/acc-invests-30m-reduce-falls-and-fractures-older-new-zealanders accessed September 29th 2021.
6. Rubenstein LZ. Falls in older people: epidemiology, risk factors and strategies for prevention. *Age and Ageing* 2006;35(suppl_2):ii37-ii41.
7. Ambrose AF, Paul G, Hausdorff JM. Risk factors for falls among older adults: a review of the literature. *Maturitas* 2013;75(1):51-61.
8. Hopewell S, Copsey B, Nicolson P, et al. Multifactorial interventions for preventing falls in older people living in the community: a systematic review and meta-analysis of 41 trials and almost 20 000 participants. *British Journal of Sports Medicine* 2020;54(22):1340-50. doi: 10.1136/bjsports-2019-100732
9. Hsieh KL, Sosnoff JJ. A motor learning approach to reducing fall-related injuries. *Journal of Motor Behavior* 2020:1-5.
10. Moon Y, Sosnoff J. Safe landing strategies during a fall: systematic review and meta-analysis. *Archives of Physical Medicine and Rehabilitation* 2017;98(4):783-94.
11. Groen BE, Smulders E, De Kam D, et al. Martial arts fall training to prevent hip fractures in the elderly. *Osteoporosis International* 2010;21(2):215-21.
12. Groen BE, Weerdesteyn V, Duysens J. Martial arts fall techniques decrease the impact forces at the hip during sideways falling. *Journal of Biomechanics* 2007;40(2):458-62.
13. Groen BE, Weerdesteyn V, Duysens J. The relation between hip impact velocity and hip impact force differs between sideways fall techniques. *Journal of Electromyography and Kinesiology* 2008;18(2):228-34.
14. Weerdesteyn V, Groen BE, Van Swigchem R, et al. Martial arts fall techniques reduce hip impact forces in naive subjects after a brief period of training. *Journal of Electromyography and Kinesiology* 2008;18(2):235-42. doi: 10.1016/j.jelekin.2007.06.010
15. Lo J, McCabe GN, DeGoede KM, et al. On reducing hand impact force in forward falls: results of a brief intervention in young males. *Clinical Biomechanics* 2003;18(8):730-36.
16. Tan J-S, Eng JJ, Robinovitch SN, et al. Wrist impact velocities are smaller in forward falls than backward falls from standing. *Journal of Biomechanics* 2006;39(10):1804-11.

17. McNay EC, Willingham DB. Deficit in learning of a motor skill requiring strategy, but not of perceptuomotor recalibration, with aging. *Learning & Memory* 1998;4(5):411-20.
18. Serbruyns L, Gooijers J, Caeyenberghs K, et al. Bimanual motor deficits in older adults predicted by diffusion tensor imaging metrics of corpus callosum subregions. *Brain Structure & Function* 2015;220(1):273-90.
19. Voelcker-Rehage C. Motor-skill learning in older adults—a review of studies on age-related differences. *European Review of Aging and Physical Activity* 2008;5(1):5-16.
20. Light LL, Anderson PA. Working-memory capacity, age, and memory for discourse. *Journal of Gerontology* 1985;40(6):737-47.
21. Hultsch DF, MacDonald SWS, Dixon RA. Variability in reaction time performance of younger and older adults. *The Journals of Gerontology Series B: Psychological Sciences and Social Sciences* 2002;57(2):P101-P15.
22. Mendelson DN, Redfern MS, Nebes RD, et al. Inhibitory processes relate differently to balance/reaction time dual tasks in young and older adults. *Aging, Neuropsychology, and Cognition* 2009;17(1):1-18.
23. Le Goic M, Wang D, Vidal C, et al. An initial passive phase that limits the time to recover and emphasizes the role of proprioceptive information. *Frontiers in Neurology* 2018;9:986.
24. Liao C-M, Masters RSW. Analogy learning: A means to implicit motor learning. *Journal of Sports Sciences* 2001;19(5):307-19.
25. Masters RS. Theoretical Aspects of Implicit Learning in Sport. *International Journal of Sport Psychology* 2000
26. Lam WK, Maxwell JP, Masters R. Analogy versus explicit learning of a modified basketball shooting task: Performance and kinematic outcomes. *Journal of Sports Sciences* 2009;27(2):179-91.
27. Masters RSW. Knowledge, knerves and know-how: The role of explicit versus implicit knowledge in the breakdown of a complex motor skill under pressure. *British Journal of Psychology* 1992;83(3):343-58.
28. Masters RSW. Theoretical aspects of implicit learning in sport. *International Journal of Sport Psychology* 2000:530-40.
29. Masters RSW, van Duijn T, Uiga L. Advances in implicit motor learning. In: Hodges NJ, Williams MA, eds. Skill acquisition in sport: research, theory and practice. Third ed. UK: Routledge 2020:p.75-95.
30. Steenbergen B, Van Der Kamp J, Verneau M, et al. Implicit and explicit learning: applications from basic research to sports for individuals with impaired movement dynamics. *Disability and Rehabilitation* 2010;32(18):1509-16.
31. Chauvel G, Maquestiaux F, Hartley AA, et al. Age effects shrink when motor learning is predominantly supported by nondeclarative, automatic memory processes: Evidence from golf putting. *Quarterly Journal of Experimental Psychology* 2012;65(1):25-38.
32. Tse ACY, Wong TWL, Masters RSW. Examining motor learning in older adults using analogy instruction. *Psychology of Sport and Exercise* 2017;28:78-84.
33. Kim S-M, Qu F, Lam W-K. Analogy and explicit motor learning in dynamic balance: Posturography and performance analyses. *European Journal of Sport Science* 2021;21(8):1129-39.
34. Jie L-J, Goodwin V, Kleynen M, et al. Analogy learning in Parkinson's disease: a proof-of-concept study. *International Journal of Therapy and Rehabilitation* 2016;23(3):123-30.
35. Kleynen M, Wilson MR, Jie L-J, et al. Exploring the utility of analogies in motor learning after stroke: a feasibility study. *International Journal of Rehabilitation Research* 2014;37(3):277-80.
36. Donnelly CM, McDaniel MA. Use of analogy in learning scientific concepts. *Journal of Experimental Psychology: Learning, Memory, and Cognition* 1993;19(4):975.
37. Koedijker JM, Poolton JM, Maxwell JP, et al. Attention and time constraints in perceptual-motor learning and performance: Instruction, analogy, and skill level. *Consciousness and Cognition* 2011;20(2):245-56.
38. Meier C, Frank C, Grben B, et al. Verbal instructions and motor learning: How analogy and explicit instructions influence the development of mental representations and tennis serve performance. *Frontiers in Psychology* 2020;11:2.

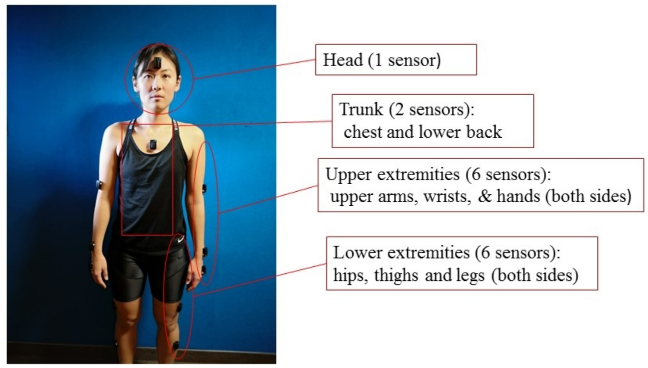
39. Masters RSW, Liao C. Chunking as a characteristic of implicit motor learning. European Congress of Sport Psychology, 2003.
40. Meier C, Frank C, Gröben B, et al. Verbal Instructions and Motor Learning: How Analogy and Explicit Instructions Influence the Development of Mental Representations and Tennis Serve Performance. *Frontiers in Psychology* 2020;11:2-2.
41. Poolton JM, Masters RSW. Chunking/Dechunking. *Encyclopedia of Sport and Exercise Psychology* 2014:129-30.
42. Masters RSW, Barbour K, Hébert-Losier K, et al. Promoting safer landing by older adults who fall unexpectedly. *The Journal of Sport and Exercise Science* 2018;2:31.
43. Oladi S, Uiga L, Hébert-Losier K, et al. Using inertial measurement units to determine the potential efficacy of a motor analogy for improving landing from self-initiated falls. *The Journal of Sport and Exercise Science* 2019;3:32.
44. Oladi S, Uiga L, Hébert-Losier K, et al. Using a motor analogy to promote safe-landing from unexpected fall. *The Journal of Sport and Exercise Science* 2020;4:30.
45. Sampaio A, Marques-Aleixo I, Seabra A, et al. Physical fitness in institutionalized older adults with dementia: association with cognition, functional capacity and quality of life. *Aging Clinical and Experimental Research* 2020:1-10.
46. Alexander NB. Postural control in older adults. *Journal of the American Geriatrics Society* 1994;42(1):93-108.
47. Raz N, Williamson A, Gunning-Dixon F, et al. Neuroanatomical and cognitive correlates of adult age differences in acquisition of a perceptual-motor skill. *Microscopy Research and Technique* 2000;51(1):85-93.
48. Wang S, Williams J, Wilmut K. Constraints on motor planning across the life span: Physical, cognitive, and motor factors. *Psychology and Aging* 2020;35(3):421.
49. Horak FB, Wrisley DM, Frank J. The balance evaluation systems test (BESTest) to differentiate balance deficits. *Physical Therapy* 2009;89(5):484-98.
50. Myers AM, Fletcher PC, Myers AH, et al. Discriminative and evaluative properties of the activities-specific balance confidence (ABC) scale. *The Journals of Gerontology Series A: Biological Sciences and Medical Sciences* 1998;53(4):M287-M94.
51. Powell LE, Myers AM. The activities-specific balance confidence (ABC) scale. *The Journals of Gerontology Series A: Biological Sciences and Medical Sciences* 1995;50(1):M28-M34.
52. Masters RSW, Eves FF, Maxwell JP. Development of a movement specific reinvestment scale. International Society of Sport Psychology (ISSP) World Congress: International Society of Sport Psychology (ISSP), 2005.
53. Uiga L, Capio CM, Ryu D, et al. The role of movement-specific reinvestment in visuomotor control of walking by older adults. *The Journals of Gerontology: Series B* 2020;75(2):282-92. doi: 10.1093/geronb/gby078
54. Borson S, Scanlan JM, Chen P, et al. The Mini-Cog as a screen for dementia: validation in a population-based sample. *Journal of the American Geriatrics Society* 2003;51(10):1451-54.
55. Cardinal BJ, Cardinal MK. Preparticipation physical activity screening within a racially diverse, older adult sample: comparison of the original and Revised Physical Activity Readiness Questionnaires. *Research Quarterly for Exercise and Sport* 2000;71(3):302-07.
56. Cardinal BJ, Esters J, Cardinal MK. Evaluation of the revised physical activity readiness questionnaire in older adults. *Medicine and Science in Sports and Exercise* 1996;28(4):468-72.
57. Schepens S, Goldberg A, Wallace M. The short version of the Activities-specific Balance Confidence (ABC) scale: Its validity, reliability, and relationship to balance impairment and falls in older adults. *Archives of Gerontology and Geriatrics* 2009;51(1):9-12.
58. Malhotra N, Poolton JM, Wilson MR, et al. Examining movement-specific reinvestment and performance in demanding contexts. *Journal of Sport and Exercise Psychology* 2015;37(3):327-38.
59. Marques A, Almeida S, Carvalho J, et al. Reliability, Validity, and Ability to Identify Fall Status of the Balance Evaluation Systems Test, Mini–Balance Evaluation Systems Test, and Brief–Balance Evaluation Systems Test in Older People Living in the Community. *Archives of Physical Medicine and Rehabilitation* 2016;97(12):2166-73.

60. O'Hoski S, Sibley KM, Brooks D, et al. Construct validity of the BESTest, mini-BESTest and briefBESTest in adults aged 50 years and older. *Gait & Posture* 2015;42(3):301-05.
61. Padgett PK, Jacobs JV, Kasser SL. Is the BESTest at its best? A suggested brief version based on interrater reliability, validity, internal consistency, and theoretical construct. *Physical Therapy* 2012;92(9):1197-207.
62. Sibley KM, Beauchamp MK, Van Ooteghem K, et al. Using the systems framework for postural control to analyze the components of balance evaluated in standardized balance measures: a scoping review. *Archives of Physical Medicine and Rehabilitation* 2015;96(1):122-32.
63. Dillman Carpentier FR. Agenda setting and priming effects based on information presentation: revisiting accessibility as a mechanism explaining agenda setting and priming. *Mass Communication & Society* 2014;17(4):531-52. doi: 10.1080/15205436.2013.816744
64. Ericson MB, Sandberg C, Gudmundson F, et al. Fluorescence contrast and threshold limit: implications for photodynamic diagnosis of basal cell carcinoma. *Journal of Photochemistry and Photobiology B: Biology* 2003;69(2):121-27.
65. Hay GA, Chesters MS. Signal-transfer functions in threshold and suprathreshold vision. *Journal of The Optical Society of America* 1972;62(8):990-98.
66. Venture G, Ayusawa K, Nakamura Y. A numerical method for choosing motions with optimal excitation properties for identification of biped dynamics-an application to human. IEEE International Conference on Robotics and Automation: IEEE, 2009:1226-31.
67. Degen T, Jaeckel H, Rufer M, et al. SPEEDY: a fall detector in a wrist watch. Seventh IEEE International Symposium on Wearable Computers: ISWC, 2003:184-87.
68. Kangas M, Vikman I, Nyberg L, et al. Comparison of real-life accidental falls in older people with experimental falls in middle-aged test subjects. *Gait & Posture* 2012;35(3):500-05.
69. Groen BE, Weerdesteyn V, Duysens J. The relation between hip impact velocity and hip impact force differs between sideways fall techniques. *Journal of Biomechanics* 2006(39):88.
70. DeGoede KM, Ashton-Miller JA, Schultz AB. Fall-related upper body injuries in the older adult: a review of the biomechanical issues. *Journal of Biomechanics* 2003;36(7):1043-53.
71. Melton 3rd LJ, Cummings SR. Heterogeneity of age-related fractures: implications for epidemiology. *Bone and Mineral* 1987;2(4):321-31.
72. Dumas R, Cheze L, Verriest JP. Adjustments to McConville et al. and Young et al. body segment inertial parameters. *Journal of Biomechanics* 2007;40(3):543-53.
73. Augat P, Reeb H, Claes LE. Prediction of fracture load at different skeletal sites by geometric properties of the cortical shell. *Journal of Bone and Mineral Research* 1996;11(9):1356-63.
74. Benjamini Y, Hochberg Y. Controlling the false discovery rate: a practical and powerful approach to multiple testing. *Journal of the Royal Statistical Society: Series B (Methodological)* 1995;57(1):289-300.
75. Jie L-J, Kleynen M, Meijer K, et al. The effects of implicit and explicit motor learning in gait rehabilitation of people after stroke: protocol for a randomized controlled trial. *JMIR Research Protocols* 2018;7(5):142.



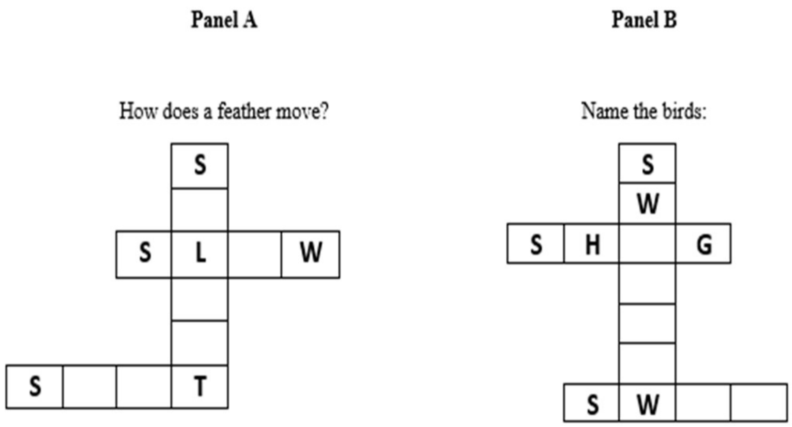
Flow diagram of the data collection session.

338x190mm (96 x 96 DPI)



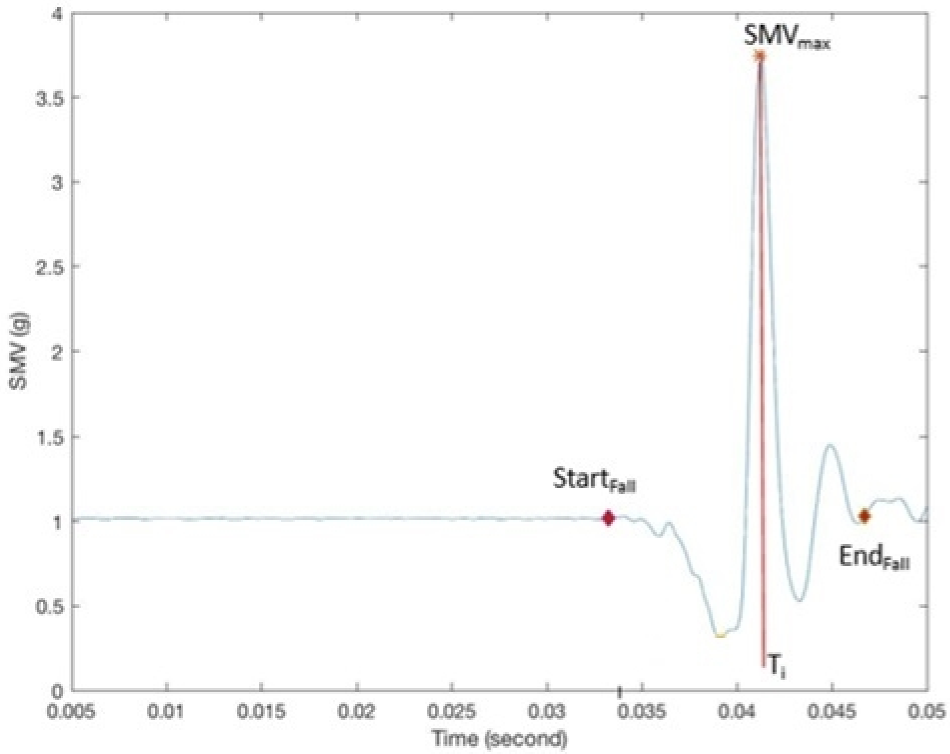
Positioning of inertial measurement units on different body segments

338x190mm (96 x 96 DPI)



Crossword puzzles for priming participants. Panel A: soft, slow, silent. Panel B: swallow, shag, swan.

338x190mm (96 x 96 DPI)



Signal magnitude vector (SMV) of the lower back inertial measurement unit during an unexpected backward fall. Start of fall (StartFall), time of impact (Ti) and end of fall (EndFall) are displayed.

127x100mm (96 x 96 DPI)

Section/item	Item #	Description	Page #
Administrative information			
Title	1	Descriptive title identifying the study design, population, interventions, and, if applicable, trial acronym	2
Trial registration	2a	Trial identifier and registry name. If not yet registered, name of intended registry	3
	2b	All items from the World Health Organization Trial Registration Data Set	NA
Protocol version	3	Date and version identifier	1
Funding	4	Sources and types of financial, material, and other support	15
Roles and responsibilities	5a	Names, affiliations, and roles of protocol contributors	1; 15
	5b	Name and contact information for the trial sponsor	NA
	5c	Role of study sponsor and funders, if any, in study design; collection, management, analysis, and interpretation of data; writing of the report; and the decision to submit the report for publication, including whether they will have ultimate authority over any of these activities	15
	5d	Composition, roles, and responsibilities of the coordinating centre, steering committee, endpoint adjudication committee, data management team, and other individuals or groups overseeing the trial, if applicable (see Item 21a for data monitoring committee)	NA
Introduction			
Background and rationale	6a	Description of research question and justification for undertaking the trial, including summary of relevant studies (published and unpublished) examining benefits and harms for each intervention	3-7
	6b	Explanation for choice of comparators	3-7
Objectives	7	Specific objectives or hypotheses	7
Trial design	8	Description of trial design including type of trial (eg, parallel group, crossover, factorial, single group), allocation ratio, and framework (eg, superiority, equivalence, noninferiority, exploratory)	7-8
Methods: Participants, interventions, and outcomes			
Study setting	9	Description of study settings (eg, community clinic, academic hospital) and list of countries where data will be collected. Reference to where list of study sites can be obtained	9-11
Eligibility criteria	10	Inclusion and exclusion criteria for participants. If applicable, eligibility criteria for study centres and individuals who will perform the interventions (eg, surgeons, psychotherapists)	8

Interventions	11a	Interventions for each group with sufficient detail to allow replication, including how and when they will be administered	11
	11b	Criteria for discontinuing or modifying allocated interventions for a given trial participant (eg, drug dose change in response to harms, participant request, or improving/worsening disease)	NA
	11c	Strategies to improve adherence to intervention protocols, and any procedures for monitoring adherence (eg, drug tablet return, laboratory tests)	NA
	11d	Relevant concomitant care and interventions that are permitted or prohibited during the trial	NA
Outcomes	12	Primary, secondary, and other outcomes, including the specific measurement variable (eg, systolic blood pressure), analysis metric (eg, change from baseline, final value, time to event), method of aggregation (eg, median, proportion), and time point for each outcome. Explanation of the clinical relevance of chosen efficacy and harm outcomes is strongly recommended	12-13
Participant timeline	13	Time schedule of enrolment, interventions (including any run-ins and washouts), assessments, and visits for participants. A schematic diagram is highly recommended (see fig 1)	9
Sample size	14	Estimated number of participants needed to achieve study objectives and how it was determined, including clinical and statistical assumptions supporting any sample size calculations	13
Recruitment	15	Strategies for achieving adequate participant enrolment to reach target sample size	13
Methods: Assignment of interventions (for controlled trials)			
Allocation:			
Sequence generation	16a	Method of generating the allocation sequence (eg, computer-generated random numbers) and list of any factors for stratification. To reduce predictability of a random sequence, details of any planned restriction (eg, blocking) should be provided in a separate document that is unavailable to those who enrol participants or assign interventions	8
Allocation concealment mechanism	16b	Mechanism of implementing the allocation sequence (eg, central telephone; sequentially numbered, opaque, sealed envelopes), describing any steps to conceal the sequence until interventions are assigned	8
Implementation	16c	Who will generate the allocation sequence, who will enrol participants, and who will assign participants to interventions	8
Blinding (masking)	17a	Who will be blinded after assignment to interventions (eg, trial participants, care providers, outcome assessors, data analysts) and how	8-9

	17b	If blinded, circumstances under which unblinding is permissible and procedure for revealing a participant's allocated intervention during the trial	NA
Methods: Data collection, management, and analysis			
Data collection methods	18a	Plans for assessment and collection of outcome, baseline, and other trial data, including any related processes to promote data quality (eg, duplicate measurements, training of assessors) and a description of study instruments (eg, questionnaires, laboratory tests) along with their reliability and validity, if known. Reference to where data collection forms can be found, if not in the protocol	9-10
	18b	Plans to promote participant retention and complete follow-up, including list of any outcome data to be collected for participants who discontinue or deviate from intervention protocols	NA
Data management	19	Plans for data entry, coding, security, and storage, including any related processes to promote data quality (eg, double data entry; range checks for data values). Reference to where details of data management procedures can be found, if not in the protocol	13
Statistical methods	20a	Statistical methods for analysing primary and secondary outcomes. Reference to where other details of the statistical analysis plan can be found, if not in the protocol	13
	20b	Methods for any additional analyses (eg, subgroup and adjusted analyses)	NA
	20c	Definition of analysis population relating to protocol non-adherence (eg, as randomised analysis), and any statistical methods to handle missing data (eg, multiple imputation)	13
Methods: Monitoring			
Data monitoring	21a	Composition of data monitoring committee (DMC); summary of its role and reporting structure; statement of whether it is independent from the sponsor and competing interests; and reference to where further details about its charter can be found, if not in the protocol. Alternatively, an explanation of why a DMC is not needed	13
	21b	Description of any interim analyses and stopping guidelines, including who will have access to these interim results and make the final decision to terminate the trial	NA
Harms	22	Plans for collecting, assessing, reporting, and managing solicited and spontaneously reported adverse events and other unintended effects of trial interventions or trial conduct	NA
Auditing	23	Frequency and procedures for auditing trial conduct, if any, and whether the process will be independent from investigators and the sponsor	NA

Ethics and dissemination			
Research ethics approval	24	Plans for seeking research ethics committee/institutional review board (REC/IRB) approval	2
Protocol amendments	25	Plans for communicating important protocol modifications (eg, changes to eligibility criteria, outcomes, analyses) to relevant parties (eg, investigators, REC/IRBs, trial participants, trial registries, journals, regulators)	15
Consent or assent	26a	Who will obtain informed consent or assent from potential trial participants or authorised surrogates, and how (see Item 32)	Lead investiga tor ; 11
	26b	Additional consent provisions for collection and use of participant data and biological specimens in ancillary studies, if applicable	NA
Confidentiality	27	How personal information about potential and enrolled participants will be collected, shared, and maintained in order to protect confidentiality before, during, and after the trial	13
Declaration of interests	28	Financial and other competing interests for principal investigators for the overall trial and each study site	19
Access to data	29	Statement of who will have access to the final trial dataset, and disclosure of contractual agreements that limit such access for investigators	13
Ancillary and post-trial care	30	Provisions, if any, for ancillary and post-trial care and for compensation to those who suffer harm from trial participation	NA
Dissemination policy	31a	Plans for investigators and sponsor to communicate trial results to participants, healthcare professionals, the public, and other relevant groups (eg, via publication, reporting in results databases, or other data sharing arrangements), including any publication restrictions	11
	31b	Authorship eligibility guidelines and any intended use of professional writers	NA
	31c	Plans, if any, for granting public access to the full protocol, participant-level dataset, and statistical code	NA
Appendices			
Informed consent materials	32	Model consent form and other related documentation given to participants and authorised surrogates	NA
Biological specimens	33	Plans for collection, laboratory evaluation, and storage of biological specimens for genetic or molecular analysis in the current trial and for future use in ancillary studies, if applicable	NA
Figure			15
References		Descriptive title identifying the study design, population, interventions, and, if applicable, trial acronym	16-19