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An interdisciplinary cross-cultural study of acceptable and effective exercise for improving physical function, cognition, and wellbeing in older adults
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DECLARATIONS

Declaration of any previous submission of the work

The material presented here for examination for the award of a higher degree by research has not been incorporated into a submission for another degree.

Candidate's signature. . . . . . [redacted] . . . .

Declaration of authorship

I am the author of this thesis, and the work described therein was carried out by myself personally. Individual chapters are accompanied by an authorship statement indicating my contribution to the work.

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Abstract

Maintaining physical function is imperative to counter degenerative diseases and preserve independence during later life. Weak muscular strength and compromised balance impede daily activities and elevate the risk of falls. Despite UK government recommendations for older adults to engage in resistance and balance training twice weekly, 85% of British individuals aged over 65 do not meet the muscle strengthening and balance exercise guidelines. Common exercise barriers in older adults include safety concerns, limited accessibility, financial constraints, and time limitations. To tackle these challenges, home-based exercises and 'exercise snacks' (i.e., breaking a continuous session into short bouts) have emerged as potential solutions.

A number of studies have discussed the efficacy of home-based exercise interventions. However, none have systematically reviewed the effectiveness of unsupervised home-based exercises, which have been shown to yield similar effects and have equivalent or even greater adherence than supervised ones. The systematic review with meta-analysis conducted in Chapter 2 unveiled a dearth of exploration on the effectiveness of entirely unsupervised home-based exercises on physical functions in older adults, based on existing literature. Despite limited studies and small sample sizes potentially influencing results, this study acknowledged the potential impact of unsupervised home-based exercises on physical functions in older adults. However, cultural variations explored through Western and Eastern cultures were hindered by the absence of eligible Mandarin literature.

Research has suggested that daily home-based exercise snacking may be an effective alternative to traditional resistance in older adults for increasing muscle strength. To maintain or improve balance, studies have indicated that Tai-chi is beneficial and can improve not only balance, muscle functions, but also reduce fall risks and enhance wellbeing in older adults. While Tai-Chi has long been acknowledged for its positive impact on physical and mental health, the unique snacking format of Tai-Chi remained unexplored. The feasibility of exercise and Tai-chi snacking in home settings, as well as the acceptability of exercise snacking in Eastern populations and Tai-chi snacking in Western populations, were also unknown in previous

literature. This thesis aimed to comprehensively understand the home-based exercise and Tai-chi snacking, applying in older adults' daily routines.

Subsequently, Chapter 3 explored the acceptability of home-based exercise and Tai-Chi snacking amongst healthy older adults with various physical function levels and different cultural backgrounds, specifically British and Taiwanese. This qualitative study included 63 participants and employed semi-structured interviews based on the Theoretical Framework of Acceptability. Findings revealed the acceptability of both exercise and Tai-Chi snacking in older adults, with minimal differences observed between UK and Taiwanese participants.

Chapter 4 investigated the feasibility of remotely delivering 4-week home-based exercise and Tai-Chi snacking, offering worthwhile 'stay active' strategies during the Covid-19 pandemic. This remote four-arm randomised feasibility study demonstrated increased muscle strength, physical activity levels in self-isolating UK older adults. The programmes offered opportunities for physical activity during Covid-19 lockdowns and identified the feasibility of remote delivery to older populations.

Finally, Chapter 5 examined the effectiveness of these novel home-based exercises with a prolonged intervention period on both physical function and overall health in pre-frail older adults in the UK. This study consisted of a mixed methods randomised controlled trial over 12 weeks, targeting on pre-frail older adults. Notable improvements in strength, balance, and mobility were observed in the intervention group compared to the control group. The study highlighted the programme's acceptability and convenience for older adults.

Taken together, the results of these four studies provide evidence on the potential benefits of unsupervised home-based exercise interventions in protecting older adults from frailty and mobility impairment. Specifically, the acceptability of home-based exercise and Tai-chi snacking was identified through cross-cultural investigations. The programme is accessible and feasible to deliver remotely to older adults, with significant improvement in lower body physical functions and general health, not only in healthy older adults but also pre-frail populations.

This thesis highlights the need for further research to comprehensively understand the effectiveness of unsupervised home-based exercise interventions across diverse cultural contexts, notwithstanding the demonstrated potential positive effects. The findings within this thesis contribute to the development of an implementable, acceptable, and effective home-based exercise and Tai-Chi snacking programme and inform future research on exercise strategies tailored for promoting healthy ageing.

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List of Abbreviations

1RM - One Repetition Maximum

BREQ-3 - Behaviour Regulation Exercise Questionnaire

CI - Confidence Interval

EQ-5D-5L - EuroQoL Five-Dimension, Five-Level Questionnaire

ES - Exercise Snacking

IPAQ-E - International Physical Activity Questionnaire - Elderly (short form)

IADL - Instrumental Activities of Daily Living

MOEES - Multidimensional Outcome Expectations for Exercise Scale

NHS - National Health Service

RCTs - Randomized Controlled Trials

SCI - Spinal Cord Injury

SEE - Self-Efficacy for Exercise

SF-36 - Short Form (36) Health Survey

S&B - Strength and Balance

SPPB - Short Physical Performance Battery

STS - Sit-to-Stand

TCS - Tai-chi Snacking

TFA - Theoretical Framework of Acceptability

TUG - Timed Up-and-Go Test

TW - Taiwanese

UK - United Kingdom

WEMWBS - Warwick-Edinburgh Mental Wellbeing Scales

1 Chapter I – Introduction

Introduction

‘Sit less, move more’ might be the best advice for health in later life. However, 'move more' is ambiguous guidance, so this thesis sets out to provide clarity.

The world’s population is rapidly ageing. The number of people over the age of 60 is expected to double by 2050, rising to 1.5 billion or rather 20% of the world’s population (World Population Prospects, 2017). Ageing is associated with physical and cognitive degeneration and these ageing related health problems could cause tremendous health costs and exhaust the national health and social care resources worldwide (Prince et al., 2015, Eun-Jung et al., 2018). Preventing onset or controlling progression of aged-related diseases would transform public health and incur enormous societal benefits (World Health Organization, 2015; Rakesh et al., 2017).

The importance of physical activity in public health has been extensively studied over the past decades. Physical activity, physical inactivity, and health-related factors are closely linked. Sedentary time increases as people age, for example from 7.7 hours in 20s to 9.6 hours in 70s per day (Jefferis et al., 2014; Sparling et al., 2015). The similar phenomenon was presented in NHS report (2019). More time in sedentary behaviour is related to impaired cognition, and a higher risk of being overweight, having metabolic syndrome-related pathologies, cardiovascular diseases, cancers, diabetes, and all-cause mortality (Ploeg et al., 2012; Wilmot et al., 2012). Regular physical activity is considered an essential component of prevention for heart disease, obesity, bone and joint disease, specific cancers, metabolic syndrome-related pathologies (Donnelly et al., 2009; McKinney et al., 2016; Warburton, Nicol, & Bredin, 2006). Regular physical activity can also prevent the reduction of fitness functions, maintain activities of daily living, decrease disability in older adults (Bauman et al., 2016). The links between physical activities and exercises and fitness functions are significant and strong. Therefore, breaking up sedentary lifestyle, maintaining functional status, reducing health disparities, increasing physical activities, and establishing regular exercise habits are necessary for older populations.

The World Health Organisation, along with numerous national governing bodies, recommend that to maintain good health older adults should engage in a minimum of 150 minutes per week of moderate to vigorous aerobic activity, and exercise to train strength and balance twice per week (World Health Organization, 2011; UK Chief Medical Officers, 2019). Recent surveys suggest that many older adults do not meet these guidelines. Data from the UK suggests that over 48% of men and 58% of women aged over 75 are completely inactive (Public Health England, 2015). Similarly, 32% Taiwanese older adults aged over 65 do not exercise regularly (Ministry of Health and Welfare, Taiwan, 2017). More recent audits that focus on different types of exercise, demonstrate that only 19% of adults aged between 65-74, and 10% aged 75 or greater meet both aerobic and muscle strengthening guidelines in England (Health Survey for England, 2021). Most notably, the same data suggests only 2% of adults aged between 65-74 and 1% aged over 75 meet muscle strengthening guidelines (see Figure 1-1) (Health Survey for England, 2021).

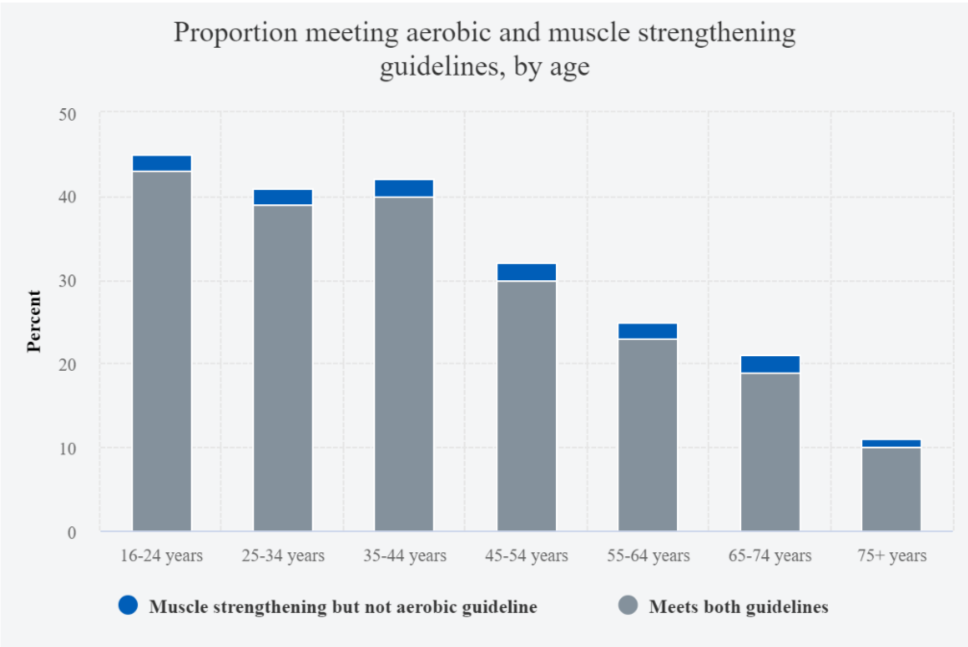

Figure 1-1. The proportion of British adults meeting aerobic and muscle strengthening guidelines by age group (NHS, 2021)

This thesis focuses on these ‘forgotten’ muscle strength and balance guidelines, aimed at improving physical function (Strain et al., 2016). Improving physical function is key to ageing well as it facilitates a more active lifestyle which supports better social relationships, prolonged independence, and greater wellbeing (den Ouden et al., 2013, Brach et al., 2004). This review summarises the relationship between physical function and health, existing evidence on the role of exercise in maintaining physical function in later life, and the barriers to exercise in certain older adults of different cultural origins.

Health-related fitness function including physical and cognitive components may degenerate as people get older (Pate et al., 1995). Indeed, functional decline due to ageing which increases the risk of dependence and death is inevitable, but the progression can be delayed significantly by lifestyle factors (Lunney et al., 2003). Physical function is the ability to perform activities of daily living. Muscle strength, endurance, flexibility, balance, and gait speed are commonly used to assess physical fitness and functional status (Studenski et al., 2011, Guralnik et al., 1994, Vellas et al., 1997, Freiberger et al., 2012). Previous research has shown that ageing and insufficient physical activity participation are related to decreased muscle mass and bone density and greater risks of having chronic diseases (Thompson et al., 2012). Brach et al. (2004) indicated that older adults who exercise regularly had better leg muscle strength and walking endurance, and might have lower risk for immobility and disability in later life. Similarly, researchers demonstrated that exercise has beneficial effects on enhancing gait speed, balance, and performance in daily-living activities (Chou et al., 2012, Giné-Garriga et al., 2014) as well as reducing nursing home and hospital admissions with ageing (Beswick et al., 2008). Thus, being adequately physically active and maintaining or, indeed, improving physical fitness function are crucial to healthy ageing. Beyond these physiological benefits, muscle strength and balance exercise can also contribute to psychological well-being and improved quality of life for older adults (Kadariya et al., 2019, An et al., 2020, Benlidayi, 2023). As such, understanding the intricate relationship between exercise and older adult physical function is of paramount importance for healthcare professionals, researchers, and policymakers seeking to enhance the health and well-being of ageing populations.

The American College of Sports Medicine’s guidelines suggest that older adults should perform resistance training with 1-3 sets of 60-85% of 1-RM, undertaking 8-10 exercises, completing 10-15 repetitions, twice per week for muscle strengthening. Resistance training is universally accepted to be beneficial to muscle strength, body composition, and body mineral density, and can reduce the risk of cardiovascular disease in middle-aged and older adults (Tambalis et al., 2009, Deschenes and Kraemer, 2002). Takarada and Ishii (2002) found that low intensity resistance exercise with 30 seconds rest in between each movement led to a significant improvement of 38.2±8.5% in knee extension 1RM in middle-aged females. A study reported that both muscle strength and the rate of force development were improved in older adults after resistance training (Guizelini et al., 2018). Geirsdottir et al. (2012) found that 12 weeks of resistance training resulted in improved physical performance in older adults, evidenced by a 53.5N increase in quadriceps strength and a reduction of 0.6 seconds in the time taken to perform the time-up-and-go test. Furthermore, their quality of life, measured by the T-score of a health-related quality of life questionnaire, increased by 1.2 points.". Bemben et al. (2000) demonstrated that resistance training can not only enhance muscle endurance, cardiovascular fitness, but insulin sensitivity, and basal metabolic rate. Resistance training within a multimodal programme has been shown to improve ankle, hip, shoulder, and neck rotation range of motion (Raab et al., 1988, Carneiro et al., 2015). Nevertheless, it is noteworthy that resistance training alone may inadvertently reduce flexibility if a specific flexibility component isn't included within the programme.

Another exercise format receiving increasing attention in ageing research is Tai-chi. Tai-chi originating from China in 18th century, performed with slow movement and mental concentration, it is one of the traditional Chinese martial arts. It is an exercise training that involves whole body movements because of its circular movement mode and the imagination of the flow of Qi (the practitioners think of themselves as a balloon that expands and shrinks) (Sang, 2005). The movements are blended with tranquillity, and while performing the movements, one maintains a mindful and relaxed state. A number of studies found that practicing Tai-chi positively impacts balance, flexibility, lower extremity functions, and cardiovascular functions (Liu, 2008, Miller and Taylor-Piliae, 2018, Wayne et al., 2014, Li et al., 2004, Field, 2011). Lan et al. (1998) found that 12-months of Tai-chi training can increase older adults' trunk flexibility. Another study indicated that Tai-chi could improve core muscle strength and balance in older females with osteoarthritis (Song et al., 2003). Son et al. (2016) indicated that practicing Tai-chi, improved community-dwelling older women's muscle strength, mobility, gait speed, and balance control to a similar extent as the Otago exercise programme. Practicing Tai-chi can also enhance knee flexion and extension strength (Lan et al., 2000, Choi et al., 2005), while further research has also found that older Tai-chi practitioners had better ankle and knee proprioception, longer single-leg stance time, stronger lower limb muscles, and better jumping ability (Xu et al., 2006, Mak and Ng, 2003, Gyllensten et al., 2010). Moreover, Tai-chi benefits immune system, enhances quality of sleep, and promotes mental health (Taylor-Piliae et al., 2006, Liu et al., 2019, Yeh et al., 2006). Given its' benefits, the NHS and other organisations recommend Tai-chi to support muscle health in older adults (NHS, 2021).

As mentioned, despite the public health recommendations and health benefits, very few older adults undertake sufficient strength and balance exercise in their daily life. In the UK, Strain et al. (2016) reported that older populations were less likely to meet muscle strength, balance, and coordination guidelines than younger groups. Lin et al. (2018) found that only 22.4% of 1068 Taiwanese older adults aged over 65 all over Taiwan meet both aerobic and muscle strengthening recommendation. Jang et al. (2016) demonstrated that exercise participation is affected by motivational, social and environmental factors which include differences in training, motivation, exercise habits, social support, socioeconomic gradient, and neighbourhood characteristics (Carlston, 1983, Booth et al., 2000, Farrell et al., 2013). Manaf (2013) indicated that the most common exercise barriers to older adults were feeling tired, lack of motivation, and believing that they are already active enough. Others have found that older adults consider poor health status, being too busy, lack of self-efficacy (i.e., confidence to lift weights and do exercise), inconvenient leisure site location or lack of access, economic considerations, and fear of injury or adverse health events like stroke or heart attack to be their substantial barriers to exercise participation (Lees et al., 2005, Burton et al., 2017, Cavill and Foster, 2018). Furthermore, there is a direct correlation between the percentage of older adults who perceive poor health as a barrier and their age (Kaleta et al., 2009, Castaño-Vergara and Cardona-Arango, 2015). These barriers to participation are exacerbated by age, meaning that the older people are, the less likely they are to do health-harnessing exercise (Ribeiro et al., 2015). They may also be at a higher risk of cardiovascular disease, obesity, bone and joint disease (osteoporosis), and metabolic syndrome-related pathologies (Lian et al., 2017, Muniyappa and Tella, 2018); and might experience increased anxiety regarding their balance (Yang et al., 2011, Darwesh et al., 2014). As to gender differences, a study showed that females were more likely to report lack of access or opportunities to exercise than males (Moschny et al., 2011). In addition, some older adults feel lack of self-efficacy to perform exercises and some feel under pressure when taking group classes in the gym (Franco et al., 2015). Thus, understanding older adults' preference and acceptance to different exercise training methods, and offering suitable and effective exercise interventions are essential for better health in later life.

Conversely, motivators to exercise participation in older adults included encouragement, personal beliefs, preventing fitness function degeneration, reducing risk of falls, improving muscle conditions, living independently, and having better wellbeing (Franco et al., 2015, Burton et al., 2017). Particularly, high self-efficacy and outcome expectancy (i.e., belief in the benefits) for exercise interventions are key factors for promoting adherence. Previous studies have shown that a clear and simple description of exercise instruction, good communication, and support and encouragement may also increase exercise participation (Flegal et al., 2007, Sjösten et al., 2007). Additionally, Jakicic et al. (1999) indicated that intermittent home-based exercise might improve long-term exercise adherence. However, a review has shown that exercise adherence rates were higher in supervised exercise interventions (Picorelli et al., 2014). Franco et al. (2015) explained that older adults who prefer supervised/group exercises might not only feel a sense of belonging and enjoyment but are able to make friends. Indeed, interventions that offer social support and instructor-led classes have been demonstrated to improve physical function in robust evaluations (Pahor et al., 2014, Stathi et al., 2022) but that these are resource intensive and do not attract all older adults who would benefit from intervention in a more accessible and familiar format. The costs of accessibility are one of the most common barriers.

Studies have demonstrated that home-based resistance training, which is low-cost and easy to implement, and unloaded resistance exercise, which has the same effects on fitness function as loaded exercises in older adults, might be practical alternatives to traditional training and more acceptable to older adults with fear of traditional weightlifting exercise (Glenn et al., 2015, Orange et al., 2019). Nelson et al. (2004) also found that a home-based strength, balance, and functional training with minimal supervision was safe and feasible for older adults. Moreover, as reducing exercise barriers such as tiredness, and safety for exercise modalities, decreasing training load with short recovery times may also be more appropriate to older adults, especially who are losing function. Several studies have found that intermittent short-bout exercises have higher adherence than long-bout exercises (Jakicic et al., 1995, King et al., 1995, Sparling et al., 2015). Francois et al. (2014) invented the term 'exercise snacks' to describe breaking up a single session of continuous exercise into several short periods of exercise spread throughout the day. Perkin et al. (2019) considered home-based exercise snacking, which improved maximal force production of 5% in older adults, to be a safe, attractive, and promising alternative exercise. In addition, a recent study indicated that dividing a continuous exercise session into shorter bouts of the same total duration throughout the day elicited similar health benefits (Murphy et al., 2019). Consequently, home-based exercise might be a practical strategy and more appropriate for individuals who lack access and have economic, time, and distance constraints than gym-based exercise, and would probably potentially better suit to a less functional population (i.e., with reduced functional abilities or limited mobility).

In terms of Tai-chi, releasing stress, improving balance and wellbeing are key facilitators as well as outcomes, yet, the major barriers are lack of awareness of benefits, long-duration format, and financial concern for traditional leisure centre based offerings (Braithwaite et al., 1998, Lo et al., 2020). Studies have reported that the unbalanced proportion of teaching to beginners compared to regular practitioners in Tai-chi group classes also affects learners' retentions and some considered waving hands in the air to be unreasonable (Gryffin et al., 2015). Nevertheless, simplifying Tai-chi movements might be a practical way for improving self-efficacy, and minimising monetary and time cost, which may further enhance take-up rates. As a matter of fact, given that practicing Tai-chi does not require any equipment and is easy to implement, and its' movements are performed slowly and gently which may be relatively safe to older adults, it may be a suitable format of exercise for the home setting.

Despite its popularity, few studies have investigated Tai-chi interventions in home settings, and few have compared the differences of the effects of Tai-chi and other home-based exercise programmes. In addition, few studies have discussed home-based exercise participation in older population from cross-cultural angles. Previous studies indicated that ethnic-specific factors such as religious beliefs and cultural practices (Horne et al., 2013), and also the values of family responsibilities, community stereotypes, and institutional thoughts (Koshoedo et al., 2015, Horne et al., 2013) may affect exercise participation. Moreover, cultural differences in preferences of body shapes, exercise motivations, and exercise environments may also influence exercise and physical activity participation (Furnham and Nordling, 1998, Weinberg et al., 2000).

When examining the percentages of older adults meeting aerobic and muscle strengthening guidelines, similarities emerge between British (20%) and Taiwanese (22%) populations in physical activity levels (Health Survey for England, 2021, Lin et al., 2018). However, nuanced cultural differences become evident when considering beliefs about gender roles, weather conditions, and societal attitudes toward body image between the UK and Taiwan. These nuances demonstrate varied barriers to exercise in each culture. In Taiwan, perceptions and cultural attitudes toward health literacy create nuanced barriers, intertwined with reduced confidence in utilising assistive devices such as walking sticks or Zimmer frames, potentially influenced by societal attitude toward body image. The perception and acceptance of these aids when leaving the house might diverge between these cultures. While British society might view these aids as enhancing independence, Taiwanese culture might attach different significance or stigma to their use, impacting older adults’ willingness to engage in outdoor activities. Moreover, environmental factors play a role. In the UK, the outdoor environment encourages active commuting, making walking and outdoor activities more accessible and enjoyable due to favourable weather conditions, whereas in Taiwan, crowded neighbourhoods, and humid weather act as barriers to outdoor exercise (Giles-Corti and Donovan, 2002). Additionally, older adults in Asian societies tend to have lower confidence levels and rely more on external motivation and support, whereas British culture often emphasises individual autonomy, differing significantly from the familial and community-based emphasis found in Taiwanese society.

However, despite these cultural variations, the underlying motivation for physical activity and exercise remains similar in both countries. These cultural nuances alongside varying gender roles and perceptions, are essential contextual factors influencing exercise attitudes and participation in older adults. Understanding and exploring these distinctions are crucial for designing effective interventions and addressing barriers specific to each context. They underscore the necessity for cross-cultural investigations to discern insights that may not generalise across cultures.

Particularly, Tai-chi is not yet as popular in Western as in Eastern countries and few studies have discussed the environmental, social, and cultural influences that may determine why this is the case. Even more, none have explored the acceptability or efficacy of Tai-chi in a snacking format. Thus, understanding older adults' preference and acceptance to home-based exercise interventions cross-culturally, developing novel approaches to improve engagement in strength and balance exercise, and concluding suitable and effective ones which can break up exercise barriers are necessary to improve older adults' later life worldwide.

Based on the above preliminary review, this thesis aims to find effective home-based exercise training methods for improving physical functions and explore whether home-based exercise snacking and Tai-chi snacking can be made feasible, acceptable and effective for improving physical function in older adults, based on different cultural backgrounds in order to promote healthy ageing and life expectancy in all-around groups. Hence, this thesis additionally investigates whether there are differences between people of different cultural backgrounds, specifically, UK and Taiwan.

To investigate these aims, the following research questions have been proposed to be addressed within this thesis:

Research question 1: What does the current literature say about the effectiveness of unsupervised home-based exercise for improving physical function in western and eastern cultures?

Research question 2: What is the acceptability of exercise snacking and Tai-chi in healthy British and Taiwanese older adults?

Research question 3: How feasible and acceptable is the assessment and delivery of home-based exercise snacking and Tai-Chi snacking when delivered remotely to self-isolating older adults?

Research question 4: How effective is home-based exercise snacking and Tai-chi snacking for improving physical function and wellbeing in pre-frail older adults?

In order to answer the research questions, a systematic review of literature was conducted to synthesise the evidence on the effectiveness of unsupervised home-based exercise programmes for engaging older adults and improving lower body physical function in older adults (Chapter 2). This study further considered the impact of different cultural aspects. Secondly, in order to design an intervention that will be acceptable (Chapter 5), understanding older adults' feelings about the exercise snacking and Tai-chi snacking was necessary. How one feels about exercise participation, with respect to self-efficacy and affective attitude may affect exercise take-up and adherence rates. Thus, Chapter 3 reports a qualitative study discussing the acceptability of exercise snacking and Tai-chi snacking in older adults. The study interviewed older adults both in the UK and Taiwan to investigate whether their views vary from different countries and cultures. Afterwards, Chapter 4 investigated the feasibility and acceptability of 4-week home-based exercise and Tai-chi snacking programmes delivered remotely. Due to the COVID-19 pandemic, this study was against the backdrop of self-isolation restrictions for older adults, and the study was conducted entirely remotely. Finally, in Chapter 5, a randomised controlled study involving a 12-week exercise and Tai-chi snacking intervention, designed according to the results of the first three studies, was conducted to understand its effectiveness on physical functions in pre-frail older adults. This study also involved qualitative interviews to understand whether the long-term progressive unsupervised home-based exercise and Tai-chi snacking programme is considered feasible and acceptable in pre-frail older adults.

Figure 1-2. Summary of the research questions addressed in this thesis and overall aim.

1.1 Note on format

This thesis is comprised of one systematic review and three research studies, presented as journal-formatted writing style, incorporation of papers accepted in or submitted to peer-reviewed journals (i.e., ‘alternative format’). Table 1-1 shows the thesis contents, including chapters and the state of each article and/or the reference to the published papers.

It is important to note that following examiner feedback and subsequent peer review iterations of chapters submitted but not accepted at the time of examination, the work presented in this thesis may differ in aspects of discussion, layout, or formatting from that found in journal publications. However, no data or results have been altered.

Each chapter starts with a ‘context’ section for the purpose of introducing the rationale for conducting the research and the research questions. After the ‘context’ section, a statement of authorship is presented in order to declare the publication and copyright status and acknowledge the candidate’s contribution to the paper in four components: (a) formulation of the ideas, (b) design of methodology, (c) experimental work, (d) presentation of data in journal format. Finally, a ‘summary’ section is displayed at the end of each chapter to link chapters together and explain the ideological coherence between each chapter.

The accepted manuscript of each publication has been integrated and reformatted into this thesis to suit the layout of the thesis presenting style.

Table 1-1. Overview of thesis contents

Chapter	**Journal articles**
Chapter 1: Introduction	
Chapter 2: The Effectiveness of Unsupervised Home-Based Exercise for Improving Physical Function in Western and Eastern Cultures: A Systematic Review and Meta-Analysis	[under review in *Ageing Research Reviews*]
Chapter 3: The Acceptability of Home-Based Exercise Snacking and Tai-chi amongst high and low function UK and Taiwanese Older Adults	[published] Liang, I. J., Francombe-Webb, J., McGuigan, M. P., Perkin, O. J., Thompson, D., & Western, M. J. 2023. *Frontiers in Aging*, 4, 1180939.
Chapter 4: Feasibility and Acceptability of Home-Based Exercise Snacking and Tai-Chi Snacking Delivered Remotely to Self-Isolating Older Adults During The COVID-19 Pandemic	[published] Liang, I.J., Perkin, O.J., McGuigan, P.M., Thompson, D. and Western, M.J., 2021. *Journal of Aging and Physical Activity*, 30(1), pp.33-43.
Chapter 5: The Efficacy of 12-week Progressive Home-Based Strength and Tai-Chi Exercise Snacking in Older Adults: A Mixed-Method Exploratory Randomised Control Trial	[under review in *The Journal of Frailty and Aging*]
Chapter 6: General Discussion	

2 Chapter II – Literature review

The Effectiveness of Unsupervised Home-Based Exercise for Improving Physical Function in Older Adults in Western and Eastern Cultures: A Systematic Review and Meta-Analysis

2.1 Context

Previous research has indicated that lack of transportation, lack of time, lack of self-efficacy, and financial considerations are common barriers to gym or leisure centre-based exercise and these issues reduce older adults' exercise adherence (Nowalk et al., 2001, Bakhshayeh et al., 2019, Burton et al., 2017). Alternative strategies such as home-based exercise programmes may overcome these barriers, owing to the more suitable setting in which to engage in regular muscle strength and balance exercise (Jette et al., 1999, Sparling et al., 2015). Studies have examined the efficacy of supervised and minimally supervised home-based exercise, highlighting its benefits for enhancing physical functions in older adults (Kis et al., 2019, Chaabene et al., 2021). Some studies even indicate that unsupervised home-based exercise may have greater adherence than other exercise approaches (Orange et al., 2019, Lacroix et al., 2016).

A literature review was performed looking into the existing evidence to ascertain what benefits to physical function older adults aged over 65 might gain from the unsupervised home-based exercise programmes. Furthermore, to address a gap in the literature regarding whether the findings in the scientific literature can be generalised across Western and Eastern cultures, the review aimed to scrutinise literature from both Westernised and East Asian settings. Knowing the effectiveness of unsupervised home-based exercise programmes would be useful to design the optimal and appropriate home-based training regime for older adults in the future. Understanding the cultural impact of exercise interventions would bring insight on the acceptability and feasibility of prescribing exercise programmes to older adults with different cultural backgrounds. Altogether, understanding the findings of existing evidence and the research gap could confirm the study ideas of this thesis and shape the direction of my future work. Therefore, this chapter addressed the following research question.

Research Question 1: What does the current literature say about the effectiveness of unsupervised home-based exercise for improving physical function in western and eastern cultures?

2.2 Statement of authorship

This declaration concerns the article entitled:	
The Effectiveness of Unsupervised Home-Based Exercise for Improving Physical Function in Older Adults in Western and Eastern Cultures: A Systematic Review and Meta-Analysis	
Publication status (tick one)	
Draft manuscript ☐ **Submitted** ☐ **In review** ✔ **Accepted** ☐ **Published** ☐	
Publication details (reference)	Under review in *Ageing Research Reviews* Ian Ju Liang[1], Oliver J. Perkin[1], Polly M. McGuigan[1], Bruno Spellanzon[1], Molly Robb[1], Chien-Yu Liu[2], Linda L Lin[3], Dylan Thompson[1], Max J. Western[1*] [1]Department for Health, University of Bath [2]Department of Physical Education and Sport Sciences, National Taiwan Normal University [3]Graduate Institute of Physical Education, Health & Leisure Studies, National Cheng Kung University
Copyright status (tick the appropriate statement)	
The material has been published with a CC-BY license ✔	The publisher has granted permission to replicate the material included here ☐
Candidate's contribution to the paper (provide details, and also indicate as a percentage)	The candidate contributed to / considerably contributed to / predominantly executed the… Formulation of ideas: 80% Design of methodology: 80% Experimental work: 80% Presentation of data in journal format: 90%
Statement from Candidate	This paper reports on original research I conducted during the period of my Higher Degree by Research candidature.
Signed (typed signature)	**Date**

2.3 Paper 1: The Effectiveness of Unsupervised Home-Based Exercise for Improving Physical Function in Older Adults in Western and Eastern Cultures: A Systematic Review and Meta-Analysis

2.3.1 *Abstract*

Background and objectives: Ageing leads to decreased physical function, which can impact independent living and raise health risks, increasing the need for healthcare resources. Finding affordable and accessible exercises to improve physical function is necessary for a population resistant to strength and balance training in leisure settings. This review aimed to evaluate whether unsupervised home-based exercises improve lower extremity function in older adults.

Research design and methods: We systematically searched for randomised controlled trials (RCTs) and cluster RCTs studies investigating unsupervised home-based exercises' effects on physical function in older adults through English and Mandarin databases. Studies' methodological quality was assessed using the Cochrane's Risk of Bias Tool. Meta-analyses were conducted on lower extremity functions outcomes.

Results: Of the 6791 identified articles, 10 studies (907 participants) were included, 8 studies (839 participants) were used for final meta-analysis, with no Mandarin literature. Studies were largely based in Europe with mostly moderate risk of bias. Most interventions were multicomponent lasting 10-40 minutes/session, 3 times/week. Meta-analysis showed no significant differences in 5 sit-to-stand ($p = 0.05$; $I^2 = 0\%$), maximal knee extension strength ($p = 0.61$; $I^2 = 71\%$), 10m maximal walking speed ($p = 0.22$; $I^2 = 30\%$), time-up-to-go ($p = 0.54$; $I^2 = 0\%$), and SPPB ($p = 0.32$; $I^2 = 98\%$) between exercise and control groups.

Discussion and implications: This meta-analysis suggests that unsupervised home-based exercises have little impact on lower extremity functions in older adults. This review is limited by the small number of included studies, sample sizes, and high heterogeneity. There is a need to better understand why this format lacks efficacy, and design more beneficial home-based exercise programmes.

2.3.2 Introduction

The number of people over the age of 65 is expected to more than double by 2050 [1]. Specifically, according to the World Health Organization, the number of older adults in the European region and Asia region are forecast to be higher, increasing by 11% and 12.3% from 2010 to 2050 respectively. Ageing is associated with physiological deterioration, for example muscle function decline [2-4], mobility and balance functional decline [5-7], and a higher risk of having osteoporosis and/or sarcopenia caused by physical inactivity [8-11]. These physical declines can lead to loss of independence, higher fall and hospitalization risks. As societies become 'super-aged' (with over 20% of total populations aged over 65) [12], related health issues are predicted to rise, impacting quality of life and straining healthcare resources [13, 14]. Interventions that support adults to maintain robust physical function in later life are essential for improving wellbeing and minimizing the economic burden of physical frailty and associated morbidity [15, 16].

Regular physical exercise is recommended to prevent a loss of physical function, maintain activities of daily living, and decrease disability in older adults [17-19]. Previous studies have investigated the effects of exercise interventions on physical fitness, balance, falls, and wellbeing in older adults and found that progressive resistance training significantly enhanced muscle strength and performance in older adults [20]. The trainer-led 'Otago' exercise programme for example, focusing on leg strength and balance, has been shown to improve mobility, balance, and muscle strength, and reduced falling risk and mortality [21-23]. Multicomponent exercises, including strength, endurance, and balance training, effectively maintained or even improved lower limbs physical function in older adults [24], especially in those who are diagnosed as frail [25, 26]. In fact, even endurance exercise alone, which would not typically be expected to improve strength related outcomes, enhanced muscle functions in older adults with minimal strength [27, 28]. Accordingly, functional/strength improvements might be a biproduct of any exercise programmes in older populations. It is clear that all forms of exercise bring benefits in physical fitness in older adults with different physical activity levels.

However, research has reported lack of time, apathy towards exercise, lack of access or convenient spaces for activity, feeling pressured or a lack of belonging in group leisure or gym settings, lack of self-efficacy for exercise, and economic constraints as common, critical, barriers to regular exercise participation amongst older adults [29-33]. Such barriers make exercise programmes in specialist exercise facilities unfeasible for many older adults, while supervised exercise provision, particularly non-group based, is a resource intensive form of intervention. As an alternative to traditional exercise provision, home-based exercise might be an effective and acceptable option that overcomes the typical participatory barriers, especially formats that are of no or low cost, motivating, safe and easy to undergo in onces familiar home-environment [34-36]. Previous reviews found supervised and minimally supervised home-based exercise programmes to be advantageous to muscle strength, mobility, and balance [37-39]. Some studies have even demonstrated that unsupervised home-based exercise interventions have higher adherence amongst older adults, presenting as a practical alternative to resource intensive supervised training programmes [40-42].

While there is evidence supporting the feasibility and acceptability of unsupervised home-based exercise programmes, its effectiveness has not yet been comprehensively reviewed. Additionally, a criticism of previous reviews is that they are limited to the monolingual scope of searches, potentially neglecting a large body of literature. To our knowledge, there have been no attempts to synthesize the evidence on the cultural differences of the effective and optimal mode of home-based exercise interventions in older adults in one review. Identifying cultural differences is also important for suggesting appropriate exercise training methods to older adults from different countries since exercise participation is affected by cultural values [43]. Therefore, the aim of this study was to review the effectiveness of unsupervised, home-based, exercise programmes on lower extremity physical functions in older adults and investigate whether the effects and benefits of different unsupervised home-based exercises vary across Western and Eastern cultures.

2.3.3 *Methods*

The study protocol was registered with the International Prospective Register of Systematic Reviews (PROSPERO) (registration number: CRD42023395942). This systematic review followed the Population, Intervention, Comparison, Outcomes and Study (PICOS) framework to determine the design of the review search and extraction strategy. In summary, the participants of the study were community dwelling older adults from Western (namely anglospheric European countries) or Eastern (namely sinospheric east Asian countries) cultures. The intervention of interest was any self-directed strength balance or general physical function programme targeting the lower body. The comparison group were participants undertaking usual care or an active non-exercise intervention. The outcomes of interest were quantitative measures of strength, balance, or general physical function. And the study design was a randomised controlled trial. We followed PRISMA guidelines to ensure all relevant information was included (see Supplementary file A).

Eligibility criteria

Studies had to be: (a) RCTs or cluster RCTs; (b) self-guided home-based exercise interventions of any type; (c) control groups with usual care or no exercise; (d) objective quantitative outcome measures of strength and balance or general physical function; and (e) community dwelling or non-institutionalised older adults aged over 65 years who did not reside in nursing or care homes. No restriction on disease or cognitive function was included, however, studies whose participants had lower-limb exercise precluding physical disability (i.e., wheelchair users, spinal cord injury (SCI) patients) were excluded. Studies were excluded if they were: (a) observational, quasi-experimental, single group designs, and feasibility or qualitative studies; (b) without intervention descriptions; (c) group-based, gym-based, and lab-based settings; (d) upper-body training only; (e) interventions with supervision, home visits, follow-up visits, or any in-person/telephone feedback for progression adjustment; (f) without strength- or balance-related outcome measures; and (g) non-English or non-Mandarin publications. Interventions needed to be self-guided; a one-off introduction session or non-instructive calls (i.e., motivational calls) were permissible.

Search strategy

We included English and Mandarin literatures regarding the cultural context. The English studies were inclusive those being conducted in Europe, North America, Australia and New Zealand, whereas the Mandarin studies had to be conducted in East Asian states. English literature was searched on March 6, 2020, and updated on April 27, 2022, in PubMed, Web of Science, and Embase. Mandarin literature search dates were May 23, 2020, and June 12, 2022, in AiritiLibrary, China National Knowledge Infrastructure, and NCL Taiwan Periodical Literature databases. In addition, reference lists from relevant systematic reviews and meta-analyses were searched to identify any additional studies. Manual searches and literature extracts were conducted along with the screening reference lists of systematic reviews. See Supplementary B for the searching strategy and terms.

Identification of relevant studies

After database searches, two reviewers screened study titles and abstracts. Full texts were sought for articles not excluded after title and abstract screening. English study selection involved IJL, MR, and BS; Mandarin study selection involved IJL and CYL. Disagreements wer resolved by MW and OP. Full texts were reviewed in two phases: phase one involved two reviewers discussing eligibility, and phase two involved single-author (IJL) screening. Unclear cases were discussed with MW. In case of missing, incomplete, or unclear information, the corresponding authors were contacted to provide additional data and further details.

Assessment of methodological quality

Studies' methodological quality was evaluated using Cochrane's Risk of Bias Tool 2.0 [44], which assesses six domains (the randomisation process, deviations from intended interventions, missing outcome data, measurement of the outcome, selection of the reported result, and overall bias). Domains were rated as "low risk of bias", "some concerns", or "high risk of bias". The study was judged to be at low risk of bias if all domains were classified as having a low risk of bias. If the study was judged to raise some concerns in at least one domain but not to be at high risk of bias for any domain, the study was judged as having some concerns. If the study was judged to be at high risk of bias in at least one domain, the study was considered to be at high risk of bias [44]. Three reviewers (IJL, MW and BS) independently assessed the studies' quality.

Data extraction

Data from each study were extracted by two reviewers (IJL and BS) independently. Descriptive data extracted included: authors, study country, participant characteristics (age, gender, sample size, health status, physical activity level), intervention delivery type (DVD, computer units, online platforms, with or without one-off introductory session), duration and frequency of interventions, intervention type, follow up period, and outcome measures.

Regarding gender and sex terminology in the reviewed literature, while some studies explicitly differentiated between the two, others used these terms interchangeably or omitted specific terminology. Our extraction process relied on the information provided within each study, aiming to capture all pertinent data.

Data analysis

Meta-analyses were conducted to examine the effects on lower extremity functions. Hedges's g was used to calculate the standardized mean differences between intervention and control arms of the study based [45]. A random effects model, using the restricted maximum likelihood method [46], was utilised to calculate the pooled effect size, as the included studies had different conditions (e.g. types of exercise, exercise intensity, intervention duration, target populations) which means the heterogeneity between the studies is assumed [45]. The I^2 test for heterogeneity was used to identify the proportion of variability across studies [47]. SPSS version 28 (IBM Corp, Armonk, NY) was used for all analyses.

2.3.4 *Results*

In English database, 4606 records, including 55 systematic reviews, were identified after removing duplicates. There were 960 articles manually extracted from those 55 systematic reviews. This led to 5566 titles and abstracts screening, resulting in 308 articles for full-text screening. Accordingly, 298 articles were excluded, leaving 10 articles for inclusion in this systematic review. In Mandarin database, 1128 records were returned, including 27 systematic reviews. 97 articles were extracted manually from those 27 systematic reviews. Thus, 1225 titles and abstracts were screened. Of these 1225 articles, 63 articles were included for full-text screening. Consequently, none of the articles were included. See Figure 2.1 for the screening process.

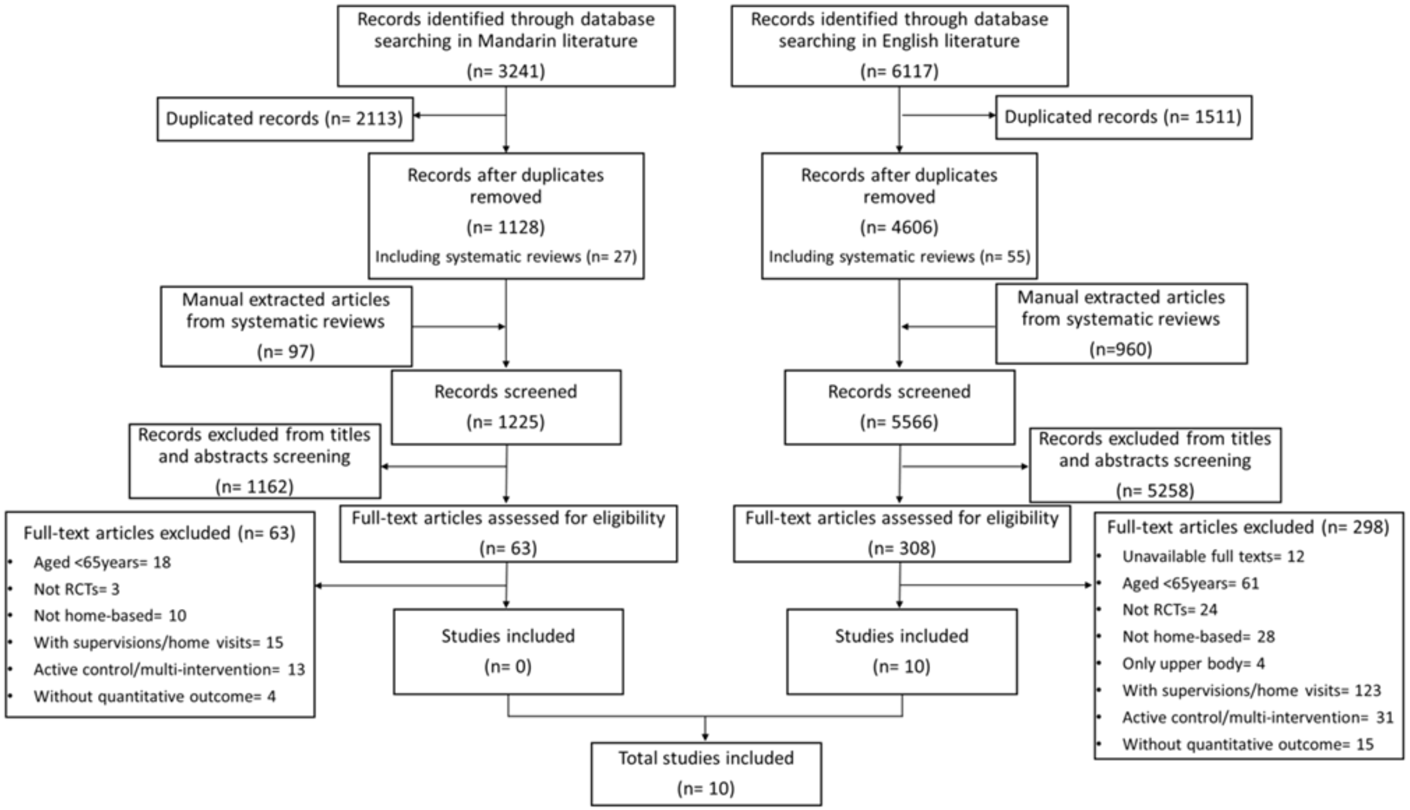

Figure 2-1. Literature screening flowchart

Study characteristics

The ten included studies were all RCTs, with three based in the USA [48-50], four in Europe [51-54], two in Australia [55, 56], and one in Asia (Japan) [57], which were all identified in the English published literature. Accordingly, comparisons between Western and Eastern cultures in terms of effectiveness were not permissible, and the results from hereon in compiles all studies included in the review. Table 2-1 displays the individual study characteristics.

Participants

Six studies recruited community dwelling older adults [48, 49, 51, 53, 55, 56], one study [54] recruited participants from a rehabilitation centre, and the remaining three studies [50, 52, 57] recruited participants from clinical practices for special populations (i.e., patients with knee osteoarthritis, dialysis, and prostate cancer). Three studies recruited female participants only [53, 54, 57], and one involved male participants only [50]. In total, 907 participants were involved in these 10 studies, with 264 men, 611 women, and 32 unknown due to unreported gender. Amongst them, 455 were in exercise groups and 452 in control groups.

Table 2-1. Summary of included studies

Author, date, setting, location	**Population/health condition, age, gender**	**Intervention: type, delivery type, duration, frequency, length, additional support**	**Lower extremity outcome measures**	**Adherence and record methods**
Adcock 2020 (Adcock et al., 2020) Home-based exercise intervention, Switzerland.	Healthy older adults, able to stand at least for 10 minutes without assistance. I: n = 15, 77 yrs. 67% female C: n = 16, 70 yrs. 38% female	I: Tai Chi-inspired exercises, dancing, and step-based cognitive games, utilising computer software and hardware (i.e., straps). C: Usual care (normal daily living). 18 weeks, 3 times/week, 30-40 minutes/session. One-off 1-hour introductory session, and biweekly motivational call.	SPPB extended balance test, 30-sec sit-to-stand, 2min stepping test, and 10m walking speed.	70% of the total training sessions, daily log sheets

Aoki 2009 (Aoki et al., 2009) Home-based exercise intervention, Tokyo, Japan.	Female older adults with knee osteoarthritis. I: n = 17, 72.3 yrs. C: n = 19, 74.4 yrs.	I: Knee stretching exercises, using written instructions. C: Usual care (normal daily living). 30-140 days depends on the time of total knee arthroplasty, 7 times/week, 30 seconds for each exercise for 10 reps.	10m gait speed, knee ROM in supine position, and knee ROM from maximum flexion to extension during gait (with a goniometer)	93% of the total training sessions, daily log sheets
Baggetta 2018 (Baggetta et al., 2018) Home-based exercise intervention, Reggio Calabria, Italy.	Older adults with dialysis, able to walk 550m in 6 min. I: n = 53, 73 yrs. 36% female C: n = 62, 75 yrs. 34% female	I: Personalised home-based walking exercise, using online video instructions (i.e., YouTube). C: Usual care with healthy ageing advice. 6 months, 3 times/week, 15 minutes/session. 5 motivational calls during the intervention.	6-min walking distance and 5-time sit-to-stand test	49% had low adherence and 51% had high adherence (undefined adherence definition), assessed by evaluating the residual battery charge in the metronome

Delbaere 2021 (Delbaere et al., 2021) Home-based exercise intervention, Sydney metropolitan area, Australia.	Healthy and independent-living community dwelling older adults, able to walk household distances without the use of a walking aid. I: n = 114, 77.1 yrs. 70% female C: n = 112, 77.7 yrs. 65% female	I: The StandingTall programme focusing on standing balance, targeted stepping, and step-up exercises, with exercise equipment (foam cushion, stepping box, exercise mat), utilising tablet computers. C: Usual care with health education. 2 years, started from 40mins/week increased to 120mins/week by week 9. One-off 1-hour introductory session.	Standing balance, maximum forward-backwards balance, and controlled leaning balance, time up-to-go, SPPB, and 10m walking speed.	40%, 34%, 33%, and 30% of participants achieved the prescribed dose over 6, 12, 18, and 24 months respectively, automatic data from tablet computers.
McAuley 2013 (McAuley et al., 2013) Home-based DVD exercise intervention, east-central Illinois, USA.	Physically inactive older adults. I: n = 158, 70.6 yrs. 72% female C: n = 149, 71.4 yrs. 83% female	I: Six progressive exercise sessions focusing on balance, strength, and flexibility with exercise equipment (two resistance bands and a yoga mat), following Flexibility, Toning, and Balance (FlexToBa) trial, using DVD delivery. C: Usual care with healthy	SPPB and sit-and-reach test.	76% (range: 93% at month 1 to 60% at month 6) of the total training sessions, daily log sheets

		ageing advice. 6 months, 3 times/week, 6-month follow-up. Biweekly motivational call in the first 2 months.		
Niemelä 2011 (Niemelä et al., 2011) Home-based exercise intervention, Finland.	Community dwelling female older adults. I: n = 26, 79.8 yrs. C: n = 25, 80.7 yrs.	I: Ten rocking-chair exercises focusing on improving muscle strength in the lower limbs and mobility, using written instructions. C: Usual care (normal daily living). 6 weeks, 10 times/week, 15 minutes/session. One-off 1-hour introductory session.	Maximal isometric knee extension, 5-time sit-to-stand, stand on one leg test, the Berg Balance Scale, and 10m walking speed.	96% of the total training sessions, daily log sheets

Sajid 2016 (Sajid et al., 2016) Home-based exercise intervention, Chicago (Illinois) and New York, USA.	Sedentary male older adults with prostate cancer on androgen deprivation therapy, able to walk 4m. I1: n = 8, 70-87 yrs. I2: n = 6, 67-93 yrs. C: n = 5, 67-80 yrs.	I1: A tailored, multi-component technology-mediated exercise program utilising the Wii-Fit technology. I2: A tailored, multi-component, home-based aerobic and progressive resistance exercise program (including moderately intense aerobic walking exercise and low to moderate intensity progressive resistance exercises), using written instructions. C: Usual care (normal daily living). 6 weeks, 5 times/week, 12-week follow-up. One-off 45-min introductory session, and weekly motivational call.	SPPB.	70% (undefined adherence definition), daily log sheets

Schoene 2013 (Schoene et al., 2013) Home-based videogame exercise intervention, retirement village in Sydney, Australia.	Healthy and independent-living older adults, able to walk without a walking aid for 20 m and to step in place unassisted on a step pad. I: n = 15, 77.5 yrs. C: n = 17, 78.4 yrs.	I: Step video games with three levels of difficulty through a computerised step pad system (modified Dance Dance Revolution game, StepMania), utilising the computer unit. C: Usual care (normal daily living). 8 weeks, 2-3 times/week, 10-20 minutes/session. One-off 90-min introductory session, and 4 motivational calls.	Time up-to go, 5-time sit-to-stand, alternative step test for functional balance, and the Physiological Profile Assessment (including isometric knee extension, anterior-post Sway, and med-lat Sway tests).	N/A

Vestergaard 2008 (Vestergaard et al., 2008) Home-based DVD exercise intervention, Denmark.	Physically inactive female older adults. I: n = 25, 81 yrs. C: n = 28, 82.7 yrs.	I: Home-based exercise comprised 15 minutes of warm-up, focusing on flexibility and dynamic balance exercises, 6 minutes of strengthening exercises using the elastic band for arms and legs, and 5 minutes of aerobic exercises, using DVD delivery. C: Usual care (normal daily living). 5 months, 3 times/week, 26 minutes/session. One-off 1-hour introductory session, and biweekly motivational call.	Maximal leg extensor power, 5-time sit-to-stand, semi-tandem stand balance test, the Physical Performance Test for assessing activities of daily living, and 10m walking speed.	89.2% (ranging from 45-100%) (undefined adherence definition), daily log sheets
Yates 2001 (Yates & Dunnagan, 2001) Home-based exercise intervention,	Independent-living community dwelling older adults. I: n = 18, 69-90 yrs. 72% female	I: 19 chair-based exercises for improving strength (with 5-lb adjustable weights), coordination, balance, and mobility, following guidelines of the Movement Matters: Home Based Exercise Program, using	Time up-to-go, Tinetti balance test, and lower extremity power.	55% of participants achieved the prescribed dose, daily log sheets

rural southwest Montana, USA.	C: n = 19, 69-88 yrs. 68% female	written instructions. C: Usual care (normal daily living). 10 weeks, 3 times/week, 15 minutes/session. One-off 1-hour introductory session, and health education.

I= intervention group, C= control group, yrs.= years, SPPB= short physical performance battery test, ROM= range of motion.

Exercise interventions

Across the included 10 studies, there were 11 different home-based exercise programmes comprising multicomponent interventions focusing on balance, strength, mobility, and flexibility (n=8) [48-50, 53-56] (particularly balance, strength and flexibility [48, 53], balance and mobility [55, 56], strength and mobility [54], balance, strength, and mobility [49, 50]), walking (n=1) [52], stretching (n=1) [57], and Tai-chi 'inspired' exercises (n=1) [51]. Eight interventions had one-off introductory sessions (as described in Table 2-1). Delivery types varied, with two using DVD, four using computer/ tablet systems, four with written instructions, and one via online platforms (i.e., prerecorded YouTube videos). Interventions lasted 1 to 24 months, often 3 times weekly (n=6), lasting 10 to 40 minutes per session.

Outcome measures

Regarding the instruments for lower extremity functional assessment, five studies assessed the 5-time sit-to-stand test and two assessed the knee extension strength for lower extremity strength; five studies measured 10-meter walking speed and three measured time-up-to-go for mobility; three studies measured the SPPB for evaluating overall lower extremity function. However, of the 10 included studies, only 8 studies, involving 839 participants, were finally used for statistical meta-analyses due to the lack of essential data (i.e. mean and standard deviation) of two studies [49, 51]. Thus, meta-analysis was conducted in the following outcome measures: 5 sit-to-stand (n=5) [52-56], knee extension strength (n=2) [54, 56], 10m walking speed (n=4) [53-55, 57], TUG (n=2) [55, 56], and SPPB (n=3, including one three-arm study) [48, 50, 55]. Where one study [50] was a three-arm RCT with two exercise intervention arms and one control arm, the control group was split equally between 2 intervention arms to avoid double counting of participants.

The effectiveness on 5 sit-to-stand

Five studies, involving 464 participants, were included for meta-analysis (Figure 2-2). Pooled results demonstrated that the unsupervised home-based exercise interventions did not have a statistically significant intervention effect in 5 sit-to-stand (random-effects estimate: 0.05, 95% CI [−0.36,0.00]). Heterogeneity was low ($I^2 = 0\%$).

The effectiveness on knee extension strength

Two studies, involving 83 participants, were included for meta-analysis (Figure 2-3). The analysis did not identify a statistically significant intervention effect in knee extension strength (random-effects estimate: 0.61, 95% CI [− 0.60,1.03]). $I^2 = 71\%$ represented substantial heterogeneity.

The effectiveness on 10m walking speed

Four studies, involving 357 participants, were included for meta-analysis (Figure 2-4). Pooled results revealed no statistically significant intervention effect in 10m walking speed (random-effects estimate: 0.22, 95% CI [− 0.10,0.46]). Heterogeneity was moderate ($I^2 = 30\%$).

The effectiveness on time-up-to-go (TUG)

Two studies, involving 258 participants, were included for meta-analysis (Figure 2-5). The analysis did not identify a statistically significant intervention effect in TUG (random-effects estimate: 0.54, 95% CI [− 0.32,0.17). Heterogeneity was low ($I^2 = 0\%$).

The effectiveness on SPPB

Three studies (one study (Sajid et al., 2016) appears twice as it was a three-arm trial), involving 505 participants in total, were included for meta-analysis (Figure 2-6). No statistically significant intervention effect was observed in SPPB (random-effects estimate: 0.32, 95% CI [− 1.09,3.37]). Heterogeneity was considerable ($I^2 = 98\%$).

Overall, the meta-analysis, using random-effects analysis, showed that there were no significant differences between unsupervised home-based exercise programmes and control groups in all measures of physical function. Given the paucity of studies, no subgroup analyses were conducted.

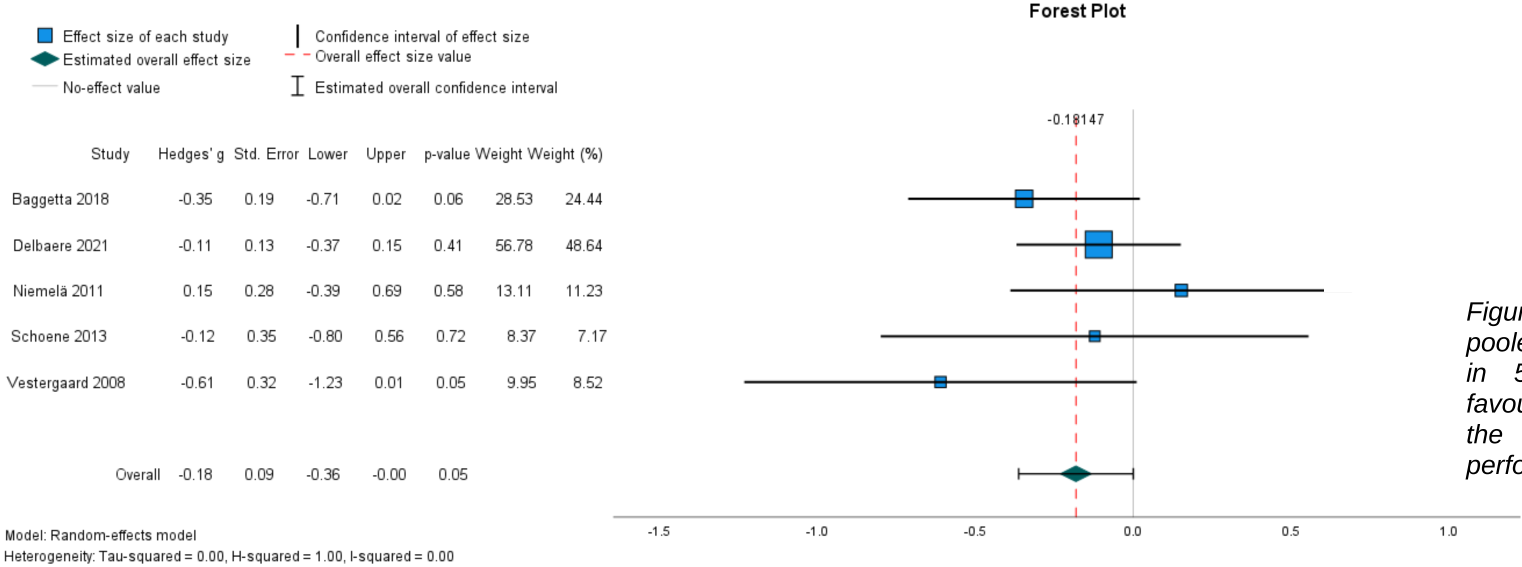

Figure 2-2. Forest plots depicting the pooled standardised mean difference in 5-time sit-to-stand. Outcomes favouring intervention are depicted to the right, favouring shorter time performing 5-time sit-to-stand test.

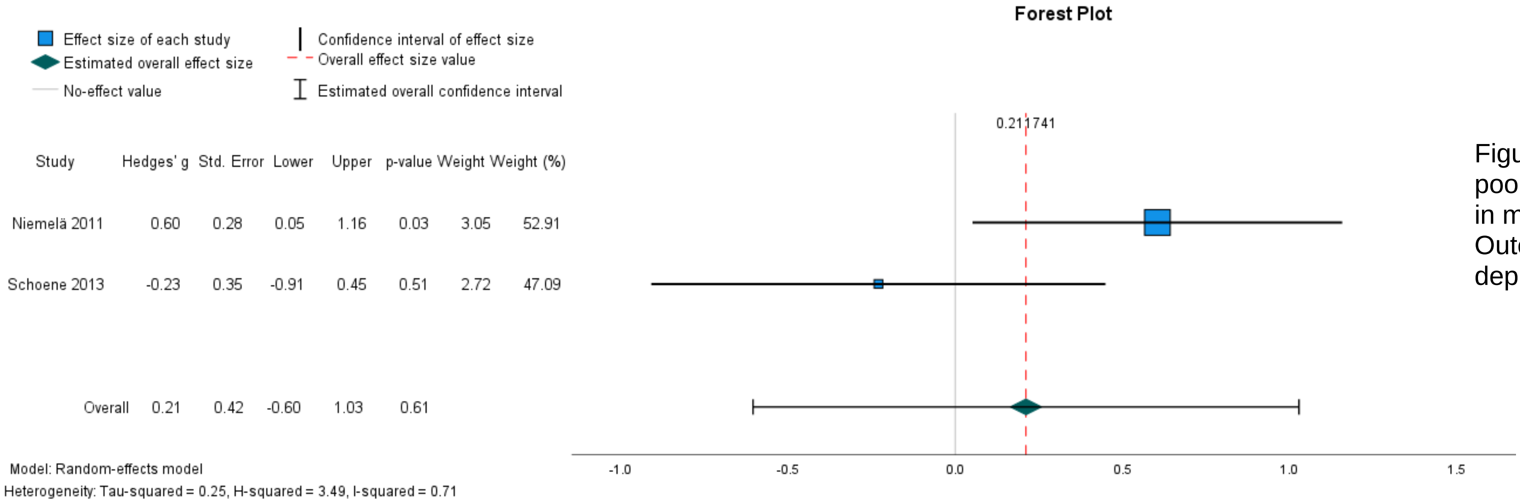

Figure 2-3. Forest plots depicting the pooled standardised mean difference in maximal knee extension strength. Outcomes favouring intervention are depicted to the left.

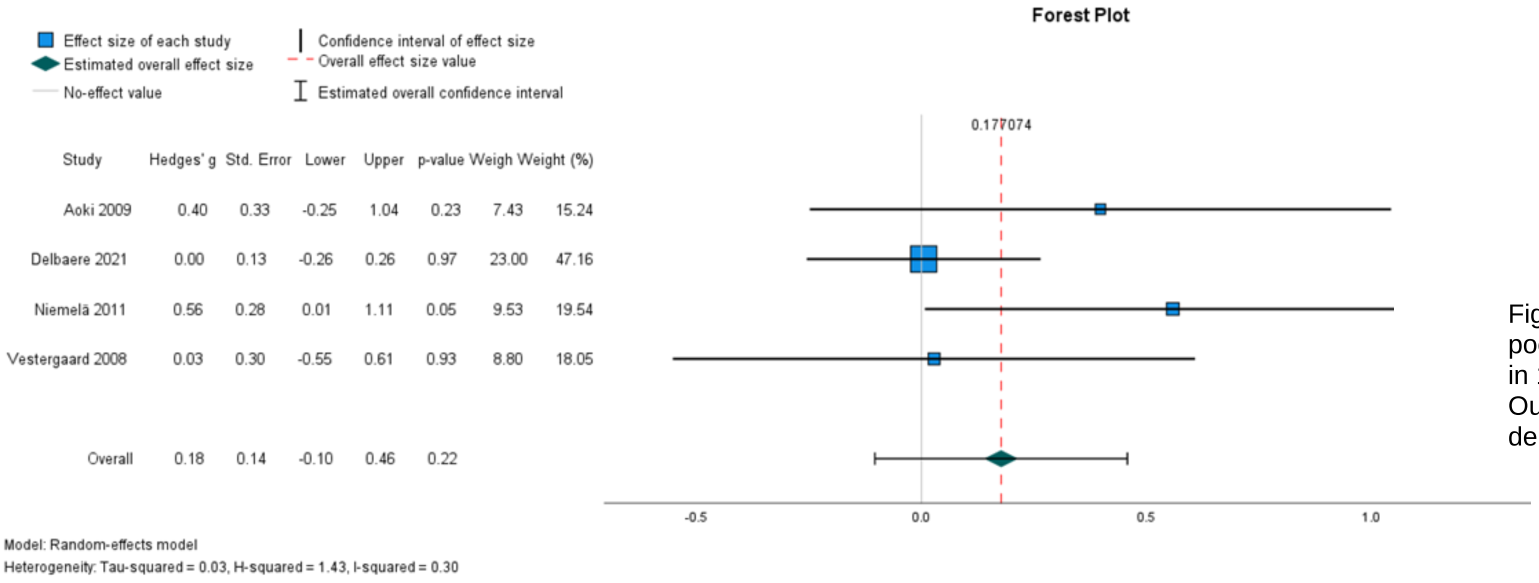

Figure 2-4. Forest plots depicting the pooled standardised mean difference in 10-metre maximal walking speed. Outcomes favouring intervention are depicted to the left.

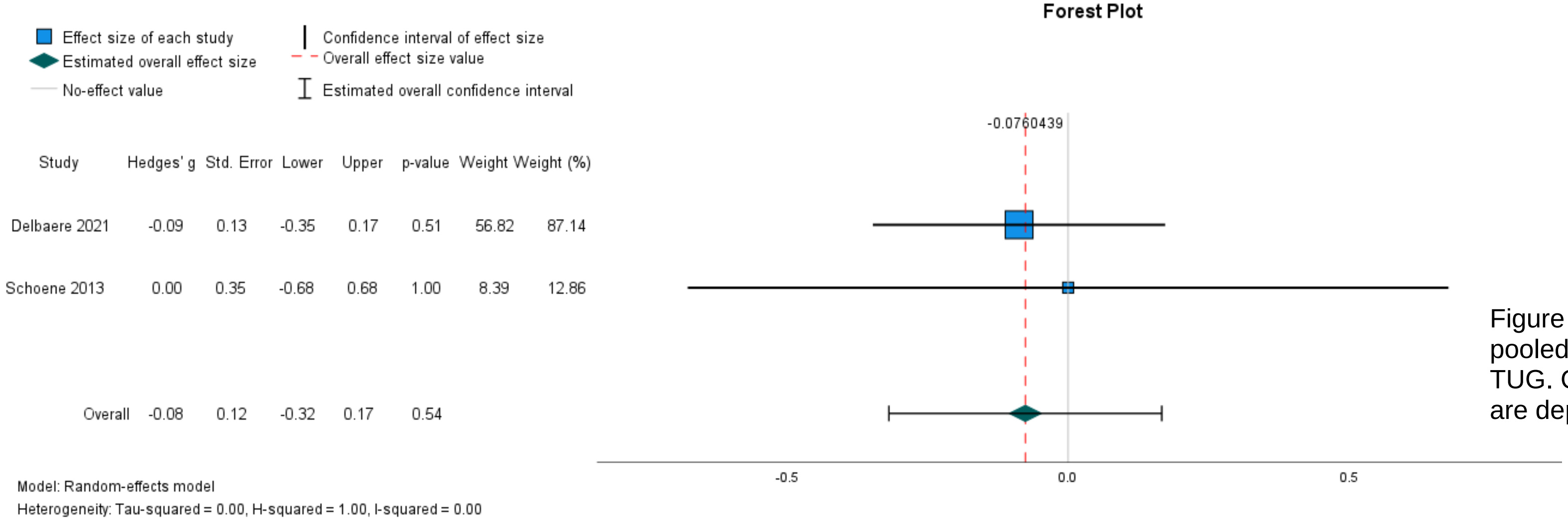

Figure 2-5. Forest plots depicting the pooled standardised mean difference in TUG. Outcomes favouring intervention are depicted to the right.

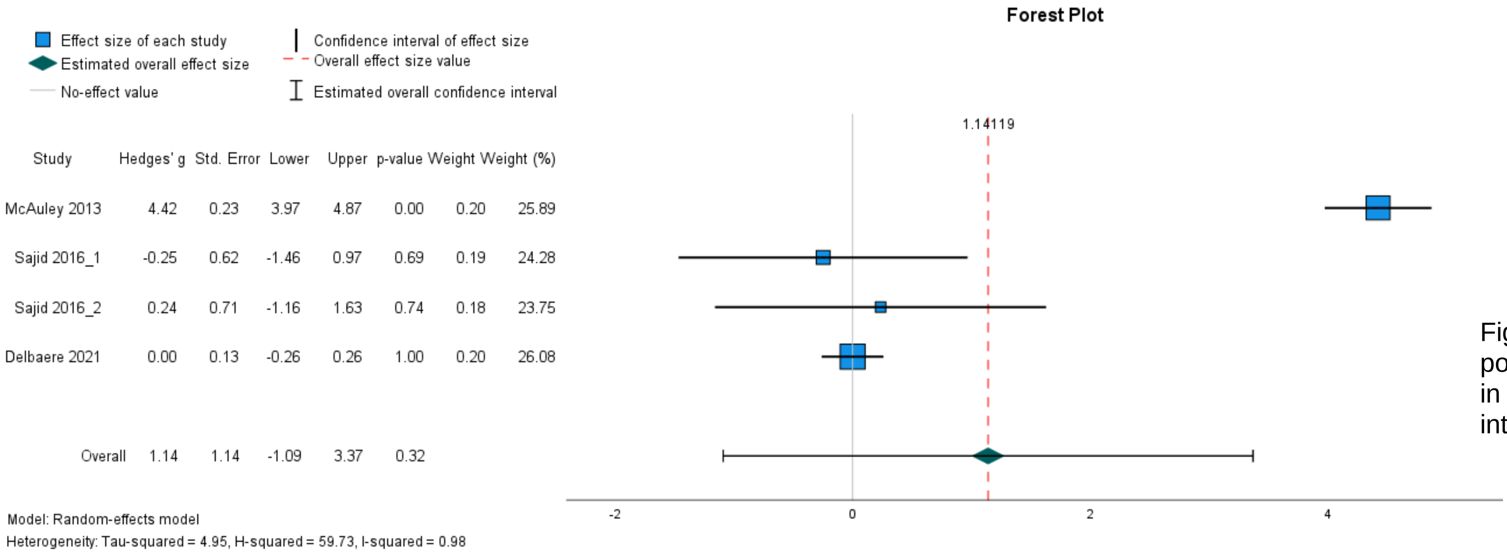

Figure 2-6. Forest plots depicting the pooled standardised mean difference in SPPB. Outcomes favouring intervention are depicted to the left.

Adherence

Adherence to interventions were between 30% and 96%. Most studies reported medium to high adherence via self-reported daily logs [48-51, 53, 54, 57]. Adherence rates decreased over time in two studies, from 40% at month-6 to 30% at month-24 [55], and from 93% to 60% over 6 months [48] respectively. Amongst all studies, six involved motivational calls which might affect the intervention adherence. Specifically, the study [48] which reported adherence had decreased by time, only had motivational calls in the first 2 months. One study [56] did not report adherence. Given the heterogeneity of methods and thresholds for defining adherence, and data availability, a meta-regression for determining the impact of adherence on effectiveness was not performed.

Adverse events

Six out of ten trials reported adverse event data, involving only 45 participants. In particular, five adverse events (i.e falls) related to the intervention, which led to minor injuries, were reported in three participants in the StandingTall programme [55]; four adverse events, associated with participants' pre-existing knee pain, were reported in the FlexToBa programme [48]; and few adverse events (i.e leg pain, joint pain, and breathlessness), which were not limiting the programme execution, were reported in the EXCITE programme [52]. No adverse event related to the interventions were reported in other interventions [51, 53, 56]. Overall, no serious adverse events relating to the interventions were reported in the included studies.

Methodological quality

All 10 of the included studies were assessed for risk of bias (Figure 2-7). One study was considered low risk of bias for all domains [55] and the rest nine studies had at least one domain judged to be moderate risk of bias [48-54, 56, 57]. Particularly, half of the studies reported that investigators were aware of allocation where the investigator-reported outcomes may involve some judgement, with regards to assessor blinding. Overall, nine studies were considered to be of moderate risk of bias with moderate quality and one was judged as low risk of bias with high quality.

Study	Randomisation process	Deviations from the intended interventions	Missing outcome data	Measurement of the outcome	Selection of the reported result	Overall
Adcock 2020	+	+	+	!	!	!
Aoki 2009	+	+	+	!	!	!
Baggetta 2018	+	+	!	!	+	!
Delbaere 2021	+	+	+	+	+	+
McAuley 2013	+	+	!	+	+	!
Niemelä 2011	!	+	+	+	!	!
Sajid 2016	+	+	+	+	!	!
Schoene 2013	+	+	+	+	!	!
Vestergaard 2008	!	+	+	!	!	!
Yates 2001	+	+	+	!	!	!

Figure 2-7. Risk of bias assessment for included studies where green=low risk of bias, yellow= moderate risk of bias, and red=high risk of bias

2.3.5 Discussion

This systematic review and meta-analysis aimed to explore the impact of unsupervised home-based exercises on lower extremity physical function in older adults and to investigate whether such a format is effective, and whether the effects and benefits of different home-based exercises vary across Western and Eastern cultures. However, no Mandarin articles met the inclusion criteria and were included in this review, and only one study that met our inclusion criteria was conducted in an East Asian country, Japan [57]. The common excluding reasons were interventions with supervisions or home visits, and active control groups. This indicates that very few randomised controlled trials of unsupervised, home-based, exercise interventions with usual care control arms for older adults have been evaluated, with none identified in Mandarin speaking countries. This small number of high-quality intervention trials is somewhat surprising and suggests more research into the unsupervised home-based exercises is needed to fully understand the benefit of this format of exercise in improving physical function in older adults, and for exploring cross-cultural differences in effect.

The meta-analysis of included studies indicated that entirely unsupervised home-based exercise interventions did not significantly improve lower extremity functions in older adults. It is noteworthy to consider that the increased effectiveness reported in this study suggests that supervision could be an important component of an exercise intervention for older adults. Specifically, Mahjur and Norasteh [38] reviewed the effectiveness of minimally to none supervised (i.e., supervision ratios lower than 33%) home-based exercises in people over 60 and found significant intervention effect in TUG and Berg balance scale. Furthermore, a meta-analysis showed that home-based exercises with supervision ratios less than 20% led to significant improvements in balance and muscle functions in healthy older adults [39]. A previous systematic review indicated that minimal-supervised (i.e., supervision ratios lower than 15%) home-based exercise programmes had positive effects on lower body strength and mobility in people over 60 [37].

The advantages of home-based exercise programmes are multicomponent for not only healthy older adults but also those with declining or impaired physical function. Importantly, home-based exercises tackle the exercise barriers from its execution convenience and low cost [35, 58]. However, many previous studies investigating the effectiveness of home-based exercises include some degree of direct supervision, compared to the present review that sought only to review studies with no supervision. Our screening excluded 41% and 24% of potential English and Mandarin due to interventions with supervision, revealing a lack of research on entirely unsupervised home-based exercises for older adults. While supervision of older adults is important, implementing such programmes over time would place an enormous demand on health and social care resources. Accordingly, the need to develop and evaluate more unsupervised solutions is necessary, as such solutions could help resource-low areas seeking to support older adults in the community help more people at scale. In short, more methodological robust trials with greater sample size exploring the effectiveness of unsupervised home-based exercises are needed [59].

It is important when making comparisons to recognise the differences between the studies and their limitations. Notably, only 8 studies, involving 839 participants, were used for statistical meta-analyses rendering the study and participant sample sizes small. These limited trials with small samples, ranging between 83-505 in each outcome measure, may misrepresent the results [60]. Also, high heterogeneity in two measures (i.e., knee extension strength and SPPB) suggested that the meta-analysis for these two measures may not be meaningful [61]. In expanding upon their limitations, the reviewed trials described short-term intervention periods [48, 49, 57], small sample sizes [48, 50-52, 56], and ceiling effects in healthy and high-functioning participants [51, 56], may potentially affected their outcomes. Furthermore, some control groups in these studies had received healthy ageing advice which might induce behaviour changes that could affect the outcomes and reduce the statistical power [52, 55]. These original study limitations led to weaker output in the current meta-analysis in compliance with the stated study limitations in a recent meta-analysis [38]. Nevertheless, the studies included in this systematic review were mostly of moderate risk of bias.

Indeed, methodological problems such as sample size, statistical power, lack of robustness in study designs, and inter-study heterogeneity may bias the results when conducting meta-analyses [62-64]. The number of included studies and samples in similar meta-analyses were relatively more than in the present study. For instance, these earlier meta-analyses incorporated 12 to 17 studies, involving a larger participant pool ranging from 1160 to 2570 participants [37-39, 65], whereas our analysis comprised 8 trials with 839 participants. While these studies supported supervised to minimally supervised home-based exercises for enhancing physical functions in older adults, the trials included in our study lasted 4 weeks to 24 months with participants engaging in exercise routines averagely three times per week for 10 to 40 minutes per session, which aligns closely with similar studies where intervention durations ranged from 4 weeks to 26 months, with sessions occurring averagely three times per week involving 10 to 60 minutes each. Both our study and these meta-analyses demonstrated an overall moderate risk of bias, while only one study deemed the included trials as mostly high quality [65].

A recent meta-analysis indicated that higher adherence to home-based interventions correlates with increased effectiveness and benefits in physical function [66]. Most included studies reported medium to high adherence, though the intervention period varied between 1 month and 24 months and the frequency and the length of the interventions were also different. However, according to McAuley et al. [48] and Delbaere et al. [55], it seems that the longer the intervention periods went by, the lower the adherence rates were. In line with the report of McAuley et al. [48], telephone call check ins might increase the intervention adherence as the report showed that the adherence rates decreased after the telephone check ins ceased. This finding is consistent with previous research which mentioned that telephone calls are a helpful element for home-setting programmes [67, 68]. The study suggests that providing encouragement, affirmation of progress, verbal rewards, and giving participants opportunity to discuss any concerns to the interventions via phone calls are valuable and supportive for older adults who typically have low exercise self-efficacy [67, 69] and can help general adherence to unsupervised home-based interventions.

Finally, only 5% of participants (45 out of 907 participants) reported adverse events during the interventions. Of all reported adverse events, only few were related to the interventions. These intervention-induced adverse events included falls, muscle soreness, joint pain, and shortness of breath occurred during the interventions. None of them were classified as severe (or serious) adverse events. This may confirm the previous research findings that unsupervised home-based exercise interventions are safe and feasible for older adults. Indeed, the safety of the leisure setting exercise for older adults is undoubtfully important to consider in light of the potential risks in performing exercises [70, 71]. The exercise types and intensities need to be considered when designing home-based exercise programmes.

To our knowledge this is the first systematic review and meta-analysis that integrated data from randomised control trials on the effectiveness of ‘unsupervised’ home-based exercise programmes on lower extremity functions in older adults. Additionally, most prior reviews were limited to the monolingual scope of searches, and this current study is the first systematic review that systematically searched not only English literature but also Mandarin literature, although no eligible Mandarin studies were identified. Nevertheless, while we included English and Mandarin language studies, it's possible that evidence from other languages might have been missed, affecting the comprehensiveness of the review. Furthermore, several study limitations should be noted. Firstly, the low number of eligible studies and overall small sample sizes weaken the study quality due to underpowered analyses. Secondly, the lack of consistent outcome measures in our included studies used to run the meta-analysis in a single outcome measure may mislead the findings and overlook the generalizability. Also, the findings in the current study need to be presented with caution since we were unable to get the necessary data from two eligible articles. The rather moderate to high heterogeneity among the included studies is another limitation of this meta-analysis and this could weaken the accuracy of the results. Moreover, it is impossible to analyse the results amongst healthy versus not healthy individuals, length of intervention, or exercise modality, due to the low number of included studies and participants. Many outcome measures in the identified studies had shortcomings in quality ratings considering their risk of bias, potentially reducing the robustness of the evidence. This highlights the need for improving the quality and minimizing bias within unsupervised exercise interventions in future research. Therefore,, these findings should be considered preliminary, and future research is required to verify whether or not unsupervised, home-based exercise is effective for improving the physical function of older adults.

2.3.6 *Conclusion*

This systematic review and meta-analysis demonstrated that no significant effects of unsupervised home-based exercises in lower extremity physical functions in older adults were found. That said, there is a paucity of high-quality research into entirely unsupervised home-based exercises, which precludes making any firm conclusions at this moment. Based on data from the included studies, potential positive effects were reported for lower extremity outcome measures from individual study results and further research is needed to evaluate whether and there are formats of home-based exercise that are acceptable engaging and impactful for older adults. Moreover, further research is needed in different cultural settings, as we were unable to identify any papers in Eastern cultures that met our inclusion criteria. Extending systematic reviews to broader cultural contexts may tackle the generalizability issue and bring us a new worldwide sight of the effectiveness of unsupervised home-based exercise programmes.

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None reported.

Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Systematic Reviews (PROSPERO) (registration number: CRD42023395942). Of the 10 studies included in this review, none had undergone pre-registration of their protocol, yet one published a protocol paper in a peer-reviewed journal, and four had a Clinical Trial database Registration. The analytic methods used in this research are available upon request from the first or corresponding authors.

2.3.7 Reference

1. United Nations, *World Population Ageing 2019 Highlights*, D.o.E.a.S. Affairs, Editor. 2019, United Nations.

2. Neves, T., et al., *Prevalence and factors associated with sarcopenia and dynapenia in elderly people.* Journal of Frailty, Sarcopenia and Falls, 2018. 3(4): p. 194.

3. Runge, M., et al., *Is muscle power output a key factor in the age-related decline in physical performance? A comparison of muscle cross section, chair-rising test and jumping power.* Clinical physiology and functional imaging, 2004. 24(6): p. 335-340.

4. Rosenberg, I.H., *Sarcopenia: origins and clinical relevance.* The Journal of nutrition, 1997. 127(5): p. 990S-991S.

5. Brown, C.J. and K.L. Flood, *Mobility limitation in the older patient: a clinical review.* Jama, 2013. 310(11): p. 1168-1177.

6. Rantakokko, M., M. Mänty, and T. Rantanen, *Mobility decline in old age.* Exercise and sport sciences reviews, 2013. 41(1): p. 19-25.

7. Horlings, C.G., et al., *A weak balance: the contribution of muscle weakness to postural instability and falls.* Nature Clinical Practice Neurology, 2008. 4(9): p. 504-515.

8. Maresova, P., et al., *Consequences of chronic diseases and other limitations associated with old age–a scoping review.* BMC public health, 2019. 19: p. 1-17.

9. Saxon, S.V., et al., *Physical change and aging: A guide for helping professions.* 2021: Springer Publishing Company.

10. Buttaro, T.M., *The Physiology and Psychology of Aging.* Case Studies in Geriatric Primary Care & Multimorbidity Management, 2019.

11. Cannataro, R., et al., *Sarcopenia: etiology, nutritional approaches, and miRNAs.* International Journal of Molecular Sciences, 2021. 22(18): p. 9724.

12. Unies, N., *World population prospects: the 2002 revision.* 2007: UN.

13. Harris, A. and A. Sharma, *Estimating the future health and aged care expenditure in Australia with changes in morbidity.* PloS one, 2018. 13(8): p. e0201697.

14. Rechel, B., et al., *How can health systems respond to population ageing?* 2009.

15. Harris, T., et al., *Longitudinal study of physical ability in the oldest-old.* American Journal of Public Health, 1989. 79(6): p. 698-702.

16. Roos, N.P. and B. Havens, *Predictors of successful aging: a twelve-year study of Manitoba elderly.* American journal of public health, 1991. 81(1): p. 63-68.

17. de Labra, C., et al., *Effects of physical exercise interventions in frail older adults: a systematic review of randomized controlled trials.* BMC geriatrics, 2015. 15: p. 1-16.

18. Chou, C.-H., C.-L. Hwang, and Y.-T. Wu, *Effect of exercise on physical function, daily living activities, and quality of life in the frail older adults: a meta-analysis.* Archives of physical medicine and rehabilitation, 2012. 93(2): p. 237-244.

19. Hamed, A., et al., *Follow-up efficacy of physical exercise interventions on fall incidence and fall risk in healthy older adults: a systematic review and meta-analysis.* Sports medicine-open, 2018. 4(1): p. 1-19.

20. Valenzuela, T., *Efficacy of progressive resistance training interventions in older adults in nursing homes: a systematic review.* Journal of the American Medical Directors Association, 2012. 13(5): p. 418-428.

21. Thomas, S., S. Mackintosh, and J. Halbert, *Does the 'Otago exercise programme'reduce mortality and falls in older adults?: a systematic review and meta-analysis.* Age and ageing, 2010. 39(6): p. 681-687.

22. Shubert, T.E., et al., *Disseminating the Otago Exercise Program in the United States: Perceived and actual physical performance improvements from participants.* Journal of Applied Gerontology, 2018. 37(1): p. 79-98.

23. Benavent-Caballer, V., et al., *The effectiveness of a video-supported group-based Otago exercise programme on physical performance in community-dwelling older adults: a preliminary study.* Physiotherapy, 2016. 102(3): p. 280-286.

24. Baker, M.K., E. Atlantis, and M.A. Fiatarone Singh, *Multi-modal exercise programs for older adults.* Age and ageing, 2007. 36(4): p. 375-381.

25. Cadore, E.L., et al., *Effects of different exercise interventions on risk of falls, gait ability, and balance in physically frail older adults: a systematic review.* Rejuvenation research, 2013. 16(2): p. 105-114.

26. Li, Y., et al., *Effects of multicomponent exercise on the muscle strength, muscle endurance and balance of frail older adults: A meta-analysis of randomised controlled trials.* Journal of clinical nursing, 2022.

27. Rubenstein, A.B., et al., *Skeletal muscle transcriptome response to a bout of endurance exercise in physically active and sedentary older adults.* American Journal of Physiology-Endocrinology and Metabolism, 2022. 322(3): p. E260-E277.

28. Buchner, D., et al., *A comparison of the effects of three types of endurance training on balance and other fall risk factors in older adults.* Aging Clinical and Experimental Research, 1997. 9: p. 112-119.

29. Martín-Moya, R., et al., *Psychological and environmental factors for older adults to exercise: A systematic review.* Revista de psicología del deporte, 2020. 29(2): p. 93-104.

30. Burton, E., et al., *Motivators and barriers for older people participating in resistance training: a systematic review.* Journal of aging and physical activity, 2017. 25(2): p. 311-324.

31. Burton, E., et al., *Identifying motivators and barriers to older community-dwelling people participating in resistance training: a cross-sectional study.* Journal of Sports Sciences, 2017. 35(15): p. 1523-1532.

32. Franco, M.R., et al., *Older people's perspectives on participation in physical activity: a systematic review and thematic synthesis of qualitative literature.* British journal of sports medicine, 2015. 49(19): p. 1268-1276.

33. Lees, F.D., et al., *Barriers to exercise behavior among older adults: a focus-group study.* Journal of aging and physical activity, 2005. 13(1): p. 23-33.

34. Kanemaru, A., et al., *The efficacy of home-based muscle training for the elderly osteoporotic women: the effects of daily muscle training on quality of life (QoL).* Archives of gerontology and geriatrics, 2010. 51(2): p. 169-172.

35. Clemson, L., et al., *Integration of balance and strength training into daily life activity to reduce rate of falls in older people (the LiFE study): randomised parallel trial.* Bmj, 2012. 345.

36. Glenn, J.M., M. Gray, and A. Binns, *The effects of loaded and unloaded high-velocity resistance training on functional fitness among community-dwelling older adults.* Age and Ageing, 2015. 44(6): p. 926-931.

37. Kis, O., et al., *Minimally supervised home-based resistance training and muscle function in older adults: A meta-analysis.* Archives of gerontology and geriatrics, 2019. 84: p. 103909.

38. Mahjur, M. and A.A. Norasteh, *The effect of unsupervised home-based exercise training on physical functioning outcomes in older adults: A systematic review and meta-analysis of randomized controlled trials.* Biological research for nursing, 2021. 23(3): p. 504-512.

39. Chaabene, H., et al., *Home-based exercise programmes improve physical fitness of healthy older adults: A PRISMA-compliant systematic review and meta-analysis with relevance for COVID-19.* Ageing research reviews, 2021. 67: p. 101265.

40. Lacroix, A., et al., *Effects of a supervised versus an unsupervised combined balance and strength training program on balance and muscle power in healthy older adults: a randomized controlled trial.* Gerontology, 2016. 62(3): p. 275-288.

41. Orange, S.T., et al., *Short-term training and detraining effects of supervised vs. unsupervised resistance exercise in aging adults.* The Journal of Strength & Conditioning Research, 2019. 33(10): p. 2733-2742.

42. Perkin, O.J., P.M. McGuigan, and K.A. Stokes, *Exercise snacking to improve muscle function in healthy older adults: a pilot study.* Journal of aging research, 2019. 2019.

43. Jang, H., et al., *Cultural influences on exercise participation and fall prevention: a systematic review and narrative synthesis.* Disability and rehabilitation, 2016. 38(8): p. 724-732.

44. Sterne, J.A., et al., *RoB 2: a revised tool for assessing risk of bias in randomised trials.* bmj, 2019. 366.

45. Borenstein, M., et al., *Introduction to meta-analysis.* 2021: John Wiley & Sons.

46. Veroniki, A.A., et al., *Methods to estimate the between-study variance and its uncertainty in meta-analysis.* Research synthesis methods, 2016. 7(1): p. 55-79.

47. Higgins, J.P., et al., *Measuring inconsistency in meta-analyses.* Bmj, 2003. 327(7414): p. 557-560.

48. McAuley, E., et al., *Effects of a DVD-delivered exercise intervention on physical function in older adults.* Journals of Gerontology Series A: Biomedical Sciences and Medical Sciences, 2013. 68(9): p. 1076-1082.

49. Yates, S.M. and T.A. *Dunnagan, Evaluating the effectiveness of a home-based fall risk reduction program for rural community-dwelling older adults.* The Journals of Gerontology Series A: Biological Sciences and Medical Sciences, 2001. 56(4): p. M226-M230.

50. Sajid, S., et al., *Novel physical activity interventions for older patients with prostate cancer on hormone therapy: a pilot randomized study.* Journal of geriatric oncology, 2016. 7(2): p. 71-80.

51. Adcock, M., et al., *Effects of an in-home multicomponent exergame training on physical functions, cognition, and brain volume of older adults: A randomized controlled trial.* Frontiers in medicine, 2020. 6: p. 321.

52. Baggetta, R., et al., *Effect of a home based, low intensity, physical exercise program in older adults dialysis patients: a secondary analysis of the EXCITE trial.* BMC geriatrics, 2018. 18: p. 1-7.

53. Vestergaard, S., C. Kronborg, and L. Puggaard, *Home-based video exercise intervention for community-dwelling frail older women: a randomized controlled trial.* Aging clinical and experimental research, 2008. 20: p. 479-486.

54. Niemelä, K., et al., *Benefits of home-based rocking-chair exercise for physical performance in community-dwelling elderly women: a randomized controlled trial—a pilot study.* Aging clinical and experimental research, 2011. 23: p. 279-287.

55. Delbaere, K., et al., *E-health StandingTall balance exercise for fall prevention in older people: results of a two year randomised controlled trial.* bmj, 2021. 373.

56. Schoene, D., et al., *A randomized controlled pilot study of home-based step training in older people using videogame technology.* PloS one, 2013. 8(3): p. e57734.

57. Aoki, O., et al., *Home stretching exercise is effective for improving knee range of motion and gait in patients with knee osteoarthritis.* Journal of Physical Therapy Science, 2009. 21(2): p. 113-119.

58. Simek, E.M., et al., *What are the characteristics of home exercise programs that older adults prefer?: A cross-sectional study.* American Journal of Physical Medicine & Rehabilitation, 2015. 94(7): p. 508-521.

59. Egger, M., G.D. Smith, and A.N. Phillips, *Meta-analysis: principles and procedures.* Bmj, 1997. 315(7121): p. 1533-1537.

60. Egger, M., et al., *Bias in meta-analysis detected by a simple, graphical test.* Bmj, 1997. 315(7109): p. 629-634.

61. Deeks, J.J., et al., *Analysing data and undertaking meta-analyses.* Cochrane handbook for systematic reviews of interventions, 2019: p. 241-284.

62. EAGLY, W.W.A.H., *Advantages of certainty and uncertainty.* The handbook of research synthesis and meta-analysis, 2009: p. 455.

63. Bailey, K.R., *Inter-study differences: How should they influence the interpretation and analysis of results?* Statistics in Medicine, 1987. 6(3): p. 351-358.

64. Schulz, K.F., et al., *Empirical evidence of bias: dimensions of methodological quality associated with estimates of treatment effects in controlled trials.* Jama, 1995. 273(5): p. 408-412.

65. Hill, K.D., et al., *Individualized home-based exercise programs for older people to reduce falls and improve physical performance: A systematic review and meta-analysis.* Maturitas, 2015. 82(1): p. 72-84.

66. Kraemer, M.B., et al., *Home-based, supervised, and mixed exercise intervention on functional capacity and quality of life of colorectal cancer patients: A meta-analysis.* Scientific reports, 2022. 12(1): p. 2471.

67. Chao, D., C.G. Foy, and D. Farmer, *Exercise adherence among older adults: challenges and strategies.* Controlled clinical trials, 2000. 21(5): p. S212-S217.

68. Simek, E.M., L. McPhate, and T.P. Haines, *Adherence to and efficacy of home exercise programs to prevent falls: a systematic review and meta-analysis of the impact of exercise program characteristics.* Preventive medicine, 2012. 55(4): p. 262-275.

69. Geraedts, H., et al., *Effects of remote feedback in home-based physical activity interventions for older adults: a systematic review.* Patient education and counseling, 2013. 91(1): p. 14-24.

70. Zaleski, A.L., et al., *Coming of age: considerations in the prescription of exercise for older adults.* Methodist DeBakey cardiovascular journal, 2016. 12(2): p. 98.

71. Lee, P.G., E.A. Jackson, and C.R. Richardson, *Exercise prescriptions in older adults.* American family physician, 2017. 95(7): p. 425-432.

2.3.8 Supplementary file

Supplementary A. PRISMA checklist

Section and Topic	Item #	Checklist item	Location where item is reported
TITLE			
Title	1	Identify the report as a systematic review.	Title page
ABSTRACT			
Abstract	2	See the PRISMA 2020 for Abstracts checklist.	1
INTRODUCTION			
Rationale	3	Describe the rationale for the review in the context of existing knowledge.	2-3
Objectives	4	Provide an explicit statement of the objective(s) or question(s) the review addresses.	3
METHODS			
Eligibility criteria	5	Specify the inclusion and exclusion criteria for the review and how studies were grouped for the syntheses.	4
Information sources	6	Specify all databases, registers, websites, organisations, reference lists and other sources searched or consulted to identify studies. Specify the date when each source was last searched or consulted.	4 and Supplementary file B

Section and Topic	Item #	Checklist item	Location where item is reported
Search strategy	7	Present the full search strategies for all databases, registers and websites, including any filters and limits used.	4 and Supplementary file B
Selection process	8	Specify the methods used to decide whether a study met the inclusion criteria of the review, including how many reviewers screened each record and each report retrieved, whether they worked independently, and if applicable, details of automation tools used in the process.	5
Data collection process	9	Specify the methods used to collect data from reports, including how many reviewers collected data from each report, whether they worked independently, any processes for obtaining or confirming data from study investigators, and if applicable, details of automation tools used in the process.	5
Data items	10a	List and define all outcomes for which data were sought. Specify whether all results that were compatible with each outcome domain in each study were sought (e.g. for all measures, time points, analyses), and if not, the methods used to decide which results to collect.	3-5
	10b	List and define all other variables for which data were sought (e.g. participant and intervention characteristics, funding sources). Describe any assumptions made about any missing or unclear information.	3-5
Study risk of bias assessment	11	Specify the methods used to assess risk of bias in the included studies, including details of the tool(s) used, how many reviewers assessed each study and whether they worked independently, and if applicable, details of automation tools used in the process.	5
Effect measures	12	Specify for each outcome the effect measure(s) (e.g. risk ratio, mean difference) used in the synthesis or presentation of results.	5
Synthesis methods	13a	Describe the processes used to decide which studies were eligible for each synthesis (e.g. tabulating the study intervention characteristics and comparing against the planned groups for each synthesis (item #5)).	5

Section and Topic	Item #	Checklist item	Location where item is reported
	13b	Describe any methods required to prepare the data for presentation or synthesis, such as handling of missing summary statistics, or data conversions.	5
	13c	Describe any methods used to tabulate or visually display results of individual studies and syntheses.	5
	13d	Describe any methods used to synthesize results and provide a rationale for the choice(s). If meta-analysis was performed, describe the model(s), method(s) to identify the presence and extent of statistical heterogeneity, and software package(s) used.	5
	13e	Describe any methods used to explore possible causes of heterogeneity among study results (e.g. subgroup analysis, meta-regression).	5
	13f	Describe any sensitivity analyses conducted to assess robustness of the synthesized results.	-
Reporting bias assessment	14	Describe any methods used to assess risk of bias due to missing results in a synthesis (arising from reporting biases).	5
Certainty assessment	15	Describe any methods used to assess certainty (or confidence) in the body of evidence for an outcome.	5
RESULTS			
Study selection	16a	Describe the results of the search and selection process, from the number of records identified in the search to the number of studies included in the review, ideally using a flow diagram.	6
	16b	Cite studies that might appear to meet the inclusion criteria, but which were excluded, and explain why they were excluded.	6 and Figure 1

Section and Topic	Item #	Checklist item	Location where item is reported
Study characteristics	17	Cite each included study and present its characteristics.	6 and Supplementary file C
Risk of bias in studies	18	Present assessments of risk of bias for each included study.	9
Results of individual studies	19	For all outcomes, present, for each study: (a) summary statistics for each group (where appropriate) and (b) an effect estimate and its precision (e.g. confidence/credible interval), ideally using structured tables or plots.	6-9
Results of syntheses	20a	For each synthesis, briefly summarise the characteristics and risk of bias among contributing studies.	7-9
	20b	Present results of all statistical syntheses conducted. If meta-analysis was done, present for each the summary estimate and its precision (e.g. confidence/credible interval) and measures of statistical heterogeneity. If comparing groups, describe the direction of the effect.	7-8 and Figure 2-6
	20c	Present results of all investigations of possible causes of heterogeneity among study results.	7-8 and Figure 2-6
	20d	Present results of all sensitivity analyses conducted to assess the robustness of the synthesized results.	-
Reporting biases	21	Present assessments of risk of bias due to missing results (arising from reporting biases) for each synthesis assessed.	9
Certainty of evidence	22	Present assessments of certainty (or confidence) in the body of evidence for each outcome assessed.	9
DISCUSSION			
Discussion	23a	Provide a general interpretation of the results in the context of other evidence.	9-12
	23b	Discuss any limitations of the evidence included in the review.	12

Section and Topic	Item #	Checklist item	Location where item is reported
	23c	Discuss any limitations of the review processes used.	12
	23d	Discuss implications of the results for practice, policy, and future research.	13
OTHER INFORMATION			
Registration and protocol	24a	Provide registration information for the review, including register name and registration number, or state that the review was not registered.	3-4
	24b	Indicate where the review protocol can be accessed, or state that a protocol was not prepared.	3-4
	24c	Describe and explain any amendments to information provided at registration or in the protocol.	-
Support	25	Describe sources of financial or non-financial support for the review, and the role of the funders or sponsors in the review.	13
Competing interests	26	Declare any competing interests of review authors.	13
Availability of data, code and other materials	27	Report which of the following are publicly available and where they can be found: template data collection forms; data extracted from included studies; data used for all analyses; analytic code; any other materials used in the review.	-

Supplementary B. Searching strategies and terms

English search strategy and terms

The search was built around five groups of key words: Population (e.g. ‘’older’’, ‘’retired’’, “over 65*”, ‘’adults’’, ‘’older adults’’); Intervention (e.g. ‘’physical activity’’, ‘’strength training’’, ‘’balance training’’, ‘’yoga’’, ‘’otago’’, ‘’pilates’’, ‘’ tai chi’’, ‘’personal training’’); Context (e.g. ‘’home based’’, ‘’residen*’’, ‘’habitation’’, ‘’residence’’); Study design (e.g. ‘’RCT’’, ‘’rct’’, ‘’randomi?ed controlled trial’’); and Outcome (e.g. ‘’ physical function’’, ‘’strength’’, ‘’balance’’, ‘’lower extremity function’’, ‘’mobility’’).

-Example of search terms used in Pubmed publication database

((elder* OR elderly OR older OR retire* OR retired OR "over 65*" OR "over sixty five*" OR senior* OR senior OR pensioner* OR pensioners OR age* OR aged OR layer li*" OR adult* OR adults OR later life)) AND ("physical* activ*" OR physical activity OR "exercise participation" OR strength and balance training OR strength training OR balance training OR resistan* OR resistance OR exercise OR exercise* OR yoga OR otago OR keep fit OR physiotherap* OR cal?isthen* OR isometric* OR isometric OR isotonic OR work?out OR rehab* OR rehabilitation OR circuit training OR plates OR tai chi*" OR tai chi OR tai chi chung OR qigong OR weightlift* OR weightlifting OR fitness OR function* OR function OR personal training OR PT OR aerobic* OR aerobic OR sport OR movement OR step OR climbing)) AND (home based OR home-based OR home OR residen* OR abode OR habituation OR residence)) AND (rct OR RCT OR "randomi?ed controlled trial*" OR "randomi?ed controlled trial")) AND (physical function*" OR physical function OR strength OR balance OR lower extremity function*" OR lower leg function*" OR fall* OR falling OR falls OR mobilit* OR mobility OR power OR frail* OR frail OR frailty OR ‘’daily active*" OR daily activity OR acceptability OR preference OR adherence OR maintenance OR belie* OR attitud* OR believe OR attitude))

Mandarin search strategy and terms

The search for the Mandarin literature was built with five groups of key words: Population (e.g. ‘’老人’’, ‘’退休’’, “65 歲”, ‘’成人’’, ‘’銀髮族’’, ‘’老齡人口’’); Intervention (e.g. ‘’身體活動’’, ‘’重量訓練’’, ‘’平衡訓練’’, ‘’瑜珈’’, ‘’奧塔格運動’’, ‘’皮拉提斯’’ , ‘’太極拳’’, ‘’自主訓練’’); Context (e.g. ‘’居家’’, ‘’自主’’, ‘’住所’’, ‘’住宅’’); Study design (e.g. ‘’RCT’’, ‘’隨機對照試驗’’, ‘’隨機分配’’); and Outcome (e.g. ‘’ 身體功能’’, ‘’肌力’’, ‘’平衡’’, ‘’下肢功能’’, ‘’活動度’’).

See the below table for the searching terms in Mandarin:

Population		**Intervention**		**Context**		**Study Design**		**Outcome**	
Older Adults	老人	Exercise	運動	Home based	居家	RCT		Strength	力量/肌力
Elderly	銀髮族	Strength training	重量訓練/力量訓練/體能訓練	Home	家庭	Randomised Controlled Trial	隨機對照試驗/隨機對照研究/隨機分配/	Balance	平衡

							隨機分派/隨機控制		
Elders	老年人/老年群體	Balance training	平衡/平衡訓練/平衡運動	At home	在家			Physical function	身體功能/身体机能/躯体功能
Senior citizen	高齡族群/高齡人群/高齡群体/长者	Resistance	阻力	Personal	自主			Mobility	活動度/柔韌性/灵活度
Adults	成人/成年人	Training	訓練/鍛鍊	Residence	宅 /住宅			Lower leg function	下肢功能
Over 65	65 歲以上	Fitness	體適能/體能	Abode	居住/舍			Power	爆發力

65+		Function	功能/功能性	Habitation	住所			Activities of daily life	身體活動/日常身體活動/日常锻炼/日常活动
Pensioners	養老/退休人士/退休人员/养老金领取者	Tai Chi	太極/太極拳						
Ageing	銀髮族/老龄人口	Yoga	瑜珈/瑜伽					Acceptability	接受度/接受性
Later life	晚年	Otago	奥塔格運動					Preference	偏好/偏愛

Retired	退休	Activity	活動					Adherence	依從姓/運動遵從度/堅持度
		Physical activity	身體活動					Maintenance	持續性
		Personal training	私人訓練/一對一訓練/自主訓練/自主運動訓練						
		Keep-fit	維持體適能/保持健康/保持身材						

		Aerobics	有 氧 / 有氧運動						
		Circuit training	循環式訓練 / 循 环训练						
		Sport	運 動 / 體育						
		movement	動作						
		Physiotherapy	復 健 / 治療/理疗						
		Callisthenics	體 操 / 健美 操 / 廣						

			場舞/有氧舞蹈						
		Isometrics	等長訓練/等長收縮訓練/静力训练/静力性训练						
		Isotonic	等張訓練						
		Work out	锻炼						
		rehabilitation	修復/復健/康复						

		step	階 梯 / 台阶						
		climbing	登階						
		pilates	皮拉提斯/普拉提						
		qigong	氣功						
		Weightlifting	举重						

2.4 Summary

This chapter presented a systematic review and meta-analysis on the effectiveness of entirely unsupervised home-based exercise programmes amongst older adults aged 65 years and above. The meta-analysis of 8 studies, using random-effects analysis, showed no significant differences between unsupervised home-based exercise programmes and usual care control groups in all physical function tests evaluated (i.e., 5STS, knee extension strength, 10m walking speed, TUG, and SPPB). This may be caused by inadequate studies and small sample size for each included study. Furthermore, we originally planned to discover whether the effects and benefits of different unsupervised home-based exercises vary across Western and Eastern cultures, and therefore searched and screened both English and Mandarin literatures. Surprisingly, there were no eligible Mandarin articles. Consequently, there is a lack of evidence to draw conclusions on my original research question. Including only English-language papers also limited the study results from non-English publications and could leave the cultural and social influence out of consideration on the findings.

Given the potential for home-based exercise to overcome the societal burden of age-associated muscle decline at scale, it remains a worthy scientific cause to expand on the paucity of existing evidence and seek to develop an acceptable and effective programme that overcomes participatory barriers. The ten studies reviewed provide little insight on the typical format that is more or less likely to be well adhered to or beneficial. It is noteworthy that there were very few adverse events suggesting that unsupervised formats are potentially safe for older adults. Further research is needed to understand the effectiveness of completely unsupervised home-based exercise programmes comprehensively.

Indeed, the diverse frequency and duration of programmes evaluated in the review may not align with the intended functional outcomes. Similar challenges were also identified by Giné-Garriga et al. (2014) who encountered difficulties in concluding the effectiveness of various exercise modalities. Interventions lacking specificity to the functional outcomes may also affect the findings. Studies have identified that short bout strength-based ‘exercise snacks’ with little to no supervision offer an accessible and alternative option to traditional resistance training in older adults (Perkin et al., 2019, Huang and Yen, 2023). These exercise snacking interventions, in particular, may warrant closer examination in light of the findings of this review as they offer more flexible and accessible approaches that could better suit the needs and preferences of older adults. Therefore, exercise snacking may be a valuable area for further investigation due to its flexibility and accessibility for older adults.

To link the existing literature and make up the research gap, the following chapters aimed to explore unsupervised home-based exercises in different perspectives (i.e., from preliminary understanding on participants’ acceptability, interventions’ feasibility, to its effectiveness on overall physical fitness function in older adults), specifically focusing on snacking exercises, and discuss the findings in different cultural contexts. The next chapter therefore sought to address the following research question.

Research question 2: What is the acceptability of exercise snacking and Tai-chi in British and Taiwanese older adults?

3 Chapter IV – Qualitative study

The Acceptability of Home-Based Exercise Snacking and Tai-chi amongst high and low function UK and Taiwanese Older Adults

3.1 Context

With the results of the systematic review and meta-analysis in Chapter 2, it showed that unsupervised home-based exercises have potential benefits on physical functions in older adults. Nevertheless, understanding the acceptability and ethicality of the home-based exercises was indispensable for applying this exercise regime to older adults' everyday lives in practice.

Home-based exercise snacking has been identified as an accessible and alternative to traditional resistance training in older adults with the potential to improve leg strength (Perkin et al., 2019). Alternatively, Tai-chi, a traditional Chinese martial art originating from China in 18th century, (performed with whole-body coordination, continuous rhythmic movements, weight shifting, and single leg balancing (Hackney and Wolf, 2014)) could improve balance, mobility, and strength in older adults (Yang et al., 2022). To a similar extent as home-based exercise snacking, Tai-chi requires no equipment and little space with movements performed slowly and gently. Due to its relatively low intensity, Tai-chi is also considered safe and appropriate for older adults to perform in the home settings without supervision (Sungkarat et al., 2017). However, none has explored Tai-chi in a short-bout "snacking" format. Therefore, we created a 'snacking' format of Tai-chi regime based on traditional Cheng Style Tai-Chi movements aiming to investigate what the acceptability of Tai-chi snacking in older adults, especially older adults in the UK where Tai-chi is not as popular as in Asia.

Acceptability, in the context of health behaviour interventions, can be defined as the extent to which potential users like and are willing to do the intervention (Diepeveen et al., 2013, Perski and Short, 2021). Considering acceptability is crucial in the design, evaluation, and implementation of exercise interventions as it will likely predict how well a programme is taken-up, engaged with, and ultimately be beneficial. However, it's important to note that acceptability is a complex, multidimensional concept. As previous literature had provided limited information on the definition of acceptability and no research suggested the way to measure it, Sekhon et al. (2017) developed a comprehensive theoretical framework for assessing the acceptability of healthcare interventions. The theoretical framework of acceptability, as it has been called, offers a systematic way to consider both anticipated (prospective) and experienced (retrospective) acceptability which can help researchers and practitioners better understand how interventions are perceived and received. This framework consists of seven components including affective attitude (individuals' feelings toward the intervention), burden (perceived effort and difficulty when doing the intervention), perceived effectiveness (individuals' belief in the intervention's potential benefits), ethicality (the appropriability and acceptability of performing the intervention), intervention coherence (the clarity and comprehensibility of the intervention), opportunity costs (what individuals need to give up or sacrifice to engage with the intervention), and self-efficacy (individuals' belief in their ability to perform the intervention effectively). High acceptability across all components is more likely to result in better engagement and outcomes.

Given that exercise snacking and Tai-chi snacking are relatively new exercise interventions for older adults, understanding their acceptability is crucial for enhancing the development and implementation of these intervention programmes. To explore this research question effectively, a qualitative study was deemed the most suitable approach. Conducting semi-structured interviews based on the seven domains of the theoretical framework of acceptability created by Sekhon et al. (2017), participants could provide structured feedback on these new exercise intervention formats, avoiding open-ended questions.

Altogether, this chapter explored the acceptability of a short-trial exercise snacking and Tai-chi snacking in older adults, using the theoretical framework of acceptability (Sekhon et al., 2017). In addition, we discussed whether the experience differs from older adults with varying levels of lower extremity functions and whether the acceptability varies across UK and Taiwanese older adults. It would provide further information on suggesting appropriate exercise training methods to older adults from different countries since exercise participation is affected by cultural values.

3.2 Statement of authorship

This declaration concerns the article entitled:	
The Acceptability of Home-Based Exercise Snacking and Tai-chi amongst high and low function UK and Taiwanese Older Adults	
Publication status (tick one)	
Draft manuscript ☐ **Submitted** ☐ **In review** ☐ **Accepted** ☐ **Published** ✔	
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Copyright status (tick the appropriate statement)	
The material has been published with a CC-BY license ✔	The publisher has granted permission to replicate the material included here ☐
Candidate's contribution to the paper (provide details, and also indicate as a percentage)	The candidate contributed to / considerably contributed to / predominantly executed the… Formulation of ideas: 80% Design of methodology: 80% Experimental work: 95% Presentation of data in journal format: 90%
Statement from Candidate	This paper reports on original research I conducted during the period of my Higher Degree by Research candidature.
Signed (typed signature)	**Date**

3.3 Paper 2: The Acceptability of Home-Based Exercise Snacking and Tai-chi amongst high and low function UK and Taiwanese Older Adults

3.3.1 *Abstract*

Exercise ‘snacking’ and Tai-chi ‘snacking’ protocols are designed to overcome typical barriers to older adults’ participation in muscle strength and balance exercise, using short bouts of home-based exercise. This study aimed to investigate the acceptability of homebased exercise- and Tai-chi snacking in British and Taiwanese older adults of high and low physical function. Thirty-three British and Thirty Taiwanese older adults took part in semi-structured interviews, after trying one-week of exercise- and Tai-chi snacking. The interview schedule and deductive framework analysis was based on the seven components of the Theoretical Framework of Acceptability (TFA). Differences between the Taiwanese and UK participants and those considered high versus low physical function were also analysed. Both snacking regimes were found to be convenient and easy to implement. Participants reported that no activity had to be given up, and considered the programmes would be beneficial to their physical and mental health. Interestingly, more UK-based participants preferred the elegant and relaxing movements of Tai-chi snacking, yet participants with low physical function experienced difficulties when mastering Tai-chi movements. A few high physical function participants perceived exercise snacking to be tedious. Overall, the snacking exercise was found to be acceptable and useful. Personal affective attitude and different cultural backgrounds may affect exercise participation. Nevertheless, it is important to consider individuals’ physical function when designing exercise regimens. The findings indicate that making Tai-chi snacking easier to master initially, building in progression and adding some upper body movements in the exercise snacking may further enhance acceptability.

Keywords: exercise snacking, Tai-chi, acceptability, physical function, older adults, cultural differences

3.3.2 Introduction

Regular strength and balance exercises can prevent a loss of physical function, maintain activities of daily living, and decrease disability or fall risk in older adults (Bauman et al., 2016, Chou et al., 2012, de Labra et al., 2015, Hamed et al., 2018). To recognize these benefits, the World Health Organization along with numerous national governing bodies recommend that older adults should engage in exercises to train strength twice per week and balance three times per week, typically advocating structured exercise sessions as the best solution (ACSM, 2018, UK Government, 2019, WHO, 2020). However, recent surveys suggest that many older adults do not meet these guidelines and research has shown that diversifying the types of structured exercise offered may benefit older adults' physical and mental health as well as quality of life (Chen et al., 2021). For instance, there is growing evidence to support the health benefits of regular Tai-chi practice, including improved physical, cognitive, and psychological function (Chen et al., 2021). Packaging strength exercise and Tai-chi in 'snacking' formats recognizes that older adults' participation in traditional group-based exercise sessions is impacted by a variety of preventative factors that may reduce exercise and physical activity among older people. The aim of this qualitative study, therefore, is to explore older adults' experiences of exercise snacking as a specific form of structured exercise session and to explore the acceptability of exercise and Tai-chi snacking for older adults of varying levels of physical function. Moreover, our analysis examines cross-cultural differences in terms of the experiences of older adults in the United Kingdom (UK) and Taiwan.

Older Adults' Exercise & Exercise Snacking

Without intervention, muscle function degenerates as people get older, increasing their risk of comorbidity, dependence and premature mortality (Pate et al., 1995, Lunney et al., 2003). Advancing age is accompanied by sarcopenia and loss of muscle size and strength, with data from longitudinal studies suggesting that muscle strength is lost at 3-4% and 2.5-3% per year in males and females respectively from the age of 75 onwards (Mitchell et al., 2012). Weak muscular strength and poor balance limits the ability to safely execute daily activities and can increase the likelihood of falling in older populations (Jung, 2008). Consequently, age-associated loss of physical function can place an enormous strain on health and social care systems around the world (Pinedo-Villanueva et al., 2019, Bruyère et al., 2019, Beaudart et al., 2014, Florence et al., 2018). Qualitative studies have demonstrated that older adults' perceptions of frailty and their fear of falling can have a significant impact on wellbeing, sense of self, choice of daily activities as well as on physical health outcomes (Schoenborn et al., 2018, Van Damme et al., 2020, Warmoth et al., 2016). As the global population ages, the healthcare cost of falling is forecast to dramatically rise in the coming years (Fields et al., 2015, Government, 2020). Preserving or even improving muscle strength, balance and overall physical function is therefore an essential strategy for enhancing older adults' quality of life and reducing the detrimental health and economic impacts of a loss of mobility.

One of the main factors associated with loss of muscle function is a reduction in physical activity, specifically exercise or movements that test one's strength, balance, or physical function (Thompson et al., 2012, Leveille et al., 2002, Cadore et al., 2014). Focusing on older adults in the UK and Taiwan, latest data from the UK suggests that only 12% of adults aged 65, and 5% aged over 75 meet the twice-weekly muscle strengthening and balance guidelines (Department of Health, 2016). Similarly, Lin et al. (2018) found that only 22.4% of 1068 Taiwanese older adults met both aerobic and muscle strengthening recommendations.

Exercise participation for older adults is affected by motivational, social, and environmental factors which include differences in training, motivation, exercise habits, social support, socioeconomic status, transport links and infrastructure, and neighborhood characteristics (Jang et al., 2016, Farrell et al., 2013, Booth et al., 2000). Research has found that older adults often cite lack of time, feeling lazy, apathy towards exercise, lack of self-efficacy for exercise, fear of falling, lack of access or convenient spaces for activity, insufficient support, feeling pressured in group leisure or gym settings, and economic constraints as major barriers to regular exercise participation (Martín-Moya et al., 2020, Burton et al., 2017a, Lees et al., 2005, Burton et al., 2017b, Franco et al., 2015). To overcome these barriers, supporting older adults to engage in unsupervised home-based strength and balance exercise might be a practical alternative to traditional exercise training and more acceptable to older adults with fear, discomfort, or dislike of traditional resistance exercise and gym settings (Glenn et al., 2015, Orange et al., 2019).

Several studies have found that intermittent short-bout exercises have higher adherence than long-bout exercises (Jakicic et al., 1995, King et al., 1995, Sparling et al., 2015). The term 'exercise snacks' has been used to describe breaking up a single session of continuous exercise into several short periods of exercise spread throughout the day (Francois et al., 2014). A daily home-based exercise snacking regime is considered to be an accessible and effective alternative to traditional resistant exercise in older adults wanting to improve their physical function (Perkin et al., 2019). However, more research is required on the subjective experiences of older adults engaged in exercise snacking to understand their experiences and ensure recommendations are meaningful and relevant to this population (Phoenix, Griffin & Smith, 2015).

Tai-chi as a Form of Exercise Snacking

Tai-chi is receiving increased attention within ageing research. Originating from China in 18th century, Tai-chi is performed with slow movements and mental concentration; it is one of the traditional Chinese martial arts (Chila, 1996). Tai-chi is based on balancing 'Yin and Yang' energies, meaning 'dark-bright' or positive-negative, and is an ancient Chinese philosophy (Kuo, 2004). A number of studies have found that practicing Tai-chi positively affected balance, flexibility, lower extremity functions, and cardiovascular functions (Miller and Taylor-Piliae, 2018, Easwaran et al., 2020, Liu, 2008) and can lower the risk of falls (Li et al., 2005, Nyman, 2020, Li et al., 2021). Researchers have also found that older Tai-chi practitioners had better ankle and knee proprioception, longer single-leg stance time, stronger lower limb muscles, and better jumping ability (Mak and Ng, 2003, Gyllensten et al., 2010, Zhong et al., 2020).

As with traditional resistance training, Tai-chi is typically advocated or performed in leisure centers or settings, and in extended (i.e., 45-60 minute) group-based sessions and has yet to be trialed in a 'snacking' format. The creation of an easy to master home-based Tai-chi snacking programme may help engage more older adults as well as improve self-efficacy and adherence. This format and structure of Tai-chi snacking marks a break in the traditional format mentioned previously that includes long, sometimes expensive, group sessions (Lo et al., 2020, Braithwaite et al., 1998). Our team has studied the effectiveness of exercise snacking on leg muscle size and strength (Perkin et al. (2019)), and also begun to explore the feasibility of implementing exercise and Tai-chi snacking (Liang et al., 2021). It is also imperative to explore, alongside this, the qualitative experiences of older adults themselves and whether it is an acceptable and meaningful mode of exercise within their everyday lives. It is this qualitative aspect that this paper focuses on. Before moving on to the methods and data analysis, however, we will firstly spend some time considering the unique cultural contexts of the UK and Taiwan and the theoretical framework that underpins the study.

Exercise & Ageing in the UK and Taiwan

Few studies have discussed home-based exercise participation in older populations from cross-cultural angles, as such, this paper makes a significant contribution to knowledge about cross-cultural experiences of exercise snacking acceptability that can improve older adults' later life whilst recognizing the need for analyses that are culturally diverse and sensitive to context.

The first author grew up and has lived in Taiwan, having learnt and practiced Tai-chi for over 20 years. Upon moving to the UK, she recognized that Tai-chi was not as popular or widespread. In fact, what resonated for her were some distinct socio-cultural and spatial similarities and differences in physical activity and exercise participation in Taiwan and the UK. For example, the outdoor environment in the UK is more conducive to active commuting and the weather makes walking and being active outdoors easier and more enjoyable, whereas Taiwanese neighbourhoods are busier, with more traffic congestion and the weather is a barrier to participation. Yet physical activity and exercise are engaged for similar health and body image outcomes across both countries (Giles-Corti and Donovan, 2002). The experiences of growing up, living and now researching in different countries with different values around physical activity, exercise and health have shaped the project aims as a whole. Moreover, it is these differences that also need further research as the health of ageing populations are of global concern.

Guiding Framework: The Theoretical Framework of Acceptability

Given the social-historical differences, the distinct cultural origins of Tai-chi (i.e., East Asia) and the strength exercise snacking developed in the UK, the present research aims to explore the acceptability of strength-based exercise-snacking and Tai-chi snacking and discuss whether the acceptability of these interventions varies from British to Taiwanese populations.

The theoretical framework of acceptability presents seven components that are key to understanding acceptability of an intervention targeting health behaviors (Sekhon et al., 2017). Specifically, the framework focuses on how people feel about an intervention (affective attitude); the amount of effort the intervention would require (burden); how well the intervention relates to peoples beliefs and values (ethicality); how well the intervention is understood (coherence); whether or not other benefits need to be given up to engage with the intervention (opportunity cost); whether people believe the intervention will work for them as intended (perceived effectiveness); and an individual's confidence in their ability perform the intervention (self-efficacy). It is through this systematic lens that the present study will explore how acceptable exercise and Tai-chi-snacking is to older adults of varying levels of physical function and whether the acceptability of these interventions differs in both Western and Eastern older adults residing in the UK and Taiwan.

3.3.3 *Methods*

Study design

To examine the experiences and acceptability of exercise snacking and Tai-chi snacking a qualitative study design was developed. This included a preliminary screening assessment which was used to characterize and screen participants for eligibility and demonstrate the exercise and Tai-chi snacking protocol. Participants then were asked to try out each of the exercise formats over the proceeding 7 days (i.e., 3 consecutive days of each format with a rest day in between). Subsequently, on day 8, the participants engaged in one-to-one semi-structured qualitative interviews exploring their experiences of the exercise programmes. Ethical approval for the study was provided by the University of Bath Research Ethics Approval Committee for Health (Reference: EP 18/19 107).

Participants

The present study recruited both male and female adults aged 65 to 80 years inclusive who were not regularly engaging in recreational sports or structured exercise. Participants were excluded if they: (a) were diagnosed with and treating any chronic illness, including cardiac, pulmonary, liver, or kidney abnormalities, uncontrolled hypertension, cancer, peripheral arterial disease, (b) had musculoskeletal injuries that would hamper or prevent their participation in exercise, (c) suffered from unwanted responses to exercise including chest pain, dizziness, or loss of consciousness, or have been instructed by their doctor to only do physical activity recommended by them, and (d) scored less than 4 on the Short Physical Performance Battery (SPPB, Guralnik et al. (1994)) or scored zero on any component of the test. To enable comparisons between two distinct cultures, participants were recruited from both the UK and Taiwan. Thirty-three British and 30 Taiwanese older adults were recruited.

Taiwanese participant recruitment and protocol

The Taiwanese-based protocol was advertised by local retirement communities or carried out by word of mouth. Potential participants were provided with a participant information sheet and asked to sign an informed consent form and a screening questionnaire to ensure that participants did not exhibit any physiological condition that posed an undue personal risk.

Eligible Taiwanese participants underwent baseline eligibility screening assessments using SPPB for characterizing. Participants who scored less than 4 on SPPB or scored zero on any component of the test were excluded. Participants who scored SPPB over 8 were classified as ‘high physical function’ and who scored 4-7 were in ‘low physical function group’. Participants were given an exercise demonstration on how to safely perform the exercise snacking and Tai-chi snacking activities at home. This took place in either their houses or local community centers chosen by them and were asked to record self-reported exercise logs. Participants were then asked to do 3 days of Tai-chi snacking and 3 days of exercise snacking (in a randomly assigned order) with a day off in between. Taiwanese participants underwent an in-person qualitative interview focusing on their experiences of the Tai-chi snacking and exercise snacking activities they undertook the day after finishing their trial week. 30 Taiwanese participants completed the study.

UK participant recruitment and protocol

To recruit UK participants the study was advertised on the University web pages and distributed to local charity organizations and social clubs with an older adult membership. Interested participants were invited to the University campus and asked to sign an informed consent form and complete a screening questionnaire. Thereafter, participants underwent the SPPB test and an exercise demonstration in the lab and, a week after trialling the exercises at home with 3 days for each exercise format and a day of rest in between, returned to the University for a semi-structured interview. A total of 34 individuals initially signed up to the study; however, only 16 participants completed the in-person assessments before UK lockdown restrictions came into effect in response to the COVID-19 pandemic in March 2020.

In response to the COVID-19 lockdown policies (i.e., staying at home, shielding for vulnerable people, social distancing), the research team received ethical approval to adapt the original study to make all procedures remote. Those 18 individuals, who did not start prior to the national lockdown were approached again and sent a revised participant information sheet to see if they would like to take part in this adapted remote study. The key adaptations that made the study COVID-safe and compliant with current regulations were:

a) all screening was conducted via online survey and an adapted video call-based assessment of physical function

b) the demonstration of exercise- and Tai-chi snacking was delivered via video calling software

c) interviews were conducted via video call.

Interested participants were sent a hyperlink directing to a web page with the participant information sheet and a consent tick box. Participants were contacted and asked their preferred time to do the physical function screening. 17 of 18 participants took up and completed the adapted remote study.

The physical function screening included the SPPB strength and balance items, using the successfully implemented protocol we tested during the initial COVID-19 lockdown (Liang et al., 2021). Safety to complete the assessment remotely was evaluated, followed by outcome assessments of strength (the number of sit-to-stands one can complete in 60 seconds) and balance (time one can stand on one leg, up to 60 seconds) only, with the requirement to score 4 on SPPB removed as participants were no longer testing gait speed as it was deemed unreliable for administration via video call. Participants were stratified as high/low physical function by 5-reps sit-to-stand (scoring low if >13.69s and high if ≤13.69s) and standing on one leg (scoring low if time standing on either leg was <10s and high if ≥10s) in the strength and balance tests. Participants who met the inclusion criteria and scored at least 1 in both the strength and balance components of the SPPB were given a virtual exercise demonstration and underwent an observed practice by a trained instructor (first author). UK participants underwent an in-person/video calling qualitative interview focusing on their experiences of the Tai-chi snacking and exercise snacking activities they undertook the day after finishing their trial week.

Exercise snacking and Tai-chi snacking protocol

Both home-based exercise snacking and Tai-chi snacking programmes included five movements which focused on lower body strength and balance training (see Supplementary file A for exercise description). In the exercise demonstration session, participants were instructed how to perform exercise snacking and Tai-chi snacking movements safely at home. Particularly, researchers introduced the elements of the two different exercise protocols (such as the repetitive mode of the exercise snacking and the meditative concept of the Tai-chi) to participants and advised participants to perform Tai-chi snacking with flowing and connecting movements as well as the focus on breathing. Participants had opportunities to discuss any concerns with researchers in the demonstration session. After the exercise demonstration session, participants were asked to do 3 days of Tai-chi snacking and 3 days of exercise snacking (in a randomized order) with a day off in between. Participants were told they could complete the exercises at a convenient time of their choosing and instructed to perform each of the five movements for one minute with one-minute rest in between. In the exercise snacking programme, participants were advised that the aim was to complete as many repetitions as possible in the minute. In Tai-chi snacking programme, participants were advised to perform the movements as accurately and gently as possible. Exercise written instructions (Supplementary file A) and video instructions on YouTube were provided. [YouTube Link: https://www.youtube.com/watch?v=B_u-IYrSOsA&feature=youtu.be]

Interview

The semi-structured interview topic guide was created based on the seven dimensions of the theoretical framework of acceptability (TFA; Sekhon et al. (2017)). Specifically, questions explored affective attitude, e.g. 'How did you feel about the exercise snacking/Tai-chi before/during doing it?'; burden, e.g. 'How did you find doing the exercises every day?'; opportunity costs, e.g. 'Do you have to sacrifice or give up doing something for the exercises?'; perceived effectiveness, e.g. 'What improvements did you expect to see from these exercises?' and 'Do you feel that the exercises themselves had or could have any effect on you?'; intervention coherence, e.g., 'Was there any part of the exercises that you found particularly difficult to understand or perform?'; ethicality, e.g. 'Do you think that exercise snacking and/or Tai-chi snacking are appropriate and suitable for you and people in your age group?'; self-efficacy, e.g. 'Do you think you would carry on doing the exercise snacking and/or Tai-chi snacking on your own in the future?'. The interviews of Taiwanese participants were conducted in Mandarin using the same topic guide, which was translated and verified by a Mandarin speaking academic.

The semi-structured interview guide allowed participants to speak freely and they were encouraged to answer the questions in as much detail as possible. To comprehensively understand participants' experiences, additional probing questions (e.g., 'could you elaborate?') were added when necessary. All interviews were conducted by the first researcher and audio recorded with participant's consent.

Data analysis

Digital recordings of interviews were transcribed verbatim in Microsoft Word in an anonymized format and then uploaded to QSR NVivo12 for coding and data organization. The Taiwan-based interviews were transcribed and coded in Mandarin, and then translated into English for illustration of quotes. Data were analyzed using a deductive framework analysis (Ritchie et al., 1994) aligned to aspects of the Theoretical Framework of Acceptability (Sekhon et al., 2017) and an inductive thematic analysis (Clarke and Braun, 2014) to gather any other relevant information regarding barriers and facilitators to participation, future motivation, and any opportunities to refine or develop the exercise and Tai-chi snacking protocols. This data analysis was primarily conducted by the first author (IJL); however, two further authors with qualitative research experience (JFW and MJW) checked the themes for trustworthiness and accuracy of meaning. Differences between the Taiwanese and UK participants and those considered high versus low physical function were also explored and highlighted where relevant.

Within the remainder of this paper, we critically examine the qualitative data from the older adult participants and their experiences of exercise and Tai-chi snacking. The discussion will be structured thematically in line with the 7 domains of the theoretical framework of acceptability (Sekhon et al., 2017). Guided by the thematic analysis (Clarke and Braun, 2014), emerging sub-themes related to cultural context and older adults' functional movement will also be explored.

3.3.4 Results and discussion

Figure 3-1 indicates the flow of participants through the study. There were 34 initial UK volunteers and 33 Taiwanese volunteers. One UK volunteer withdrew due to Covid-19 symptoms and 33 underwent and passed the eligibility screening tests. Of the 33 Taiwanese participants who underwent the eligibility screening tests, 3 of them were excluded due to low fitness function. A total of 63 participants completed the study. Characteristics of included participants are shown in Table 3-1. Compared to UK participants, the Taiwanese sample had a higher proportion of female and employed participants, were slightly younger, had fewer living alone, and had lower educational attainment. Of the UK participants, 19 were considered to have high physical function and 14 low physical function, whereas the Taiwanese sample comprised 23 participants with high physical function and 7 with low physical function.

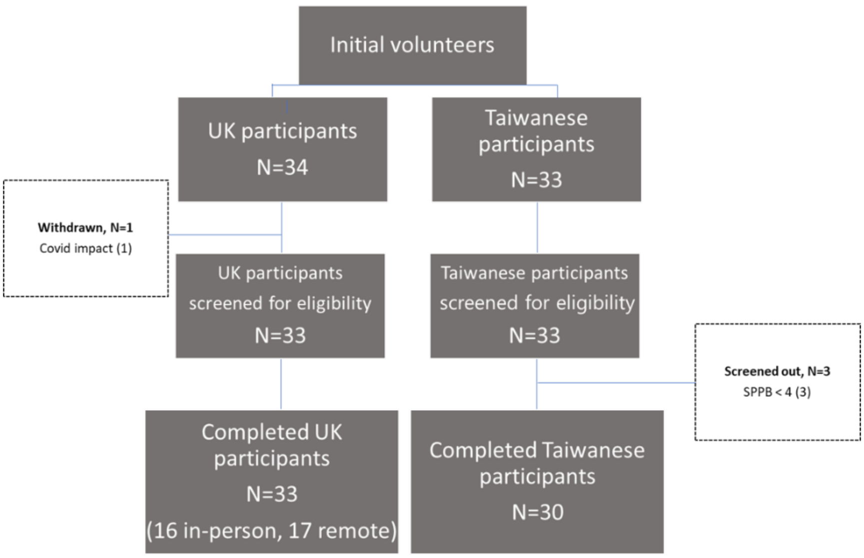


Figure 3-1. Flow diagram of participation throughout the study.

Table 3-1. Demographic characteristics for UK and Taiwanese participants

	Total N=63	UK N=33	TW N=30	*P* difference
Female, n (%)	43(68)	19(58)	24(80)	.056[a]
Age, mean ± SD	72.7±4.8	73.7±3.9	71.6±5.5	.002[b]
Living alone, n (%)	14(22)	12(36)	2(7)	.005[a]
Marital status, n (%)				.279[a]
Married/ civil part.	45(71)	21(64)	24(80)	
Divorced/Separated	3(5)	3(9)	0(0)	
Widowed	9(14)	5(15)	4(13)	
Single	6(10)	4(12)	2(7)	
Employment, n (%)				.047[a]
Retired	52(83)	30(91)	22(73)	
Doing unpaid work	6(9)	3(9)	3(10)	
Still working	5(8)	0(0)	5(17)	
Educational status, n (%)				>.001[a]
Secondary Education	22(35)	2(6)	20(67)	
Post-Secondary	8(13)	4(12)	4(13)	
Vocational Qualification	5(8)	3(10)	2(7)	
Undergraduate Degree	17(27)	14(42)	3(10)	
Post-graduate Degree	11(17)	10(30)	1(3)	
Physical function, n (%)				.108[a]
High[c]	42(67)	19(58)	23(77)	
Low[d]	21(33)	14(42)	7(23)	

[a] Differences between groups were analysed using Chi-square tests.
[b] Analysed using independent-samples t test.
[c] High physical function: Participants scored over 8 on SPPB or for those who undertook the tests remotely, doing 5-reps sit-to-stand ≤13.69s and standing on one leg ≥10s.
[d] Low physical function: Participants scored 4-7 on SPPB or for those who undertook the tests remotely, doing 5-reps sit-to-stand >13.69s and standing on one leg <10s.

The results are based on the analysis of 63 interviews of the United Kingdom (UK) and Taiwanese (TW) participants. Participant quotes are presented along with individual characteristics [Country + study ID; age; physical function category; sex].

Affective attitude: participants' feelings and attitude towards the intervention

The participants' affective attitudes highlighted how they felt about taking part in the exercise and Tai-chi snacking exercises. The UK participants expressed an interest and willingness to explore alternative training methods that differed from their previous experiences. Tai-chi was of particular interest to the participants for whom this was a completely new form of physical activity. A female participant from the UK, who engaged in other forms of exercise, remarked on this:

> *Well, I was interested. I thought it was a programme of exercise which I didn't have. I've always done some exercise, but mainly flexibility exercise... And trying to tune up muscles as it were but never anything in an organized way… So that's my basic reaction to my opinion before I tried... so I was pleased to have an opportunity to actually become more organized. [UK028, 69yrs, low function, female]*

For others it was the combination of the exercise snacking format and Tai-chi as a form of body movement that was appealing, one UK male commented that he was 'intrigued' to find out what exercise snacking meant and what benefits could it bring:

> *I was intrigued to find out what benefit I would get from it. Um, something that I wasn't familiar with. I realised what was involved with the exercise snacking and I can understand that the Tai-chi was something I'd never known before. And I'd only seen it on the television, somebody waving their arms slowly, and I thought, well, it's got to be good. So, give it a try. [UK006, 73yrs, high function, male]*

Interestingly, following engagement with both the exercise and Tai-chi snacking protocols, a number of UK-based participants expressed that they preferred Tai-chi snacking. The reasons for this varied, from enjoyment in new ways of moving the body that were felt as graceful, expressive, and relaxing to enjoying a new form of training and using muscles they rarely used. Research suggests that pleasure and enjoyment are often under-researched and under-theorized components within health studies and older adults (Phoenix and Orr, 2014). It is therefore important to identify these moments of pleasure and the multiple forms of enjoyment the participants experienced when they engaged in the snacking activities (Kirkland et al., 2011) because ‘enjoyment and pleasure are a central argument for maintaining people’s habit of health behaviours (Crossley, 2006, Phoenix and Orr, 2014, p. 94).

Some of the participants derived enjoyment and simply from being active, feeling the sensations of their moving bodies. Others enjoyed the sense of skill mastery and/or acquisition that learning new activities offered. For participants with low physical function, Tai-chi snacking was experienced as relaxing and had the benefit of not requiring strenuous exertion:

> *I'm quite keen to master the Tai-chi bits… I felt very relaxed and I really enjoyed it. I felt like my whole body was moving, but no sort of muscle strain. They're not strenuous exercises… I think that's better really because I don't suffer from muscle fatigue the next day. [UK022, 76yrs, low function, male]*

Alternatively, a high functioning female participant enjoyed the way her muscles were activated in ways that felt novel and were ‘quite fun’:

> *I thought a couple of them (Tai-chi snacking) were quite fun. It worked muscles that I don’t normally use, particularly I thought the snake creep through the grass one because that was like squatting, and it worked the muscles of the front to my thighs, which don't get much use and they're not my best muscles. [UK033, 67yrs, high function, female]*

Nevertheless, studies have demonstrated that people tend to become bored with repetitive activities after a time, the simplicity and lack of variation are common barriers to adherence (Resnick and Spellbring, 2000, Chen et al., 2017, Hinman, 2002). These are consistence with the findings in the current study that some participants with high physical function expressed. For these participants the exercise snacking programme was too short and easy which they would not carry on doing it because of being bored and lacking interest:

> *I don’t think I’ll keep doing it (exercise snacking) after your study. It’s a bit easy and I think doing each movement for one minute is not enough for me. [TW019, 79yrs, high function, female]*

> *…I think I might get bored (doing exercise snacking). The exercise snacking isn't strenuous enough. [UK013, 79yrs, high function, male]*

Overall, being interested in learning a new form of exercise was indicated by most participants before they tried the snacking protocols, feeling enjoyment, being energized, and well-satisfied were experienced after they did the protocols. Interestingly, there were differences between participants' preferred snacking exercises, depending on different physical functions and nationalities. More UK-based participants preferred Tai-chi snacking, citing its' elegant and relaxing movements as a core reason. For participants with low physical function, Tai-chi snacking was gentler and less physically effortful. Few participants expressed that they might get bored of the repetitive exercise snacking movements if they were to do the programme for longer term especially for participants with high physical function. Therefore, targeting those who would benefit most with the snacking exercises is important, as well as tailoring the exercise intensity and allowing for progression or adaptations to make it optimally challenging for those who feel more capable (Teixeira et al., 2012).

Burden: the perceived amount of effort that required to take part in the intervention

The differing nature of the two snacking protocols were not only highlighted by the participants but they remarked on how demanding they were, both physically and cognitively. Both exercise and Tai-chi snacking were reported as being physically demanding. For these two low functioning participants, one in Taiwan and the other in the UK, the exercise snacking especially left them breathless and tired but feeling stronger:

> *Exercise snacking was good and some of it were strenuous. I was a little bit breathless possibly after doing the exercise snacking. [TW022, 79yrs, low function, male]*
>
> *The exercise snacking ones, I really did feel that my leg was 100% strengthening, it wasn't hurting. The Tai-chi ones where I was lifting my leg and arms like that... (stand on one leg and front heel kick), I did find it very tiring… [UK026, 77yrs, low function, female]*

The female participant from the UK here identified an increase in strength as a perceived outcome from their participation. This perceived physiological impact can also have a positive impact on older adults' wellbeing as they feel confident that they had the capability to complete everyday tasks. Likewise, studies have shown that the feeling of confidence and sense of accomplishment are important when engaging in physical activities and would lead to beneficial health outcomes (Codina et al., 2020, Molina and Myrick, 2021).

Most participants found that Tai-chi snacking needs more cognitive effort than the repetitive exercise snacking and required multitasking as participants had to memorize the movements, concentrate on breaths, and maintain balance at the same time. A few participants described Tai-chi snacking as a coordinated training because of the combination of upper and lower body movements:

> *I think your brain when you're learning it needs to be engaged a lot more with Tai-chi than it does with the exercise snacking. It took a bit more concentration for me to do. [UK034, 72yrs, low function, female]*

Specifically, participants with low physical function reported that following the programmes takes more physical effort and some struggled with continually doing the movements for one minute:

> *I found it quite tiring because I'm not used to it. I've had to get support by touching a table or a chair. And I found it quite difficult to balance… I did it when I felt like it because I struggled to continue to do it for one minute. [UK011, 75yrs, low function, male]*

> *When practicing Tai-chi exercises, I found them to be quite exhausting, especially the 'snake creeps down' movement. [TW034, 79yrs, low function, female]*

For some participants time was a factor, they remarked that learning Tai-chi was time consuming but demonstrated that although time intensive, they believed that this would not persist beyond the initial phase of ‘trying to learn what I’m supposed to do’:

> *The exercises themselves didn't take lots of time, but reminding myself about the Tai-chi, because it was only three days. In the long term that wouldn't be an issue. [UK033, 67yrs, high function, female]*

> *It took too long to do the Tai Chi, because I was spending hours looking at video instructions… But that's only because I'm trying to learn what I'm supposed to do. [TW021, 66yrs, low function, female]*

When it comes to cross-cultural comparison in the burden dimension, no differences were found between the UK and Taiwanese participants. Although Tai-chi is a common exercise form and has been part of recreations in Taiwan, the perceived effort in Taiwanese participants did not differ from the UK participants.

Taken literally, both exercise and Tai-chi snacking required physical effort, yet both of the protocols did not seem overly burdensome:

> *I find it really straightforward and not strenuous. You do have a break, you know, which is good. [UK003, 78yrs, high function, female]*

> *It's not tiring. And you don't have to spend too much time on doing it. I mean, it only takes 10 minutes... [TW030, 68yrs, high function, female]*

However, some participants with lower physical function indicated that these snacking exercises were a bit overly physically demanding, suggesting gentle progression to get up to the 1-minute protocol may be needed. Similarly, Tai-chi snacking was reported to require more cognitive effort and was time consuming for some beginners. Supportive guidance to help them mastering the movements would seem necessary to reduce this burden.

Opportunity costs: the extent to which benefits, profits or values need to be given up engaging with the intervention

The qualitative interviews focused the lived experiences of older adults engaging in exercise and Tai-chi snacking. The notion of sacrifice came to the fore, and whether participants had to sacrifice doing their other activities for the exercise and Tai-chi snacking programmes. Most participants did not have to give up or sacrifice their time to incorporate the snacking exercises into their daily lives. This is probably a strength of the simple mode of snacking exercises that do not require lots of time and does not require people to go to a gym. The findings indicate that snacking exercises are acceptable and achievable exercise routines:

> *Certainly 10 minutes per day… I don't have to give up doing anything. Also, I have plenty of time. I can't make any excuses about not having time… You can do them anytime and I usually did them while watching TV. [TW016, 66yrs, high function, female]*

> *You can fit it in with other tasks you have to do at home, like clean the room*

and other things outside of the door… [UK011, 75yrs, low function, male]

I didn't have to stop doing anything else to do it because I have the time. I mean, 10 minutes isn't much to the day and I can fit 10 minutes in every day... and you do it at home, you don't need any special equipment. [TW020, 77yrs, low function, female]

It's easy to do, you don't have to get dressed. You don't have to go to the gym. You don't have to go through a real procedure… You can always do bits of it sitting in the chair and things in anytime. You can do these exercises in the privacy of your own home. You can do it in 5, 10 minutes here or there. [UK002, 78yrs, low function, male]

A number of participants proposed that building new habits, fitting the exercises into their routine, having self-discipline, being prompted to exercise and for some, having rewards or motivations were necessary and would be supportive for them to carry on doing the programme. According to previous studies, individuals with higher conscientiousness and self-discipline tend to engage in healthy habits (Kern and Friedman, 2008, Bogg and Roberts, 2004). The notion of habit emerged from this high functioning UK participant:

I think you just go and get it into the habit. It's remembering and having a time; it's trying to organize a time when you do it. You have to sort of discipline yourself to do it on a regular basis. [UK003, 78yrs, high function, female]

Homebased snacking exercise is designed to capture those individuals who do not engage in those social or group-based activities. A social setting can become a barrier to participation for individuals who are pre-frail, started to become frailer, and/or have lost confidence to go out and engage with leisure settings (Yardley et al., 2006, Biedenweg et al., 2014). Yet the fact that the exercise snacking protocol took place in individual homes had an impact on this participant’s engagement, they felt that exercise and a sense of social cohesion and interaction was an important motivator according to their previous experiences. Without ‘friends’ to ‘socialize a bit’ with, they commented that their motivation for the exercise snacking was reduced:

I believe that these exercises are good for my physical health, but I’d prefer joining group classes. You know, you can make friends and socialise a bit. Doing exercises on my own at home... sometimes I just felt lazy and didn’t *want to do them… [TW004, 67yrs, high function, female]*

Research has found that when it comes to the preferred mode of exercise programmes, it is personal and varies between individuals (Sandlund et al., 2018, Franco et al., 2015). Therefore, it seems prudent to understand the preferences for social exercise, and ensure that home-based strength and balance interventions are not implied to displace other forms of group-based exercise.

Generally, participants acknowledged the snacking exercise only takes 10 minutes per day and does not need any equipment which is easy and convenient to do at home. The participants reported that no activity had to be given up engaging in our home-based snacking exercise programmes. We suppose that the convenience of our home-based snacking exercise is applicable and suitable for older people and this does not vary from British to Taiwanese populations.

Perceived effectiveness: the effectiveness participants expect to receive from the intervention and whether they consider it to be good for them

Perceived effectiveness was explored in relation to participants' views or beliefs about the physical or mental health benefits of exercise and Tai-chi snacking. The expected and the experienced effectiveness were positive overall. In particular, participants perceived that the snacking exercises could improve their muscle strength and balance. These two participants who lived in the UK and have low functionality, articulated explicitly these perceived improvements in their balance, strength and mobility:

> *I think it [Tai-chi snacking] is good for me. I think probably it's good for balance. I felt my balance was getting better through it. And the snacking one [exercise snacking] I felt it's good for me, for my bottom part, lower body part... I think it probably does improve strength. [UK019, 72yrs, low function, female]*

> *Well, the surprise is that I can lift my legs up higher than I did before I started. That's an improvement. The main improvement is that I'm able to jump up, go out and start walking down the street with no aches or walking up and down stairs. [UK011, 75yrs, low function, male]*

Studies have shown that motivators to exercise participation in older adults included preventing physical function degeneration, reducing risk of falls, improving muscle conditions, living independently, and having better wellbeing (Franco et al., 2015, Burton et al., 2017a). These are findings that cohere with the experiences of the participants in this study. When interviewed, the participants were referring to keeping up the snacking protocol going beyond the study as they considered being physically active and maintaining their mental health to be important. For one female participant the COVID-19 global pandemic and associated lockdowns have brought these concerns to the forefront, meaning she is 'very keen' to continue undertaking the snacking protocol:

> *The thing is that we've been isolating since March, we're not going out. And I'm quite worried about our physical fitness and mental fitness... I think because exercise helps to stop getting Alzheimer's. And if you've got memory loss, it improves it because of the blood supply so I'm very keen. [UK026, 77yrs, low function, female]*

Similarly, other participants anticipated that continued exercise and Tai-chi snacking could improve their, already high, physical function and prevent physical and cognitive functions degeneration:

> *I'm aware that I'm getting older and less fit, and I needed some extra help, perhaps. [TW009, 67yrs, high function, male]*

> *This may allay fear… like fear of falling, fear of getting dementia, you know, all this kind of getting-old fears that you're doing something to help yourself. [UK033, 67yrs, high function, female]*

In addition to these perceived effects, other participants also expressed that their mental well-being, cognitive condition, memory, and even sleeping quality was enhanced, even after just a few days of exercise:

> *I feel more flexible than before. I think these exercises ease my stiffness on my joint. My sleeping quality has improved. And because I enjoyed the exercises, I think it's good for mental health. [TW007, 69yrs, high function, female]*

Some participants described that feeling their muscles working motivated them. Specifically, some participants revealed that Tai-chi snacking was felt to be beneficial for their balance and overall physical functions as well as their mental health. Some reflected that their flexibility and posture were better after practicing Tai-chi snacking. Participants also expected that the snacking exercises, especially Tai-chi snacking, would be beneficial for their coordination. These effects are similar to the findings from existing literature which demonstrated that practising Tai-chi can improve muscle strength, balance, mobility, and flexibility (Son et al., 2016, Chen, 2019), and is good for brain function and mental health (Wayne et al., 2014, Chen et al., 2002).

> *These exercises will increase my stamina… there would be flexibility and strength as well. [UK023, 73yrs, high function, female]*

> *I think Tai-chi is good for coordination because you need to wave your hands and move your feet at the same time. [TW010, 75yrs, high function, male]*

> *I think practicing Tai-chi is good for my balance and can strengthen my thigh muscles… I felt brighter after doing Tai-chi snacking and my sleeping quality had gotten better. [TW017, 66yrs, high function, female]*

Like the effects of Tai-chi snacking mentioned above, Gryffin et al. (2015) reported that psychological benefits and improvement of balance are identified as facilitators to Tai-chi. However, some considered lack of awareness of benefits to be a barrier (Lo et al., 2020). To some people, it is the unknown and unfamiliar that impacted their experiences of Tai-chi. This lack of familiarity may have shaped their interpretation of the activities and the practitioners too (Gryffin et al., 2015). Since Tai-chi is relatively new in countries such as the UK, and given there is insufficient knowledge of it, UK-based participants specifically thought that introducing the principles and the background of Tai-chi was needed:

> *I think Tai-chi is probably very beneficial based on my knowledge of what happens in Asian side. But I think we need a clearer and longer introduction to it to make it possible to do it in any effective way. [UK010, 77yrs, low function, male]*

> *The Tai-chi is lovely and if I knew more about it and could do it better, I think it would be fine… I think I prefer the Tai-chi, because it's more peaceful and more restful... probably very good for your mental health. [UK024, 72yrs, low function, female]*

Nevertheless, most participants indicated that the one-week trial was too short to see any significant improvement or changes and believed that the positive effects would be more long-term. Altogether, participants considered that the exercise and Tai-chi snacking would be of physical, mental, and cognitive health benefit to them. Indeed, the participants especially those UK-based were keen to learn more about the origins and values of Tai-chi and thought that this introductory information would enhance their experiences of Tai-chi snacking.

Intervention coherence: the extent to which the understanding of the intervention and the capability of executing it

Here we focused on interpreting how confident participants were that they understood the exercise and Tai-chi snacking programmes and how the snacking exercises worked. In general, exercise snacking movements were more coherent and easier to perform than Tai-chi snacking movements. Participants found exercise snacking to be straightforward to learn, when compared to Tai-chi on the basis that it was less complicated and time-consuming as movements didn't need to be learnt and/or memorized. On the other hand, some found Tai-chi snacking more peaceful and had less pressure to perform. Nevertheless, there were not many differences between the UK and Taiwanese participants.

> *The exercise snacking, I found um... I mean I had no problems doing it. They are relatively straightforward. And I found the Tai-chi much more difficult. [UK002, 78yrs, low function, male]*
>
> *The snacking bit was quite easy, but with the Tai-chi… I found it a bit hard to learn and some movements were complex. Actually, I spent lots of time watching your video and tried to get to do it (Tai-chi) on the first two days. [TW001, 70yrs, high function, female]*
>
> *Personally, I enjoyed the Tai-chi. I felt more relaxed. The exercise snacking is a bit of challenge. I think because my joints are stiff. But Tai-chi was quite relaxing. [TW019, 79yrs, high function, female]*
>
> *I would really like to say I prefer doing Tai-chi... I think it's less pressure on your knees... And the other one (exercise snacking) ... It puts pressure on the knees. [UK014, 71yrs, high function, female]*

For several participants, difficulty executing certain exercises arose more from their physical capability than their understanding of what to do. One UK participant considered seated leg kick to be the most difficult movement because of the weakness of his quadriceps (UK009, 80yrs, low function, female); one Taiwanese participant considered standing knee bend to be the most difficult movement as her hamstring was weaker (TW038, 79yrs, low function, female). Regarding Tai-chi snacking movements especially snake creep through the grass was considered to be the most difficult movement because of its squatting posture which could cause muscle soreness. Participants with poorer balance ability found single leg movements to be difficult:

> *The snake creeps... I always found that difficult when I was doing Tai-chi anyway. I couldn't squat down because I have stiff hips and back so that's quite a challenging one to do. It put pressure on my knees... but I could feel my muscles working. [TW011, 70yrs, high function, female]*

> *Standing on one leg and front heel kick… it's a question of the balance. The snake creep defeated me. The snake got away I think... [UK010, 77yrs, low function, male]*

A clear and simple description of exercise instruction, good communication, and encouragement are important and may increase the exercise participation (Flegal et al., 2007, Sjösten et al., 2007). Accordingly, participants felt that they need more instructions and continuous feedback on Tai-chi snacking programme. Most participants said that it would be nice and more motivating to go to a class or have tutorial to learn Tai-chi:

> *I think that [a tutorial] is always good for motivation. But I think with the Tai-chi as I explained, because it's something that we're not familiar with… that kind of movement I think that would be very useful. [UK014, 71yrs, high function, female]*

> *I think it's quite hard to learn Tai-chi from watching the video and from reading the instructions you've sent to us together with the photographs… Having your feedback straightaway, I think, would be a big improvement. I think possibly you need to be with a teacher in the room who watches you and says "move your hands to the left", or whatever it might be... The Tai-*

chi, I'd be quite happy to do it, but I need to go and do a course with an instructor. [TW003, 79yrs, high function, female]

Finally, participants made recommendations for adding upper body movements in exercise snacking programme and simplifying Tai-chi snacking movements which they thought would be better for novices and avoid the feeling of frustration and improve self-efficacy.

I think probably to maintain a certain amount of strength of muscles, you need to do that sort of thing to use all the bodies, not just legs. We need to do something for the upper body. Because when you get older, your shoulders get very stiff. [UK024, 72yrs, low function, female]

The exercise snacking would have to be much more strenuous and the Tai-chi much easier. [UK013, 79yrs, high function, male]

Overall, participants found that the snacking exercises were convenient, particularly the fact that no equipment was necessary, and it can be done anywhere anytime. The short bout snacking format was considered to be attractive and motivational. However, concerning coherence, understanding and execution, exercise snacking was more acceptable. For new audiences, making Tai-chi snacking easier to master initially and breaking it down into several levels, and having some exercise snacking movements for upper body would be more acceptable.

Ethicality: the extent to which an intervention aligns with participants' values

Participants reflected on the role that exercise played day to day, the meaning and value they attributed to it and how it came to 'fit' within the push and pull of their lives as well as in relation to their age and fitness levels. Most participants found the snacking exercises were appropriate and essential for people in their age group. They found it easy to do the snacking exercises at home. Participants commented that the organization of the programme, with its specified duration and type of exercises was helpful and suitable for older people:

I found it very helpful. I felt that it [snacking exercises] was something very relevant to people as they get older… I am losing my fitness. But I want to keep it as good as possible for as long as possible to be able to enjoy myself. And I think this is definitely helping… Introducing to five somewhat *basic exercises in each of the two disciplines is a great idea for older people. [UK002, 78yrs, low function, male]*

Nelson et al. (2004) found that a home-based training with minimal supervision was safe and feasible for older adults. Similarly, some of the participants in this study expressed that snacking exercises are somehow safer than traditional exercise training methods and gym exercise machines which for some people are stressful and the risks of getting injury would be higher. However, a small number of participants felt pressure, even pain on their knees while doing exercise snacking movements compared to Tai-chi snacking movements. Studies have shown that unpleasant experience and negative self-perception (i.e. feelings of joint pressure and fear of getting injured) would affect exercise participation and adherence (De Groot and Fagerström, 2011, Reynes et al., 2019). These factors should be considered more carefully when designing exercise programmes in future:

I think for older people, because their knees are not so good. It (exercise snacking) puts pressure on the knees...It's better to do the other exercises which are more gentle on the knees in order to warm up… Tai-chi has greater depth... I like the fluidity and the kind of being on a bended knee. I think it's less pressure on your knees. It's very good for balance and core strength. [UK014, 71yrs, high function, female]

A few participants thought that some movements (i.e. calf raises, seated leg kick, single whip, snake creep through the grass) would be too difficult for people aged over 80 or for those who have osteoarthritis, joint replacement, and/or musculoskeletal injury history, therefore simplifying particular movements and creating a progressive snacking exercise programme are necessary and could be more useful and helpful for more diverse populations:

As you get older, your feet become a little bit arthritic. And so doing that standing on your toes (calf raises) can be a bit painful. [UK014, 71yrs, high function, female]

I think the balance is a bit demanding (Tai-chi snacking). I would have thought it would be very difficult for people who are older than me. [TW018, 69yrs, high function, female]

I think these movements are suitable for older people. However, it would be inappropriate for people with special sport injuries or degenerative joint disease. Simplifying the movements would be better regarding the safety of doing these snacking exercises at home. [TW014, 68yrs, high function, male]

For a small number of participants, it was hard to fit the exercises in with their household chores, specifically more Taiwanese female participants reported this to be an issue in their busy life. Time for physical activity is an important consideration but time is also a gendered issue (Festini et al., 2019). Some female participants in this research highlighted that their various commitments everyday meant their lives felt hectic and busy. Analysis of their comments suggests that they have taken on much of the household work as well as childcare responsibilities. This unpaid labor is often gendered in terms of its uneven distribution onto women and reflective of cultural context and values too. For instance, this participants' experiences are constituted by the patriarchal early Chinese cultural values that infuse Taiwanese lives and subjective experiences (Fuligni, 1998) of women living busy lives and therefore having little room for physical activities and exercise:

I found it hard to do the exercises every day. At home...you've got lots of distractions. I have so many things to do… I have to take care of my grandchildren, go grocery shopping, attend community events… I couldn't do your programme every day in this week and I don't think I'll do it in the future. I'm too busy. [TW006, 70yrs, high function, female]

Furthermore, Tai-chi ethos is closely related to traditional Chinese Taoist culture (Su, 2013). Tai-chi, rooted in the Taoist tradition (the Chinese religious-philosophical movement), is supposed to be aligning more to Asian beliefs, and Taoism values. However, we have not found differences between the UK and Taiwanese participants when it comes to religious and cultural identities. The findings are consistent with those of Brown (2016), who stated that 'Tai-chi intermingles religious and holistic forms of spirituality without contradiction.' (p. 317).

In addition, when asked to feedback on the exercise instructions participants suggested that video instruction filmed as a mirror image or from the back would facilitate easier learning and movement following. They specifically recommended a 'follow-me' video approach, taking them through a full minute of each movement, particularly in the context of Tai-chi snacking movements..

> *Maybe because of the different sides, not the mirror image doesn't make it easy. I guess it would be easier for me to do these five movements if the video took you through one minute of one exercise. [UK028, 69yrs, low function, female]*
>
> *The video instruction is helpful, but I would say with the Tai-chi, the only difficulty was initially when you said ''go to the left", you then do the opposite… Your video was face on. I got confused as to whether I should be doing the same leg or mirroring you. [TW008, 67yrs, high function, female]*

Given these points, participants found the short bout exercise and Tai-chi snacking programmes to be convenient and appropriate concerning the perceptions of ageing. In terms of gender identity, some Taiwanese female participants considered themselves to be too busy to do the snacking exercises impacted by their personal beliefs and cultural background. Nonetheless, we need to modify some specific movements, provide more options given individuals' fitness levels and physical conditions for targeting the right groups, and perhaps create progressive exercise programmes in the future.

Self-efficacy: the participants' confidence of the ability to perform the behaviour required to participate in the intervention

Self-efficacy is a moderating factor regarding exercise participation and adherence (Luszczynska et al., 2011). Studies have shown that the sense of achievement and enjoyment may enhance the engagement in physical activities (Lee et al., 2007, Lewis et al., 2016). Similar findings were found in this study. In most participants, feelings of satisfaction, enjoyment, and being energized were common experiences that can help explain their willingness to do the snacking exercises. A small number of participants also found that they were better equipped and more confident exercising by themselves. However, some participants reported that they had lower confidence in performing Tai-chi snacking, specifically those participants who were considered low on physical function. For these participants there was more hesitancy about engaging with the snacking protocol and for some they were more fearful:

I had a lot of energy. I felt satisfied after doing the programmes... If I've done well, I think, 'oh, well, that's good.'. I felt better if I achieved it. It's good to make the brain do different things. [UK030, 78yrs, high function, female]

Tai-chi, I can't practice it very well. And my balance doesn't help. If you've got your balance, I can understand it's quite relaxing. [UK010, 77yrs, low function, male]

A small minority of participants found Tai-chi snacking frustrating since they could not receive immediate feedback and were not sure if they did the movements properly.

The trouble is, I forgot some of the moves because there's five moves. And to remember all the angles... I just couldn't get that right. I think if we'd been in a class where you've been here, and you'd said, 'Do this snake creep through the grass', and got us doing it four or five times until we really got it. That would have been fine. [TW024, 70yrs, high function, female]

Few participants expressed that they would not carry-on doing Tai-chi snacking, whereas most participants were willing to keep doing exercise snacking over time in the future. This notion would be supported by previous studies indicating that self-efficacy is influenced by personal affective and behavioral factors, and has a direct correlation with exercise participation and adherence (Oman and King, 1998, McAuley et al., 2003, McAuley et al., 2011).

I certainly want to continue doing the exercise snacking. However, I don't think I'll carry on doing the Tai-chi snacking. With the fact that I think a lot of older people would have trouble with Tai-chi. [TW031, 78yrs, high function, female]

I think the exercise snacking I will continue to do after your study, but Tai-chi, I think unless I'm really sure that I know what I'm doing... I think it'd be more difficult... I'll do the exercise snacking. Tai-chi, at the moment, that would be impossible. I think I need more feedback. [UK020, 77yrs, low function, male]

Accordingly, participants felt their physical function to be better than they thought and had been more confident exercising on their own, whereas some participants particularly with low physical function thought themselves to be not fit enough, and experienced difficulties and felt unsafe when practicing Tai-chi snacking. Thus, to avoid lack of confidence and improving the engagement in participating exercises, it is important to consider individuals' physical function when designing exercise regime, and finding ways of supporting the initial engagement and mastering the movements via in person or, perhaps, video instruction and support.

Above all, there were not many differences between the UK and Taiwanese participants when it comes to the capability of executing the exercise and Tai-chi snacking programmes and the confidence in the ability to perform them. Both UK and Taiwanese participants considered the snacking exercise easy and convenient to do at home and they did not have to sacrifice doing something for our exercise programmes. Moreover, the perceived effort did not vary from UK to Taiwanese participants even if Tai-chi is a relatively widespread exercise form in Taiwan. Altogether, we have not found many differences between the Taiwanese and UK participants in the burden dimension, the opportunity costs, the intervention coherence, as well as the self-efficacy dimension. Furthermore, we have not found differences between the UK and Taiwanese participants when it comes to religious and cultural identities although Tai-chi is supposed to be more relative to Asian beliefs, and Taoism values as it is based on the Chinese religious philosophy (Brown, 2016, Wang et al., 2000).

However, some Taiwanese female participants reported that living busy lives, and having much household work and childcare responsibilities prevented them from being able to do physical activities and exercises. This gender identity affected by different cultural backgrounds, especially the influence of the patriarchal early Chinese cultural values in Taiwan, is an interesting cultural finding in our study and may warrant further exploration and attention in the context of physical activity and exercise promotion amongst this demographic. We also found that more UK participants preferred Tai-chi snacking because of its elegant and relaxing movements regarding participants' feelings and attitudes towards the snacking exercises. UK participants also expressed their interest in learning the origins and values of Tai-chi as this represents a new format of exercise for them. Some UK participants mentioned that understanding the spiritual-cultural origins of Tai-chi (such as the concepts of Yin and Yang, and qi) may enhance their experiences of Tai-chi snacking, whereas for Taiwanese participants this was more familiar. Given these points, personal affective attitude and different cultural backgrounds may affect exercise participation; yet how participants feel about the snacking exercise did not appear to differ between the backgrounds and nationalities included in the present study.

3.3.5 *Conclusions*

The Theoretical Framework of Acceptability analysis has provided us with a useful lens for examining the thoughts and feelings of Taiwanese and British older adults towards exercise and Tai-chi snacking providing novel understanding of how this format of exercise could be implemented into older adults' homes. Taking a deep dive into the different dimensions of acceptability has shone a light on the strengths of this novel format of muscle strength and balance exercise that make it an attractive proposition for older adults, such as the convenience and appropriateness of performing 10-minutes of exercise per day, and belief in its utility in improving physical function. We have also identified ways that it might be enhanced for certain people to improve uptake and engagement, such as the need to provide more guidance to improve confidence and mastery of Tai-chi movements for people with lower physical function, and opportunities for more challenging, whole body, exercises to avoid tedium for those with higher function.

In this study we found very little difference in the perspectives of British and Taiwanese participants towards the exercise and Tai-chi snacking protocols. The snacking protocols are designed to deviate from traditional class-based or leisure setting provision by offering participants a convenient mode to engage in strength and balance training in a safe and comfortable way. In our study, Tai-chi snacking was seemingly more favourable in specific dimensions such as effectiveness and lack of burden, whereas when it came to coherence and understanding and being able to execute, exercise snacking was more acceptable. Tai-chi, which harnesses different skills, focuses on breathing, and is more about flow, connection, and meditation, and less mechanical and functional, connects participants to different cultural values. Although Tai-chi is rooted in the Chinese religious tradition, cultural or religious alignment of our study participants seemingly mattered little in their judgement of acceptability. In fact, UK-based participants seemed to express stronger preferences for the elegant and relaxing movements of Tai-chi snacking and a desire to learn more about the origins and values of this enjoyable new form of exercise. It should be noted that in a snacking format aspect of traditional Tai-chi delivery may be lost such as the prolonged, instructor-led, meditative components, and comparisons to long-format Tai-chi cannot be made. However, as the goal of our reduced dose exercise is to support initial engagement of muscle strength and balance exercise amongst older adults doing nothing rather than a long-term solution, it was encouraging to witness acceptability. Accordingly, these findings offer encouragement to practitioners who may be seeking new ways to engage older adults in exercise and demonstrate the potential of deviating from instrumental exercise promotion that focuses purely on physical health in a simple and inclusive format.

The strengths of the current work include the in-depth interviewing of two cultural backgrounds and of varying functional status, which enabled us to compare and contrast the experiences of our new exercise protocols in a heterogenous population. This is also the first study, to our knowledge, that has explored the acceptability of a snacking model of Tai-chi. However, a limitation of our study design is the short exposure to the snacking protocols (3 days each) meaning we have only evaluated participants initial judgement, and so the long-term acceptability and understanding if perceived interest would translate to sustained engagement and effectiveness remains unknown. Also, quantitative methods in larger sample sizes could be used in future studies to determine how generalizable and externally valid our findings on the acceptability of exercise and Tai-chi snacking are. Based on the findings, and to address these limitations, a longer-term experimental study of the efficacy of exercise and Tai-chi snacking for improving physical function would be required to understand how well older adults adhere to these exercise and Tai-chi snacking protocols in the modified, shortened format, and their impact on other health and wellbeing outcomes.

Conflict of Interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Author Contributions

IJL, JFW and MJW drafted the manuscript. PM, OP, and DT were responsible for manuscript revision. All authors have read and agreed to the published version of the manuscript.

3.3.6 References

ACSM. 2018. Physical Activity Guidelines for Americans, 2nd edition [Online]. the U.S. Department of Health and Human Services. [Accessed].

Bauman, A., Merom, D., Bull, F. C., Buchner, D. M. & Fiatarone Singh, M. A. 2016. Updating the evidence for physical activity: summative reviews of the epidemiological evidence, prevalence, and interventions to promote “active aging”. The gerontologist, 56, S268-S280.

Beaudart, C., Rizzoli, R., Bruyère, O., Reginster, J.-Y. & Biver, E. 2014. Sarcopenia: burden and challenges for public health. Archives of Public Health, 72, 1-8.

Biedenweg, K., Meischke, H., Bohl, A., Hammerback, K., Williams, B., Poe, P. & Phelan, E. A. 2014. Understanding older adults’ motivators and barriers to participating in organized programs supporting exercise behaviors. The journal of primary prevention, 35, 1-11.

Bogg, T. & Roberts, B. W. 2004. Conscientiousness and health-related behaviors: a meta-analysis of the leading behavioral contributors to mortality. Psychological bulletin, 130, 887.

Booth, M. L., Owen, N., Bauman, A., Clavisi, O. & Leslie, E. 2000. Social–cognitive and perceived environment influences associated with physical activity in older Australians. Preventive medicine, 31, 15-22.

Braithwaite, R. L., Griffin Jr, J. P., Stephens, T., Murphy, F. & Marrow, T. 1998. Perceived exercise barriers and participation in Tai Chi for elderly African American. American Journal of Health Studies, 14, 169.

Brown, D. 2016. Taoism Through Tai Chi Chuan: Physical Culture as Religious or Holistic Spirituality? Spirituality across Disciplines: Research and Practice:. Springer.

Bruyère, O., Beaudart, C., Ethgen, O., Reginster, J.-Y. & Locquet, M. 2019. The health economics burden of sarcopenia: a systematic review. Maturitas, 119, 61-69.

Burton, E., Farrier, K., Lewin, G., Pettigrew, S., Hill, A.-M., Airey, P., Bainbridge, L. & Hill, K. D. 2017a. Motivators and barriers for older people participating in resistance training: a systematic review. Journal of aging and physical activity, 25, 311-324.

Burton, E., Hill, A.-M., Pettigrew, S., Lewin, G., Bainbridge, L., Farrier, K., Airey, P. & Hill, K. D. 2017b. Why do seniors leave resistance training programs? Clinical interventions in aging, 12, 585.

Cadore, E. L., Casas-Herrero, A., Zambom-Ferraresi, F., Idoate, F., Millor, N., Gómez, M., Rodriguez-Mañas, L. & Izquierdo, M. 2014. Multicomponent exercises including muscle power training enhance muscle mass, power output, and functional outcomes in institutionalized frail nonagenarians. Age, 36, 773-785.

Chen, K.-M., Snyder, M. & Krichbaum, K. 2002. Tai Chi and well-being of Taiwanese community-dwelling elders. Clinical Gerontologist, 24, 137-156.

Chen, S. Effect of Tai Chi exercises on the balance, functional gait, and flexibility of elderly Filipino males. Proceedings of the 2nd symposium on health and education, 2019.

Chen, T. L., Bhattacharjee, T., Beer, J. M., Ting, L. H., Hackney, M. E., Rogers, W. A. & Kemp, C. C. 2017. Older adults' acceptance of a robot for partner dance-based exercise. PloS one, 12, e0182736.

Chen, Y., Ringdahl, D., Trelstad-Porter, R. & Gurvich, O. V. 2021. Feasibility of Implementing a Tai Chi Program in an Assisted Living Facility: Reducing Fall Risks and Improving Quality of Life. Journal of Clinical Medicine, 10, 1277.

Chila, T. C. 1996. An exercise option for older adults.

Chou, C.-H., Hwang, C.-L. & Wu, Y.-T. 2012. Effect of exercise on physical function, daily living activities, and quality of life in the frail older adults: a meta-analysis. Archives of physical medicine and rehabilitation, 93, 237-244.

Clarke, V. & Braun, V. 2014. Thematic analysis. Encyclopedia of critical psychology. Springer.

Codina, N., Pestana, J. V. & Stebbins, R. A. 2020. Fitness training as a body-centered hobby: The serious leisure perspective for explaining exercise practice. Revista de Psicología del Deporte (Journal of Sport Psychology), 29, 73-81.

Crossley, N. 2006. In the gym: Motives, meaning and moral careers. Body & society, 12, 23-50.

De Groot, G. C. L. & Fagerström, L. 2011. Older adults' motivating factors and barriers to exercise to prevent falls. Scandinavian Journal of Occupational Therapy, 18, 153-160.

De Labra, C., Guimaraes-Pinheiro, C., Maseda, A., Lorenzo, T. & Millán-Calenti, J. C. 2015. Effects of physical exercise interventions in frail older adults: a systematic review of randomized controlled trials. BMC geriatrics, 15, 154.

Department of Health 2016. Health Survey for England 2016: Physical activity in adults.

Easwaran, K., Gopalasingam, Y., Green, D. D., Lach, V., Melnyk, J. A., Wan, C. & Bartlett, D. J. 2020. Effectiveness of Tai Chi for health promotion for adults with health conditions: a scoping review of meta-analyses. Disability and rehabilitation, 1-12.

Farrell, L., Hollingsworth, B., Propper, C. & Shields, M. A. 2013. The socioeconomic gradient in physical inactivity in England, Citeseer.

Festini, S. B., Hertzog, C., Mcdonough, I. M. & Park, D. C. 2019. What makes us busy? Predictors of perceived busyness across the adult lifespan. The Journal of general psychology, 146, 111-133.

Fields, J., Alturkistani, T., Kumar, N., Kanuri, A., Salem, D. N., Munn, S. & Blazey-Martin, D. 2015. Prevalence and cost of imaging in inpatient falls: the rising cost of falling. ClinicoEconomics and outcomes research: CEOR, 7, 281.

Flegal, K., Kishiyama, S., Zajdel, D., Haas, M. & Oken, B. 2007. Adherence to yoga and exercise interventions in a 6-month clinical trial. BMC Complementary and Alternative Medicine, 7, 37.

Florence, C. S., Bergen, G., Atherly, A., Burns, E., Stevens, J. & Drake, C. 2018. Medical costs of fatal and nonfatal falls in older adults. Journal of the American Geriatrics Society, 66, 693-698.

Franco, M. R., Tong, A., Howard, K., Sherrington, C., Ferreira, P. H., Pinto, R. Z. & Ferreira, M. L. 2015. Older people's perspectives on participation in physical activity:

a systematic review and thematic synthesis of qualitative literature. Br J Sports Med, 49, 1268-1276.

Francois, M. E., Baldi, J. C., Manning, P. J., Lucas, S. J. E., Hawley, J. A., Williams, M. J. A. & Cotter, J. D. 2014. 'Exercise snacks' before meals: a novel strategy to improve glycaemic control in individuals with insulin resistance. Diabetologia, 57, 1437-1445.

Fuligni, A. J. 1998. Authority, autonomy, and parent–adolescent conflict and cohesion: A study of adolescents from Mexican, Chinese, Filipino, and European backgrounds. Developmental psychology, 34, 782.

Giles-Corti, B. & Donovan, R. J. 2002. Socioeconomic status differences in recreational physical activity levels and real and perceived access to a supportive physical environment. Preventive medicine, 35, 601-611.

Glenn, J. M., Gray, M. & Binns, A. 2015. The effects of loaded and unloaded high-velocity resistance training on functional fitness among community-dwelling older adults. Age and ageing, 44, 926-931.

UK Government. 2020. Falls: applying All Our Health [Online]. GOV.UK. Available: https://www.gov.uk/government/publications/falls-applying-all-our-health/falls-applying-all-our-health [Accessed].

Gryffin, P. A., Chen, W. C., Chaney, B. H., Dodd, V. J. & Roberts, B. 2015. Facilitators and barriers to tai chi in an older adult community: a theory-driven Approach. American Journal of Health Education, 46, 109-118.

Guralnik, J. M., Simonsick, E. M., Ferrucci, L., Glynn, R. J., Berkman, L. F., Blazer, D. G., Scherr, P. A. & Wallace, R. B. 1994. A short physical performance battery assessing lower extremity function: association with self-reported disability and prediction of mortality and nursing home admission. Journal of gerontology, 49, M85-M94.

Gyllensten, A. L., Hui-Chan, C. W. & Tsang, W. W. 2010. Stability limits, single-leg jump, and body awareness in older Tai Chi practitioners. Archives of physical medicine and rehabilitation, 91, 215-220.

Hamed, A., Bohm, S., Mersmann, F. & Arampatzis, A. 2018. Follow-up efficacy of physical exercise interventions on fall incidence and fall risk in healthy older adults: a systematic review and meta-analysis. Sports medicine-open, 4, 56.

Hinman, M. R. 2002. Comparison of two short-term balance training programs for community-dwelling older adults. Journal of Geriatric Physical Therapy, 25, 10-16.

Jakicic, J. M., Wing, R., Butler, B. & Robertson, R. 1995. Prescribing exercise in multiple short bouts versus one continuous bout: effects on adherence, cardiorespiratory fitness, and weight loss in overweight women. International journal of obesity and related metabolic disorders: journal of the International Association for the Study of Obesity, 19, 893-901.

Jang, H., Clemson, L., Lovarini, M., Willis, K., Lord, S. R. & Sherrington, C. 2016. Cultural influences on exercise participation and fall prevention: a systematic review and narrative synthesis. Disability and rehabilitation, 38, 724-732.

Jianyu Wang M.A. & L. Allison Stringer PhD. 2000. The Impact of Taoism on Chinese Leisure. World Leisure Journal, 42:3, 33-41.

Jung, D. 2008. Fear of falling in older adults: Comprehensive review. Asian Nursing Research, 2, 214-222.

Kern, M. L. & Friedman, H. S. 2008. Do conscientious individuals live longer? A quantitative review. Health psychology, 27, 505.

King, A. C., Haskell, W. L., Young, D. R., Oka, R. K. & Stefanick, M. L. 1995. Long-term effects of varying intensities and formats of physical activity on participation rates, fitness, and lipoproteins in men and women aged 50 to 65 years. Circulation, 91, 2596-2604.

Kirkland, R. A., Karlin, N. J., Stellino, M. B. & Pulos, S. 2011. Basic psychological needs satisfaction, motivation, and exercise in older adults. Activities, adaptation & aging, 35, 181-196.

Kuo, S. 2004. Yin-Yang in Tai-Chi Chuan and Daily Life, North Atlantic Books.

Lee, L.-L., Avis, M. & Arthur, A. 2007. The role of self-efficacy in older people's decisions to initiate and maintain regular walking as exercise—Findings from a qualitative study. Preventive medicine, 45, 62-65.

Lees, F. D., Clark, P. G., Nigg, C. R. & Newman, P. 2005. Barriers to exercise behavior among older adults: a focus-group study. Journal of aging and physical activity, 13, 23-33.

Leveille, S. G., Bean, J., Bandeen-Roche, K., Jones, R., Hochberg, M. & Guralnik, J. M. 2002. Musculoskeletal pain and risk for falls in older disabled women living in the community. Journal of the American Geriatrics Society, 50, 671-678.

Lewis, B. A., Williams, D. M., Frayeh, A. & Marcus, B. H. 2016. Self-efficacy versus perceived enjoyment as predictors of physical activity behaviour. Psychology & health, 31, 456-469.

Li, F., Harmer, P., Fisher, K. J., Mcauley, E., Chaumeton, N., Eckstrom, E. & WILSON, N. L. 2005. Tai Chi and fall reductions in older adults: a randomized controlled trial. The Journals of Gerontology Series A: Biological Sciences and Medical Sciences, 60, 187-194.

Li, Y., Song, Q., Li, L., Sun, W. & Zhang, C. 2021. Tai Chi practitioners have lower fall risks under dual-task conditions during stair descending. PLoS one, 16, e0246292.

Liang, I. J., Perkin, O. J., Mcguigan, P. M., Thompson, D. & Western, M. J. 2021. Feasibility and Acceptability of Home-Based Exercise Snacking and Tai Chi Snacking Delivered Remotely to Self-Isolating Older Adults During COVID-19. Journal of Aging and Physical Activity, 1, 1-11.

Lin, C.-Y., Park, J.-H., Hsueh, M.-C., Sun, W.-J. & Liao, Y. 2018. Prevalence of total physical activity, muscle-strengthening activities, and excessive TV viewing among older adults; and their association with sociodemographic factors. International Journal of Environmental Research and Public Health, 15, 2499.

LIU 2008. *Taijiquan Fitness Theory Interpretation.* Beijing Sports University Press, CH

Lo, O.-Y., Conboy, L. A., Rukhadze, A., Georgetti, C., Gagnon, M. M., Manor, B., Lachman, M. E., Lipsitz, L. A. & Wayne, P. M. 2020. In the eyes of those who were randomized: Perceptions of disadvantaged older adults in a Tai Chi trial. The Gerontologist, 60, 672-682.

Lunney, J. R., Lynn, J., Foley, D. J., Lipson, S. & Guralnik, J. M. 2003. Patterns of functional decline at the end of life. Jama, 289, 2387-2392.

Luszczynska, A., Schwarzer, R., Lippke, S. & Mazurkiewicz, M. 2011. Self-efficacy as a moderator of the planning–behaviour relationship in interventions designed to promote physical activity. Psychology and Health, 26, 151-166.

Mak, M. K. & Ng, P. L. 2003. Mediolateral sway in single-leg stance is the best discriminator of balance performance for Tai-Chi practitioners. Archives of physical medicine and rehabilitation, 84, 683-686.

Martín-Moya, R., Ruiz-Montero, P. J., García, E. R. & Leeson, G. 2020. Psychological and environmental factors for older adults to exercise: A systematic review. Revista de psicología del deporte, 29, 93-104.

Mcauley, E., Jerome, G. J., Marquez, D. X., Elavsky, S. & Blissmer, B. 2003. Exercise self-efficacy in older adults: social, affective, and behavioral influences. Annals of behavioral medicine, 25, 1-7.

Mcauley, E., Mailey, E. L., Mullen, S. P., Szabo, A. N., Wójcicki, T. R., White, S. M., Gothe, N., Olson, E. A. & Kramer, A. F. 2011. Growth trajectories of exercise self-efficacy in older adults: influence of measures and initial status. Health Psychology, 30, 75.

Miller, S. & Taylor-Piliae, R. E. 2018. The association between Tai Chi exercise and safe driving performance among older adults: An observational study. Journal of sport and health science, 7, 83-94.

Mitchell, W. K., Atherton, P. J., Williams, J., Larvin, M., Lund, J. N. & Narici, M. 2012. Sarcopenia, dynapenia, and the impact of advancing age on human skeletal muscle size and strength; a quantitative review. Frontiers in physiology, 3, 260.

Molina, M. D. & Myrick, J. G. 2021. The ‘how’ and ‘why’of fitness app use: investigating user motivations to gain insights into the nexus of technology and fitness. Sport in Society, 24, 1233-1248.

Nelson, M. E., Layne, J. E., Bernstein, M. J., Nuernberger, A., Castaneda, C., Kaliton, D., Hausdorff, J., Judge, J. O., Buchner, D. M. & Roubenoff, R. 2004. The effects of multidimensional home-based exercise on functional performance in elderly people. The Journals of Gerontology Series A: Biological Sciences and Medical Sciences, 59, M154-M160.

Nyman, S. R. 2020. Tai chi for the prevention of falls among older adults: a critical analysis of the evidence. Journal of aging and physical activity, 1, 1-10.

Oman, R. F. & King, A. C. 1998. Predicting the adoption and maintenance of exercise participation using self-efficacy and previous exercise participation rates. American Journal of Health Promotion, 12, 154-161.

Orange, S. T., Marshall, P., Madden, L. A. & Vince, R. V. 2019. Short-Term Training and Detraining Effects of Supervised vs. Unsupervised Resistance Exercise in Aging Adults. The Journal of Strength & Conditioning Research, 33, 2733-2742.

Pate, R. R., Pratt, M., Blair, S. N., Haskell, W. L., Macera, C. A., Bouchard, C., Buchner, D., Ettinger, W., Heath, G. W. & King, A. C. 1995. Physical activity and public health: a recommendation from the Centers for Disease Control and Prevention and the American College of Sports Medicine. Jama, 273, 402-407.

Perkin, O. J., Mcguigan, P. M. & Stokes, K. A. 2019. Exercise Snacking to Improve Muscle Function in Healthy Older Adults: A Pilot Study. Journal of aging research, 2019.

Phoenix, C. & Orr, N. 2014. Pleasure: A forgotten dimension of physical activity in older age. Social science & medicine, 115, 94-102.

Pinedo-Villanueva, R., Westbury, L. D., Syddall, H. E., Sanchez-Santos, M. T., Dennison, E. M., Robinson, S. M. & Cooper, C. 2019. Health Care Costs Associated With Muscle Weakness: A UK Population-Based Estimate. Calcified Tissue International, 104, 137-144.

Resnick, B. & Spellbring, A. M. 2000. Understanding what motivates older adults to exercise. SLACK Incorporated Thorofare, NJ.

Reynes, E., Dumoulin, C., Robert, B. & Berthouze, S. E. 2019. Why aren’t they involved in physical activities? The hypothesis of negative self-perception due to past physical activity experiences. Cogent Psychology, 6, 1570691.

Ritchie, J., Spencer, L., Bryman, A. & Burgess, R. 1994. Qualitative data analysis for applied policy research. Analyzing qualitative data, 173, 194.

Sandlund, M., Pohl, P., Ahlgren, C., Skelton, D. A., Melander-Wikman, A., Bergvall-Kåreborn, B. & Lundin-Olsson, L. 2018. Gender perspective on older people's exercise preferences and motivators in the context of falls prevention: A qualitative study. BioMed research international, 2018.

Schoenborn, N. L., Rasmussen, S. E. V. P., Xue, Q.-L., Walston, J. D., Mcadams-Demarco, M. A., Segev, D. L. & Boyd, C. M. 2018. Older adults' perceptions and informational needs regarding frailty. BMC geriatrics, 18, 1-7.

Sekhon, M., Cartwright, M. & Francis, J. J. 2017. Acceptability of healthcare interventions: an overview of reviews and development of a theoretical framework. BMC health services research, 17, 1-13.

Sjösten, N. M., Salonoja, M., Piirtola, M., Vahlberg, T. J., Isoaho, R., Hyttinen, H. K., Aarnio, P. T. & Kivelä, S.-L. 2007. A multifactorial fall prevention programme in the community-dwelling aged: predictors of adherence. European Journal of Public Health, 17, 464-470.

Son, N.-K., Ryu, Y. U., Jeong, H.-W., Jang, Y.-H. & Kim, H.-D. 2016. Comparison of 2 different exercise approaches: Tai Chi versus Otago, in community-dwelling older women. Journal of geriatric physical therapy, 39, 51-57.

Sparling, P. B., Howard, B. J., Dunstan, D. W. & Owen, N. 2015. Recommendations for physical activity in older adults. Bmj, 350, h100.

Su, J. 2013. The Historical Origin of the Chinese Taoist and Tai Chi'. Physical Education of Northwestern Polytechnical University, 58 (25), 111-114.

Teixeira, P. J., Carraça, E. V., Markland, D., Silva, M. N. & Ryan, R. M. 2012. Exercise, physical activity, and self-determination theory: a systematic review. International journal of behavioral nutrition and physical activity, 9, 1-30.

Thompson, W. W., Zack, M. M., Krahn, G. L., Andresen, E. M. & Barile, J. P. 2012. Health-related quality of life among older adults with and without functional limitations. American journal of public health, 102, 496-502.

UK Government 2019. UK Chief Medical Officers' Physical Activity Guidelines In: Department of health and social care (ed.).

Van Damme, J., Neiterman, E., Oremus, M., Lemmon, K. & Stolee, P. 2020. Perspectives of older adults, caregivers, and healthcare providers on frailty screening: a qualitative study. BMC geriatrics, 20, 1-12.

Warmoth, K., Lang, I. A., Phoenix, C., Abraham, C., Andrew, M. K., Hubbard, R. E. & Tarrant, M. 2016. 'Thinking you're old and frail': a qualitative study of frailty in older adults. Ageing & Society, 36, 1483-1500.

Wayne, P. M., Walsh, J. N., Taylor-Piliae, R. E., Wells, R. E., Papp, K. V., Donovan, N. J. & Yeh, G. Y. 2014. Effect of Tai Chi on cognitive performance in older adults: Systematic review and meta-Analysis. Journal of the American Geriatrics Society, 62, 25-39.

WHO. 2020. WHO guidelines on physical activity and sedentary behaviour [Online]. Geneva: World Health Organization. Available: https://www.who.int/publications/i/item/9789240015128 [Accessed].

Yardley, L., Bishop, F. L., Beyer, N., Hauer, K., Kempen, G. I., Piot-Ziegler, C., Todd, C. J., Cuttelod, T., Horne, M. & Lanta, K. 2006. Older people's views of falls-prevention interventions in six European countries. The Gerontologist, 46, 650-660.

Zhong, D., Xiao, Q., Xiao, X., Li, Y., Ye, J., Xia, L., Zhang, C., Li, J., Zheng, H. & Jin, R. 2020. Tai Chi for improving balance and reducing falls: An overview of 14 systematic reviews. Annals of physical and rehabilitation medicine.

Exercise snacking instructions

What is exercise snacking?

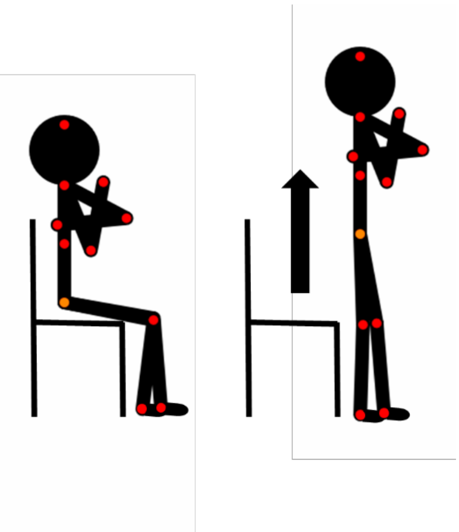
This is a method of structuring exercise into short bouts. We are asking you to try this short exercise snacking routine on 3 days this week, which will include 5 minutes of exercise and 1 minute of rest between each exercise. The exercises themselves are safe for the home and don't require a warm-up before starting. The exercises do not require any sports clothing or equipment; just a kitchen chair.

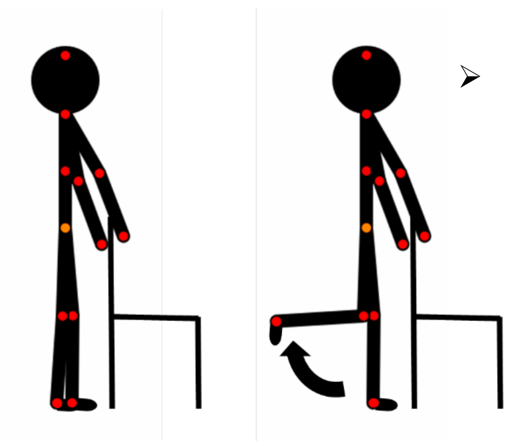
How is the exercise performed?

During each exercise bout, spend one minute performing each of the five exercises detailed below. Complete repetitions of each exercise at a self-selected pace that is comfortable to maintain for the full minute, with the aim being to complete as many repetitions as possible in that minute. If your legs begin to feel unduly sore during the any of the exercises, you may of course stop that exercise at that time. Take one minute between each exercise to rest.

What is the exercise snacking routine?

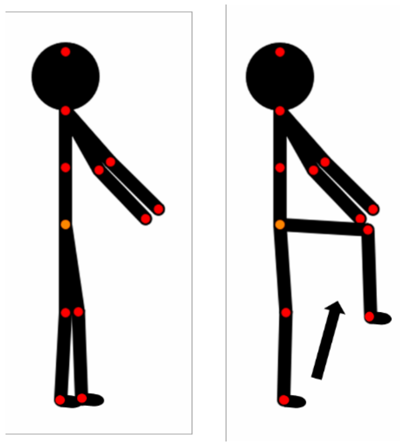
- **Sit-to-stand:** This exercise is simply repetition of rising from an up-right seated position on a kitchen chair, and then returning to the seated position. Try to keep your arms folded across your chest to avoid using your arms to aid rising from the chair, making sure that your legs are doing the work. We suggest that this always be the first exercise performed in the routine, and recording the number of sit-to-stands performed in the minute each time lets you track your progress.

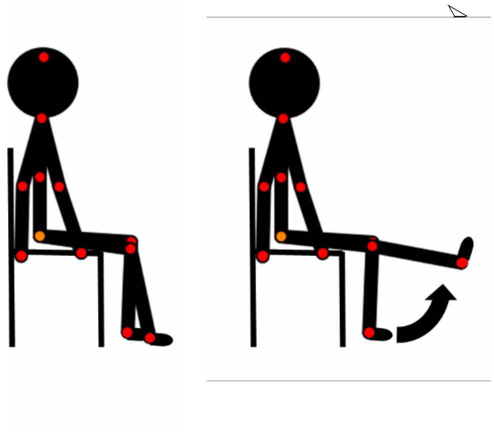




- **Standing knee bends:** Standing up-right and holding onto something stable for balance if needed, raise one foot at a time by bending your knee to roughly a right angle. Then return that foot to the floor, regain your balance if necessary, and repeat with the opposite leg.

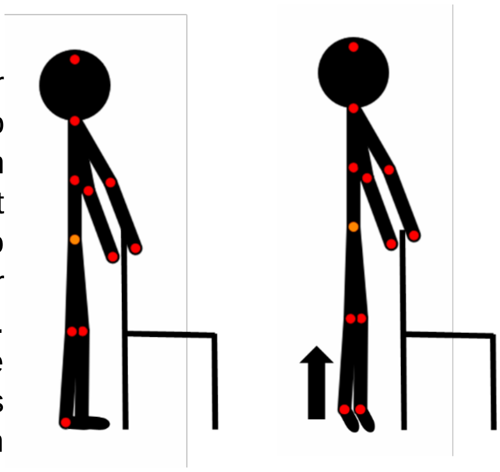
- **March on the spot:** Standing up-right, put your arms out in front of you and your hands roughly at waist height, raise one leg up by bending your knee and hip as per the diagram. Aim to get your thigh as close to horizontal as possible, with the top of your thigh touching your hands, then return to a standing position, regain balance if necessary, and repeat with the other leg. If you struggle with balance, you can hold onto something stable like the back of a chair with one hand.





- **Seated leg kicks:** Sitting up-right in a chair, straighten your knee to raise your leg out in front of you at a controlled speed, and then return that leg to the starting position, and repeat using the other leg. If you have quite long legs, it may help to place a rolled up towel under your thigh to raise your knee a little higher in the start position.

- **Standing calf raises:** Start with your feet flat on the floor and rise up onto your tip-toes as high as you can, then return to the start position with feet flat on the floor. It is advisable to hold onto something stable like a chair, table, or door frame to maintain balance. Perform the raises on both legs at the same time, and try to complete as many as you can in a minute, and then rest for a minute.



What are the risks of performing the exercise?
As with any exercise, you are likely to feel tired towards the end of the session and in the time straight afterwards. However, the principle of exercise snacking is that the bouts should not be excessively demanding, with each exercise of the regime performed for only one minute at a self-selected repetition speed. The primary risk when performing the exercise is loss of balance during the standing exercises. This risk can be mitigated by performing the movements at a controlled, and by holding onto a stable object such as a chair, table, or door frame. This exercise regime has been designed specifically to avoid any cardiovascular load, as might be experienced during running. If your legs begin to feel unduly sore during the any of the exercises, you may of course stop that exercise at that time.

Tai-chi instructions

What is Tai-chi?

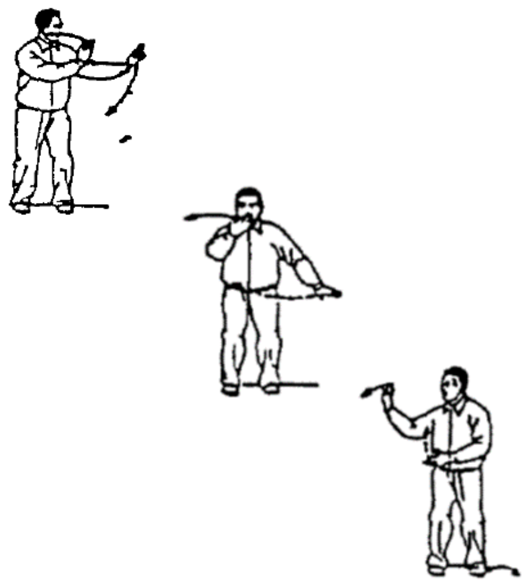
Tai-chi combines deep breathing and relaxation with flowing movements. The five main lower limb movements are selected for this routine. We are asking you to try this short Tai-chi routine on 3 days this week, which will include 5 minutes of exercise and 1 minute of rest between each exercise. The exercises themselves are safe for the home and don't require a warm-up before starting. The exercises do not require any sports clothing or equipment; just a kitchen chair if you feel you need extra support.

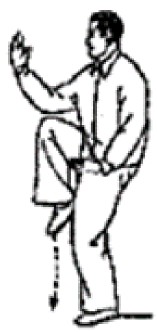
How is the exercise performed?

During each exercise bout, spend one minute performing each of the five exercises detailed below. Complete repetitions of each exercise at a self-selected pace that is comfortable for you to maintain for the full minute, with the aim being to complete them as accurately and smoothly as possible (based on correct posture and proper alignment). If your legs begin to feel sore during the any of the exercises, you may of course stop that exercise. Make sure you take one minute of rest between each exercise.

What is the Tai-chi 5 main movements routine?

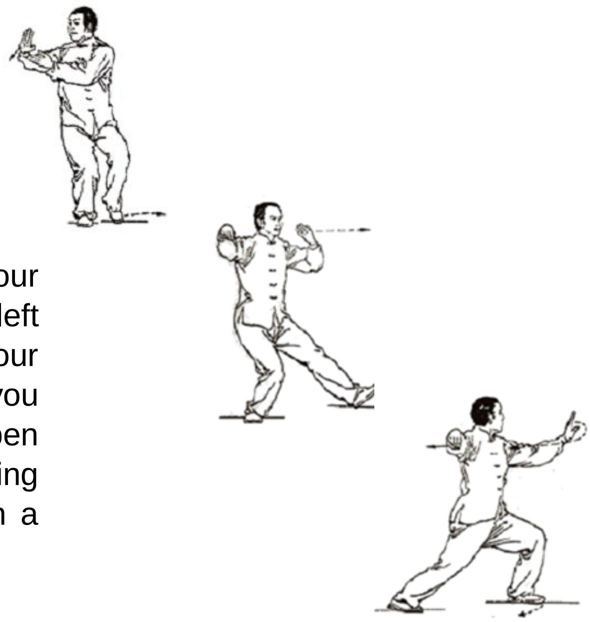
- **Cloud hands, going left :** Standing with your knees slightly bent, feet shoulder width apart and facing forward, shifting your body weight from the right leg to left leg with the hands crossing from right to left (with left palm facing you at shoulder height and right palm facing the floor at waist height). After shifting your body weight to left leg completely, take a small step to bring your right foot back in and change arms so the right is on top, and left at waste height. Shift your body weight back to the right leg, and repeat the movement. We suggest that this always be the first exercise performed in the routine.

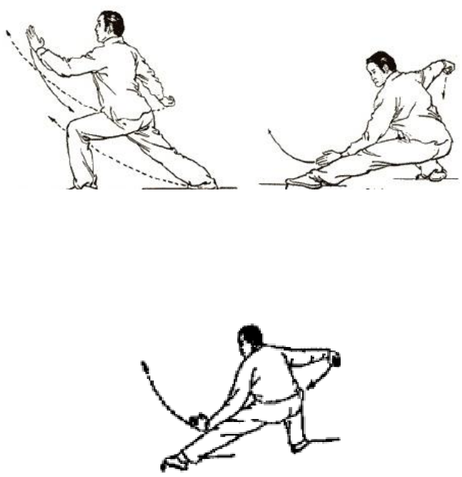




- **Stand on one leg:** Start in a standing position with your hands by your side. Shift your weight to left leg; lift the right heel off the ground and then raise your right leg off the floor and right arm with hand facing inwards in a slow steady movement. Keep your left knee slightly bent and left arm by your side. Aim to get your right thigh as close to horizontal as possible, then return that foot to the floor, regain your balance if necessary, and repeat with the right leg for 30 seconds after doing stand on left leg for 30 seconds. If you struggle with balance, you can hold onto something stable like the back of a chair.

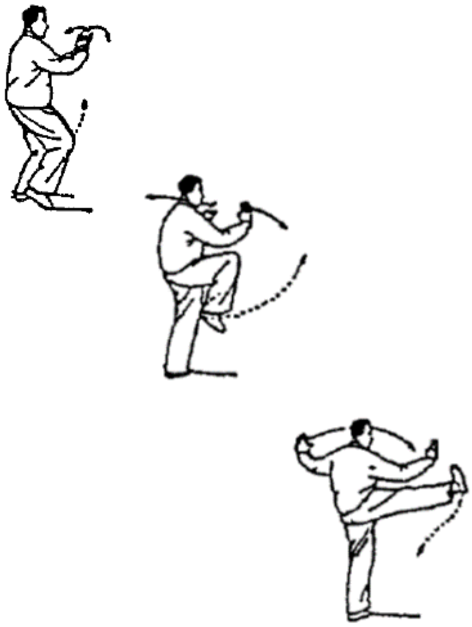
- **Single whip:** Hook your fingers and thumb of the right hand in a slight closure and place the left hand nearer to your face with palm facing yourself; shift back and lift the left heel. Try to keep your weight on single leg stably then shift your body weight from your right leg onto your left leg slowly and then take a step out with your left leg (pushing with the right leg when you get beyond halfway). Turn your hips and open your arms outward at the same time, making sure that your legs are doing the work in a slow, controlled motion.





- **Snake creeps through the grass:** Starting from the final posture of the Single whip exercise, turn out the right toe (so your feet are at 90 degrees) and open your hip joint. Shift back and sit into the right leg, slowly drop down as low as possible with left hand crossing near your ankle. Then push off the right leg with left leg bending progressively, and shift your body weight to the left leg, go forward with left hand end at shoulder height. The most important thing is keeping your spine as straight as possible, not how low you go.

- **Front heel kick:** From a standing position with your hands cross, sit gradually into the left hip and lift the right heel. Try to keep your weight on left leg and remain stable while raising your right leg with your knee bent, then kicking the right leg forward slowly and open the arms outward at the same time. Aim to kick your leg (slowly) in a controlled manner as high as possible, then slowly return that foot to the floor. Regain your balance if necessary and repeat with the left leg kicking for 30 seconds after doing right leg kicking for 30 seconds. If you struggle with balance, you can hold onto something stable like the back of a chair with one hand.



What are the risks of performing the exercise?
As with any exercise, you are likely to feel tired towards the end of the session and in the time straight afterwards. However, the principle of Tai-chi is that the movements should not be excessively demanding, with each exercise of the routine performed for only one minute at a self-selected repetition speed. The primary risk when performing the exercise is loss of balance. This risk can be mitigated by performing the movements at a controlled speed, and by holding onto a stable object such as a chair, table, or door frame. This exercise regime has been designed specifically to avoid any cardiovascular load, as might be experienced during running. If your legs begin to feel overly sore during the any of the exercises, you may of course stop that exercise at that time.

3.4 Summary

This chapter investigated the acceptability of home-based exercise snacking and Tai-chi snacking in UK and Taiwanese older adults and showed that both exercise snacking and Tai-chi snacking were reported to be acceptable and feasible to implement in home settings for older adults. Notably, very little difference between the UK and Taiwanese participants in the experiences of the exercise snacking and Tai-chi snacking regime was found. Based on the seven domains of the theoretical framework of acceptability, the results of semi-structured interviews demonstrated that:

i. Affective attitude: the preferred snacking exercise mode was dependent on participants' different physical functions and nationalities.
ii. Burden: older adults with lower physical function reported the snacking exercises to be too intense and some found Tai-chi snacking movements to be complicated.
iii. Opportunity costs: the convenience of the 10-minute snacking exercise regime was reported.
iv. Perceived effectiveness: participants believed that the snacking exercises would benefit their physical and mental health in longer-term, yet they indicated the one-week short trial to be too short to see any changes.
v. Intervention coherence: exercise snacking was considered to be more acceptable than Tai-chi snacking, for which some thought the movements could be changed to easier patterns for beginners.
vi. Ethicality: participants found the snacking exercises to be appropriate for people in their age groups, while some Taiwanese older women reported their busy lives to be barriers to participation.
vii. Self-efficacy: considering individuals' physical function and finding ways to support the initial engagement are important for improving self-efficacy and exercise adherence.

Overall, the findings indicated that these novel exercise and Tai-chi snacking programmes are convenient and safe to older adults aged over 65. Overall, this qualitative study of acceptability shows that the exercise and Tai-chi snacking programme is acceptable, however more support may be a welcome addition. According to the participants' feedback, simplifying Tai-chi snacking movements and adding upper body movements in exercise snacking programme should be considered. Improvements to the video instructions were also recommended, with suggestions of making the video instruction a mirror image or filmed from the back for a full minute of one movement so participants could learn by copying. It is also imperative to consider individuals' physical function when designing exercise regimens. Given these points, the progressive exercise and Tai-chi snacking programme, including upper body exercises, was created and utilised in Chapter 5. The newly made videos were also released and applied in Chapter 5.

Concerning the limitation of the short-term initial investigation in this study, doing longer-term snacking exercise interventions, and investigating its effectiveness and adherence could address whether the perceived interest would translate to long-term engagement. However, due to the restrictions and lost time caused by the COVID-19 pandemic, I had to make adjustments to the thesis's scope. Originally, I had planned to examine potential differences in the interventions' efficacy between Taiwanese and UK participants. However, given the challenges and uncertainties posed by the pandemic, the cross-cultural aspect of the thesis was dropped at this stage. Despite this fact, the qualitative findings in this chapter showed very little difference between Taiwanese and UK participants.

In response to the COVID-19 pandemic, a part of this study was conducted remotely. The circumstances at the time lead us to the idea of investigating whether delivering an exercise and Tai-chi snacking programme entirely remotely was feasible in older adults. Furthermore, this necessitated that we attempt to conduct all quantitative outcome measures via video meeting too, so the acceptability of remote assessment as well as remote intervention delivery was raised. With these points in mind, the next chapter sought to answer the following research question.

Research question 3: How feasible and acceptable is the assessment and delivery of home-based exercise snacking and Tai-Chi snacking when delivered remotely to self-isolating older adults?

4 Chapter V – Covid-19 remote study

Feasibility and Acceptability of Home-Based Exercise Snacking and Tai Chi Snacking Delivered Remotely to Self-Isolating Older Adults During COVID-19

4.1 Context

In Chapter 3, we preliminarily understood that home-based exercise and Tai-chi snacking programme was acceptable in healthy older adults with different cultural backgrounds. However, this preliminary qualitative study only involved one-week intervention trial with one-off exercise demonstration sessions. In any case, we also acknowledged that we needed to find better ways to deliver home-based strength and balance exercises as to reduce the burden and cost of personal training according to the findings of the systematic review and meta-analysis in Chapter 2. Based on these ideas, it is undoubtfully important to understand whether longer-term intervention of our programme is feasible, applicable for older adults and whether lengthening the programme would change the acceptability which we found in the previous chapter.

Following the restrictions of Covid-19 lockdowns, the partial UK-based data collection in the qualitative study (Chapter 3) was conducted online with 17 participants who completed the study remotely. Given the successful online protocols used in Chapter 3, the current chapter provided remote home-based exercises to older adults during the Covid-19 pandemic and assessed whether these exercises could maintain older adults' abilities of daily life, physical activity levels, and physical health and mental wellbeing.

Consequently, this chapter investigated the feasibility and acceptability of remotely delivered, unsupervised 4-week home-based exercise programmes in older adults who were self-isolating during the COVID-19 pandemic. Additionally, we explored the effectiveness of the home-based exercise programmes on physical function, exercise cognitions, and wellbeing. This chapter would help us understand the possibility of delivering home-based exercises unsupervised and remotely as well as provide further strategies on applying suitable home-based exercises in older adults who are limited to movement or avoiding physical contact that may affect physical activity behaviours.

4.2 Statement of authorship

This declaration concerns the article entitled:	
Feasibility and Acceptability of Home-Based Exercise Snacking and Tai Chi Snacking Delivered Remotely to Self-Isolating Older Adults During COVID-19	
Publication status (tick one)	
Draft manuscript ☐ **Submitted** ☐ **In review** ☐ **Accepted** ☐ **Published** ✔	
Publication details (reference)	Liang, I.J., Perkin, O.J., McGuigan, P.M., Thompson, D. and Western, M.J., 2021. Feasibility and acceptability of home-based exercise snacking and tai chi snacking delivered remotely to self-isolating older adults during COVID-19. Journal of Aging and Physical Activity, 30(1), pp.33-43.
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Candidate's contribution to the paper (provide details, and also indicate as a percentage)	The candidate contributed to / considerably contributed to / predominantly executed the… Formulation of ideas: 80% Design of methodology: 80% Experimental work: 85% Presentation of data in journal format: 80%
Statement from Candidate	This paper reports on original research I conducted during the period of my Higher Degree by Research candidature. The EMA substudy included in the published article is removed from my thesis since I was not the lead researcher of the EMA substudy.
Signed (typed signature)	**Date**

4.3 Paper 3: Feasibility and Acceptability of Home-Based Exercise Snacking and Tai Chi Snacking Delivered Remotely to Self-Isolating Older Adults During COVID-19

4.3.1 Abstract

The purpose of this study was to examine the feasibility and acceptability of remotely delivered, home-based exercise programs on physical function and well-being in self-isolating older adults during the COVID-19 pandemic. In a four-arm randomized controlled trial, 63 participants (aged 65 years and older) were allocated to one of three home-based daily (2 × 10-min) exercise interventions (exercise snacking, tai chi snacking, and combination) or control (UK National Health Service Web pages). Functional assessments were conducted via video call at baseline and 4-week follow-up. A web-based survey assessed the acceptability of each exercise program and secondary psychological/well-being outcomes. All intervention groups saw increased physical function at follow-up and displayed good adherence with exercise snacking considered the most acceptable program. Further studies are needed with larger, more diverse demographic samples.

Keywords: active aging, physical activity, physical function, randomized controlled trial

4.3.2 Introduction

During the COVID-19 pandemic, adults aged over 70 years in the United Kingdom were directed to remain in their homes at all times for 12 weeks from March 22, 2020, except for emergencies (UK Government, 2020). The experience of "shielding" will no doubt have varied widely for older adults; however, it is likely that the constraints on movement and social contact will have altered physical activity behaviours.

Maintaining physical activity is crucial in preventing age-related loss of muscle strength and other key health outcomes (Booth & Hargreaves, 2011). Reduced strength increases the likelihood of frailty, falls, and loss of independence, hugely impacting individuals' quality of life while also placing an enormous burden on health and social care systems (Pinedo-Villanueva et al., 2019). Even a small period of reduced activity can lead to meaningful losses in muscle function (Oikawa, Holloway, & Phillips, 2019). In a recent global survey, gerontology researchers and clinicians ranked the wider societal impact, identification of interventions to promote healthy behaviours, remote delivery of treatments, and use of technology in older adults as COVID-19 research priorities (Richardson et al., 2020).

The U.K. Chief Medical Officer's guidance specifies the importance of exercises for muscle strength in older adults, recommending that resistance exercise be performed twice per week and that those with poor mobility train their balance three times a week (UK Government, 2019). However, many older adults report a dislike for structured exercise (Burton, Lewin, & Boldy, 2013) and very few U.K. older adults meet the recommended strength and balance guidelines even in usual conditions (Department of Health, 2016; Strain, Fitzsimons, Kelly, & Mutrie, 2016). Identifying strategies to facilitate strength and balance training in self-isolating older adults is a key step in mitigating functional decline. Furthermore, higher physical activity levels are associated with better well-being (Anokye, Trueman, Green, Pavey, & Taylor, 2012). Studies have shown that improvements in older adults' quality of life can result from positive effects on fitness functions, performance of daily activities, and enjoyment of exercise interventions (Elavsky et al., 2005; Kallings, Leijon, Hellénius, & Ståhle, 2008; Langlois et al., 2013). Consequently, exercising may also alleviate the impact of shielding on well-being in older adults during a sustained period of self-isolation. It is imperative that the introduction of exercise into older adults' lives is in compliance with self-isolation guidelines and does not bring undue risk of adverse events, particularly while the NHS is under the strain of a pandemic.

Home-based exercise snacking (ES) has been identified as an accessible and low-risk alternative to traditional resistance exercise in older adults with the potential to improve leg strength without the need for specialist facilities (Perkin, McGuigan, & Stokes, 2019). The ES model previously explored saw participants attempt as many repetitions as possible in 1 min for one exercise before resting for 1 min and repeating the process with four more exercises. This temporal structure and intensity of exercise deviates from the traditional resistance exercise model but allows more frequent bouts of exercise. Alternatively, practicing Tai-chi has been demonstrated to improve mobility in community-dwelling older women to a similar extent as the Otago home-based strength and balance training program (Son, Ryu, Jeong, Jang, & Kim, 2016). Tai-chi also requires no equipment and little space with movements performed slowly and gently, so is considered relatively safe for older adults to perform in the home and unsupervised (Huston & McFarlane, 2016; Wayne, Berkowitz, Litrownik, Buring, & Yeh, 2014).

Several studies have indicated that practicing Tai-chi can improve cardiopulmonary function and balance in older adults (Kutner, Barnhart, Wolf, McNeely, & Xu, 1997; Rogers, Larkey, & Keller, 2009), but none has explored Tai-chi in a simple “snacking” format, which may help novices engage with this form of exercise in a home setting (Barrado-Martín, Heward, Polman, & Nyman, 2019). Evidence suggests that for the more frail older adults, Tai-chi alone may not be sufficient to prevent falls (Nyman & Skelton, 2017), so combining both strength exercise and Tai-chi snacking (TCS) may be a useful light-touch intervention. These exercise strategies may lend themselves to remote delivery for older adults in the context of the COVID-related lockdown restrictions. As researchers and clinicians adapt to the constraints of fewer face-to-face interactions, it will be crucial to understand the attitudes of older adults toward the remote delivery of health interventions.

Given the unique context afforded by the COVID-19 pandemic as well as the effectiveness on function, it would be interesting to understand the role of ES and TCS on older adults’ psychological states. Furthermore, exploring the effects of exercise cognition could provide valuable insights into behaviour change among older adults and how exercise cognition influences their willingness and confidence in engaging in physical activity. Exercise cognitions include individuals’ beliefs, attitudes, and self-confidence toward exercise (Kwan & Bryan, 2010; Cousins, 1996; Neupert, Lachman, & Whitbourne, 2009). Given the barriers around motivation and self-efficacy for traditional exercise, it is worth exploring whether exercise cognitions may be altered following participation in home-based ES and TCS as an alternative strategy in individuals with low self-confidence in participating in regular exercise. The goal is to determine whether participation in a simple snacking exercise programme positively impacts participants' exercise cognitions in a positive way that might impact their future engagement in muscle strength and balance exercise.

The primary aim of this study was to test the feasibility and acceptability of 4 weeks of home-based ES, TCS, or combined exercise interventions delivered remotely to self-isolating older adults during the COVID-19 pandemic. The secondary aim was to explore whether any of these exercise strategies showed signs of improving strength and balance, exercise cognitions, mood, and well-being.

4.3.3 *Methods*

Study Design

This U.K.-based study used a four-arm, assessor blind, randomized controlled trial design, implementing a 4-week exercise intervention between two remote assessments. Ethical approval for the study was provided by the University of Bath Research Ethics Approval Committee for Health (Reference: EP 19/20 034).

Participant Recruitment and Screening

Participants who were ≥65 years and not participating in regular structured exercise were recruited between May 4th and 25th, 2020, to ensure the 4-week intervention was undertaken within the prescribed 12-week COVID-19 lockdown. The study was advertised on the University of Bath Web page, by local retirement communities or older adult organizations, to prior research participants, and on social media. Potential participants were directed to an online participant information sheet, informed consent form, and screening questionnaire.

Participants were excluded if they had a chronic disease (cardiac, pulmonary, liver or kidney abnormalities, uncontrolled hypertension, or peripheral arterial disease), a current musculoskeletal injury precluding exercise participation, contraindications to exercise (chest pain, dizziness, or loss of consciousness), or had been instructed by their doctor to only do physical activity recommended by them. For safety, potential participants scoring >4 on the Groningen Frailty Indicator (GFI; Peters, Boter, Burgerhof, Slaets, & Buskens, 2015) were also excluded.

Eligible participants, all of whom provided informed consent, completed the following validated questionnaires online: the International Physical Activity Questionnaire-elderly short-form (Hurtig-Wennlöf, Hagströmer, & Olsson, 2010); the Short Form Health Survey (Ware, Kosinski, & Keller, 2001) in which higher scores represent better mental or physical health; the Beck Anxiety Inventory (Beck, Epstein, Brown, & Steer, 1988) and Beck Depression Inventory (Beck, Ward, Mendelson, Mock, & Erbaugh, 1961) in which lower scores represent low anxiety or depression symptoms; and the Subjective Vitality Scale (Ryan & Frederick, 1997) and Satisfaction With Life Scale (Diener, Emmons, Larsen, & Griffin, 1985), both of which are scored from 1 (low) to 7 (high).

Participants were also asked to score various exercise cognitions, namely, their perceived competence (Williams & Gill, 1995), which uses a Likert scale from 1 (low competence) to 7 (high competence); self-efficacy (Resnick & Jenkins, 2000), which asks participants to rate their confidence in overcoming eight barriers to exercise, such as boredom, pain, and stress, from 0 (low self-efficacy) to 100 (high self-efficacy); outcome expectancies (Wójcicki, White, & McAuley, 2009), which uses a Likert scale to rank 15 statements about the expected benefits of exercise from 1 (low outcome expectancy) to 5 (high outcome expectancy); and habit strength (Verplanken & Orbell, 2003), which uses a Likert scale ranging from 1 (weak habit) to 7 (strong habit). Thereafter, participants were contacted to arrange a video assessment of their strength and balance.

The video assessment was conducted using participants' preferred video calling software. During the call, participants were given the chance to ask questions about the study and provided with instructions for the assessment. Following the initial safety screening using the chair rise (excluded if five repetitions took >16.7 s) and balance (excluded if unable to balance >10 s with feet together or in semitandem stand) components of the short physical performance battery (Guralnik et al., 1994), eligible participants completed a baseline functional assessment. With the camera positioned such that the researcher could see the participant's whole body in the frame, the maximum number of sit-to-stands from a hard-based kitchen chair in 60 s was used to assess muscle function. The researcher provided verbal instructions to start and stop the test. Participants then completed tandem stance and single-leg balance tests (on both legs), aiming to balance unaided for a maximum possible duration of up to 60 s. The post-intervention assessor was blind to the intervention group. All functional and questionnaire outcomes were reassessed at a 4-week follow-up.

Feasibility and Acceptability

To evaluate study feasibility, descriptive data on participant demographics, the remote assessment of physical function, randomization procedures, retention of participants at follow-up in the main trial, and completeness of data collection (including outcome data, and adherence logs) were collated. Acceptability was measured at follow-up with an eight-item online questionnaire based on the dimensions of the theoretical framework of acceptability (Sekhon, Cartwright, & Francis, 2017). This questionnaire was asked within the context of participants' allocated intervention with those in the combination group answering twice, once for each mode of exercise. An open question invited participants to provide feedback on the study procedures and the intervention they received.

Participants were randomized by an external researcher using block randomization. To ensure comparability in baseline physical function between study groups, participants were stratified for strength (scoring "low" if Five-repetition sit-to-stand >13.69 s and "high" if ≤13.69 s) and balance (scoring "low" if time standing on either leg was <10 s and high if ≥10 s). Couples wishing to take part were allocated to the same group to prevent contamination. The lead researcher (I.J. Liang) was blinded from participants' group allocation until all follow-up assessments were completed.

Table 4-1 summarizes the interventions. Participants in the ES, TCS, and combination groups were e-mailed instructions (in written and video format) on how to safely perform the exercises. Participants were also asked to keep an exercise log to record both program-related and additional outdoor exercise undertaken during the 4-week period. They were also instructed to report any adverse events (i.e., injury or illness) that were sustained during the duration of the study. Supplementary Material 1 includes the instructions and adherence logs that participants received.

Data Handling and Analysis

Descriptive statistics on recruitment and adherence were used to interpret the feasibility of this remote assessment, and baseline differences between groups were tested using one-way analysis of variance on IBM SPSS Statistics (version 25.0; IBM Corp., Armonk, NY) or chi-square/Fisher's exact tests for frequency data on R (version 3.6.1; R core team, Vienna, Austria; R core Team) with RStudio (version 1.2.1335; RStudio, Boston, MA; RStudio Team, 2019). For quantitative outcomes, baseline and follow-up unadjusted means (SDs) were calculated.

Table 4-1. Description of the Exercise Interventions That Each Trial Arm Was Asked to Complete

Intervention Arm	Description	Frequency
Exercise snacking	Five movements (sit-to-stand from a chair, seated knee extensions of alternating legs, standing knee bends of alternating legs, marching on the spot, and standing calf raises), each undertaken for one minute with the aim of completing as many repetitions as possible. Participants rested for one minute between exercises.	Twice per day for 28 days
Tai-chi snacking	Five Chen Style Tai-Chi movements (cloud hands, going left, stand on one leg, single whip, snake creeps through the grass, front heel kick), each undertaken for one minute with the aim of completing them as accurately and gently as possible. Participants rested for one minute between exercises.	Twice per day for 28 days
Combination	Participants were instructed to do one exercise snacking bout and one Tai-chi snacking bout (as described above).	One set of each exercise per day for 28 days
Control	Participants were provided with a link to the NHS webpage titled 'Physical activity guidelines for older adults' (NHS, 2019)	Not prescribed

4.3.4 Results

Feasibility

Figure 4-1 indicates the flow of participants through the study. Of the 99 volunteers who responded to the study adverts, 63 passed screening tests, and 56 (89%) completed their follow-up assessment. The main reason for exclusion at the screening was scoring high for frailty. It should be noted that a further three participants initially scored >4 on the GFI owing to misinterpretation of that particular online survey, which was explained to the lead researcher during an exclusion call. Upon reassessment of GFI, those scoring ≤4 were subsequently included in the study, providing they also passed the functional safety screening. The reassessment led to an inclusion of an additional (n=3) participant in the study.

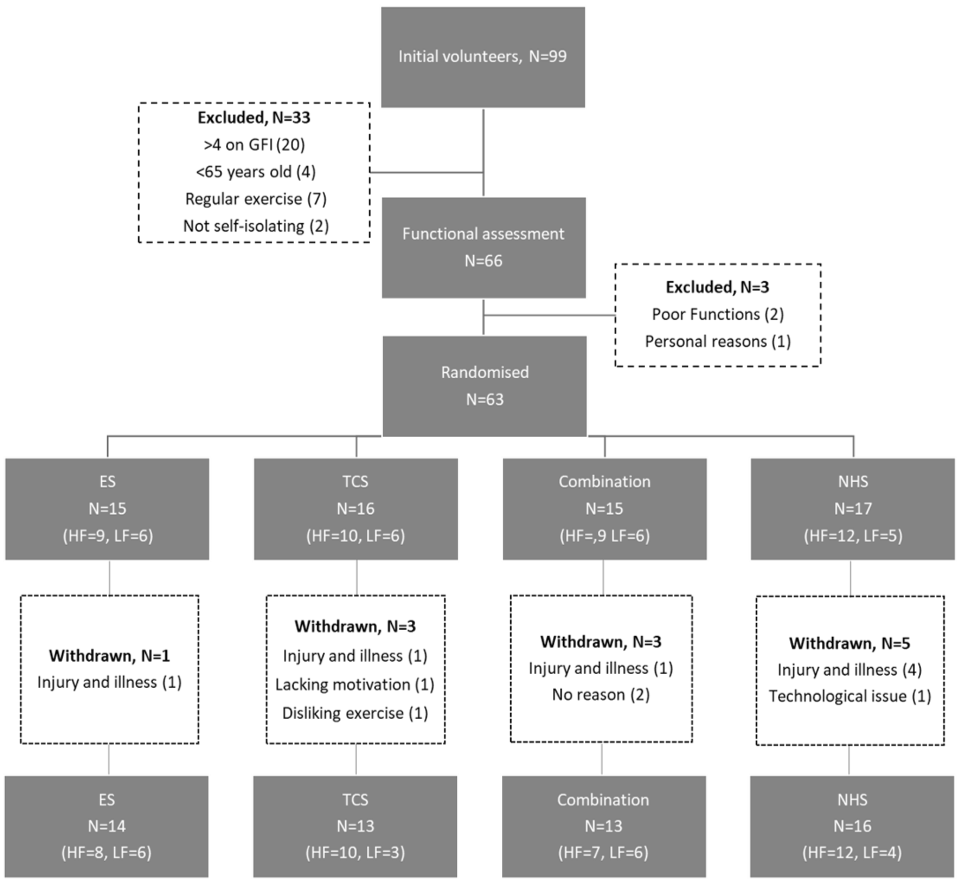


Figure 4-1. Flow diagram of participation throughout all aspects of the study. A total of 33 participants were deemed ineligible. ES = exercise snacking; TCS = Tai-chi snacking; combination, exercise snacking and tai chi; NHS, NHS exercise advice; HF = high function; LF = low function; GFI = Groningen Frailty Indicator.

Baseline characteristics are shown in Table 4-2. No significant differences were observed in demographic characteristics between groups, which were also well balanced for physical function. The sample represented a good split on biological sex and had an age range of 65–83 years but was predominately married, White British, educated at degree level or greater, and of high socioeconomic status.

Table 4-2. Baseline Characteristics of Randomized Study Participants

Characteristics	**Total (*N* = 63)**	**ES (*N* = 15)**	**TCS (*N* = 16)**	**Combination (*N* = 15)**	**Control (*N* = 17)**	***P* difference**
Female, *n* (%)	34 (54)	10 (67)	10 (63)	5 (33)	9 (53)	.259[a]
Age (years), mean (*SD*)	72.2 (4.7)	71.1 (3.6)	72.6 (5.0)	73.3 (5.3)	71.9 (4.7)	.598[c]
65–73 years old, *n* (%)	40 (63)	12 (80)	10 (63)	8 (53)	10 (59)	
≥74 years, *n* (%)	23 (37)	3 (20)	6 (38)	7 (47)	7 (41)	.458[a]
Living alone, *n* (%)	13 (21)	2 (13)	4 (25)	2 (13)	5 (29)	.629[b]
Marital status, *n* (%)						.884[b]
Married/ civil partnership	47 (75)	13 (87)	10 (63)	12 (80)	12 (71)	
Divorced/separated	8 (13)	2 (13)	2 (13)	1 (7)	3 (18)	

Characteristics	Total (*N* = 63)	ES (*N* = 15)	TCS (*N* = 16)	Combination (*N* = 15)	Control (*N* = 17)	*P* difference
Widowed	3 (5)	0 (0)	1 (6)	1 (7)	1 (6)	
Cohabiting	3 (5)	0 (0)	2 (13)	1 (7)	0 (0)	
Single	2 (3)	0 (0)	1 (6)	0 (0)	1 (6)	
Employment, *n* (%)						.117[b]
Retired	52 (83)	10 (67)	12 (75)	15 (100)	15 (88)	
Employed part-time	8 (13)	3 (20)	3 (19)	0 (0)	2 (12)	
Doing unpaid work	2 (3)	2 (13)	0 (0)	0 (0)	0 (0)	
Unable to work	1 (2)	0 (0)	1 (6)	0 (0)	0 (0)	
Educational status, *n* (%)						.547[b]
Secondary education	5 (8)	1 (7)	0 (0)	2 (13)	2 (12)	
Postsecondary	8 (13)	2 (13)	2 (13)	2 (13)	2 (12)	

Characteristics	Total (*N* = 63)	ES (*N* = 15)	TCS (*N* = 16)	Combination (*N* = 15)	Control (*N* = 17)	*P* difference
Vocational qualification	12 (19)	2 (13)	1 (6)	4 (27)	5 (29)	
Undergraduate degree	18 (29)	5 (33)	4 (25)	4 (27)	5 (29)	
Postgraduate degree	15 (24)	4 (27)	8 (50)	1 (7)	2 (12)	
Doctorate	5 (8)	1 (7)	1 (6)	2 (13)	1 (6)	
Index of Multiple Deprivation decile						.747[c]
n	57	14	13	14	16	
Mean (*SD*)	8.0 (2.2)	8.4 (1.8)	7.8 (2.7)	7.6 (1.9)	8.3 (2.4)	
Physical function, *n* (%)						.911[a]
High	40 (63)	9 (60)	10 (63)	9 (60)	12 (71)	

Characteristics	Total (*N* = 63)	ES (*N* = 15)	TCS (*N* = 16)	Combination (*N* = 15)	Control (*N* = 17)	*P* difference
Low	23 (37)	6 (40)	6 (38)	6 (40)	5 (29)	
GFI, mean (*SD*)	2.0 (1.2)	1.7 (1.2)	2.4 (1.4)	2.1 (1.0)	1.9 (1.3)	.449[c]
Pre-COVID IPAQ						.151[c]
n	56	13	15	13	15	
MET (min/week), mean (*SD*)	2986 (1419)	3691 (1310)	2705 (1708)	2514 (1123)	3066 (1294)	

Note. GFI = Groningen Frailty Indicator; IPAQ = International Physical Activity Questionnaire; MET = metabolic equivalent of task; ES = exercise snacking; TCS = tai chi snacking.

[a]Differences between groups were analysed using Chi-square tests. [b]Analysed using Fisher's exact test. [c]Analysed using one-way ANOVA with a Scheffe post hoc test. For the multilevel logistic regression models testing whether prior exercise (program or outdoor) predicted current feelings of energy, the maximum number of function evaluations for the “bobyqa” optimizer was extended to 200,000. IPAQ data were processed, cleaned, and analyzed in accordance with recommendations outlined in the “Guidelines for Data Processing and Analysis of the International Physical Activity Questionnaire” manual. “Pre-COVID IPAQ” refers to participants' estimated physical activity levels in a “typical” week prior to the lockdown period.

Video assessments of included participants, which included the screening and physical function assessment and any discussion about the study or future steps, ranged from 8 min 19 s to 16 min 13 s with a mean (SD) duration of 11 min 33 s (2 min 23 s) at baseline. At follow-up, the assessment time ranged from 5 min 27 s to 15 min 29 s with a mean (SD) duration of 9 min 4 s (2 min 47 s). The preferred platforms for participants were Zoom (65%) and Skype (25%) with the remaining 10% using FaceTime and WhatsApp. Anecdotally, we learned that some participants had recently become competent in using Zoom and other video calling mediums during the COVID-19 pandemic to contact friends and family and participate in social events during the lockdown. Others, however, were still novices in using these technologies and needed support locating their camera and positioning their physical device appropriately. There were no adverse events or safety concerns in any of the 119 functional assessments completed before and after the intervention. There were, however, five reported adverse events during the active 4-week intervention phase of the study, only one of which was deemed potentially related to undertaking exercise in the ES group: an exacerbation of a previously sustained knee injury during the sit-to-stand exercise. The four other adverse events unrelated to the intervention were a back injury, a minor elective surgery, a severe bacterial infection, and an ankle injury not sustained during the study exercise.

Adherence and Acceptability

Of the 56 participants who completed follow-up, five stopped exercising before the end of the 4-week program. Completed logs were available for 47 participants. These indicated a mean (SD) number of days attempted (out of 28) of 26 (3) for the ES group, 26 (6) for the TCS group, and 26 (4) for the combination group. The mean percentage adherence in completing all prescribed intervention exercises over the 4 weeks (out of 280) was 90% for the ES group, 84% for the TCS group, and 83% for the combination group. From the exercise logs, we observed that primary reasons for missing exercises included symptoms of illness, fatigue, bodily pain, or lack of time due to other commitments (e.g., work). The control group reported a mean of 12 out of 28 days, upon which the NHS website-informed exercises were completed. Conversely, they reported a higher mean (SD) amount of “other outdoor exercise” across the intervention period, recording 103 (76) min per day compared with 49 (28) min in the ES, 48 (27) min in the TCS, and 68 (60) min in the combination groups.

Exercise snacking was rated as the most acceptable intervention, outscoring TCS and NHS control in all theoretical framework of acceptability domains apart from coherence (clarity on how the intervention helps strength and balance; Figure 4-2). Qualitative feedback provided at follow-up indicated that ES had clear instructions and was easy to do and record. However, for some participants who were used to doing more strenuous sport or exercise, it was deemed “boring.” For others, focusing on upper- and lower-body muscles would have been of interest. Several TCS participants mentioned that the video and descriptive instructions lacked clarity and that they would prefer to follow mirrored demonstrations in real time. Although some liked the Tai-chi, others said that their lack of ability to perform exercises accurately was frustrating and undermined their confidence to continue. The NHS website was criticized for lacking specificity, although it did help some individuals initiate new exercises.

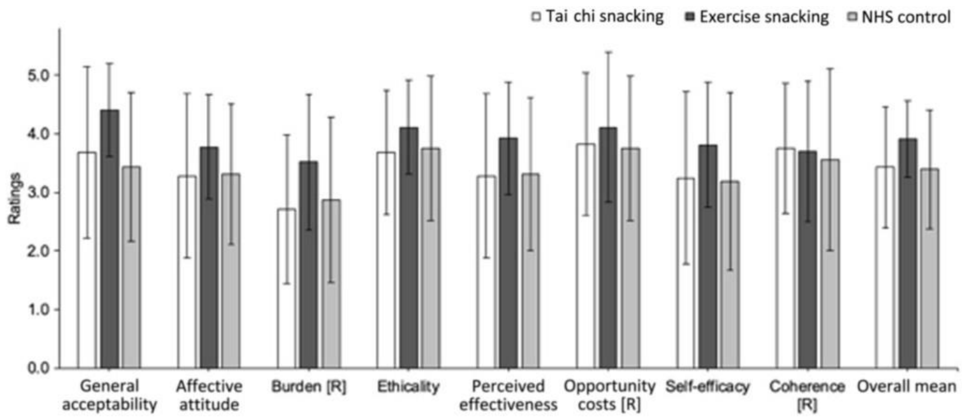


Figure 4-2. Acceptability of the respective intervention formats based on TFA dimensions. Data are means with error bars representing the SD. Tai chi snacking, n = 28; exercise snacking, n = 27; NHS control, n = 16. [R] indicates ratings were reverse coded. TFA = theoretical framework of acceptability.

Outcome Data

Table 4-3 displays the mean prescores and postscores for all outcome data in each trial arm. All four groups saw an increase in 60 s chair rise number and a reduction in five-repetition time at 4 weeks. Balance scores were mixed, with the ES and combination groups observing a reduction in right leg balance, albeit with wide variance in scores at the group level. Total physical activity, moderate-to-vigorous physical activity, and sedentary time all improved at follow-up relative to baseline; however, walking time went down in each group. There was a notable trend in barrier self-efficacy reducing between pre-assessment and post-assessment across the four groups with little change in other exercise cognitions. Vitality, life satisfaction, and quality of life scores remained stable in all groups, and although some fluctuation in anxiety and depression scores were observed, these remained at subclinical levels (i.e., scores <9 anxiety [Julian, 2011], <13 depression [Beck, Steer, & Brown, 1996]).

Table 4-3. Mean (SD) Unadjusted Outcome Data for Each Group Preintervention and Postintervention

Outcome	Exercise snacking		Tai-chi snacking		Combination		Control	
	Pre (N=15)	Post (N=14)	Pre (N=16)	Post (N=15)	Pre (N=15)	Post (N=14)	Pre (N=17)	Post (N=16)
Physical function, n	15	14	16	13	15	13	17	16
5 reps sit-to-stand speed (s)	9.6(3.3)	7.9(3.5)	10.5(2.3)	9.0(1.7)	10.5(2.6)	8.9(2.5)	11.0(2.4)	9.6(2.5)
60-s sit-to-stand (N reps)	35.6(12.3)	41.9(15.5)	30.1(9.8)	36.0(10.1)	31.5(7.6)	35.3(10.0)	29.5(6.6)	33.2(7.8)
Right leg standing balance (s)	44.9(23.0)	39.5(19.3)	26.0(20.8)	34.5(23.9)	36.9(23.7)	29.8(19.3)	39.3(21.6)	38.9(21.9)
Left leg standing balance (s)	35.0(24.4)	41.2(22.1)	31.5(24.4)	40.0(21.3)	30.6(24.1)	40.2(22.3)	31.1(22.4)	43.1(18.2)
Physical activity, n	13	14	14	14	15	13	16	14
IPAQ score (MET-mins·week^{-1})	3464(1910)	3617(2502)	2916(2422)	3732(2716)	2731(1532)	3665(2678)	3176(2878)	3761(2604)
MVPA time (min·day^{-1})	67.4(56.4)	73.0(60.2)	45.3(46.8)	76.2(56.5)	61.9(59.2)	87.6(81.1)	43.6(62.7)	64.2(57.9)
Sedentary time (min·day^{-1})	408.5(113.3)	357.9(130.7)	413.6(124.1)	382.0(144.3)	452.6(130.8)	382.1(136.3)	449.3(135.2)	395.1(121.4)
Walking Time (min·day^{-1})	64.2(52.6)	63.2(51.4)	62.4(47.8)	58.5(56.3)	40.8(30.5)	38.0(30.1)	78.2(52.9)	71.4(48.2)
Exercise Cognitions								
Barrier self-efficacy	70.5(14.6)	62.9(16.9)	67.3(18.2)	56.3(17.7)	65.1(14.8)	62.4(19.0)	71.4(15.3)	56.4(14.6)
Competence	6.4(0.9)	6.2(1.0)	5.6(1.3)	5.5(1.5)	6.1(1.1)	6.1(1.3)	6.4(0.9)	6.0(1.2)
Habit strength	5.2(1.3)	4.5(1.7)	2.9(1.7)	3.9(1.6)	3.5(1.8)	3.6(1.9)	4.6(1.0)	4.4(1.6)
Outcome expectancies	62.3(7.7)	60.4(8.4)	53.8(10.0)	53.8(13.6)	59.4(7.9)	56.4(10.0)	60.6(6.3)	57.3(8.2)
Health and Wellbeing								
Anxiety	2.1(2.3)	4.0(4.8)	5.3(6.2)	7.9(10.4)	5.1(3.7)	3.9(2.3)	4.6(5.4)	4.2(5.3)
Depression	5.8(4.2)	9.4(8.8)	8.6(7.0)	8.8(8.4)	8.1(4.6)	8.6(5.3)	7.0(3.2)	6.2(4.8)
Vitality	4.9(1.2)	4.7(1.2)	4.2(0.9)	4.6(1.4)	4.3(1.2)	4.5(1.4)	4.4(1.1)	4.7(1.2)
Satisfaction with life	26.5(5.5)	25.2(8.3)	23.7(6.8)	25.1(6.5)	25.4(5.7)	26.1(6.0)	27.6(3.9)	28.5(3.8)
Physical health (SF-36)	51.9(5.2)	49.5(9.7)	47.6(11.1)	46.8(11.2)	47.0(7.3)	48.6(6.6)	49.8(7.3)	48.6(9.1)
Mental health (SF-36)	56.0(7.7)	53.9(6.8)	52.8(10.7)	56.2(5.5)	57.2(5.0)	55.6(7.6)	54.4(6.3)	55.1(7.7)

4.3.5 Discussion

In this study, we provide evidence for the acceptability of remotely delivered home-based exercise programs for older adults undergoing self-isolation and assessing older adults' physical function via video calling technology. Remote assessments that comprised two components of the validated short physical performance battery and other bespoke strength and balance activities were performed safely and efficiently, with 89% of participants completing their follow-up assessment. The intervention arms were well adhered to in the trial, with ES being considered the most acceptable format and all groups improving functional outcome scores.

Only one adverse event (exacerbating a preexisting injury) relating to the intervention was observed in the ES group, suggesting that each program was safe. Qualitative feedback suggests that ES is considered useful in the self-isolation context but may be better suited to people who are otherwise unable or lack the desire to do other forms of exercise in normal conditions. Tai-chi snacking may be made more acceptable for home delivery with improved real-time video instruction and simpler movements for novices. Regarding the open-ended survey question feedback, please refer to the qualitative feedback Appendix for comprehensive insights.

These data suggest that undertaking any form of exercise may help to improve certain measures of physical function and well-being over a 4-week period of self-isolation. Nevertheless, it is important to consider the context and reliability of measures when interpreting these findings. Sixty-second sit-to-stand scores at baseline in the present study (32 [9]) were comparable with a previous laboratory-based investigation in healthy older adults (29 [11]) (Perkin et al., 2019). However, all groups in the present study improved sit-to-stand scores, whereas the control group in the aforementioned study saw no change in sit-to-stand scores. With low sample sizes, it is difficult to identify whether this was due to the interventions themselves or due to the lack of familiarization with the test before baseline assessment. Additionally, the improvements seen in the 60-second chair rise number and the reduction in five-repetition time may likely be attributed to practice effects, as repeated performance in these movements could lead to enhanced familiarity and efficiency, thus impacting the measured outcomes. Moreover, the reduction in right leg balance observed in the ES and combination group could potentially be due to the fact that the ES training programme did not specifically emphasise balance training, unlike the TCS group, which placed more focus on improving balance through its exercises. This may also be influenced by variations in participant characteristics (e.g., asymmetrical balance issues) and individual responses to the interventions. Although the functional assessments were successfully administrated in this study, the precision of timing and scoring has yet to be validated for remote delivery.

It is worth noting that the improvements in physical function observed in the current study align with the Otago program, known for its positive impact on mobility, balance, and muscle strength (Thomas et al., 2010; Shubert et al., 2018; Benavent-Caballer et al., 2016). However, when considering the total training time of exercise and Tai-chi snacking (2x10 minutes per day, totalling 140 minutes per week) compared to the Otago programme (3x30 minute sessions per week, totalling 90 minutes per week), it is essential to understand why the current study's outcomes did not surpass those achieved by Otago, another unsupervised home-based programme that demonstrated more significant changes in strength and balance. Factors such as exercise intensity, exercise type, or individual adherence to the programme may have contributed to the observed differences in outcomes.

The observed decrease in barrier self-efficacy across all groups might be attributed to the participation in the study, suggesting that engaging in the exercise programme potentially influenced their perceived barriers. It is plausible that trying out the exercise programme led participants to find it more manageable and beneficial, I in a similar way to that of other short dose physical activity (John et al., 2020; Gokal et al., 2022). Similarly, in spite of social distancing regulations, some members of the recruited population (i.e., those <70 years [32% in this study]) may have also increased their overall physical activity behaviour, as was observed in the pre and post International Physical Activity Questionnaire scores for all groups, due to relaxing of social distancing measures. In analysing the self-reported logs used to measure programme adherence as well as outdoor activities, it was observed that the control group reported engaging in a higher amount of outdoor exercise compared to the intervention groups. In addition, the reduction in walking time across all groups could potentially be linked to the limitations and alterations in daily routines imposed by the lockdown measures. Participants' reduced mobility due to restrictions and safety concerns might have influenced this outcome, illustrating the impact of external factors beyond the intervention itself. The self-reported one hour per day of MVPA and the reported sedentary behaviour of seven hours daily indicate an already active lifestyle among the participants. As the target population for this study consisted of healthy older adults, they typically exhibit higher baseline activity levels compared to more sedentary cohorts. However, objective monitoring of physical activity behaviours in a larger study could provide more accurate insights, especially when assessing key outcomes. Incorporating objective measurements alongside self-reports would strengthen the validity of physical activity data, ensuring a more comprehensive understanding of the participants' activity levels (McCarthy et al., 2021). Future research may seek to employ accelerometer and gyroscope integrated technology to provide objective data on behaviour and movement characteristics.

As the world moves through and beyond the COVID-19 pandemic, it is expected that telemedicine and remote delivery of health care and research, including preventive medicine, will be commonplace (Richardson et al., 2020). It is important to ensure that moves toward an eHealth landscape do not widen health inequalities (Hargittai, Piper, & Morris, 2019). In the present study, it was encouraging to observe that older adults were able to undergo efficient video call assessments and retrieve video instruction with little requirement for support. However, participants were well-educated individuals from areas of low deprivation who, owing largely to the web and email-based recruitment and assessment methods, may have possessed a reasonable digital literacy.

Likewise, the snacking interventions themselves were designed to be inclusive, requiring very little time or equipment, and the general adherence was accordingly very good. However, with 20% of potential participants excluded due to a GFI score over 4 (Figure 4-1), ensuring that individuals who are arguably more in need of improving physical function can safely be provided with exercise interventions remotely remains a challenge. Indeed, in the present study, there were three further participants who would have been excluded but for a reassessment of GFI after raising their misreporting with the lead researcher, suggesting that a snapshot assessment using a self-report, multidimensional measure may not be the optimal strategy for assessing frailty. Investigating ways of recruiting those who would benefit most, that is, potentially frail clinical outpatient populations and those of lower socioeconomic status for whom technology may be a pertinent barrier, is another important future step.

Strengths of the study include the randomized design, the blinding of the outcome assessment, and the comprehensive logging of adherence and other activity undertaken during the intervention period. There are, however, important limitations to acknowledge. Firstly, given the exploratory nature of this study and primary focus on establishing feasibility, this study was not powered for a robust statistical analysis of the intervention effect. Further trials with larger sample sizes are needed to establish the efficacy of the ES and TCS interventions used in the present trial. Secondly, there were elements of the feasibility data capture that were reported anecdotally and whose precision could be improved in further studies. This includes the reporting of participant competence in using video-calling software and the degree of support required and the call duration, which used the total call time from available software and could not disaggregate the assessment from other talking within the call. Furthermore, it's important to acknowledge instances of missing or incomplete data, which could influence the overall findings. For instance, some participants withdrew from the study, resulting in missing data points. Additionally, a few participants declined to complete certain online surveys due to their length or similarity to previous questions, contributing to incomplete datasets. These factors may impact the comprehensiveness of our results. Finally, although the dose exercise within the three intervention arms was equivalent, the nature of the exercises themselves were not, and therefore, differences in how these were received and any impact on functional and mental health may be a result of discrepancies in modality. Future studies should not only look at the efficacy but also the mechanisms by which ES and TCS may benefit people when coming up with an optimal implementation strategy.

4.3.6 *Conclusion*

During the COVID-19 pandemic, older adults were asked to socially distance themselves in their homes, which may have contributed to reduced physical function. Finding ways to maintain strength and balance in the home setting that conform to social distancing policy and do not risk injury could be a critical step in this and future pandemics. Remote assessment of physical function and delivery of ES and TCS interventions were deemed to be acceptable and safe. Future research should seek to optimize these exercise formats, precisely measure physical activity and function, and recruit more diverse samples that would benefit from simple, effective home-based exercise.

4.3.7 References

Anokye, N.K., Trueman, P., Green, C., Pavey, T.G., & Taylor, R.S. (2012). Physical activity and health related quality of life. BMC Public Health, 12(1), 624. doi:10.1186/1471-2458-12-624

Barrado-Martín, Y., Heward, M., Polman, R., & Nyman, S.R. (2019). Acceptability of a dyadic tai chi intervention for older people living with dementia and their informal carers. Journal of Aging and Physical Activity, 27(2), 166–183. PubMed ID: 30160584 doi:10.1123/japa.2017-0267

Beck, A., Steer, R., & Brown, G. (1996). BDI-II, Beck depression inventory: Manual. San Antonio, TX: The Psychological Corporation.

Beck, A.T., Epstein, N., Brown, G., & Steer, R.A. (1988). An inventory for measuring clinical anxiety: Psychometric properties. Journal of Consulting and Clinical Psychology, 56(6), 893. PubMed ID: 3204199 doi:10.1037/0022-006X.56.6.893

Beck, A.T., Ward, C.H., Mendelson, M., Mock, J., & Erbaugh, J. (1961). An inventory for measuring depression. Archives of General Psychiatry, 4(6), 561–571. doi:10.1001/archpsyc.1961.01710120031004

Booth, F.W., & Hargreaves, M. (2011). Understanding multi-organ pathology from insufficient exercise. Bethesda, MD: American Physiological Society.

Burton, E., Lewin, G., & Boldy, D. (2013). Physical activity levels of older adults receiving a home care service. Journal of Aging and Physical Activity, 21(2), 140–154. PubMed ID: 22832235 doi:10.1123/japa.21.2.140

Dasenbrock, L., Heinks, A., Schwenk, M., & Bauer, J.M. (2016). Technology-based measurements for screening, monitoring and preventing frailty. Zeitschrift für Gerontologie und Geriatrie, 49(7), 581–595. PubMed ID: 27637581 doi:10.1007/s00391-016-1129-7

Department of Health. (2016). Health survey for England 2016: Physical activity in adults. Retrieved from https://files.digital.nhs.uk/publication/m/3/hse16-adult-phy-act.pdf

Diener, E., Emmons, R.A., Larsen, R.J., & Griffin, S. (1985). The satisfaction with life scale. Journal of Personality Assessment, 49(1), 71–75. PubMed ID: 16367493 doi:10.1207/s15327752jpa4901_13

Elavsky, S., McAuley, E., Motl, R.W., Konopack, J.F., Marquez, D.X., Hu, L., . . . Diener, E. (2005). Physical activity enhances long-term quality of life in older adults: Efficacy, esteem, and affective influences. Annals of Behavioral Medicine, 30(2), 138–145. PubMed ID: 16173910 doi:10.1207/s15324796abm3002_6

Gokal, K., Amos-Hirst, R., Moakes, C. A., Sanders, J. P., Esliger, D. W., Sherar, L. B., ... & Daley, A. J. (2022). Views of the public about Snacktivity™: a small changes approach to promoting physical activity and reducing sedentary behaviour. BMC Public Health, 22(1), 618.

Guralnik, J.M., Simonsick, E.M., Ferrucci, L., Glynn, R.J., Berkman, L.F., Blazer, D.G., Wallace, R.B. (1994). A short physical performance battery assessing lower extremity function: Association with self-reported disability and prediction of mortality and nursing home admission. Journal of Gerontology, 49(2), M85–M94. PubMed ID: 8126356 doi:10.1093/geronj/49.2.M85

Hargittai, E., Piper, A.M., & Morris, M.R. (2019). From internet access to internet skills: Digital inequality among older adults. Universal Access in the Information Society, 18(4), 881–890. doi:10.1007/s10209-018-0617-5

Hurtig-Wennlöf, A., Hagströmer, M., & Olsson, L.A. (2010). The International Physical Activity Questionnaire modified for the elderly: Aspects of validity and feasibility. Public Health Nutrition, 13(11), 1847–1854. PubMed ID: 20196910 doi:10.1017/S1368980010000157

Huston, P., & McFarlane, B. (2016). Health benefits of tai chi. Canadian Family Physician, 62(11), 881. PubMed ID: 28661865

Julian, L.J. (2011). Measures of anxiety: State-trait anxiety inventory (STAI), beck anxiety inventory (BAI), and hospital anxiety and depression scale-anxiety (HADS-A). Arthritis Care & Research, 63(Suppl. 11), S467–S472. doi:10.1002/acr.20561

Kallings, L.V., Leijon, M., Hellénius, M.L., & Ståhle, A. (2008). Physical activity on prescription in primary health care: A follow-up of physical activity level and quality of life. Scandinavian Journal of Medicine & Science in Sports, 18(2), 154–161. PubMed ID

Kutner, N.G., Barnhart, H., Wolf, S.L., McNeely, E., & Xu, T. (1997). Self-report benefits of Tai Chi practice by older adults. The Journals of Gerontology, Series B: Psychological Sciences & Social Sciences, 52(5), P242–P246. doi:10.1093/geronb/52B.5.P242

Langlois, F., Vu, T.T., Chassé, K., Dupuis, G., Kergoat, M.J., & Bherer, L. (2013). Benefits of physical exercise training on cognition and quality of life in frail older adults. The Journals of Gerontology, Series B: Psychological Sciences & Social Sciences, 68(3), 400–404. doi:10.1093/geronb/gbs069

Maas, C.J., & Hox, J.J. (2005). Sufficient sample sizes for multilevel modeling. Methodology, 1(3), 86–92. doi:10.1027/1614-2241.1.3.86

McCarthy, H., Potts, H. W., & Fisher, A. (2021). Physical activity behavior before, during, and after COVID-19 restrictions: longitudinal smartphone-tracking study of adults in the United Kingdom. Journal of medical Internet research, 23(2), e23701.

Moineddin, R., Matheson, F.I., & Glazier, R.H. (2007). A simulation study of sample size for multilevel logistic regression models. BMC Medical Research Methodology, 7(1), 1–10. doi:10.1186/1471-2288-7-34

NHS. (2019). Physical activity guidelines for older adults. https://www.nhs.uk/live-well/exercise/physical-activity-guidelines-older-adults/

Nyman, S., & Skelton, D. (2017). The case for Tai Chi in the repertoire of strategies to prevent falls among older people. Perspectives in Public Health, 137(2), 85–86. PubMed ID: 28244837 doi:10.1177/1757913916685642

Oikawa, S.Y., Holloway, T.M., & Phillips, S.M. (2019). The impact of step reduction on muscle health in aging: Protein and exercise as countermeasures. Frontiers in Nutrition, 6, 75. doi:10.3389/fnut.2019.00075

Perkin, O.J., McGuigan, P.M., & Stokes, K.A. (2019). Exercise snacking to improve muscle function in healthy older adults: A pilot study. Journal of Aging Research, 2019, 1–9. doi:10.1155/2019/7516939

Peters, L.L., Boter, H., Burgerhof, J.G., Slaets, J.P., & Buskens, E. (2015). Construct validity of the Groningen Frailty Indicator established in a large sample of home-dwelling elderly persons: Evidence of stability across age and gender. Experimental Gerontology, 69, 129–141. PubMed ID: 25981741 doi:10.1016/j.exger.2015.05.006

Pinedo-Villanueva, R., Westbury, L.D., Syddall, H.E., Sanchez-Santos, M.T., Dennison, E.M., Robinson, S.M., & Cooper, C. (2019). Health care costs associated with muscle weakness: A UK population-based estimate. Calcified Tissue International, 104(2), 137–144. PubMed ID: 30244338 doi:10.1007/s00223-018-0478-1

Resnick, B., & Jenkins, L.S. (2000). Testing the reliability and validity of the self-efficacy for exercise scale. Nursing Research, 49(3), 154–159. PubMed ID: 10882320 doi:10.1097/00006199-200005000-00007

Richardson, S.J., Carroll, C.B., Close, J., Gordon, A.L., O'Brien, J., Quinn, T.J., . . . Witham, M.D. (2020). Research with older people in a world with COVID-19: Identification of current and future priorities, challenges and opportunities. Age and Ageing, 49(6), 901–906. PubMed ID: 32584954 doi:10.1093/ageing/afaa149

Rogers, C.E., Larkey, L.K., & Keller, C. (2009). A review of clinical trials of tai chi and qigong in older adults. Western Journal of Nursing Research, 31(2), 245–279. PubMed ID: 19179544 doi:10.1177/0193945908327529

RStudio Team. (2019). RStudio: Integrated Development for R. RStudio, Inc., Boston, MA. http://www.rstudio.com/

Ryan, R.M., & Frederick, C. (1997). On energy, personality, and health: Subjective vitality as a dynamic reflection of well-being. Journal of Personality, 65(3), 529–565. PubMed ID: 9327588 doi:10.1111/j.1467-6494.1997.tb00326.x

Sekhon, M., Cartwright, M., & Francis, J.J. (2017). Acceptability of healthcare interventions: An overview of reviews and development of a theoretical framework. BMC Health Services Research, 17(1), 1–13. doi:10.1186/s12913-017-2031-8

Son, N.-K., Ryu, Y.U., Jeong, H.-W., Jang, Y.-H., & Kim, H.-D. (2016). Comparison of 2 different exercise approaches: Tai Chi versus Otago, in community-dwelling older women. Journal of Geriatric Physical Therapy, 39(2), 51–57. PubMed ID: 25760277 doi:10.1519/JPT.0000000000000042

Spence, J. C., Rhodes, R. E., McCurdy, A., Mangan, A., Hopkins, D., & Mummery, W. K. (2021). Determinants of physical activity among adults in the United Kingdom during the COVID-19 pandemic: The DUK-COVID study. British journal of health psychology, 26(2), 588-605.

Strain, T., Fitzsimons, C., Kelly, P., & Mutrie, N. (2016). The forgotten guidelines: Cross-sectional analysis of participation in muscle strengthening and balance & co-ordination activities by adults and older adults in Scotland. BMC Public Health, 16(1), 1108. PubMed ID: 27769211 doi:10.1186/s12889-016-3774-6

UK Government. (2019). UK Chief Medical Officers' Physical Activity Guidelines. https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/832868/uk-chief-medical-officers-physical-activity-guidelines.pdf

UK Government. (2020). Major new measures to protect people at highest risk from coronavirus [Press release]. https://www.gov.uk/government/news/major-new-measures-to-protect-people-at-highest-risk-from-coronavirus

Verplanken, B., & Orbell, S. (2003). Reflections on past behavior: A self-report index of habit strength 1. Journal of Applied Social Psychology, 33(6), 1313–1330. doi:10.1111/j.1559-1816.2003.tb01951.x

Ware, J.E., Kosinski, M., & Keller, S.D. (1995). SF-12: How to Score the SF-12 Physical and Mental Health Summary Scales (Second Edition). Boston, MA: The Health Institute, New England Medical Center.

Wayne, P.M., Berkowitz, D.L., Litrownik, D.E., Buring, J.E., & Yeh, G.Y. (2014). What do we really know about the safety of tai chi?: A systematic review of adverse event reports in randomized trials. Archives of Physical Medicine and Rehabilitation, 95(12), 2470–2483. PubMed ID: 24878398 doi:10.1016/j.apmr.2014.05.005

Williams, L., & Gill, D.L. (1995). The role of perceived competence in the motivation of physical activity. Journal of Sport and Exercise Psychology, 17(4), 363–378. doi:10.1123/jsep.17.4.363

Wójcicki, T.R., White, S.M., & McAuley, E. (2009). Assessing outcome expectations in older adults: the multidimensional outcome expectations for exercise scale. The Journals of Gerontology, Series B: Psychological Sciences & Social Sciences, 64(1), 33–40.

4.3.8 Supplementary file: participant instructions for the Tai-chi snacking and exercise snacking programmes and example activity log.

Tai-chi snacking instructions

What is Tai-chi?

Tai-chi combines deep breathing and relaxation with flowing movements. The five main lower limb movements are selected for this routine. We are asking you to try this short Tai-chi routine for 4 weeks, which will include 1 minute of exercise per movement and 1 minute of rest between each exercise. The exercises themselves are safe for the home and don't require a warm-up before starting. The exercises do not require any sports clothing or equipment; just a kitchen chair if you feel you need extra support.

How is the exercise performed?

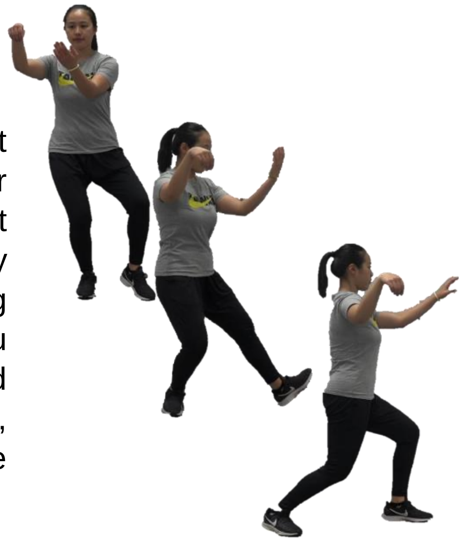
During each exercise bout, spend one minute performing each of the five exercises detailed below. Complete repetitions of each exercise at a self-selected pace that is comfortable for you to maintain for the full minute, with the aim being to complete them as accurately and smoothly as possible (based on correct posture and proper alignment). If your legs begin to feel sore during the any of the exercises, you may of course stop that exercise. Make sure you take one minute of rest between each exercise.

What is the Tai-chi 5 main movements routine?

- **Cloud hands, going left :** Standing with your knees slightly bent, feet shoulder width apart and facing forward, shifting your body weight from the right leg to left leg with the hands crossing from right to left (with left palm facing you at shoulder height and right palm facing the floor at waist height). After shifting your body weight to left leg completely, turn your palms, change arms so the right is on top, and left at waist height, and then take a small step to bring your right foot back in. Shift your body weight back to the right leg, turn your palms, change arms, and take a small step to bring your left foot go left, and repeat the movement.

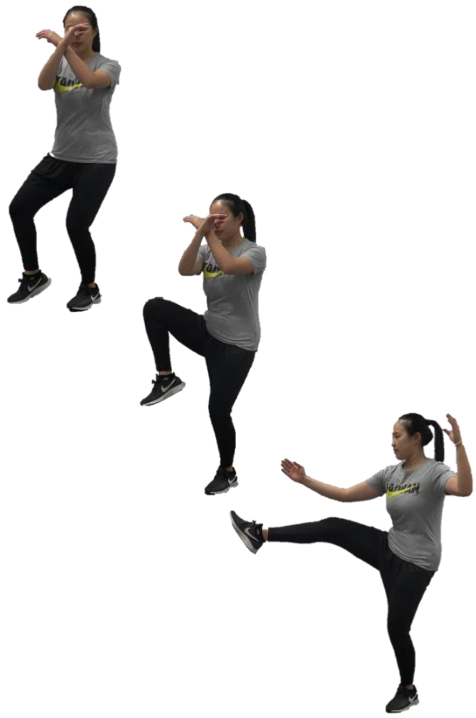
➢ **Stand on one leg:** Start in a standing position with your hands by your side. Shift your weight to left leg; lift the right heel off the ground and then raise your right leg off the floor and right arm with hand facing inwards in a slow steady movement. Keep your left knee slightly bent and left arm by your side. Aim to get your right thigh as close to horizontal as possible, then return that foot to the floor, regain your balance if necessary, and repeat with the right leg for 30 seconds after doing stand on left leg for 30 seconds. If you struggle with balance, you can hold onto something stable like the back of a chair.

➢ **Single whip:** Hook your fingers and thumb of the right hand in a slight closure and place the left hand nearer to your face with palm facing yourself; shift back and lift the left heel. Try to keep your weight on single leg stably, take a step out with your left leg, and then shift your body weight from your right leg onto your left leg slowly (pushing with the right leg when you get beyond halfway). Turn your hips and open your arms outward at the same time, making sure that your legs are doing the work in a slow, controlled motion.



➢ **Snake creeps through the grass:** Starting from the final posture of the Single whip exercise, turn out the right toe (so your feet are at 90 degrees) and open your hip joint. Shift back and sit into the right leg, slowly drop down as low as possible with left hand crossing near your ankle. Then push off the right leg with left leg bending progressively, and shift your body weight to the left leg, go forward with left hand end at shoulder height. The most important thing is keeping your spine as straight as possible, not how low you go.

- **Front heel kick:** From a standing position with your hands cross, sit gradually into the left hip and lift the right heel. Try to keep your weight on left leg and remain stable while raising your right leg with your knee bent, then kicking the right leg forward slowly and open the arms outward at the same time. Aim to kick your leg (slowly) in a controlled manner as high as possible, then slowly return that foot to the floor. Regain your balance if necessary and repeat with the left leg kicking for 30 seconds after doing right leg kicking for 30 seconds. If you struggle with balance, you can hold onto something stable like the back of a chair with one hand.



What are the risks of performing the exercise?

As with any exercise, you are likely to feel tired towards the end of the session and in the time straight afterwards. However, the principle of Tai-chi is that the movements should not be excessively demanding, with each exercise of the routine performed for only one minute at a self-selected repetition speed. The primary risk when performing the exercise is loss of balance. This risk can be mitigated by performing the movements at a controlled speed, and by holding onto a stable object such as a chair, table, or door frame. This exercise regime has been designed specifically to avoid any cardiovascular load, as might be experienced during running. If your legs begin to feel overly sore during the any of the exercises, you may of course stop that exercise at that time.

Exercise snacking instructions

What is exercise snacking?

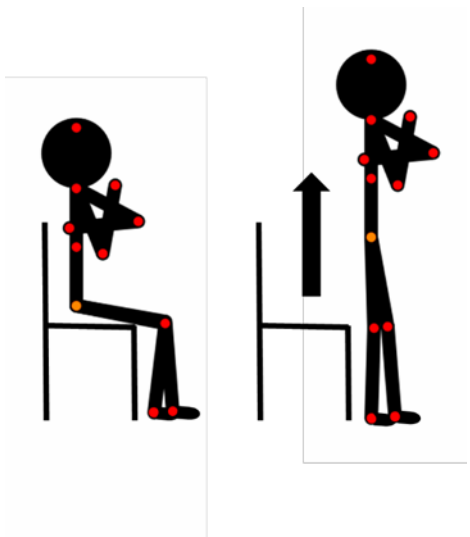
This is a method of structuring exercise into short bouts. We are asking you to try this short exercise snacking routine for 4 weeks, which will include 1 minute of exercise per activity and 1 minute of rest between each exercise. The exercises themselves are safe for the home and don't require a warm-up before starting. The exercises do not require any sports clothing or equipment; just a kitchen chair.

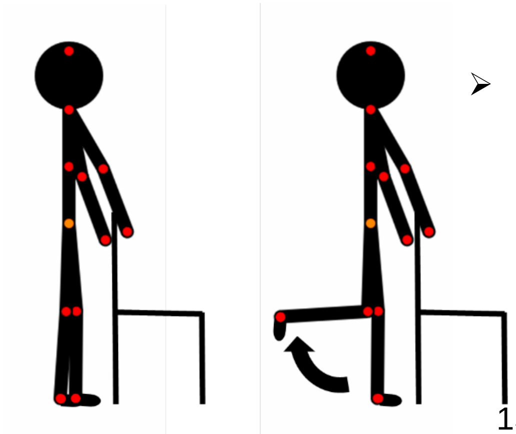
How is the exercise performed?

During each exercise bout, spend one minute performing each of the five exercises detailed below. Complete repetitions of each exercise at a self-selected pace that is comfortable to maintain for the full minute, with the aim being to complete as many repetitions as possible in that minute. If your legs begin to feel unduly sore during the any of the exercises, you may of course stop that exercise at that time. Take one minute between each exercise to rest.

What is the exercise snacking routine?

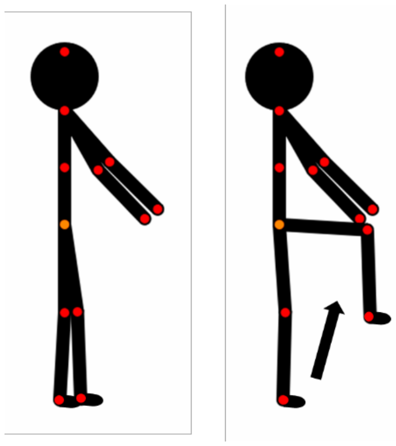
- **Sit-to-stand:** This exercise is simply repetition of rising from an up-right seated position on a kitchen chair, and then returning to the seated position. Try to keep your arms folded across your chest to avoid using your arms to aid rising from the chair, making sure that your legs are doing the work. We suggest that this always be the first exercise performed in the routine, and recording the number of sit-to-stands performed in the minute each time lets you track your progress.

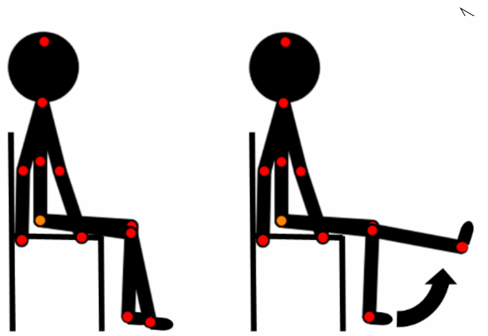




- **Standing knee bends:** Standing up-right and holding onto something stable for balance if needed, raise one foot at a time by bending your knee to roughly a right angle. Then return that foot to the floor, regain your balance if necessary, and repeat with the opposite leg.

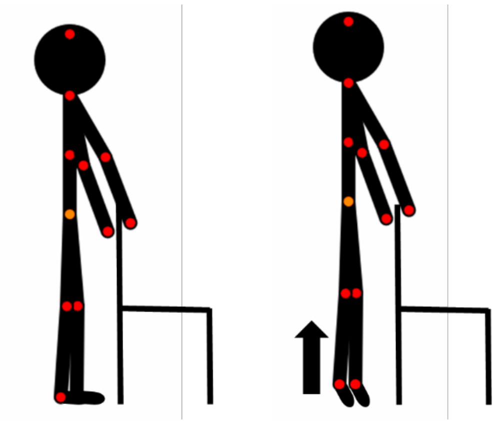
➢ **March on the spot:** Standing up-right, put your arms out in front of you and your hands roughly at waist height, raise one leg up by bending your knee and hip as per the diagram. Aim to get your thigh as close to horizontal as possible, with the top of your thigh touching your hands, then return to a standing position, and repeat with the other leg. If you struggle with balance, you can hold onto something stable like the back of a chair with one hand.





Seated leg kicks: Sitting up-right in a chair, straighten your knee to raise your leg out in front of you at a controlled speed, and then return that leg to the starting position, and repeat using the other leg. If you have quite long legs, it may help to place a rolled uptowel under your thigh to raise your knee a little higher in the start position.

➢ **Standing calf raises:** Start with your feet flat on the floor and rise up onto your tip-toes as high as you can, then return to the start position with feet flat on the floor. It is advisable to hold onto something stable like a chair, table, or door frame to maintain balance. Perform the raises on both legs at the same time, and try to complete as many as you can in a minute, and then rest for a minute.



What are the risks of performing the exercise?

As with any exercise, you are likely to feel tired towards the end of the session and in the time straight afterwards. However, the principle of exercise snacking is that the bouts should not be excessively demanding, with each exercise of the regime performed for only one minute at a self-selected repetition speed. The primary risk when performing the exercise is loss of balance during the standing exercises. This risk can be mitigated by performing the movements at a controlled, and by holding onto a stable object such as a chair, table, or door frame. This exercise regime has been designed specifically to avoid any cardiovascular load, as might be experienced during running. If your legs begin to feel unduly sore during the any of the exercises, you may of course stop that exercise at that time.

Exercise logs

Exercise Diary

This exercise log is for you to record the exercise bouts (number of repetitions, time, and duration) of the exercise snacking and tai-chi and any other exercise you do. This will help you track your progress over the four weeks and will help us to analyse how useful the programme is. You can fill these in electronically or print them out and fill them in by hand. At the end of the study we will instruct you on how to send these back to us.

Please try to practise the 'exercise snacking and tai-chi' exercises described above once each a day We recommend doing one of session of activities in the morning and another in the afternoon but this is up to you. Just try to fit the exercises in every day at a time that suits you. Please refer to the video you sent for more instructions on how to complete the exercises.

Remember to also keep following the UK government guidance on self-isolation and social distancing, which includes the suggestion that you can go out for "*one form of exercise a day, for example a walk or cycle – alone or with members of your household*" if you feel it is safe to do so. You may still take this outdoor session of exercise in addition to doing the home-based exercise we are asking you to do.

Example of how to complete your daily log in red text…

Day	**Exercise Snacking**		**Tai-chi snacking**		**Did you go outdoors for 1 bit of exercise today?**
Day 1 **01/04**	**Time of session:** *(hh:mm):* ***09:15***	**Reps in a minute?**	**Time of session:** *(hh:mm):* ***18:30***	**Complete d? (yes/no)**	***Yes*** ~~*No*~~ *(delete as appropriate)*
	Sit-to-stand*:*	**18**	Cloud hands*:*	**Yes**	
	Knee bends*:*	**23**	Stand on one leg*:*	**Yes**	*If yes, what did you do? (e.g., walking, cycling):*
	March on spot*:*	**30**	Single whip*:*	**Yes**	*Write here:* ***Walking***
	Seated leg kicks*:*	**11**	Snake creeps*:*	**No**	*At what time did you start? (hh:mm):* ***12:05***
	Calf raises*:*	**22**	Front heel kick*:*	**Yes**	*For how long? (hh:mm):* ***45 minutes***

Nb. The exercise log was adapted for those in the tai-chi snacking or exercise snacking groups so that they could record two of each session. The Control group were asked to record the time, duration and frequency of any exercises they undertook each day that was informed by the NHS guidance, and any outdoor exercise.

4.3.9 Appendix: qualitative feedback, obtained from open-ended survey question.

''Please use this space to write any thoughts you have on the study overall. We would be particularly interested in any positive and negative feedback about the exercise programme, and the video assessment you did during the study''.

Intervention arm	Feedback, presenting along with individual characteristics [Study ID; age; sex]
Exercise snacking	I stuck to the programme pretty well but found it hard at first. I am quite competitive so tried to improve and push myself throughout. The exercise programme is good and for me quite testing. [RS001; 71; Female]
	Not necessary to wait for 1 minute between exercises, I followed on each as soon as I had logged the previous exercise. This probably meant there was about a 10 to12 second gap between exercises. This enabled them to have some cardiovascular effect. This I feel was more beneficial for me. [RS037; 75; Male]
	I enjoyed this but got a bit bored during wk 2, I think because I'd stopped seeing as much improvement. 10 mins x 2 was good for me and it meant that if I didn't have time to do both sessions, I could do one and not feel I'd missed out completely. I'd have liked a bit of variety after wk 2 - maybe a two-week cycle of exercises. It gave me confidence to keep up exercise. I've lost a lot of fitness over the last couple of years (various reasons) and wanted to regain some of that but a Couch to 5k programme was too much. [RS036; 71; Female]
	All of the materials and support I have received are excellent. Thank you. I started the research hoping that it would get me into the habit of undertaking an exercise regime regularly in addition to daily gardening. I think that it will. I have found it very easy to do the set of exercises first thing in the morning. (There is very little that will stop me gardening apart from gales and torrential rain! I have a large garden and after 3 months of lockdown, it looks stunning!). [RS039; 71; Female]
	It was interesting that some days I went for speed and repetition of the exercises and some days I completed the exercises with more thoroughness. Sit down stand up was the most tiring as it entailed moving the whole body weight. The calf raises really helped with my ongoing Achilles tendon problem. [RS053; 69; Female]
	The set of exercises were not too demanding and I did find that I was able to Increase speed and improve my performance during the month as I got into a rhythm. However, they were a bit tedious and I am quite relieved at having finished the programme but I do acknowledge that I need to continue with some regular exercise for my health's sake. [RS040; 74; Female]
Tai-chi snacking	Exercise programme was enjoyable. Overall I didn't find it at all arduous. In my routine I had five separate exercises to perform.

	Two of those depend fundamentally on balance. Due to long-standing problems with my lower back and nerve damage affecting my right leg and foot in particular I found those exercises especially on my right leg very challenging and I am a little disappointed that my balance has not improved to a greater degree. During the first week I found it difficult to remember exactly how to perform each of my five exercises. Apart from the balance issue only one of the other three exercises did I find physically demanding as if it was really working some of my muscles. Towards the end I did feel that one minute was rather too short for each individual exercise. I will be quite happy to try to continue the same exercises twice a day simply for my own benefit and satisfaction. [RS025; 73; Male]
	I didn't think I could do the tai-chi exercises but over the last four weeks I've slowly gotten better at them. Can't do the balancing on 1 foot without holding on, nor can I bend my knees as low as the instructor goes. Nevertheless I quite enjoy the exercises and they have become part of my day. As now I know them I especially like doing them in the garden beside my raised bed when I need somewhere to hold on. I don't have any issues with the study although concerning the questionnaire, how long I sit etc. in a day is actually difficult and I've never measured it so my answers are my best guesses. Thanks for letting me participate. I feel what I've learned is useful. [RS032; 80; Female]
	I think a longer session of tai chi would be more beneficial. It didn’t seem long enough to produce benefit for me as I think i am quite fit for my age. [RS010; 69; Male]
	I/We (my husband and I) found the video exercises a little confusing to start with. It would have been better to have both a front and back view of the presenter doing the exercises, then a short break before the next exercise started. We found the "hard copy" of the exercises easier to follow and once we had mastered them, we could do them without any guidance. We loved having this form of home-based exercise to focus on twice daily and we intend to carry on with it even though the study has finished. Very efficient Zoom meetings and feedback. Overall a very enjoyable study during the "lockdown" and looking forward to reading the findings once they are published. Thank you so much! [RS009; 66; Female]
Combination	I consider the Exercise Snacking to be very beneficial and will continue with it. It will add to some of the exercises which I was previously doing - there were no arm or Abs exercises in the programme. I found the Tai Chi frustrating. The Stand on one leg and Front Heel kick was straightforward enough and I did these throughout the study. But the other items I got fed up with and did not feel I was mastering them and gave up after a while. It became time consuming because I needed always to refer to the video which was itself frustrating because you were always trying to do the mirror image/opposite of what was being demonstrated. It would have helped if the demonstrator had faced in the same

	direction as the participant With the Video assessment some of the mood questions are very much influenced by the frustrations associated with lock down and coming out of lock down rather than with a personal physical or emotional state and therefore were difficult to gauge the response. [RS012; 80; Male]
	I thoroughly enjoyed the study, I wished it could have carried on as it motivated me. I plan to keep a diary going of fitness etc. Thank you for the opportunity, I would be very happy to do it again. [RS031; 67; Male]
	I liked the taichi, it motivated me once I got into a routine with it...the video assessment was also very enjoyable. [RS059; 73; Female]
	Tai Chi - the video would have benefitted from the demonstrator calling/naming her limbs by the opposite side as is common during gym sessions. As a regular gym class attendee I found the videos hard to copy at the same time because I had to reverse the sides in my mind. Also the moves could have had a slow-motion section so that they could be fully understood. On the regular exercise section, I would have been more comfortable if the knee bending exercises were listed before the seated to stand exercise as the lower load exercises would have warmed up my knees. [RS007; 68; Male]
	I found the video for Tai chi very difficult to follow. I have never done Tai chi before. I am sure my movements were clumsy and inaccurate. It was demonstrated too quickly and music did not last a minute. So the exercises were done reluctantly and in silence each day. I have missed 3 separate days as did not feel motivated. I prefer following a teacher in a group and music to help. The snacking exercises were easy to understand and I was happy to do them but wouldn't continue on my own. [RS018; 76; Female]
	I graphed the number of reps and found that after 4 weeks my performance on all of them was more or less levelling out. Part of the improvement was probably related to improvement in skill, but muscular improvement was also a factor. [RS021; 77; Male]
	The snack exercise has been very helpful. Despite my best efforts I have not been able to master the Tai Chi. Standing on one leg and forward kicks are quite straightforward, of course, and I have tried to fill the time of the others with strenuous activity as close to the right ones as possible! So I have really benefitted. But I find it frustrating not to have managed the gentle and purposeful movement of arms and legs that you clearly intend. [RS063; 72; Male]
	The study is a useful reminder that I need to do exercises as well as my everyday activities. I used to go to a weekly hour-long exercise class which kept me more fit than I am now. This was cancelled, and then the virus meant other classes closed down. It was difficult to do some of the exercise snacking - marching on the spot and seated leg kicks - as they seemed to strain my abdominal

	muscles too much. The Tai Chi was enjoyable, but difficult to follow and I'm sure I wasn't doing the movements properly. Exercising to music is much more my style. Doing the video survey meant that I finally got round to setting up Zoom on my laptop, so thank you for that! [RS064; 66; Female]
NHS control	Too many exercises to choose from in NHS programme - hard to decide what to do - would have preferred less choice and more specific tasks to do daily. [RS006; 67; Female]
	The NHS programme had a large number of options but no real guidance on which were suitable. I chose to use the pilates for back pain to aid my core strength etc, in fact I have been doing similar exercises for some years after physiotherapy for back pain and sciatica. [RS002; 75; Male]
	I am glad that I participated in the study. It has got me back into feeling that I might get into some semblance of a regular exercise regime. There are many options available in the NHS programme website and I will certainly complete the 5-week Strength and flex course and use some of the other programmes to build on this. I am just not sure yet which of these is suited to a 75-year-old male who is generally healthy apart from the results of various sports injuries acquired over the years! [RS016; 75; Male]

4.4 Summary

This chapter aimed to examine the feasibility and acceptability of 4-week home-based exercise and Tai-chi snacking delivered remotely in older adults during the Covid-19 lockdowns. We found that 89% of participants completed the study which showed the remote protocols were highly feasible. Similarly, Fyfe et al. (2022) found a 4-week remote home-based strength-based exercise snacking to be feasible in Australian older adults during Covid-19. Previous studies indicated that even short periods of reduced activity can lead to significant muscle function decline (Oikawa et al., 2019). A recent study assessed a 12-week remote supervised home-based exercise programme via Zoom or phone for pre-disabled Canadian older adults who had experienced minor injuries but were still independent in daily activities during Covid-19 (Buckinx et al., 2023). These programmes improved physical activity levels and offered isolated older adults' opportunities for staying active. Research involving exercise interventions conducted during the Covid-19 pandemic indeed reduced negative effects and sedentary time, and maintain physical health and mental wellbeing as well as overall quality of life in older adults (Ghram et al., 2021).

In this study, the adherence was also high (with 90% for the exercise snacking group following by 84% for the Tai-chi snacking, and 83% for the combination group). Regarding the acceptability, the results were consistent with the findings in our qualitative study (Chapter 3) wherein exercise snacking was deemed straightforward and acceptable, while Tai-chi snacking appeared relatively intricate yet intriguing due to its unique concept and philosophy. According to participants' feedback, redesigning some movements and optimizing the snacking formats would be the next step to make the programme more manageable and useful. Moreover, exploring the effectiveness on physical activity and fitness functions with more robust measuring methods and researching the feasibility of implementing these programmes into more diverse populations would help us understand practical benefit from these accessible home-based exercises thoroughly.

Ultimately, this remote study for feasibility demonstrated that we can deliver and evaluate the home-based exercise and Tai-chi snacking programme remotely using videoconferencing technology. This chapter utilised technologies and eHealth as a novel approach to promoting healthy ageing and could serve as preparation, drawing lessons for future pandemics. The enhancement of older adults' skills in using communication technologies is undoubtedly a beneficial outcome of the pandemic, potentially yielding numerous advantages for researchers, interventionists, or practitioners seeking to access the vulnerable or harder-to-reach segments of the population.

However, we should also consider the impact of COVID-19 on other aspects of the findings in the present study. First of all, the high adherence observed in this study could have been influenced by the lockdown restrictions, as older adults were required to self-isolate and were unable to attend social events or maintain their normal busy lives, which they might have more spare time. Secondly, the control group was provided with NHS recommended physical activity guidelines, indicating that they were encouraged to maintain their physical activity levels (Richardson et al., 2021, Smith et al., 2020). Indeed, many 'control' participants reported increasing their activity levels in response to the advice on the NHS webpages, something that might be an unusual consequence of the social-isolation context of the study and may not be replicated in such a trial in more 'normal' free-living conditions. Although the findings showed that participants' total physical activities improved at follow-up in all groups, walking time decreased possibly due to restrictions on outdoor activities and mobility limitations imposed by lockdown measures. It is therefore difficult to establish whether adherence to the exercise snacking would be replicated outside of the COVID-19 context, although encouragement can be taken from the highly rated acceptability and strong adherence.

Aligning with our previous work, there were several limitations and of course solutions and improvements we could consider to the exercise snacking protocol:

i. Lessons taken from the systematic review (Chapter 2) is that more research investigating the effects of entirely unsupervised home-based exercises on physical functions in different cultural settings is needed.

ii. The qualitative study (Chapter 3) further demonstrated that some specific movements in our programme could be modified. The video instructions could be improved and more accessible.

iii. The adherence to the 4-week exercise and Tai-chi snacking programme was high in the remote study (Chapter 4). However, whether this overall high participation rate would translate to sustained longer-term engagement and whether the adherence would be steady across long-term intervention remains unknown.

iv. In terms of the target populations, the previous studies only recruited healthy older adults. It is necessary and imperative to target on wider populations (e.g., pre-frail and frail older adults who are losing their abilities of daily living, and clinical patients who may benefit from simple and convenient snacking exercises, etc.).

v. In order to meet the needs of wider populations, building in progression in exercise and Tai-chi snacking programme would be helpful and efficacious.

With these points in mind, the next chapter asked the following research questions.

Research questions 4: How effective is the 12-week progressive home-based exercise snacking and Tai-chi snacking for improving physical function and wellbeing in pre-frail older adults?

As a secondary aim, and to maintain focus on evaluating the acceptability of the revised, longer snacking exercise format, we also aimed to assess the acceptability of a prolonged home-based snacking exercise intervention in pre-frail older adults. Therefore, the following chapter also includes the results of qualitative interviews designed to understand whether the long-term progressive unsupervised home-based exercise and Tai-chi snacking programme is considered acceptable among pre-frail older adults.

5 Chapter VI – Mixed-method RCT study

The Efficacy of 12-week Progressive Home-Based Strength and Tai-Chi Exercise Snacking in Older Adults: A Mixed-Method Exploratory Randomised Control Trial

5.1 Context

Doing three sets of repeated chair stands (5-10 reps per set) for 3 times per week improved muscle thickness and power in sedentary populations (Lizama-Pérez et al., 2023). Perkin et al. (2019) found that home-based exercise snacking improved muscle functions in healthy older adults. Additionally, studies have demonstrated that simple 10-minute per day home-based snacking exercises for improving physical function is acceptable and beneficial for not only healthy older adults but also those with cognitive impairments (Chapter 3 - Liang et al. (2023), Chapter 4 - Liang et al. (2021), and Western et al. (2023)). According to the previous chapters:

i. Chapter 2 – systematic review: the findings suggested the potential positive effects of unsupervised home-based exercise interventions on the lower extremity functions in older adults. However, insufficient studies lead to research gaps in this specific topic. More research needs to be done to unravel the efficacy of unsupervised home-based exercise programmes in older populations.
ii. Chapter 3 – qualitative study: intervening 1-week trial, both home-based exercise and Tai-chi snacking were seen as convenient and practical, bringing benefits to physical and mental health. Participants expressed preferences for exercise snacking's straightforward movement design, whereas the appeal of Tai-chi snacking's philosophical concepts attracted participants' interests despite the complexity of the movements. Cultural differences and individual physical functions played roles in participants' preferences, suggesting that tailored programme designs considering these factors could further enhance its acceptability.
iii. Chapter 4 – remote study: with a notable 89% completion rate, the findings supported the high feasibility of remote exercise and Tai-chi snacking protocols. Based on the Theoretical Framework of

Acceptability (TFA) survey, the 4-week exercise and Tai-chi snacking programme was considered to be acceptable and enjoyable. All intervention groups showed improved physical functions by the end of the study, with exercise snacking being regarded as the most acceptable with highest adherence programme. The results acknowledged the need for tailored movement modifications (especially Tai-chi snacking) and enhanced accessibility to improve the practical implementation.

These studies shed light on the acceptability and potential effectiveness of novel home-based exercise interventions, providing promising insights into the optimisation of exercise strategies for older populations. Nevertheless, our previous studies only focused on healthy older adults. Our qualitative findings indicated that participants with higher physical function were less likely to require the simple snacking exercise intervention, and they often found it tedious and unstimulating. Additionally, their higher function levels meant they were likely already engaging in higher physical activities, precluding their need for this light-touch intervention. To address this gap and better target those who might benefit the most, especially individuals with lower physical functions, this chapter extended the previous studies' examination to a longer intervention period and specifically targeted pre-frail older populations. A randomised controlled trial was conducted in this chapter, investigating the effectiveness of 12-week progressive home-based exercise snacking and Tai-chi snacking on strength, balance, and overall physical functions, physical health and mental wellbeing in pre-frail older adults.

5.2 Statement of authorship

This declaration concerns the article entitled:									
The Efficacy of 12-week Progressive Home-Based Strength and Tai-Chi Exercise Snacking in Older Adults: A Mixed-Method Exploratory Randomised Control Trial									
Publication status (tick one)									
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Copyright status (tick the appropriate statement)									
The material has been published with a CC-BY license	✔	The publisher has granted permission to replicate the material included here							
Candidate's contribution to the paper (provide details, and also indicate as a percentage)	The candidate contributed to / considerably contributed to / predominantly executed the… Formulation of ideas: 85% Design of methodology: 85% Experimental work: 100% Presentation of data in journal format: 90%								
Statement from Candidate	This paper reports on original research I conducted during the period of my Higher Degree by Research candidature.								
Signed (typed signature)		**Date**							

5.3 Paper 4: The Efficacy of 12-week Progressive Home-Based Strength and Tai-Chi Exercise Snacking in Older Adults: A Mixed-Method Exploratory Randomised Control Trial

5.3.1 *Abstract*

Background: Maintaining physical function is important for independence and frailty prevention in later life, but very few older adults meet exercise recommendations. Previous studies found that 4-week 'exercise and Tai-chi snacking' as a viable alternative to traditional exercise is acceptable to healthy older adults. This study aimed to investigate the effectiveness of a 12-week progressive exercise and Tai-chi snacking programme on physical function and psychological outcomes in pre-frail older adults.

Methods: In this randomised controlled trial, we recruited 90 older adults with impaired strength and balance. Participants were randomly allocated to an intervention or waitlist control group. Physical function (SPPB, single-leg balance test and sit-to-stand test) and self-reported psychological outcomes were measured remotely at baseline, 4-, 8-, and 12-weeks. A subset of 40 participants also completed in-person functional assessments, and 26 intervention participants underwent semi-structured interviews to feedback on their experiences.

Results: The 12-week progressive home-based exercise and Tai-chi snacking improved strength, balance, and mobility at each timepoint compared to control group. Timed-up-and-go and total SPPB scores were also better in the intervention group compared to the control group in lab subset participants. Based on the qualitative findings, Participants found the programme accessible and beneficial, making it suitable for older adults and increasing self-efficacy in physical activities.

Conclusion: The home-based exercise and Tai-chi snacking programme significantly improved lower extremity strength, balance, and mobility in pre-frail older adults. This low-cost programme is acceptable and easy implemented.

Keywords: pre-frail, progressive home-based exercise, physical function improvement, Tai-chi snacking, exercise snacks

5.3.2 Introduction

Engaging in muscle strength and balance (S&B) exercise has numerous health benefits for older adults, promoting greater mobility, and preserving independence in later life (Prata and Scheicher, 2015, Aartolahti et al., 2020), reducing risk of falling and fractures (Bellomo et al., 2013, Hawley-Hague et al., 2017), and overall improved health and wellbeing (Hillsdon and Foster, 2018, Furtado et al., 2021). In the UK it is recommended that older adults do S&B training at least two days a week to maintain or improve their physical function (UK Chief Medical Officer, 2019). Unfortunately, very few older adults engage in sufficient S&B exercise to reap these benefits (Gomes et al., 2017, Bowden Davies et al., 2019, Strain et al., 2016), with a lack of time, self-efficacy and access to leisure facilities cited as key barriers to participation (Cavill and Foster, 2018, Franco et al., 2015). Finding innovative ways to promote an acceptable and engaging format of S&B exercise is a public health priority.

One novel strategy to address typical barriers to participation in older adults is through the promotion of home-based exercise 'snacks', as opposed to a more traditional, lengthy structured exercise sessions at leisure centres (Francois et al., 2014). Exercise snacking describes short bursts of exercise that are designed to be undertaken over a very short period (i.e. 10 minutes at a time to suit the user), in the home environment and without the need for any specialised exercise clothing or equipment (Perkin et al., 2019, Islam et al., 2022). This format of exercise aligns to recent calls for further exploration of 'minimal dose' approaches to exercise for improving strength in older adults (Fyfe et al., 2022b). Our laboratory and pilot intervention research suggests that 5-minute, twice daily, strength exercise- and Tai-chi-snacking is feasible to implement, well adhered to, and potentially efficacious in healthy older adults (Liang et al., 2021, Perkin et al., 2019, Liang et al., 2023) as well as clinical populations with mild-cognitive impairment and compromised physical function (Western et al., 2023).

Moreover, our low-cost 'snacking for strength' approaches have been deemed acceptable, convenient, and easy-to-fit-in to routine by older adult participants. Accordingly, we hypothesise that exercise snacking can overcome pertinent participatory barriers for older adults and be both beneficial for physical function, and act as a gateway for older adults towards meeting the S&B recommendations through improved physical and psychological preparedness (i.e., improved strength and balance, self-efficacy, knowledge, and perceived effectiveness). Particularly, our acceptability study showed that feelings of satisfaction and being energized after completing the session were common experiences that enhance participants' confidence to engage in exercise (Liang et al., 2023). Participants felt that the programmes could allay their fear of falling, getting dementia, and other fears associated with ageing. However, our qualitative feedback also indicated that our exercise snacking programme may be more acceptable with simpler Tai-chi snacking movements, should include upper body movements, and include levels of difficulty to cater for individual capabilities (Liang et al., 2023).

Whilst we have demonstrated that both healthy and pre-frail older adults can improve their physical function with four weeks of exercise snacking, these results have emerged from short pilot studies precluding our ability to draw meaningful conclusions about the effectiveness and longer-term adherence or benefit of exercise snacking. The present study aimed to build on our preliminary work by examining the efficacy of 12-weeks of progressive S&B exercise and Tai-chi snacking interventions on physical function (the Short Physical Performance Battery test; SPPB, Guralnik et al. (1994)) in a larger sample of pre-frail older adults. Our secondary aim sought to investigate any changes in other markers of physical function, psychological processes, and physical and mental health outcomes for participants engaging in the intervention.

5.3.3 *Methods*

Study overview

The present study employed a randomised controlled trial design with quantitative and qualitative outcomes. Participants were randomly assigned to either receive the 12-week progressive exercise and Tai-chi snacking intervention or maintain their current lifestyle as a control group. Assessments for all participants were taken remotely every 4 weeks, while a sub-group of 40 participants underwent further in-person laboratory-based assessment. Twenty-six intervention participants underwent a semi-structured interview to provide further feedback on the intervention. The study was registered on ClinicalTrials.gov (Identifier: NCT05758727). Ethical approval for the study was provided by the University of Bath Ethics Approval Committee for Health (REACH reference number: EP 20/21 082).

Participants

Recruitment was conducted via advertisement on the University web pages and through local media and third-sector national organizations with older adult members in the UK (e.g., U3A, AgeUK, 3SG). All participants were provided with an opportunity to ask questions about the study and then provided with an online participant information sheet and informed consent form prior to undergoing screening and taking part in the study.

Interested participants were eligible to take part if they: (a) were 65 years of age or older, (b) were able to perform daily physical activity independently, determined by the Short Physical Performance Battery (SPPB, Guralnik et al. (1994)) test, (c) had impaired mobility (scored 2-6 out of 8 in the strength and balance domains of SPPB, without either section scoring zero), (d) were not regularly engaging in recreational sports or structured exercise (once a week or more). Furthermore, participants were deemed unable to take part if they had (a) any unstable chronic illness, cardiac, pulmonary, liver, or kidney abnormalities, uncontrolled hypertension, peripheral arterial disease, severe cognitive impairment, or major surgery in the previous 6 months, (b) a physical disability or underlying health condition that would affect exercise participation, (c) medical contraindications to exercise including chest pain, dizziness, or loss of consciousness, or who had been instructed by their doctors to only do physical activity recommended by them, (d) were unable to provide informed consent, or e) could not complete the physical function familiarisation test. Eligibility was ascertained through a preliminary online screening health questionnaire which also gathered participant demographic data.

Randomisation

Participants were randomised to either the intervention group, or the control group (i.e. maintain habitual physical activity patterns), after baseline assessments were completed. Randomisation was performed using computer-generated blocked randomisation with a minimisation algorithm to balance groups by age and sex (Hopkins, 2017), by a statistician who remained independent to any assessment or intervention delivery. Participants living in the same household were treated as one unit and randomised into the same group to avoid contamination between trial arms. As a behavioural intervention, participants were required to be aware of their allocated trial arm, but no deviations from the protocol were made for either intervention or control.

Familiarisation

All participants undertook an online familiarisation session via video call (using participants' preferred software) to become accustomed to the physical function tests and undergo an exercise safety assessment. The subset of participants undertaking the laboratory-based assessment repeated the same familiarisation that they had performed remotely, with the addition of further measures of physical function.

Assessments

All assessments were completed remotely (and in person for the laboratory subgroup) at baseline, 4 weeks, 8 weeks, and 12 weeks by the lead researcher who was not blind to group allocation after randomisation. Evaluation of the usefulness and acceptability of the exercise intervention (the theoretical framework of acceptability (TFA; Sekhon et al. (2017)) survey, see Supplementary file 2) was undertaken by all participants in the intervention group at 4-, 8-, and 12-weeks.

Functional outcome measures

One week after familiarisation, all participants completed a remote functional assessment via video call. The primary physical function outcome was the SPPB strength and balance items (timed 5 x sit-to-stands, and standing balance in side-by-side, semi-tandem, and tandem foot positions). Secondary functional outcomes for all participants included assessments of muscle strength (60-second chair stand test) and balance capacity (single-leg standing balance hold for time up to 60 seconds) (Liang et al., 2021).

The subset of laboratory participants repeated these measures in person within one week of conducting the remote assessments, with additional functional measures that included the full SPPB (i.e. gait speed, strength and balance) (Guralnik et al., 1994), the timed-up-and-go test (Podsiadlo and Richardson, 1991) and a chair sit-and-reach flexibility test (Rikli and Jones, 2013). Lower limb strength and power were assessed via a 10-repetition incremental leg press test (A420, Keiser®, Fresno, CA) to establish force-velocity profile characteristics (Samozino, 2012).

Briefly, participants were asked to complete 10 discrete repetitions of leg pressing against increasing resistance up to their individual one-repetition maximum. Each repetition was required to be performed at maximum velocity, and increasing rest duration was permitted between each repetition.

Psychological process measures

Participants completed an online baseline questionnaire assessing physical activity levels measured using the International Physical Activity Questionnaire-elderly (IPAQ-E, short form) (Hurtig-Wennlöf et al., 2010), and the following psychological outcomes: the Multidimensional Outcome Expectations for Exercise Scale (MOEES) (Resnick et al., 2000), the Behaviour Regulation Exercise Questionnaire (BREQ-3) (Wilson et al., 2006, Markland and Tobin, 2004), perceived competence for exercise (Williams and Gill, 1995), the habit strength for exercise (Verplanken and Orbell, 2003), and the self-efficacy for exercise (SEE) (Resnick and Jenkins, 2000).

Health and wellbeing secondary outcomes

In addition to the psychological measures, the questionnaire pack also included scales to capture instrumental activities of daily living (IADL) (Lawton and Brody, 1969) vitality using the Subjective Vitality Scale (Ryan and Frederick, 1997), the Warwick-Edinburgh Mental Wellbeing Scales (WEMWBS) (Tennant et al., 2007), the EuroQoL five-dimension, five- level questionnaire (EQ-5D-5L) (Herdman et al., 2011), the Satisfaction With Life Scale (Diener et al., 1985), the Short Form (SF-36) Health Survey (Ware et al., 2001).

The chosen questionnaires have demonstrated validity and reliability in measuring their respective constructs in older populations. Prior research has established the psychometric properties of these instruments, supporting their appropriateness for assessing various aspects in older adult populations.

Acceptability of the intervention: TFA survey and interview

Acceptability was measured with an 8-item online questionnaire based on the seven dimensions of TFA and a general overall assessment (Sekhon et al., 2022). Specifically, the framework focuses on how people feel about an intervention (affective attitude); the amount of effort the intervention requires (burden); how well the intervention relates to people's beliefs and values (ethicality); how well the intervention was understood (coherence); whether or not other benefits needed to be given up to engage with the intervention (opportunity cost); whether people believed the intervention would work for them as intended (perceived effectiveness); and an individual's confidence in their ability perform the intervention (self-efficacy). A Total score was calculated by summing the responses to each question, assigning scores of 1-5 to the response categories from "completely unacceptable," "no opinion," to "completely acceptable," (Sekhon et al., 2017). A higher score indicated greater acceptability to the exercise programme.

After the 12-week exercise and Tai-chi snacking intervention, semi-structured interviews were conducted in a subset of intervention participants. Participants for the interviews were selected from volunteers within the intervention group. Individuals who voluntarily expressed their willingness to partake in the interviews were included. The topic guide was also based on the seven dimensions of TFA for understanding acceptability of the intervention. See Supplementary file 3 for the Interview Topic Guide.

Intervention

The 12-week intervention consisted of three progressive phases. The principle of the progression was to gradually increase the workload and intensities of each exercise by the following strategies: a) increasing range of motion, b) more focus on isolating working limbs (by removing support), c) moving onto unilateral body weight movements to increase load through a limb, d) increasing complexity of arm movements, and/or e) increasing time under tension. Progression through each phase of exercise difficulty was guided by simple progression criteria based on ability to perform a set number of repetitions of a given exercise (see Supplementary file 1). Each exercise of the programme could be progressed individually, i.e., Exercise A could progress to the next phase for that exercise, whilst Exercise B could remain at the current phase. As such, the phases of the programme were not of fixed duration but catered to an individual's capability and rate of progress.

Participants were asked to record number of repetitions completed per exercise in logbooks to monitor adherence and progression, with rating of perceived exertion (RPE) for each exercise session. Two bouts of exercise were performed each day, one exercise snack and one Tai-chi snack. Each snack consisted of 5 exercises, each performed for one minute with one minute rest in between. Exercise snacks included a leg exercise, a shoulder exercise, a single leg exercise, an arm exercise, and a plantar flexor exercise, and participants were encouraged to complete as many repetitions as possible of each exercise in that minute.

Tai-chi snacks included a single leg squat, a trunk rotation, a single leg stand, a hip and knee exercise, and an ankle mobility exercise, and participants were encouraged to complete repetitions of each exercise at a self-selected pace that was comfortable for them to maintain for the full minute, with the aim being to complete the movements as accurately and smoothly as possible based on correct posture and proper alignment.

Participants in the intervention group were provided with the exercise written instructions and the YouTube video instructions. The video instructions were demonstrated by a certified fitness instructor (IJL) and assisted by two older adults performing lighter-intensity options/modifications of the exercise movements. See Supplementary file 1 for exercise instructional sheet.

Statistical analysis

Power calculation

Using G*Power software we determined that based on finding an effect size of 0.5 (the mean difference in SPPB between intervention and control in previous study (Stathi et al., 2022)) with 90% power and a significance alpha of 0.05, we required a sample size of 86. However, we utilised only the strength and balance domains of the SPPB, not the entire SPPB scale as these were deemed to have greater assumed reliability in a remote videocall format, and have better predictive utility on physical function outcomes (Western and Malkowski, 2022). The drop-out rate in our recent remote study (Liang et al., 2021) was 19% and to allow for an anticipated higher attrition rate due to the longer duration of study we aimed for a total sample size of 102.

Quantitative data analysis

All analyses were performed using R version 4.1.2 (R Core Team 2021, R Foundation for Statistical Computing, Vienna, Austria). Data are presented as means (standard deviations), or estimated mean difference [95%CI], unless otherwise stated. A linear mixed model (using the lme4 package (Bates et al., 2014)) was used for all estimations, with sex, age, timepoints, and study groups included as fixed effects and participant ID included as a random effect to account for repeated observations. An interaction effect for 'Time × Group' was used to understand whether there was any difference in response over time between groups. Separate models were run for each outcome variable. Statistical significance was set as $p<0.05$.

Qualitative interview analysis

Digital recordings of interviews were transcribed verbatim in Microsoft Word in an anonymized format and then uploaded to QSR NVivo12 for coding and data organization. Data were analysed using a deductive framework analysis (Ritchie et al., 1994) in line with aspects of the Theoretical Framework of Acceptability (Sekhon et al., 2017) to integrate participants' perspectives on barriers and motivators to participation, future support, and any opportunities to improve the protocol.

5.3.4 *Results*

Ninety participants passed the eligibility screening tests, with 44 randomised to the intervention group and 46 to the control group. Of the 90 randomised participants, 64 (71%) completed the study. Figure 5-1 indicates the flow of participants through the study. A subset of 49 participants self-selected to take part in the lab setting assessments and 40 of them completed the study. Baseline characteristics for all randomised participants, and the self-selected lab subset participants are shown in Table 5-1. No baseline characteristics or functional status were different between completing versus withdrawing participants, and no significant differences were observed between the intervention and control groups at baseline. ($p>0.05$) (See Table 5-2).

Figures

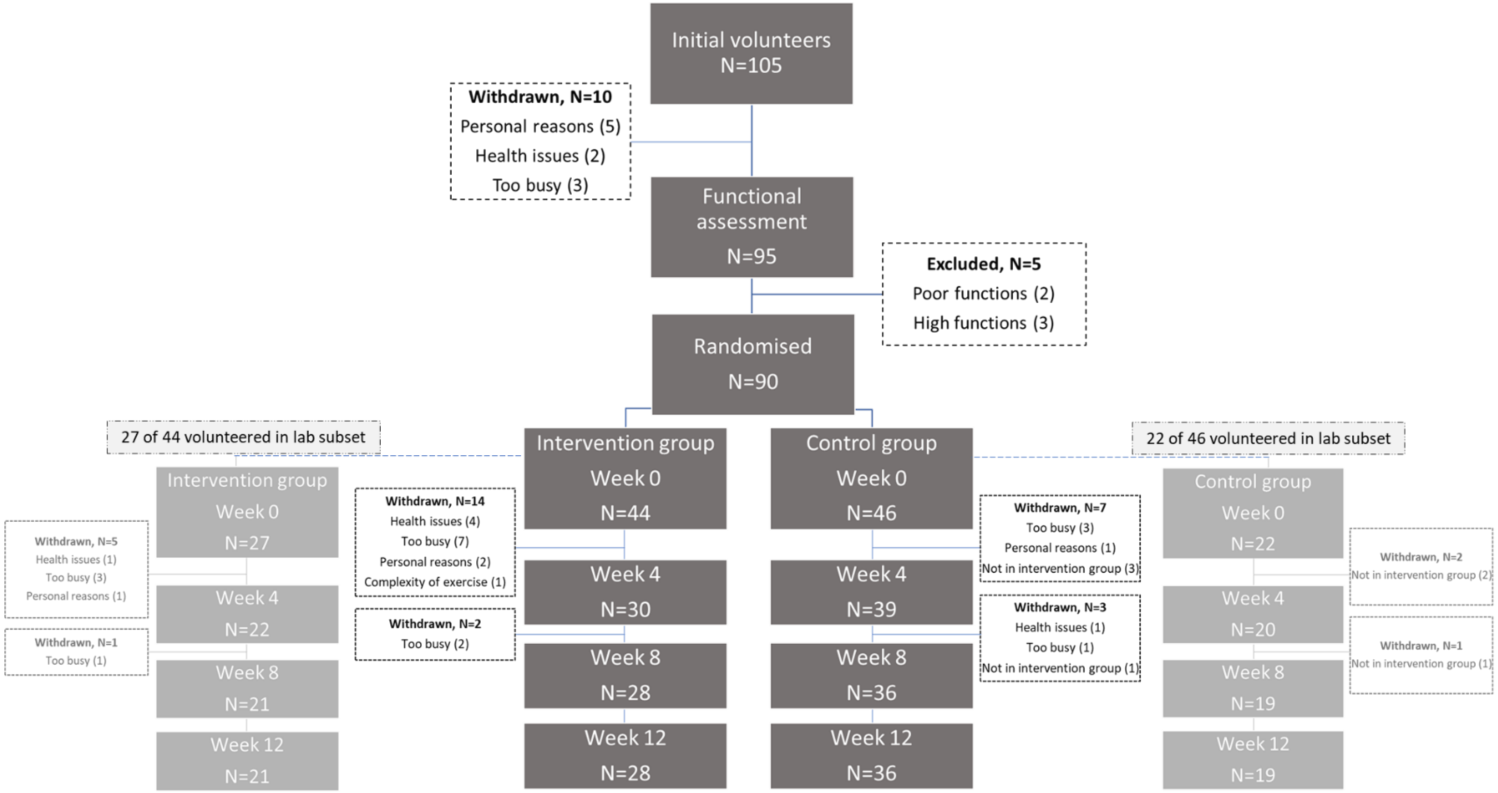

Figure 5-1. Flow diagram of participation throughout the study. Light grey boxes represent the flow of subset participants who also took part in lab-based sessions throughout the study.

Table 5-1. Baseline characteristics of participants

	All randomised participants*				Lab subset participants			
	Total N=90	**Intervention N=44**	**Control N=46**	***P* value**	**Total N=49**	**Intervention N=27**	**Control N=22**	***P* value**
Female, n (%)	64(71)	31(71)	33(72)	.893	31(63)	18(67)	1359)	.584
Age, mean ± SD	74.1±5.5	74.0±5.5	74.2±5.6	.823	74.1±5.4	73.7±5.6	74.5±5.3	.586
Height (cm), mean ± SD	167.7±8.9	168.3±8.5	167.1±9.4	.303	169.2±8.6	169.1±8.5	169.5±8.9	.700
Weight (kg), mean ± SD	74.4±14.5	71.7±12.1	76.9±16.1	.080	73.6±12.2	72.0±11.8	75.7±12.8	.485
Living alone, n (%)	30(33)	10(23)	20(44)	**.037**	25(51)	15(56)	10(46)	.482
Marital status, n (%)				.086				**.045**
Married/ civil part.	56(62)	33(75)	23(50)		30(61)	20(74)	10(45)	
Divorced/Separated	15(17)	4(9)	11(24)		8(17)	2(7)	6(27)	
Widowed	8(9)	2(5)	6(13)		4(8)	1(4)	3(14)	
Single	7(8)	4(9)	3(6.5)		5(10)	4(15)	1(5)	
Cohabiting	4(4)	1(2)	3(6.5)		2(4)	0	2(9)	
Employment, n (%)				.563				.498
Retired	82(91)	40(91)	42(91)		45(92)	25(92)	20(91)	
Doing unpaid work	1(1)	3(7)	4(9)		1(2)	1(4)	2(9)	
Employed part-time	7(8)	1(2)	0(0)		3(6)	1(4)	0(0)	
Educational status, n (%)				.979				.265
Secondary Education	10(11)	4(9)	6(13)		7(14)	3(11)	4(18)	
Post-Secondary	13(15)	7(16)	6(13)		2(4)	2(7)	0(0)	
Vocational Qualification	14(16)	7(16)	7(15)		11(23)	8(30)	3(14)	
Undergraduate Degree	32(36)	16(37)	16(35)		19(39)	11(41)	8(36)	
Post-graduate Degree	17(19)	8(19)	9(20)		8(16)	2(7)	6(27)	
Doctorate (PhD)	3(3)	1(3)	2(4)		2(4)	1(4)	1(5)	

Differences between groups were analysed using Chi-square tests.
*All randomised participants include 49 lab subset participants.

Table 5-2. Baseline characteristics for completing vs. withdrawing participants

	Completers vs Withdrawers		
	Completers N=64	**Withdrawers N=26**	***P* value**
Female, n (%)	47(73)	17(65)	.445
Age, mean ± SD	73.9±5.4	74.65±5.8	.249
Height (cm), mean ± SD	167.3±9.8	168.6±6.5	.266
Weight (kg), mean ± SD	74.7±15.5	73.7±11.8	.295
Living alone, n (%)	20(31)	10(38)	.511
Marital status, n (%)			.965
Married/ civil part.	41(64)	15(58)	
Divorced/Separated	10(16)	5(19)	
Widowed	5(8)	3(12)	
Single	5(8)	2(7)	
Cohabiting	3(4)	1(4)	
Employment, n (%)			.577
Retired	59(92)	23(88)	
Doing unpaid work	1(2)	0(0)	
Employed part-time	4(6)	3(12)	
Educational status, n (%)			.378
Secondary Education	7(11)	3(12)	
Post-Secondary	6(9)	7(26)	
Vocational Qualification	12(19)	3(12)	
Undergraduate Degree	25(39)	7(26)	
Post-graduate Degree	12(19)	5(19)	
Doctorate (PhD)	2(3)	1(4)	
Physical function, mean (SD)			
SPPB S&B items (score /8)	5.25(0.80)	5.19(0.94)	.253
SPPB strength (score /4)	2.00(0.87)	2.04(0.92)	.379
5 reps sit-to-stand speed (s)	16.61(5.98)	16.03(4.91)	.856
SPPB balance (score)	3.25(0.50)	3.15(0.54)	.657
60-s sit-to-stand (N reps)	21.06(6.70)	22.31(9.19)	.161
Right leg standing balance (s)	24.90(22.39)	27.39(23.31)	.626
Left leg standing balance (s)	25.67(21.60)	25.24(21.07)	.656

Differences between groups were analysed using Chi-square tests and unpaired t-tests.

Outcome data

Table 5-3 presents functional outcomes, with estimated mean differences between groups at all follow-up measures. See Supplementary file 4 for the mean scores of all outcomes at each timepoint (including between-group comparison).

SPPB strength and balance summed scores were significantly higher in the intervention group than in the control group at every follow-up timepoint: week 4 (estimated mean difference 1.73[95% CI 1.31/2.16]; $p<0.0001$); week 8 (1.36[95% CI 0.95/1.77]; $p<0.0001$); and week 12 (1.42[95% CI 1.00/1.85]; $p<0.0001$) and when considered in isolation (Supplementary file 4). Figure 5-2a shows the changes in SPPB strength and balance summed scores across all timepoints. The 60s STS, and stand on left leg were significantly higher in the intervention group than in the control group at every timepoint, while stand on right leg (10.81[95% CI -0.25/1.98]; $p=0.0186$) was significantly improved at week 4 but not 8 and 12. There were no significant differences found in other functional outcomes, process measures or secondary health and wellbeing outcomes.

Subset lab-based physical functional outcomes

Participants in the intervention group had significantly better performance in total SPPB total score at every follow-up timepoint compared to those in the control group (Figure 5-2b). Additionally, the scores of each individual SPPB domain (i.e., strength, balance, and gait speed) were significant different between groups at every follow-up timepoints (Supplementary file 5). 5 reps STS, TUG, and stand on right leg were found to be significantly higher in the intervention group than in the control group at week-4 and week-8. while stand on left leg was significantly higher in the intervention group at week 8 only. No significant differences were observed between groups for the peak force of Keiser leg press, or in flexibility outcomes. All outcomes between-group comparison at each timepoint for the subset lab-based participants are presented in Supplementary file 5.

Table 5-3. Raw data showing mean (SD) of physical function outcome measures at each time point, along with estimated mean differences (EMD) and p-values between groups. EMD and p-values were obtained using linear mixed models adjusted by sex and age for all follow-up measures.

Outcome	Week 0		Week 4				Week 8				Week 12			
	Int	Con	Int	Con	***Between group EMD [95%CI]***	***p value***	Int	Con	***Between group EMD [95%CI]***	***p value***	Int	Con	***Between group EMD [95%CI]***	***p value***
All participants, n	**44**	**46**	**30**	**39**			**28**	**36**			**28**	**36**		
SPPB strength (/4)	2.08 (1.0)	2.03 (0.8)	3.52 (1.1)	2.48 (0.9)	*1.05 [0.64 - 1.45]*	**<.001**	3.10 (1.2)	2.30 (0.8)	*0.79 [0.40 - 1.19]*	**<.001**	3.24 (1.0)	2.45 (0.8)	*0.79 [0.38 - 1.19]*	**<.001**
5 reps STS time (s)	16.72 (6.8)	16.01 (4.4)	9.77 (4.2)	14.09 (4.3)	*-4.32 [-6.27 - -2.37]*	**<.001**	11.79 (4.2)	15.14 (3.7)	*-3.35 [-5.26 - -1.44]*	**<.001**	11.05 (3.4)	14.39 (3.5)	*-3.34 [-5.29 - -1.38]*	**<.001**
SPPB balance (/4)	3.16 (0.5)	3.28 (0.5)	3.91 (0.5)	3.20 (0.6)	*0.71 [0.45 - 0.96]*	**<.001**	3.73 (0.5)	3.17 (0.6)	*0.57 [0.32 - 0.82]*	**<.001**	3.80 (0.3)	3.15 (0.6)	*0.65 [0.39 - 0.91]*	**<.001**
60-s STS (reps)	22.6 (7.9)	21.7 (7.1)	31.9 (8.5)	25.4 (7.4)	*6.5 [3.1 - 9.9]*	**<.001**	27.6 (10.6)	24.0 (7.0)	*3.6 [0.2 - 6.9]*	**0.038**	29.7 (10.0)	24.9 (6.7)	*4.8 [1.4 - 8.2]*	**<.001**
Right leg balance (s)	28.1 (22.4)	23.7 (22.7)	38.0(21.7)	27.2 (21.6)	*10.81 [1.83 - 19.8]*	**0.019**	33.1 (22.5)	25.8 (21.7)	*7.3 [-1.6 - 16.1]*	0.107	32.9 (22.7)	26.4 (21.9)	*6.5 [-2.4 - 15.5]*	0.152
Left leg balance (s)	30.5 (21.9)	21.6 (20.0)	35.3 (22.0)	22.7 (18.2)	*12.6 [4.1 - 21.0]*	**0.004**	37.4 (22.3)	20.1 (19.7)	*17.3 [9.0 - 25.5]*	**<.001**	35.4 (23.1)	24.6 (20.2)	*10.8 [2.4 - 19.2]*	**0.012**
Lab sub-group, n	**27**	**22**	**22**	**20**			**21**	**19**			**21**	**19**		
SPPB strength (/4)	1.7 (0.5)	1.7 (0.5)	3.38 (1.1)	2.51 (1.0)	*0.87 [0.34 - 1.39]*	**0.001**	2.85 (1.3)	2.21 (0.8)	*0.64 [0.12 - 1.16]*	**0.017**	3.4 (1.0)	2.5 (0.7)	*0.6 [0.1 - 1.1]*	**0.031**
5 reps STS time (s)	16.5 (3.7)	16.4 (4.6)	11.5 (3.3)	13.9 (4.4)	*-2.3 [-4.5 - -0.2]*	**0.035**	12.9 (4.4)	15.1 (3.3)	*-2.2 [-4.4 - 0.1]*	**0.044**	11.5 (3.4)	14.1 (3.6)	*-1.7 [-3.9 - 0.5]*	0.120
SPPB balance (/4)	3.1 (0.6)	3.1 (0.4)	3.96 (1.6)	3.11 (1.0)	*0.84 [0.54 - 1.15]*	**<.001**	3.83 (1.7)	2.94 (1.2)	*0.89 [0.59 - 1.18]*	**<.001**	3.1 (1.7)	2.7 (1.2)	*0.6 [0.3 - 0.9]*	**<.001**
SPPB gait speed (/4)	2.9 (0.5)	3.0 (0.4)	3.82 (0.6)	3.25 (0.7)	*0.56 [0.25 - 0.88]*	**<.001**	3.56 (0.6)	3.13 (0.5)	*0.43 [0.12 - 0.74]*	**0.007**	3.8 (0.4)	3.3 (0.6)	*0.6 [0.3 - 0.9]*	**<.001**
SPPB 4-m walk (s)	5.3 (0.8)	5.4 (0.7)	4.18 (0.8)	5.10 (0.9)	*-0.93 [-1.36 - -0.48]*	**<.001**	4.64 (0.7)	5.21 (0.7)	*-0.57 [-1 - -0.14]*	**0.012**	4.2 (0.8)	5.1 (0.8)	*-0.9 [-1.3 - -0.5]*	**<.001**
60-s STS (reps)	21.3 (6.8)	20.1 (4.7)	26.2 (5.5)	22.8 (6.7)	*3.4 [-0.2 - 7.1]*	0.065	23.7 (6.8)	21.6 (6.5)	*2.1 [-1.6 - 5.7]*	0.259	25.6 (6.2)	22.3 (6.1)	*2.6 [-1.1 - 6.2]*	0.163
Right leg balance (s)	30.5 (26.2)	20.2 (18.5)	32.3 (22.3)	18.2 (16.7)	*13.6 [2.0 - 25.3]*	**0.022**	30.3 (24.1)	24.3 (17.3)	*11.7 [-0.1 - 23.2]*	**0.047**	34.6 (23.7)	16.9 (14.4)	*11.3 [-0.4 - 22.9]*	0.057

Left leg balance (s)	30.0 (24.3)	21.8 (18.1)	30.6 (60.4)	24.8 (20.0)	*12.4 [-5.4 - 30.1]*	0.171	43.8 (23.2)	19.0 (22.1)	*19.5 [2.1 - 36.8]*	**0.029**	33.4 (21.3)	18.7 (17.3)	*9.6 [-8.2 - 27.3]*	0.287
Time-up-and-go (s)	10.7 (2.7)	11.1 (2.0)	8.74 (2.4)	10.6 7(2.1)	*-1.94 [-3.11 - -0.76]*	**0.002**	9.93 (2.4)	11.51 (2.1)	*-1.58 [-2.74 - -0.42]*	**0.008**	8.8 (1.7)	10.5 (2.1)	*-1.1 [-2.3 - 0.1]*	0.071
Sit-and-reach Right (cm)	-12.8 (11.1)	-10.8 (11.4)	-7.6 (9.4)	-6.3 (10.5)	*-1.24 [-7.24 - 4.75]*	0.681	-11.05 (9.3)	-8.02 (11.1)	*-3.03 [-8.98 - 2.92]*	0.313	-5.4 (8.9)	-5.5 (9.9)	*-2.0 [-8.0 - 4.0]*	0.508
Sit-and-reach Left (cm)	-12.2 (11.1)	-13.3 (12.6)	-7.4 (9.8)	-6.7 (10.8)	*-0.74 [-6.63 - 5.16]*	0.804	-10.83 (9.2)	-6.85 (10.4)	*-3.97 [-9.84 - 1.89]*	0.180	-5.0 (9.0)	-6.3 (10.5)	*-2.9 [-8.8 - 3.0]*	0.335
Keiser outcomes n	**21**	**19**	**21**	**19**			**21**	**19**			**21**	**19**		
Peak force (N)	1034 (227)	1191 (423)	1258 (253)	1260 (432)	*-2 [-170 - 166]*	0.983	1156 (230)	1233 (435)	*-77 [-246 - 91]*	0.360	1124 (300)	1191 (407)	*-107 [-275 - 62]*	0.209
Peak force/weight (N/kg)	1.5 (0.4)	1.6 (0.5)	17.1 (1.0)	16.8 (1.0)	*0.3 [-2.5 - 3.2]*	0.823	15.7 (1.0)	16.3 (1.0)	*-0.6 [-3.5 - 2.2]*	0.669	1.6 (0.5)	1.6 (0.5)	*-0.9 [-3.8 - 1.9]*	0.511

The Keiser outcomes are sum for peak force for right and left legs, and the Keiser data show in the table are translated data (i.e., what the pedals were doing).
For the chair sit-and-reach tests, the distance was measured between the tip of the fingertips and the toes. If participants' fingertips touch the toes, then the score was zero. If not, the distance between the fingers and the toes was recorded in negative scores, if they overlap, the distance was recorded in positive scores.
Int= intervention group, con= control group.

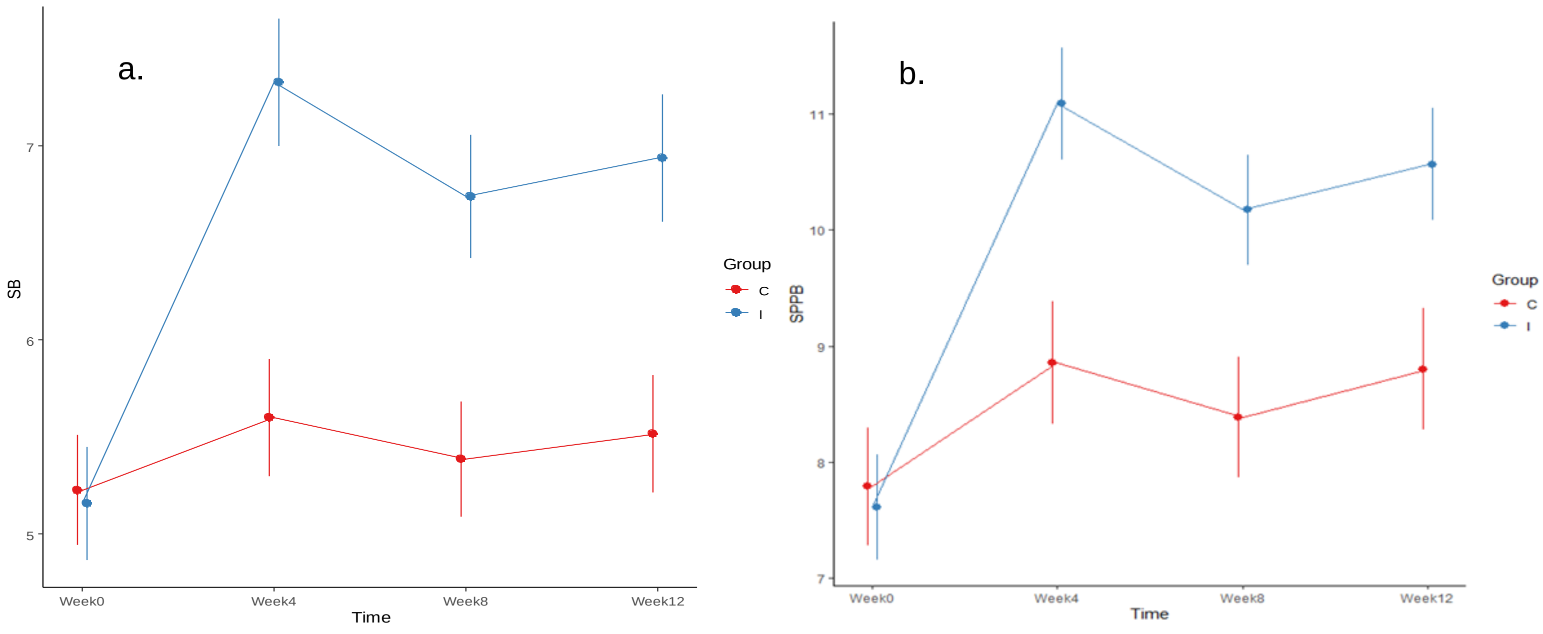

Figure 5-2. a) Predicted margins for SPPB strength and balance summed score (max. 8) with 95% CIs across all timepoints; b) Predicted margins for SPPB total score (max. 12) with 95% CIs for the lab-based subset across all timepoints

Adherence and acceptability

Completed logbooks were available from 24 intervention participants (54% of starters, 86% of completers). These indicated a mean (SD) number of sessions attempted of 77 (10) for the exercise snacking sessions and 75 (10) for the Tai-chi snacking sessions out of a possible 84. Regarding the total 168 sessions of the programme, the mean percentage adherence was 90% (152 out of 168) for those completing it. Seven participants completed all sessions. In the intervention group, 14 participants stopped exercising and withdrew from the study in the first 4 weeks and 2 participants withdrew before the end of week 8. There were 28 (63%) randomised participants who finished the 12-week programme. Based on the data from the 24 available logbooks, over half the intervention participants progressed both exercise and Tai-chi snacking movements to level 2 in the first 4 weeks, and to level 3 during week 5-8. Four participants performed all level 3 movements in the first week, whereas two participants only did level 1 exercise snacking without progression and five participants only did level 1 Tai-chi snacking without progression. Participants' progression also depended on the intensities of the movements. For instance, participants had slower progression on single leg weight bearing movements (i.e., single leg split squat and march on the spot in exercise snacking, and heel tipping, stand on one leg, and front heel kick in Tai-chi snacking).

The aggregated mean±SD acceptability score of the exercise and Tai-chi snacking intervention was initially high at week 4 (3.98±0.32) and increased at week 8 (4.21±0.34) yet decreased at week 12 (4.08±0.31). Supplementary file 6 contains the TFA scores at different study timepoints.

Qualitative data suggests most participants found the 12-week progressive exercise and Tai-chi snacking programme accessible and convenient to do in their homes and showed a liking for the 'snacking' concept. Specifically, when it comes to participants' feelings towards the intervention (i.e., affective attitude), participants reported a sense of accomplishment and satisfaction after exercise sessions. Some felt pleased they were active, getting themselves moving, and challenging themselves. Preferences varied, with some favouring the simplicity of exercise snacking and others enjoying the elegance of Tai-chi snacking. Interestingly, some thought Tai-chi snacking movements were more challenging and took more effort to learn/perform, yet they preferred them due to their relaxing nature. Nevertheless, few participants found the programme too easy and short and reported 'getting bored' and desired more variety and levels and different options on intensities. In general, the exercise and Tai-chi snacking was found to be achievable, enjoyable, and motivational.

Regarding the perceived amount of effort (i.e., burden), participants who perceived themselves to have poor balance reported Tai-chi snacking to be more physically challenging. Similarly, few participants with special neuromuscular injury histories found some specific movements to be physically demanding. For instance, a female participant reported the upper body movements to be difficult due to her autoimmune muscular problem, and another participant considered trunk rotation movements to be difficult due to her past spinal injury. However, in general, most participants found that engaging with the programme did not require too much time and effort. Nonetheless, Tai-chi snacking was perceived as more time-consuming due to its novelty in exercise format and the relatively complex movements, which demanded increased cognitive effort.

Regarding opportunity costs, participants reported that they did not have to sacrifice doing any activities and indicated that the short bout snacking programme only took 20 minutes per day which is convenient, accessible and easy to imbed in their daily routine. Nonetheless, the most common reasons for skipping sessions were holidays, social activities, house chores, illness, childcare and busy schedules. Participants mentioned that doing the programme at a certain time every day would conceivably enhance the adherence and prevent them from excusing for not doing the exercises.

In terms of perceived benefits, most participants believed the programme improved their physical fitness and mental wellbeing. Notably, participants felt that the programme brought them a better lifestyle and made them feel heathier and more confident on their activities of daily living. One female participant mentioned that *''I do feel more confident lifting my arms, or doing things… It is sufficiently a level of change that it does make my life easier. I feel better even about lifting shopping and stuff, because I feel a bit stronger.''* Most participants noticed that their strength and balance had improved and found that upper body movements were helpful and good for their shoulder flexibility and mobility. Others mentioned that the exercises had strengthened the muscles they rarely used, and stretched and softened their knees and ankles, alleviated their knee and hip stiffness, or improved ankle joint stabilisation and calf muscle relaxation.

In terms of the intervention coherence, participants did not find any movements difficult to learn or to understand, other than one participant who reported that some of the level-3 Tai-chi snacking movements were difficult to understand. Video instructions were deemed useful and indispensable, especially for learning Tai-chi snacking. Some also mentioned that having two models in the videos who were at the same age group as them performing modifications of the exercise movements helped comprehension and motivation. Participants recommended that a single in-person demonstration or personal training session in the beginning of the intervention, and feedback on their performance of movements, may increase their self-efficacy further.

Concerning the ethicality of the programme, participants expressed that short bout basic snacking exercise is attractive and accessible for older adults and felt that the snacking exercise is relevant to people losing their fitness as they get older. A few participants thought that the programme could help sedentary older adults, people lacking confidence on exercising, people with joint or bone injuries or conditions such as osteoarthritis, and even physically inactive mid-aged adults.

Regarding remote assessments, no technological issues were reported other than two reports on the disconnection of the internet. A participant said that ‘’The online assessments were very good. I was impressed with that sort of being able to do it by Zoom when your internet doesn’t let you down!’’. In fact, participants who had not used video calling products enjoyed learning new techniques and felt impressed on their technological capability. That said, most participants who underwent both remote and lab-based sessions, preferred lab-based sessions as they made them feel more encouraged and personable. Particularly, some enjoyed performing the leg-press machine (Keiser) and found receiving physical feedback from the researcher nicer than via the screen.

Finally, participants experienced a sense of satisfaction, motivation, and noticed the improvement on fitness functions after doing the programme. These factors increased their self-efficacy for exercising, encouraged them to engage in more physical activities, and gave them confidence in trying different exercises. Most participants showed willingness to continue doing the programme, and even lengthen or increase the frequency of the sessions. Accordingly, the 12-week progressive exercise and Tai-chi snacking programme was considered to be effective, it also built-up participants’ self-esteem and further improved their abilities of managing activities of daily living and increased their engagement in physical activities. See supplementary file 7 for participant quotes in seven TFA domains.

5.3.5 Discussion

The 12-week progressive home-based exercise and Tai-chi snacking programme had significant positive effects on physical functions, with improvements in the SPPB S&B domains, 5 reps STS, 60s STS, and standing on one leg. These improvements were observed in week 4 and sustained until the 12-week intervention period was over. However, after this initial improvement, we noticed a plateau effect which might be attributed to the nature (i.e., simple snacking format) of our intervention and/or participants' progression of the exercises, suggesting that while the exercises were effective in initiating improvements, they reached a point of stability without further progression. This might highlight the need for continued adaptation or progression in the exercise programme to sustain improvements beyond a certain threshold. The improvement in SPPB total score was found in lab-based subset where previous research has indicated that small changes in SPPB scores (0.4-1.5) are clinically meaningful in pre-frail older adults (SPPB scored less than 9) (Perera et al., 2014, Kwon et al., 2009). Upon reaching the SPPB scores in the 11's and acknowledging the limitations of the SPPB's ceiling effect, pursuing substantial advancements in physical function may not be imperative. The data demonstrated the efficacy of exercise snacking in elevating and sustaining high levels of physical function. However, to surpass this established threshold, it appears that a more robust stimulus, possibly attainable through weight training, could be requisite. Exploring a hybrid approach that combines the benefits of exercise snacking with more intensive modalities such as weight training could offer a promising avenue for maximising physical function in older adults.

We also found significant differences on 5 reps STS, mobility (TUG), and standing on one leg and in week 4 and week 8 amongst participants who underwent laboratory testing. Most participants reached the highest level of difficulty by week 8, potentially leading to training plateau. These findings build upon our previous pilot work, indicating that engagement with and impact of a home-based exercise snacking routine extends beyond a 4-week period, and can lead to potentially meaningful changes in physical function (Western et al., 2023, Liang et al., 2023, Liang et al., 2021). Nevertheless, while participants in the intervention group had better performance in standing on right leg at week 4, no differences were found afterwards. Qualitative interviews and logbook notes may explain this consequence. Few participants reported that they habitually put their weight on one side during exercises, possibly contributing to asymmetrical balance outcomes. Addressing this in future instructions by emphasising weight balancing and shifting techniques could potentially lead to more balanced improvements in future studies. Furthermore, no significant improvements in flexibility were observed which may be attributed to the intervention's focus on strength and balance training without specific emphasis on flexibility. Future revisions of the programme may benefit from incorporating targeted active flexibility exercises to complement the observed flexibility enhancements.

In this study, we observed that progressive home-based exercise and Tai-chi snacking improved lower extremity strength, balance, and mobility over time in pre-frail older adults. Prior studies have consistently demonstrated the positive impact of home-based strength and balance exercises on muscle function, balance, and mobility in older adults (Stookey and Katzel, 2020, Nelson et al., 2004, Yates and Dunnagan, 2001). The results align with recent reviews highlighting balance and muscle functions benefits among healthy older adults (Chaabene et al., 2021) and improved leg muscle strength and mobility for individuals over 60 (Kis et al., 2019) through home-based exercises. Comparatively, our study suggests that 20-minutes of daily exercise and Tai-chi snacking can be as effective as more complex behavioural interventions (Stathi et al., 2022, Delbaere et al., 2021). While encouraging, it should be noted that the present study had some withdrawals, and its duration was shorter than these aforementioned complex interventions. Verifying the sustained benefit of exercise snacking would be required to determine long-term equivalency.

Our qualitative findings indicate that the acceptability and ease of fitting 'exercise snacks' into participants' daily routines were suitable for older populations. Nevertheless, experiences varied among participants, with both exercise and Tai-chi snacking being physically challenging, particularly single-leg weight-bearing and air squat movements. Exercise snacking was seen as enhancing strength and stamina, while Tai-chi snacking was perceived as beneficial for balance, flexibility, and ankle mobility. These findings align with prior qualitative studies in which older participants believed that strength-based exercise snacking could improve muscle functions and alleviate joint pain (Jansons et al., 2023, Fyfe et al., 2022a, Tyldesley-

Marshall et al., 2021), whereas Tai-chi training could enhance their balance, mobility, and full body relaxation (Saravanakumar et al., 2018, Du et al., 2023, Docker, 2006, Liang et al., 2023). Regarding acceptability, Tai-chi snacking was perceived as more time-consuming and cognitively demanding yet was seen as gentler, more mindful and elegant which participants enjoyed, while exercise snacking was straightforward and repetitive, allowing for more automatic performance. These findings align with previous studies in which participants found Tai-chi to be beautiful and refreshing, in contrast to repetitive exercises (Saravanakumar et al., 2018, Du et al., 2023). However, we could not isolate the effectiveness of either approach in this study, as participants did both. Exploring different variations of this programme might be worthwhile to determine which exercise approach is more effective and promotes better engagement and physical outcomes.

As we explored the functional outcomes, valuable insights into the timing of our intervention's benefits were uncovered. The strength and balance scores of SPPB consistently favoured the intervention group from week 4 to week 12, reaffirming the sustained effects. Additionally, the SPPB strength item (5 reps STS) showed consistent improvement in the intervention group, albeit with slightly decreasing effect sizes over time. Single leg standing balance initially improved but later stabilised/decreased. In the lab subset participants, SPPB scores consistently favoured the intervention group across all time points, along with positive effects on balance, gait speed, and 5 reps STS. The varying improvement rates may be due to participants progressing through exercise levels at different paces. While previous studies have reported post-intervention benefits (de Carvalho Bastone et al., 2020, Matsuda et al., 2010, Baker et al., 2001), the specific timing of adaptations and progression remains less explored. While our measurements extended to 12 weeks, representing progression from our previous work, the question of longer-term (i.e., years) effects remains unanswered. As participants age, further investigation into these sustained changes is important for understanding the lasting effects. Moreover, we observed little impact of the intervention on exercise cognition process variables or health and wellbeing outcomes. This might suggest that the intervention's impact was more pronounced on physical function rather than subjective health and wellbeing. It is essential to acknowledge the multifaceted nature of wellbeing and consider incorporating additional psychological assessments and broader measures to comprehensively evaluate the intervention's impact across health and wellbeing as well as diverse daily activities in future studies. It would be worth further scrutinising in larger and longer studies.

Programme adherence was high (90%, 152 out of 168 sessions). Studies have identified self-efficacy and outcome expectancy as key factors for exercise participation (Luszczynska et al., 2011, Williams et al., 2005) although we observed no significant change in these constructs. However, interview with completers indicated increased self-efficacy in physical activities and exercise, boosted by a sense of accomplishment and increased confidence in performing daily activities. These findings confirmed that enjoyment, satisfaction, and perceived effectiveness have strong correlations to exercise participation (Kirkland et al., 2011, Huang et al., 2007, Leone and Ward, 2013). However, a few participants found the programme too simple and desired more variations, although this presumably depended on participants physical activity levels since some participants found the movements in level 2 and 3 to be too difficult and complicated to perform based on their health conditions, and it also depended on the specific movements that participants liked. It is important to consider programme's intensities and variability to maintain the adherence (Chen et al., 2017, Liang et al., 2023). Regarding intervention dropout, most participants withdrew during the first month, reporting busyness and lack of time as primary reasons, consistent with recent studies (Collins et al., 2022, Rossi et al., 2018).

Strengths of the study include the quantitative and qualitative mixed-method study design, the randomised design, the novel, safe and implementable remote delivered home-based exercise programme (without serious adverse events), and the thorough self-reported adherence and progression on the exercise logs. This study also discovered the feasibility of unsupervised home-based exercise programme compared with previous home-based exercise intervention studies which were mainly with supervision (Hill et al., 2015, Kis et al., 2019).

Nevertheless, this study has several limitations. Firstly, the majority of participants were female (71%) and highly educated (58%), limiting the generalisability of our findings to populations with lower socioeconomic conditions. Technology literacy is also an issue with many older adults which was assessed during the recruitment. Secondly, the validity of remote assessments of physical function remains unknown even though conducting functional assessments remotely has been deemed feasible and safe (Liang et al., 2021). Future studies can explore the validity of these remote assessments. Moreover, due to limitations in remote assessment and concerns about accuracy, we did not examine the SPPB gait speed domain via online video calling sessions, although a study demonstrated that chair stand and balance test could be substitutes if mobility/gait speed performance assessments are challenging (Cesari et al., 2009). Nonetheless, it would be ideal to find solutions and assess the full battery of physical function remotely in future research. Thirdly, the high dropout rate of 29% is an important factor to consider when interpreting our results. Nevertheless, a baseline characteristic comparison between withdrawers and completers showed no significant differences (Table 5-2), suggesting that potential biases related to baseline characteristics were minimised. However, given that we did not achieve the desired power level, conducting further research with larger sample sizes and implementing strategies to reduce attrition is essential to verify the findings. Furthermore, it's important to note that the study did not employ blinding to group allocation (non-assessor blinding), which could be considered a potential limitation in the research methodology.

Although we tested the 10-rep incremental test for mechanistic outcomes in the subset lab-based participants, some were not able to generate maximum concentric movement velocity across all repetitions (i.e., push as fast and hard on every rep) due to reasons such as being afraid of robotic gym-based machines, feeling unsafe performing the leg presses/pushing the pedals (especially those who had knee/hip replacements), and/or not knowing how to perform the pushes faster (not familiar with the performing rhythms) etc. Therefore, we could not extrapolate maximum force or velocity or interpolate maximum power in the leg press. Specifically, in 90 of 160 trials (56% of participants), it was not possible to generate force velocity profiles. This limitation may be attributed to the functional level and characteristics of our participants. Other studies examining older adults with similar functional level using the Keiser leg press have reported force velocity profiles (Shea et al., 2019, Jonathan Bean et al., 2002, Mavros et al., 2015). It's important to acknowledge that while previous studies have successfully reported force velocity data using the Keiser machine, the appropriateness of this equipment for interpreting power/force velocity profiles in our study context still requires further exploration. Researchers seeking to use the Keiser leg press machine in pre-frail older adults (a 4-8 SPPB population) need to consider these limiting factors.

Another consideration is the order of the in-person lab-based and remote assessment sessions, which could affect the results. All lab-based participants completed remote sessions first, potentially leading to improved lab-based testing performance due to familiarity. This is particularly relevant to control group participants in the lab-based subset, possibly diluting intervention effects. Similarly, we acknowledged that monthly functional tests for the control group might impact functional outcomes via familiarisation, potentially leading to improvements. In addition, our exercise programme includes both upper and lower body movements owing to PPI feedback and previous qualitative work (Liang et al., 2023), yet we did not examine upper body functions. Furthermore, we did not investigate the maintenance of physical function improvements after the intervention ceased. Future studies should include upper body functional tests and follow-up assessments beyond programme's end.

5.3.6 *Conclusion*

Among pre-frail older adults, the 12-week progressive exercise and Tai-chi snacking programme examined in this trial is an acceptable, feasible, and effective method to improve physical function. Given its low-cost and ease of implementation, exercise and tai-chi snacking could represent a scalable solution to prevent physical frailty and associated complications such as falls and loss of independence. Future research should seek to find ways to engage and retain a more diverse population in the intervention and evaluate the long-term impact of this exercise intervention on physical function, health and wellbeing.

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Conflict of interest

None declared.

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5.3.7 References

AARTOLAHTI, E., LÖNNROOS, E., HARTIKAINEN, S. & HÄKKINEN, A. 2020. Long-term strength and balance training in prevention of decline in muscle strength and mobility in older adults. Aging clinical and experimental research, 32, 59-66.

BAKER, K. R., NELSON, M. E., FELSON, D. T., LAYNE, J. E., SARNO, R. & ROUBENOFF, R. 2001. The efficacy of home based progressive strength training in older adults with knee osteoarthritis: a randomized controlled trial. The Journal of rheumatology, 28, 1655-1665.

BELLOMO, R., IODICE, P., MAFFULLI, N., MAGHRADZE, T., COCO, V. & SAGGINI, R. 2013. Muscle strength and balance training in sarcopenic elderly: a pilot study with randomized controlled trial. European Journal of Inflammation, 11, 193-201.

BOWDEN DAVIES, K. A., PICKLES, S., SPRUNG, V. S., KEMP, G. J., ALAM, U., MOORE, D. R., TAHRANI, A. A. & CUTHBERTSON, D. J. 2019. Reduced physical activity in young and older adults: metabolic and musculoskeletal implications. Therapeutic advances in endocrinology and metabolism, 10, 2042018819888824.

CAVILL, N. A. & FOSTER, C. E. 2018. Enablers and barriers to older people's participation in strength and balance activities: A review of reviews. Journal of frailty, sarcopenia and falls, 3, 105.

CESARI, M., KRITCHEVSKY, S. B., NEWMAN, A. B., SIMONSICK, E. M., HARRIS, T. B., PENNINX, B. W., BRACH, J. S., TYLAVSKY, F. A., SATTERFIELD, S. & BAUER, D. C. 2009. Added value of physical performance measures in predicting adverse health-related events: results from the Health, Aging and Body Composition Study. Journal of the American Geriatrics Society, 57, 251-259.

CHAABENE, H., PRIESKE, O., HERZ, M., MORAN, J., HÖHNE, J., KLIEGL, R., RAMIREZ-CAMPILLO, R., BEHM, D., HORTOBÁGYI, T. & GRANACHER, U. 2021. Home-based exercise programmes improve physical fitness of healthy older adults: A PRISMA-compliant systematic review and meta-analysis with relevance for COVID-19. Ageing research reviews, 67, 101265.

CHEN, T. L., BHATTACHARJEE, T., BEER, J. M., TING, L. H., HACKNEY, M. E., ROGERS, W. A. & KEMP, C. C. 2017. Older adults' acceptance of a robot for partner dance-based exercise. PloS one, 12, e0182736.

COLLINS, K. A., HUFFMAN, K. M., WOLEVER, R. Q., SMITH, P. J., SIEGLER, I. C., ROSS, L. M., HAUSER, E. R., JIANG, R., JAKICIC, J. M. & COSTA, P. T. 2022. Determinants of dropout from and variation in adherence to an exercise intervention: the STRRIDE randomized trials. Translational Journal of the American College of Sports Medicine, 7, e000190.

DE CARVALHO BASTONE, A., NOBRE, L. N., DE SOUZA MOREIRA, B., ROSA, I. F., FERREIRA, G. B., SANTOS, D. D. L., MONTEIRO, N. K. S. S., ALVES, M. D., GANDRA, R. A. & DE LIRA, E. M. 2020. Independent and combined effect of home-based progressive resistance training and nutritional supplementation on muscle strength, muscle mass and physical function in dynapenic older adults with low protein intake: a randomized controlled trial. Archives of Gerontology and Geriatrics, 89, 104098.

DELBAERE, K., VALENZUELA, T., LORD, S. R., CLEMSON, L., ZIJLSTRA, G. R., CLOSE, J. C., LUNG, T., WOODBURY, A., CHOW, J. & MCINERNEY, G. 2021. E-health StandingTall balance exercise for fall prevention in older people: results of a two year randomised controlled trial. bmj, 373.

DOCKER, S. M. 2006. Tai Chi and older people in the community: a preliminary study. Complementary Therapies in Clinical Practice, 12, 111-118.

DU, Y., ROBERTS, P. & LIU, W. 2023. Facilitators and Barriers of Tai Chi Practice in Community-Dwelling Older Adults: Qualitative Study. Asian/Pacific Island Nursing Journal, 7, e42195.

FRANCO, M. R., TONG, A., HOWARD, K., SHERRINGTON, C., FERREIRA, P. H., PINTO, R. Z. & FERREIRA, M. L. 2015. Older people's perspectives on participation in physical activity: a systematic review and thematic synthesis of qualitative literature. British journal of sports medicine, 49, 1268-1276.

FRANCOIS, M. E., BALDI, J. C., MANNING, P. J., LUCAS, S. J., HAWLEY, J. A., WILLIAMS, M. J. & COTTER, J. D. 2014. 'Exercise snacks' before meals: a novel strategy to improve glycaemic control in individuals with insulin resistance. Diabetologia, 57, 1437-1445.

FURTADO, G. E., LETIERI, R. V., SILVA-CALDO, A., TROMBETA, J. C., MONTEIRO, C., RODRIGUES, R. N., VIEIRA-PEDROSA, A., BARROS, M. P., CAVAGLIERI, C. R. & HOGERVORST, E. 2021. Combined chair-based exercises improve functional fitness, mental well-being, salivary steroid balance, and anti-microbial activity in pre-frail older women. Frontiers in Psychology, 12, 564490.

FYFE, J. J., DALLA VIA, J., JANSONS, P., SCOTT, D. & DALY, R. M. 2022a. Feasibility and acceptability of a remotely delivered, home-based, pragmatic resistance 'exercise snacking'intervention in community-dwelling older adults: a pilot randomised controlled trial. BMC geriatrics, 22, 1-12.

FYFE, J. J., HAMILTON, D. L. & DALY, R. M. 2022b. Minimal-dose resistance training for improving muscle mass, strength, and function: A narrative review of current evidence and practical considerations. Sports Medicine, 1-17.

GOMES, M., FIGUEIREDO, D., TEIXEIRA, L., POVEDA, V., PAÚL, C., SANTOS-SILVA, A. & COSTA, E. 2017. Physical inactivity among older adults across Europe based on the SHARE database. Age Ageing, 46, 71-77.

GURALNIK, J. M., SIMONSICK, E. M., FERRUCCI, L., GLYNN, R. J., BERKMAN, L. F., BLAZER, D. G., SCHERR, P. A. & WALLACE, R. B. 1994. A short physical performance battery assessing lower extremity function: association with self-reported disability and prediction of mortality and nursing home admission. Journal of gerontology, 49, M85-M94.

HAWLEY-HAGUE, H., RODEN, A. & ABBOTT, J. 2017. The evaluation of a strength and balance exercise program for falls prevention in community primary care. Physiotherapy theory and practice, 33, 611-621.

HILL, K. D., HUNTER, S. W., BATCHELOR, F. A., CAVALHERI, V. & BURTON, E. 2015. Individualized home-based exercise programs for older people to reduce falls and improve physical performance: A systematic review and meta-analysis. Maturitas, 82, 72-84.

HILLSDON, M. & FOSTER, C. 2018. What are the health benefits of muscle and bone strengthening and balance activities across life stages and specific health outcomes? Journal of Frailty, Sarcopenia and Falls, 3, 66.

HUANG, C.-H., LEE, L.-Y. & CHANG, M.-L. 2007. The influences of personality and motivation on exercise participation and quality of life. Social Behavior and Personality: an international journal, 35, 1189-1210.

ISLAM, H., GIBALA, M. J. & LITTLE, J. P. 2022. Exercise snacks: A novel strategy to improve cardiometabolic health. Exercise and sport sciences reviews, 50, 31-37.

JANSONS, P., FYFE, J. J., DALLA VIA, J., DALY, R. M. & SCOTT, D. 2023. Barriers and enablers associated with participation in a home-based pragmatic exercise snacking program in older adults delivered and monitored by Amazon Alexa: a qualitative study. Aging clinical and experimental research, 35, 561-569.

KIRKLAND, R. A., KARLIN, N. J., STELLINO, M. B. & PULOS, S. 2011. Basic psychological needs satisfaction, motivation, and exercise in older adults. Activities, adaptation & aging, 35, 181-196.

KIS, O., BUCH, A., STERN, N. & MORAN, D. S. 2019. Minimally supervised home-based resistance training and muscle function in older adults: A meta-analysis. Archives of gerontology and geriatrics, 84, 103909.

KWON, S., PERERA, S., PAHOR, M., KATULA, J., KING, A., GROESSL, E. & STUDENSKI, S. 2009. What is a meaningful change in physical performance? Findings from a clinical trial in older adults (the LIFE-P study). JNHA-The Journal of Nutrition, Health and Aging, 13, 538-544.

LEONE, L. A. & WARD, D. S. 2013. A mixed methods comparison of perceived benefits and barriers to exercise between obese and nonobese women. Journal of Physical Activity and Health, 10, 461-469.

LIANG, I. J., FRANCOMBE-WEBB, J., MCGUIGAN, P. M., PERKIN, O. J., THOMPSON, D. & WESTERN, M. J. 2023. The acceptability of homebased exercise snacking and Tai-chi snacking amongst high and low function UK and Taiwanese older adults. Frontiers in Aging, 4.

LIANG, I. J., PERKIN, O. J., MCGUIGAN, P. M., THOMPSON, D. & WESTERN, M. J. 2021. Feasibility and acceptability of home-based exercise snacking and tai chi snacking delivered remotely to self-isolating older adults during COVID-19. Journal of Aging and Physical Activity, 30, 33-43.

LUSZCZYNSKA, A., SCHWARZER, R., LIPPKE, S. & MAZURKIEWICZ, M. 2011. Self-efficacy as a moderator of the planning–behaviour relationship in interventions designed to promote physical activity. Psychology and Health, 26, 151-166.

MATSUDA, P. N., SHUMWAY-COOK, A. & CIOL, M. A. 2010. The effects of a home-based exercise program on physical function in frail older adults. Journal of geriatric physical therapy, 33, 78-84.

NELSON, M. E., LAYNE, J. E., BERNSTEIN, M. J., NUERNBERGER, A., CASTANEDA, C., KALITON, D., HAUSDORFF, J., JUDGE, J. O., BUCHNER, D. M. & ROUBENOFF, R. 2004. The effects of multidimensional home-based exercise on functional performance in elderly people. The Journals of Gerontology Series A: Biological Sciences and Medical Sciences, 59, M154-M160.

PERERA, S., STUDENSKI, S., NEWMAN, A., SIMONSICK, E., HARRIS, T., SCHWARTZ, A., VISSER, M. & STUDY, H. A. 2014. Are estimates of meaningful decline in mobility performance consistent among clinically important subgroups?(Health ABC study). Journals of Gerontology Series A: Biomedical Sciences and Medical Sciences, 69, 1260-1268.

PERKIN, O. J., MCGUIGAN, P. M. & STOKES, K. A. 2019. Exercise snacking to improve muscle function in healthy older adults: a pilot study. Journal of aging research, 2019.

PODSIADLO, D. & RICHARDSON, S. 1991. The timed “Up & Go”: a test of basic functional mobility for frail elderly persons. Journal of the American geriatrics Society, 39, 142-148.

PRATA, M. G. & SCHEICHER, M. E. 2015. Effects of strength and balance training on the mobility, fear of falling and grip strength of elderly female fallers. Journal of bodywork and movement therapies, 19, 646-650.

RIKLI, R. E. & JONES, C. J. 2013. Senior fitness test manual, Human kinetics.

RITCHIE, J., SPENCER, L., BRYMAN, A. & BURGESS, R. 1994. Qualitative data analysis for applied policy research. Analyzing qualitative data, 173, 194.

ROSSI, P. G., CARNAZ, L., BERTOLLO, W. L. & TAKAHASHI, A. C. D. M. 2018. Causes of drop out from a physical exercise supervised program specific to older adults. Fisioterapia em Movimento, 31.

SARAVANAKUMAR, P., HIGGINS, I. J., VAN DER RIET, P. J. & SIBBRITT, D. 2018. Tai chi and yoga in residential aged care: Perspectives of participants: A qualitative study. Journal of clinical nursing, 27, 4390-4399.

SEKHON, M., CARTWRIGHT, M. & FRANCIS, J. J. 2022. Development of a theory-informed questionnaire to assess the acceptability of healthcare interventions. BMC health services research, 22, 279.

STATHI, A., GREAVES, C. J., THOMPSON, J. L., WITHALL, J., LADLOW, P., TAYLOR, G., MEDINA-LARA, A., SNOWSILL, T., GRAY, S. & GREEN, C. 2022. Effect of a physical activity and behaviour maintenance programme on functional mobility decline in older adults: the REACT (Retirement in Action) randomised controlled trial. The Lancet Public Health, 7, e316-e326.

STOOKEY, A. D. & KATZEL, L. I. 2020. Home exercise interventions in frail older adults. Current geriatrics reports, 9, 163-175.

STRAIN, T., FITZSIMONS, C., KELLY, P. & MUTRIE, N. 2016. The forgotten guidelines: cross-sectional analysis of participation in muscle strengthening and balance & co-ordination activities by adults and older adults in Scotland. BMC public health, 16, 1-12.

TYLDESLEY-MARSHALL, N., GREENFIELD, S. M., PARRETTI, H. M., GOKAL, K., GREAVES, C., JOLLY, K., MADDISON, R., DALEY, A. J. & YATES, S. S. T. S. B. C. E. D. E. E. F. N. I. N. M. J. S. L. S. M. S. T. 2021. Snacktivity™ to promote physical activity: a qualitative study. International journal of behavioral medicine, 1-12.

UK CHIEF MEDICAL OFFICER 2019. UK Chief Medical Officers' Physical Activity Guidelines In: CARE, D. O. H. S. (ed.). Chief Medical Officer: Chief Medical Officer.

WESTERN, M. J., WELSH, T., KEEN, K., BISHOP, V. & PERKIN, O. J. 2023. Exercise snacking to improve physical function in pre-frail older adult memory clinic patients: a 28-day pilot study. BMC Geriatr, 23, 471.

WILLIAMS, D. M., ANDERSON, E. S. & WINETT, R. A. 2005. A review of the outcome expectancy construct in physical activity research. Annals of behavioral medicine, 29, 70-79.

YATES, S. M. & DUNNAGAN, T. A. 2001. Evaluating the effectiveness of a home-based fall risk reduction program for rural community-dwelling older adults. The Journals of Gerontology Series A: Biological Sciences and Medical Sciences, 56, M226-M230.

5.3.8 *Supplementary file*

Supplementary File

The Efficacy of 12-week Progressive Home-Based Strength and Tai-Chi Exercise Snacking in Older Adults:

A Mixed-Method Exploratory Randomised Control Trial

Supplementary file 1 – Exercise instructions

Exercise snacking

What is exercise snacking?

This is a method of doing exercise into short bouts at a time that is convenient for you. We are asking you to try this daily short exercise snacking routine, which will include 5 minutes of exercise and 1 minute of rest between each exercise, every day for the next 12-weeks. The exercise programme is progressive and has three levels. You can progress to the next level on any type of exercise if you pass the progress criteria and when you feel you are ready. The exercises themselves are safe for the home and don't require a warm-up before starting. The exercises do not require any sports clothing or equipment; just a kitchen chair and a clock or watch to time your exercise with.

How is the exercise performed?

During each exercise bout, spend one minute performing each of the five exercises detailed below. Complete repetitions of each exercise at a self-selected pace that you can maintain for the full minute, with the aim being to complete as many repetitions as possible in that minute. If your muscles begin to feel unduly sore during the any of the exercises, you may of course slow down or indeed stop that exercise at that time. Take one minute between each exercise to rest.

What are the risks of performing the exercise?

As with any exercise, you are likely to feel tired towards the end of the session and in the time straight afterwards. However, the principle of exercise snacking is that the bouts should not be excessively demanding, with each exercise of the regime performed for only one minute at a self-selected repetition speed. The primary risk when performing the exercise is loss of balance during the standing exercises. This risk can be mitigated by performing the movements at a controlled pace, and by holding onto a stable object such as a chair, table, or door frame. This exercise regime has been designed specifically to avoid excessive cardiovascular load, as might be experienced during running, but you may still notice your breathing rate increase during the exercise. If your muscles begin to feel unduly sore during the any of the exercises, you may of course slow your repetition pace down or indeed stop that exercise at that time.

We recommend starting with all the level 1 exercises when you begin the programme. If you think any of the exercises are too easy for you, and you are finding yourself consistently meeting the progression criteria we have described in the table below, then you can try the next level exercise for that movement. You do not need to progress in each, or any, of the activities at the same time and should only ever do 5 exercises in total as part of your exercise snacking bout for the day. We ask that you mark down which 5 exercises you do on your exercise logbook and record the number of repetitions you do in the minute for each exercise.

Table S5-1. exercise snacking movements

Types of exercise	Exercise	Level 1	Level 2	Level 3
Exercise snacking (strength)	**ES1** **Sit-to-stand**	**ES1.1** **Sit-to-stand** (free arms)	**ES1.2** **Sit-to-stand** (arms across chest)	**ES1.3** **Air squat**
	Entry Criteria	**NA**	**10 reps minimum**	**10 reps minimum**
	Progress criteria	**No longer need arms**	**>45 reps**	**NA**
	ES2 **Shoulder exercise** (straight arms)	**ES2.1** **Seated hip-to-hip arch overhead**	**ES2.2** **Seated wood chop**	**ES2.3** **Seated figure 8's**
	ES3 **Single leg**	**ES3.1** **March on the spot**	**ES3.2** **Single leg split squat**	**ES3.3** **Reverse lunge**
	Entry Criteria	**NA**	**5 reps per leg**	**5 reps per leg**
	Progress criteria	**No feeling of stimulus**	**12 reps per leg**	**NA**
	ES4 **Arm exercise**	**ES4.1** **Seated arm cross**	**ES4.2** **Seated front raise to overhead**	**ES4.3** **Multidimensional arm raise**

	ES5 **Ankle exercise**	**ES5.1** **Seated calf raise**	**ES5.2** **Standing calf raise**	**ES5.3** **Single leg calf raise**
	Entry Criteria	**NA**	**15 reps minimum**	**15 reps minimum**
	Progress criteria	**30 reps**	**>45 reps**	**NA**

- **Level 1 exercise snacking movements**
  - ➢ **ES1.1 Sit-to-stand** (free-arms)**:** This exercise is simply repetition of rising from an up-right seated position on a kitchen chair, and then returning to the seated position. You can use your arms for aid out of the chair.

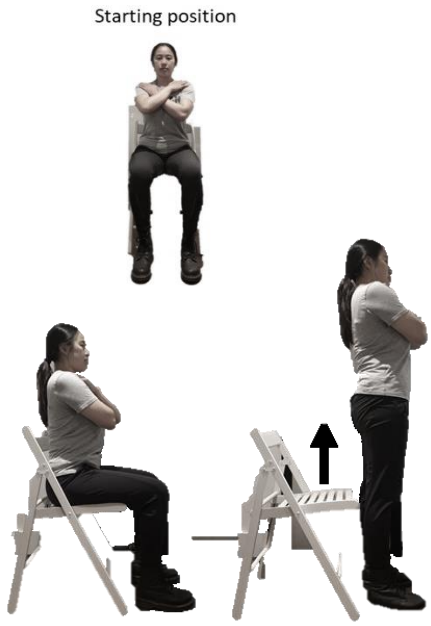
  - ➢ **ES2.1 Seated hip-to-hip arch overhead:** Starting from an up-right seated position on a kitchen chair with hands by your side. Keep your elbows slightly flexed whilst raising hands up laterally until arms by your ears. Return to the start position at a controlled pace, and repeat the movement.

  - ➢ **ES3.1 March on the spot:** Standing up-right, put your arms out in front of you and your hands roughly at waist height. Raise one leg up by bending your knee and hip as per the diagram, aiming to get your thigh as close to horizontal as possible, with the top of your thigh touching your hands. At a controlled pace, return to a standing position, regain balance if necessary, and repeat with the other leg. If you struggle with balance, you can hold onto something stable like the back of a chair or a door frame with one hand.

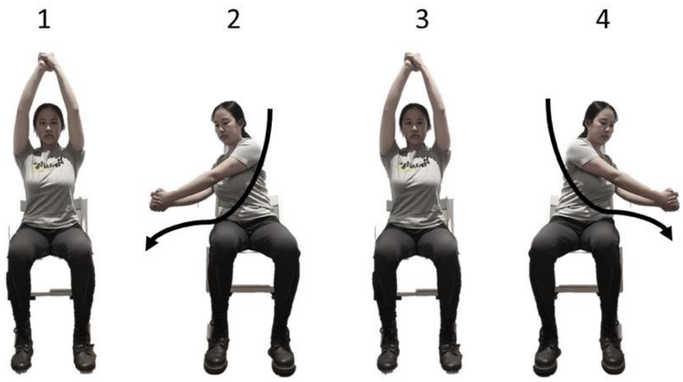
  - ➢ **ES4.1 Seated arm cross:** Start by sitting up-right in a chair with arms by your side. Keeping your arms straight, raise your hands up in front of you until arms are parallel to floor, and then cross your arms so each hand touches the opposite shoulder. Uncross your arms whilst keeping them straight out in front of you, then return to arms by side.

- **ES5.1 Seated calf raise:** Sitting up right in a chair, start with your feet fla on the floor and rise up onto you tiptoes as high as you can, then retur to the start position with feet flat on th floor. Perform the raises on both leg at the same time and try to complet as many as you can in a minute.

- **Level 2 exercise snacking movements**
  - **ES1.2 Sit-to-stand** (arms across chest)**:** This exercise is simply repetition of rising from an up-right seated position on a kitchen chair, and then returning to the seated position. Try to keep your arms folded across your chest to avoid using your arms to aid rising from the chair, making sure that your legs are doing the work.



  - **ES2.2 Seated wood chop:** Start with your hands together and your arms raised above your head. Keeping your hands together and arms straight, bring your hands diagonally down across the body, rotating your torso, until your hands are close to your hip. Return to the start position and repeat the movement with hands going towards the other hip.

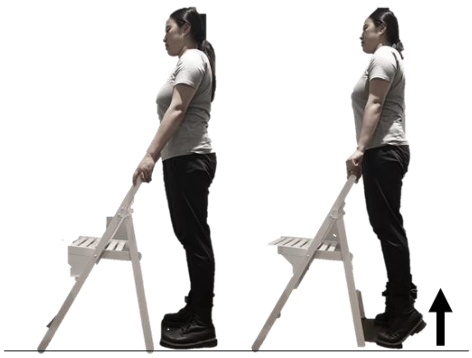


  - **ES3.2 Single leg split squat:** Stand with feet far apart, one foot forward and other foot behind. Squat down by flexing knee and hip of front leg. Allow heel of rear foot to rise up while knee of rear leg bends slightly until it almost makes contact with floor, or the thigh of your front leg is parallel to the floor. Return to original standing position by

extending hip and knee of forward leg. Do 30 seconds for each side. If you struggle with balance, you can hold onto something stable like the back of a chair with one hand.

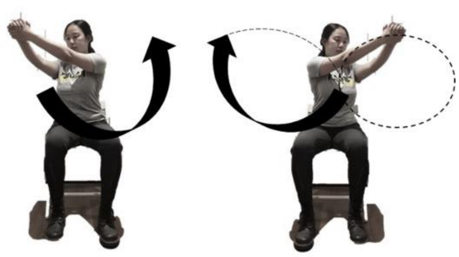
- **ES4.2 Seated front raise to overhead:** Starting from an up-right seated position on a kitchen chair with arms straight down by your side. Raise your arms in front of you, bending your elbows as you do so, and then reach your arms up over head until your elbows are straight again, and your hands touch together. Return to the starting position in a controlled pace and repeat the movement.

- **ES5.2 Standing calf raise:** Start with your feet flat on the floor and rise up onto your tiptoes as high as you can, then return to the start position with feet flat on the floor. It is advisable to hold onto something stable like a chair, table, or door frame to maintain balance. Perform the raises on both legs at the same time and try to complete as many as you can.



- **Level 3 exercise snacking movements**

  - **ES1.3 Air squat:** Stand with your feet shoulder-width apart and keep you toes pointing slightly outward. Slowly squat down as if you were about to si on a chair. Aim to keep your feet flat o the floor and maintain balance withou leaning forward excessively. Whe squatting, your hips will move dow and back, and you should aim to kee your back straight. When your knees are at right angles, stand up straight again in a controlled pace, and then repeat the movement.

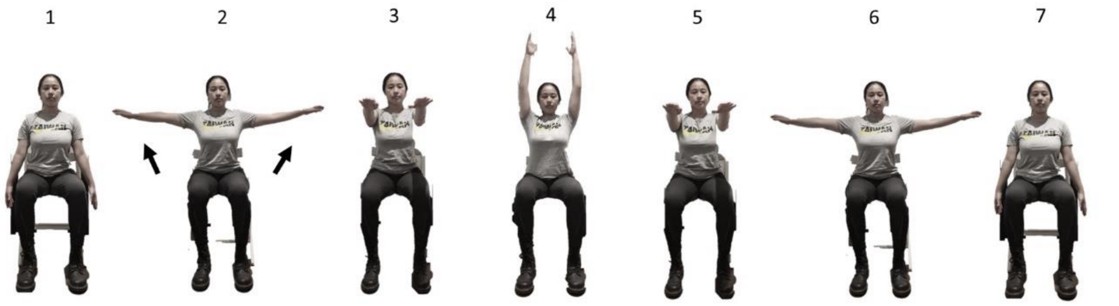


  - **ES2.3 Seated figure 8's:** Hold your hands together with your arms straight out away from your body. Slowly move your arms in a continuous motion forming the pattern of the number 8 on its side ('a figure of 8'). Repeat the movement in one direction for 30 seconds and then continue the exercise for 30 seconds forming the figure of 8 in the opposite direction.

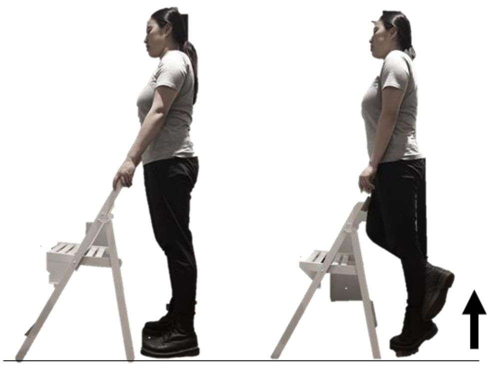
  - **ES3.3 Chair reverse lunge:** Stand straight with feet shoulder-width apart. Looking forward, take a step backward and lower your body by flexing your hips and knees. With your back leg making contact through the ball of the foo move your hip downward close t the floor, and then go back to th initial position by pushing throug the heel of your front leg, rega

balance if necessary, and repeat with the other leg. If you struggle with balance, you can hold onto something stable like the back of a chair with one hand.

- **ES4.3 Multidimensional arm raises:** Start in an up-right seated position on a kitchen chair with your arms down by your side. Keeping your arms straight, raise your hands up and out to the sides until your arms are parallel to floor. Bring your arms round so they are straight out in front of you, then raise your arms straight up over your head. Lower your arms so they are straight out in front of you, then bring your arms back up and out the sides, and then return your arms to the start position down by your side.



- **ES5.3 Single leg calf raise:** Start with your feet flat on the floor and rise up your left heel onto your tiptoes as high as you can, then return to the start position with feet flat on the floor and repeat with the other leg (rise up your right heel), and repeat the movements alternatingly. If you struggle with balance, you can hold onto something stable like the back of a chair with one hand.



Tai-chi snacking

What is Tai-chi?

Tai-chi combines deep breathing and relaxation with flowing movements. Unlike the Exercise snacking plan, the goal is not to complete the movements as fast as possible but perform them in a slow and controlled way. The Tai-chi snacking programme is progressive and has three levels. You will start from practicing basic balance movements and progress to higher levels which the movements are inspired by the principles of Tai-chi. We are asking you to try this short Tai-chi routine, which will include 5 minutes of exercises and 1 minute of rest between each exercise, every day for the next 12-weeks. The exercises themselves are safe for the home and don't require a warm-up before starting. The exercises do not require any sports clothing or equipment; just a kitchen chair or other suitable surface in case you feel you need extra support while performing the movements.

How is the exercise performed?

During each exercise bout, spend one minute performing each of the five exercises detailed below. Complete repetitions of each exercise at a self-selected pace that is comfortable for you to maintain for the full minute, with the aim being to complete them as accurately and smoothly as possible (based on correct posture and proper alignment). If your legs begin to feel sore during the any of the exercises, you may of course stop that exercise. Make sure you take one minute of rest between each exercise.

What are the risks of performing the exercise?

As with any exercise, you might feel tired towards the end of the session and in the time right afterwards. However, the principle of Tai-chi is that the movements should not be too demanding, with each exercise of the routine performed for only one minute at a self-selected repetition speed. The primary risk when performing the exercise is loss of balance. This risk can be mitigated by performing the movements at a controlled speed, and by holding onto a stable object such as a chair, table, or door frame if required. This exercise regime has been designed specifically to avoid any cardiovascular load, as might be felt during running or other strenuous exercise. If your legs begin to feel overly sore during the any of the exercises, you may of course stop that exercise at that time.

We recommend starting with all the level 1 exercises when you begin the programme. If you think any of the exercises are too easy for you, and you are finding yourself being in complete control and not losing your balance throughout the 60 seconds, then you can try the next level exercise for that movement. You do not need to progress in each, or any, of the activities at the same time and should only ever do 5 exercises in total as part of your Tai-chi snacking bout for the day. We ask that you mark down which 5 exercises you do on your exercise logbook.

Table S5-2. Tai-chi snacking movements

Types of exercise	Exercise	Level 1	Level 2	Level 3
Tai-chi snacking (Balance)	**TC1** **Single leg squat**	**TC1.1** **Single leg tiptoe squat**	**TC1.2** **Heel tipping**	**TC1.3** **Playing the lute**
	TC2 **Trunk rotation**	**TC2.1** **Grasp the sparrow's tail**	**TC2.2** **White crane spreads wings**	**TC2.3** **Cloud hand**
	TC3 **Single leg stand**	**TC3.1** **Front knee kick**	**TC3.2** **Stand on one leg**	**TC3.3** **Front heel kick**
	TC4 **Hip and knee exercise**	**TC4.1** **Open Tai-chi**	**TC4.2** **Open Tai-chi** (with calf raise)	**TC4.3** **Open Tai-chi** (with calf raise and heel stand)
	TC5 **Ankle mobility**	**TC5.1** **Heel-toe rotation**	**TC5.2** **45^0 forward ankle exercise**	**TC5.3** **Slant fly**

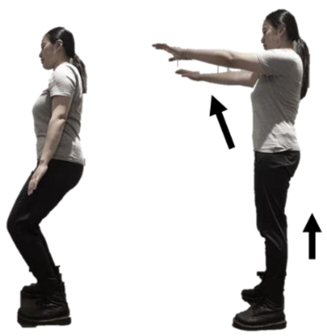
- **Level 1 Tai-chi snacking movements**

➢ **TC1.1 Single leg tiptoe squat:** Start in a standing position, shift your weight to your left leg; lift the heel of your right foot off the ground and then squat down by bending your left knee and hip in a slow steady movement before coming back up. Repeat for 30 seconds on the left leg and then swap to do the same movement for 30 seconds on the right. If you struggle with balance, you can hold onto something stable like the back of a chair.

➢ **TC2.1 Grasp the sparrow's tail:** Raise one arm forwards and turn the palm to face the middle of your chest, imagining that you are holding a large ball against your body. Bring the other hand forward to just in front of your tummy, palm facing upwards, as though you were supporting the ball from below. Circle the hand of the first arm inwards, downwards and then forwards, ending up with the fingers facing forwards, palm down. Imagine that you are holding a long object between your two hands (the "sparrow's tail"). Bring both arms downwards and backwards to the side of the bottom hand, keeping the same distance between the arms. Repeat the movement with the opposite way in a continuous motion forming the pattern of the number 8 (figure 8).

- **TC3.1 Front knee kick:** Keep your weight on left leg and remain stable, raise your right knee, then kicking the right leg forward slowly. Aim to kick your leg in a controlled manner. Regain your balance if necessary and continue doing right leg kicking for 30 seconds. Then shift your weight to stand on your right leg and complete left leg kicks for 30 seconds. If you struggle with balance, you can hold onto something stable like the back of a chair with one hand.

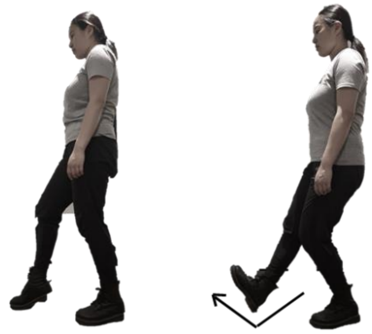
- **TC4.1 Open Tai-chi:** Standing with your knees slightly bent, feet shoulder-width apart and facing forward with hands by your side. Keep your arms straight and raise them in front until parallel to the floor, straightening your legs at the same time. Then return to your side and bend your knees slightly to return to the start position.



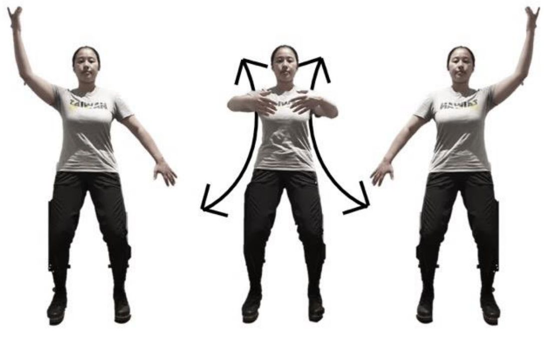
- **TC5.1 Heel-toe rotation:** Start by standing with your knees slightly bent, feet shoulder-width apart and facing forward. Raise your heels off the floor, then rotate your ankle and make the outside of your right foot and inside of your left foot touch the ground, and then keep rotating your ankles clockwise to shift your weight so that your outside of the left foot and inside of the right foot are now touching the floor (you can lean forward a little to maintain your balance). Continue rotating clockwise for 30 seconds and then repeat in the opposite direction for 30 seconds more (counterclockwise). You may wish to have a solid surface to hold on to nearby as you start this exercise.

Level 2 Tai-chi snacking movements

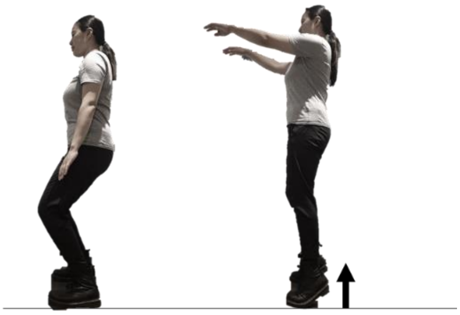
- **TC1.2 Heel tipping:** Start in a standing position, shift your weight to left leg; tip the right heel in front with your left knee slightly bent. Repeat the movement in a slow and controlled way on your left leg for 30 seconds, then swap and do the right leg for 30 seconds. If you struggle with balance, you can hold onto something stable like the back of a chair.



- **TC2.2 White crane spreads wings:** Standing with your knees slightly bent, feet shoulder width apart and facing forward with hands by your side. Raise your right arm up at your face height with palm facing yourself, and then swing your arms in front of your chest to bring your left arm up at face height and your right arm down by your side with palm facing backward. Your arms should move in the opposite direction from one another in a slow and controlled rhythm. Repeat the movement for one minute.



- **TC3.2 Stand on one leg:** Start in a standing position with your hands by your side. Shift your weight to left leg; lift the right heel off the ground and then raise your right leg off the floor and raise your right arm with your hand facing inwards in a slow steady movement. Keep your left knee slightly bent and left arm by your side. Aim to get your right thigh as close to horizontal as possible, then return that foot to the floor, regain your balance if necessary, and repeat for 30 seconds with your left leg on the ground, then swap and do 30 seconds of left leg and arm raises with the right leg on the ground. If you struggle with balance, you can hold onto something stable like the back of a chair.

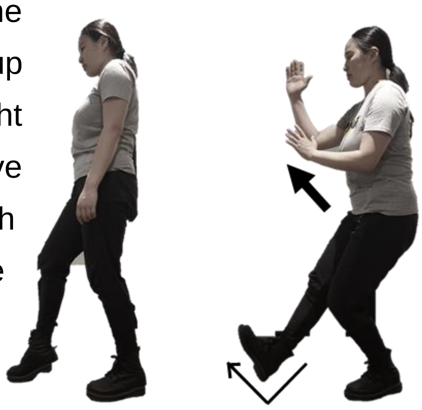


- **TC4.2 Open Tai-chi** (with calf raise)**:** Stand with feet shoulder width apart and facing forward with hands by your side. Raise your arms in front and rise your heel up at the same time so you are standing on your toes with your arms stretched out in front of your face and palms facing the floor. Return your heels to the floor and arms back to your side in a slow motion and repeat this movement for one minute.

- **TC5.2 45^0 forward ankle exercises:** Stand with knees slightly bent. Move your right foot forward and to the side a little so you can tap the ground with that toe (start from single leg tiptoe). Next, with this leg still a little in front, tap the heel to the floor. Do the consecutive heel then toe tap for 30 seconds and then repeat on the left foot for a further 30 seconds.

- **Level 3 Tai-chi snacking movements**

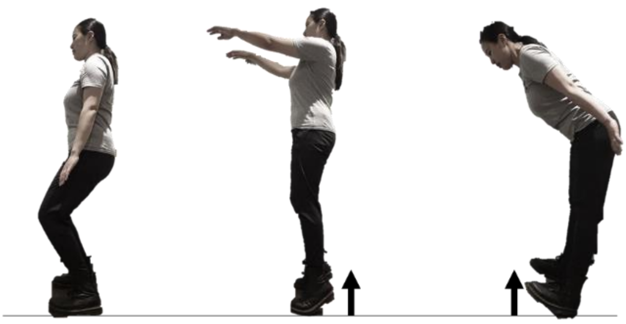
➢ **TC1.3 Playing the lute:** Start in a standing position, shift your weight to left leg; tip the right heel in front and bring your hands up in front of you (right hand at nose height and left hand at chest height), and have palms facing inward at the same time with your left knee slightly bent. Repeat the movement in a slow and controlled way on your right leg for 30 seconds, then swap and do the left leg for 30 seconds.



➢ **TC2.3 Cloud hand:** Standing with your knees slightly bent, feet shoulder width apart and facing forward with left palm facing you at shoulder height and right palm facing the floor at waist height. Cross the arms from right to left, turn your palms to have your left palm face the floor and right palm face you, change arms so the right is on top, and left at waist height. Turn your body so you face to the right as you perform the movement, then cross your arms from left to right, turn your palms, change arms and turn the body back to the left. Repeat the movement turning from left to right and crossing hands for one minute.

- **TC3.3 Front heel kick:** From a standing position with your hands cross, sit gradually into the left hip and lift your right heel slightly off the ground. Try to keep your weight on left leg and remain stable while raising your right leg with your knee bent, then kicking the right leg forward slowly and open your arms outwards at the same time. Aim to kick your leg slowly in a controlled manner as high as possible, then slowly return that foot to the floor. Regain your balance if necessary and repeat for 30 seconds on the right leg, then shift your weight to the right leg and repeat the kicking movement with your left leg for 30 seconds. If you struggle with balance, you can hold onto something stable like the back of a chair with one hand.

- **TC4.3 Open Tai-chi** (with calf raise and heel stand)**:** Stand with feet shoulder width apart and facing forward with hands by your side. Raise your arms in front and rise your heel up at the same time so you are standing on your toes. Then bring your arms back by your side in a slow and controlled manner and shift your weight back on to your heels so that when your arms are by your side your toes are off the ground. Repeat this motion returning to a flat foot starting position in between each go if necessary to regain balance. Otherwise, you can try to move from heels to toes and back again in one fluid movement while moving your arms up and down.



- **TC5.3 Slant fly:** Sit slightly into your left hip and then lift your right heel off the ground with hands in front of you (left hand in line with your chest facing the floor, and right hand in line with your waist, facing up). Your right foot should then take a step out in front and to the right of you while you bring your right hand up to shoulder height, palm facing up, and bring your left hand down to be in line with your hip, palm facing down, at the same time. Regain your balance if necessary and repeat for 30 seconds on the right leg, then shift your weight to the right leg and rotate your hands (having your right hand in line with your chest facing the floor, and left hand in line with your waist, facing up) and repeat the movement with your left leg for 30 seconds.

Exercise video instruction

Here are the links to the exercise videos for both the exercise snacking and tai chi snacking movements. We recommend starting with all the level 1 exercises when you begin the programme. If you think any of the exercises are too easy for you, and you are finding yourself consistently meeting the progression criteria, then you can try the next level exercise for that movement.

You do not need to progress in each, or any, of the activities at the same time and **you should only ever do 5 exercise snacking and 5 Tai-chi snacking movements in total as part of your two exercise bouts for the day**.

Exercise snacking – Do 1 exercise from each cluster at the most appropriate level for you each day

Sit-to-stand	
ES1.1 Sit-to-stand (free arms)	Level 1: https://youtu.be/grrw1CV17aA
ES1.2 Sit-to-stand (arms across chest)	Level 2: https://youtu.be/7lXhgQTlaJg
ES1.3 Air squat	Level 3: https://youtu.be/aSd_5vONAi0
Shoulder exercise	
ES2.1 Seated hip-to-hip arch overhead	Level 1: https://youtu.be/FSFlDGZNW8I
ES2.2 Seated wood chop	Level 2: https://youtu.be/LHGf9Peu3Pg
ES2.3 Seated figure 8's	Level 3: https://youtu.be/K1WPa2GNJEs
Single leg exercise	

ES3.1 March on the spot	Level 1: https://youtu.be/9UzTyhMGzj8
ES3.2 Single leg split squat	Level 2: https://youtu.be/Qlta9lGtGgM
ES3.3 Reverse lunge	Level 3: https://youtu.be/lJepiHlk_pA
Arm exercise	
ES4.1 Seated arm cross	Level 1: https://youtu.be/-V0-Hy9RhTU
ES4.2 Seated front raise to overhead	Level 2: https://youtu.be/1p4kquhhUro
ES4.3 Multidimensional arm raise	Level 3: https://youtu.be/3bzmop76HMg
Ankle exercise	
ES5.1 Seated calf raise	Level 1: https://youtu.be/oF8T5R6-Rio
ES5.2 Standing calf raise	Level 2: https://youtu.be/Hz1rd713SgE
ES5.3 Single leg calf raise	Level 3: https://youtu.be/f8_rwBo0MT0

Tai-chi snacking - Do 1 exercise from each cluster at the most appropriate level for you each day

Single leg squat	
TC1.1 Single leg tiptoe squat	Level 1: https://youtu.be/7t_QpTNCG1I
TC1.2 Heel tipping	Level 2: https://youtu.be/HcRMS7NZ-no
TC1.3 Playing the lute	Level 3: https://youtu.be/BhWUyW8Ph34
Trunk rotation	
TC2.1 Grasp the sparrow's tail	Level 1: https://youtu.be/ZNLRzvHYQek
TC2.2 White crane spreads wings	Level 2: https://youtu.be/1sZx1aIHv_s
TC2.3 Cloud hand	Level 3: https://youtu.be/6vvIJieVw_U
Single leg stand	
TC3.1 Front heel kick	Level 1: https://youtu.be/fYQ1IN5CBQ0
TC3.2 Stand on one leg	Level 2: https://youtu.be/Jruz_szDcas
TC3.3 Front heel kick	Level 3: https://youtu.be/A8QUhQk_dvI
Hip and knee exercise	
TC4.1 Open Tai-chi	Level 1: https://youtu.be/rd1lTpDw710

TC4.2 Open Tai-chi (with calf raise)	Level 2: https://youtu.be/YYMNqoHMcOI
TC4.3 Open Tai-chi (with calf raise and heel stand)	Level 3: https://youtu.be/TFRAcggmCT0
Ankle mobility	
TC5.1 Heel-toe rotation	Level 1: https://youtu.be/6GrNLnlltGE
TC5.2 45^0 forward ankle exercise	Level 2: https://youtu.be/z-yVOYy4hiM
TC5.3 Slant fly	Level 3: https://youtu.be/FTGoIiPWd14

Supplementary file 2 – TFA survey

Assessing Acceptability – the Theoretical Framework of Acceptability questions

General Acceptability: How acceptable did you find your exercise programme over the past 4 weeks?

Completely unacceptable	Unacceptable	No Opinion	Acceptable	Completely acceptable
1	2	3	4	5

Affective attitude: How much did you like doing your exercise programme?

Strongly dislike	Dislike	No Opinion	Like	Strongly like
1	2	3	4	5

Burden: How much effort did it take for you to follow the exercise programme?

No effort at all	A little effort	No Opinion	A lot of effort	Huge effort
1	2	3	4	5

Ethicality: how fair you think other people like you will find the exercise programme?

Very unlikely	Likely	No Opinion	Likely	Very likely
1	2	3	4	5

Perceived effectiveness: How likely is it that the programme has helped you stay fit and strong?

Very unlikely	Likely	No Opinion	Likely	Very likely
1	2	3	4	5

Opportunity costs: Continuing with this exercise programme would interfere with my other priorities.

Very unlikely	Likely	No Opinion	Likely	Very likely
1	2	3	4	5

Self-efficacy: How confident are you that you can keep doing the exercise programme?

Very unlikely	Likely	No Opinion	Likely	Very likely
1	2	3	4	5

Intervention coherence: It is clear to me how doing this exercise programme would help my strength and balance.

Very clear	Clear	No Opinion	Unclear	Very unclear
1	2	3	4	5

Supplementary file 3 – TFA interview topic guide

Thank you for taking part in the Exercise and Tai-chi snacking intervention study. This short interview is designed to get a richer understanding of your experience of the programme you have been asked to follow over the past 12 weeks, and an opportunity to provide us with feedback that will help us improve this programme in the future. Please remember there is no right or wrong answers, you can be as critical as you like as all feedback is useful to myself and the research team in understanding how useful and effective our programme can be.

Experiences of the intervention

1. How did you find the exercise programme on the whole?
2. What do you feel were the benefits of doing the programme for you personally?
3. Which element of the programme did you find the most useful? Why?
4. Which element of the programme did you find the least useful? Why?
5. When completing the exercises, how did it make you feel?
    a. During the activity itself, or afterwards?
6. Did you find any elements particularly difficult?
    a. Were any aspects of the exercise snacking particularly challenging?
    b. Were any aspects of the Tai-chi snacking particularly challenging?
7. How easy did you find it to stick the programme?
    a. Did you always feel motivated to complete the exercises? [Why not?]
    b. Do you feel the programme became part of your routine?
8. Did anything ever prevent you from being able or wanting to do the programme?
    a. What was the biggest obstacle to doing the exercise every day, if any?
9. Was there anything you did to make the programme easier to do for you? (e.g., change the environment/ set reminders/ do it with a friend)
10. How did you find undertaking the online assessments? Any technological difficulties?

Future suggestions

11. Having completed the programme what might you do going forward in terms of exercise?
    a. Will you continue to do the programme/ any aspects of it?
    b. Is there anything else you would like to try?
12. What might make the programme even more useful or enjoyable if you were continue doing it?
13. Is there any additional support you might like if you were doing this again or in the future? (e.g., support from coach, equipment, videos)

Supplementary file 4 – physical functional outcome measures

Table S5-3. The table shows the mean (SD) outcomes conducted remotely for all participants at each timepoint.

Outcome	Intervention group				Control group			
	Week 0	**Week 4**	**Week 8**	**Week 12**	**Week 0**	**Week 4**	**Week 8**	**Week 12**
Physical function, n	**44**	**30**	**28**	**28**	**46**	**39**	**36**	**36**
SPPB S&B items (score /8)	5.24(0.9)	7.42(1.2)	6.83(1.3)	7.02(1.1)	5.31(0.8)	5.68(0.9)	5.47(0.9)	5.60(1.0)
SPPB strength (score /4)	2.08(1.0)	3.52(1.1)	3.10(1.2)	3.24(1.0)	2.03(0.8)	2.48(0.9)	2.30(0.8)	2.45(0.8)
5 reps sit-to-stand time (s)	16.72(6.8)	9.77(4.2)	11.79(4.2)	11.05(3.4)	16.01(4.4)	14.09(4.3)	15.14(3.7)	14.39(3.5)
SPPB balance (score)	3.16(0.5)	3.91(0.5)	3.73(0.5)	3.80(0.3)	3.28(0.5)	3.20(0.6)	3.17(0.6)	3.15(0.6)
60-s sit-to-stand (N reps)	22.6(7.9)	31.9(8.5)	27.6(10.6)	29.7(10.0)	21.7(7.1)	25.4(7.4)	24.0(7.0)	24.9(6.7)

Right leg standing balance (s)	28.1(22.4)	38.0(21.7)	33.1(22.5)	32.9(22.7)	23.7(22.7)	27.2(21.6)	25.8(21.7)	26.4(21.9)
Left leg standing balance (s)	30.5(21.9)	35.3(22.0)	37.4(22.3)	35.4(23.1)	21.6(20.0)	22.7(18.2)	20.1(19.7)	24.6(20.2)
Physical activity, n	**44**	**30**	**28**	**27**	**46**	**39**	**36**	**36**
IPAQ score (MET-mins·week^{-1})	2161(1839)	2402(3005)	2784(3092)	2749(2575)	2441(2162)	2894(1557)	2327(1555)	2068(1817)
MVPA time (min·day^{-1})	73.5(65.5)	89.5(63.1)	83.3(74.6)	79.3(112.7)	80.2(89.1)	83.7(52.7)	72.2(72.1)	68.8(76.1)
Sedentary time (min·day^{-1})	460(185.9)	404(195.3)	430(206.5)	454(172.7)	430(202.8)	383(125.7)	389(163.2)	413(146.9)
Walking Time (min·day^{-1})	60.8(48.7)	61.1(87.6)	78.0(89.8)	76.3(56.8)	56.5(34.5)	80.0(38.9)	55.9(36.7)	57.2(62.9)
IADL (score)	7.91(0.3)	7.85(0.4)	7.87(0.6)	7.82(0.6)	7.95(0.1)	7.87(0.3)	7.90(0.4)	7.87(0.3)

Exercise Cognitions, n	**44**	**30**	**28**	**27**	**46**	**39**	**36**	**36**
Barrier self-efficacy	61.4(19.6)	50.1(21.4)	49.7(21.5)	52.2(22.4)	57.3(21.8)	52.3(21.6)	53.7(21.5)	52.8(21.4)
Competence	19.9(5.7)	18.3(5.8)	18.1(6.0)	18.8(6.6)	19.9(5.6)	18.1(5.7)	17.9(5.6)	17.5(5.5)
Habit strength	32.6(19.0)	37.4(20.7)	34.0(22.3)	35.3(21.6)	30.4(17.7)	31.9(17.3)	30.7(21.6)	32.3(19.8)
Outcome expectancies	59.1(7.1)	57.1(10.1)	57.0(6.4)	57.2(10.0)	59.1(4.8)	57.1(5.9)	57.0(5.6)	55.6(5.4)
Behaviour regulation	34.4(27.8)	35.5(24.8)	30.4(28.2)	33.7(26.6)	30.8(26.8)	26.2(24.8)	29.6(29.3)	28.4(27.5)
Health and Wellbeing, n	**44**	**30**	**28**	**27**	**46**	**39**	**36**	**36**
Vitality	28.3(7.2)	27.9(7.4)	28.2(8.0)	27.6(8.2)	27.7(7.0)	27.2(7.6)	26.3(8.3)	27.1(8.3)
Wellbeing (WEMWBS)	52.3(8.3)	54.7(8.6)	53.0(9.3)	53.5(8.9)	52.1(9.1)	53.7(9.0)	52.9(9.8)	51.6(9.9)
Satisfaction with life	24.6(6.8)	23.9(7.0)	24.5(7.1)	25.7(7.4)	23.8(7.6)	23.5(7.5)	23.8(6.8)	23.8(7.9)

Quality of life (EuroQoL score)	6.46(1.7)	6.60(1.7)	6.73(2.1)	6.98(1.9)	7.09(2.0)	7.10(1.9)	7.05(2.4)	7.17(2.2)
EQ-5D-5L (EQ VAS)	79.4(14.0)	81.1(15.7)	79.2(16.7)	79.6(13.6)	74.3(17.8)	77.1(14.9)	77.1(19.8)	73.3(17.4)
Physical health (SF-36)	79.6(19.9)	81.9(19.6)	78.9(23.8)	80.7(16.4)	77.0(18.2)	76.6(19.5)	79.1(18.2)	76.5(19.7)
Mental health (SF-36)	78.0(14.8)	81.6(14.3)	81.6(14.8)	80.9(14.8)	77.4(14.7)	79.1(15.6)	78.6(14.6)	77.9(14.7)

Table S5-4. mean (SD) outcome measures (adjusted for sex and age) for all participants at week 4

Outcome	Intervention	Control	Estimated mean difference	95% CI	P value
Physical function, n	**30**	**39**			
SPPB S&B items (score /8)	7.42(1.2)	5.68(0.9)	1.73	1.31 - 2.16	**<.0001**
SPPB strength (score /4)	3.52(1.1)	2.48(0.9)	1.05	0.64 - 1.45	**<.0001**
5 reps sit-to-stand time (s)	9.77(4.2)	14.09(4.3)	-4.32	-6.27 - -2.37	**<.0001**
SPPB balance (score)	3.91(0.5)	3.20(0.6)	0.71	0.45 - 0.96	**<.0001**
60-s sit-to-stand (N reps)	31.9(8.5)	25.4(7.4)	6.48	3.07 - 9.89	**0.0003**
Right leg standing balance (s)	38.0(21.7)	27.2(21.6)	10.81	1.83 - 19.8	**0.0186**
Left leg standing balance (s)	35.3(22.0)	22.7(18.2)	12.57	4.14 - 21.0	**0.0037**

Physical activity, n	**30**	**39**			
IPAQ score (MET-mins·week^{-1})	2402(3005)	2894(1557)	-492	-1574 - 590	0.3712
MVPA time (min·day^{-1})	89.5(63.1)	83.7(52.7)	5.77	-32.7 - 44.2	0.7679
Sedentary time (min·day^{-1})	404(195.3)	383(125.7)	21.5	-63.1 - 106	0.6170
Walking Time (min·day^{-1})	61.1(87.6)	80.0(38.9)	-18.84	-47.48 - 9.8	0.1964
IADL (score)	7.85(0.4)	7.87(0.3)	0.02	-0.17 - 0.14	0.8254
Exercise Cognitions, n	**30**	**39**			
Barrier self-efficacy	50.1(21.4)	52.3(21.6)	-2.19	-12.27 - 7.88	0.6679
Competence	18.3(5.8)	18.1(5.7)	0.19	-2.48 - 2.87	0.8859
Habit strength	37.4(20.7)	31.9(17.3)	5.51	-3.15 - 14.2	0.2102

Outcome expectancies	57.1(10.1)	57.1(5.9)	1.72	-1.61 - 5.04	0.3096
Behaviour regulation	35.5(24.8)	26.2(24.8)	9.31	-2.39 - 21.0	0.1179
Health and Wellbeing, n	**30**	**39**			
Vitality	27.9(7.4)	27.2(7.6)	0.78	-2.55 - 4.11	0.6429
Wellbeing (WEMWBS)	54.7(8.6)	53.7(9.0)	1.02	-3.04 - 5.07	0.6215
Satisfaction with life	23.9(7.0)	23.5(7.5)	0.39	-2.87 - 3.65	0.8115
Quality of life (EuroQoL score)	6.60(1.7)	7.10(1.9)	-0.51	-1.43 - 0.42	0.2837
EQ-5D-5L (EQ VAS)	81.1(15.7)	77.1(14.9)	3.94	-3.24 - 11.12	0.2800
Physical health (SF-36)	81.9(19.6)	76.6(19.5)	5.32	-2.3 - 12.93	0.1693
Mental health (SF-36)	81.6(14.3)	79.1(15.6)	2.45	-4.29 - 9.17	0.4740

IPAQ data were processed, cleaned, and analysed in accordance with recommendations outlined in the "Guidelines for Data Processing and Analysis of the International Physical Activity Questionnaire" manual. IPAQ = International Physical Activity Questionnaire (short form); MET = metabolic equivalent of task; MVPA = moderate-to-vigorous intensity physical activity; IADL = the instrumental activities of daily living; WEMWBS = the Warwick-Edinburgh Mental Wellbeing Scales; EQ-5D-5L = the EuroQoL five-dimension, five- level questionnaire; SF-36 = Short Form Health Survey.

Table S5-5. mean (SD) outcome measures (adjusted for sex and age) for all participants at week 8

Outcome	Intervention	Control	Estimated mean difference	95% CI	P value
Physical function, n	**28**	**36**			
SPPB S&B items (score /8)	6.83(1.3)	5.47(0.9)	1.36	0.95 - 1.77	**<.0001**
SPPB strength (score /4)	3.10(1.2)	2.30(0.8)	0.79	0.40 - 1.19	**0.0001**
5 reps sit-to-stand time (s)	11.79(4.2)	15.14(3.7)	-3.35	-5.26 - -1.44	**0.0007**
SPPB balance (score)	3.73(0.5)	3.17(0.6)	0.57	0.32 - 0.82	**<.0001**

60-s sit-to-stand (N reps)	27.6(10.6)	24.0(7.0)	3.56	0.19 - 6.92	**0.0383**
Right leg standing balance (s)	33.1(22.5)	25.8(21.7)	7.24	-1.58 - 16.1	0.1067
Left leg standing balance (s)	37.4(22.3)	20.1(19.7)	17.25	8.97 - 25.5	**0.0001**
Physical activity	**28**	**36**			
IPAQ score (MET-mins·week^{-1})	2784(3092)	2327(1555)	457	-569 - 1482	0.3811
MVPA time (min·day^{-1})	83.3(74.6)	72.2(72.1)	11.08	-25.3 - 47.4	0.5486
Sedentary time (min·day^{-1})	430(206.5)	389(163.2)	41.1	-39.1 - 121	0.3135
Walking Time (min·day^{-1})	78.0(89.8)	55.9(36.7)	22.08	-4.86 - 49.0	0.1078
IADL (score)	7.87(0.6)	7.90(0.4)	0.03	-0.18 - 0.12	0.6905
Exercise Cognitions, n	**28**	**36**			

Barrier self-efficacy	49.7(21.5)	53.7(21.5)	-3.93	-13.62 - 5.77	0.4248
Competence	18.1(6.0)	17.9(5.6)	0.19	-2.40 - 2.78	0.8832
Habit strength	34.0(22.3)	30.7(21.6)	3.26	-5.25 - 11.8	0.4500
Outcome expectancies	57.0(6.4)	57.0(5.6)	-0.46	-3.6 - 2.69	0.7755
Behaviour regulation	30.4(28.2)	29.6(29.3)	0.79	-10.72 - 12.3	0.8913
Health and Wellbeing, n	**28**	**36**			
Vitality	28.2(8.0)	26.3(8.3)	1.86	-1.40 - 5.12	0.2611
Wellbeing (WEMWBS)	53.0(9.3)	52.9(9.8)	0.08	-3.88 - 4.04	0.9684
Satisfaction with life	24.5(7.1)	23.8(6.8)	0.72	-2.48 - 3.92	0.6582
Quality of life (EuroQoL score)	6.73(2.1)	7.05(2.4)	-0.32	-1.21 - 0.57	0.4776

EQ-5D-5L (EQ VAS)	79.2(16.7)	77.1(19.8)	2.09	-4.91 - 9.09	0.5559
Physical health (SF-36)	78.9(23.8)	79.1(18.2)	-0.15	-7.62 - 7.32	0.9684
Mental health (SF-36)	81.6(14.8)	78.6(14.6)	2.96	-3.57 - 9.50	0.3717
IPAQ data were processed, cleaned, and analysed in accordance with recommendations outlined in the “Guidelines for Data Processing and Analysis of the International Physical Activity Questionnaire” manual. IPAQ = International Physical Activity Questionnaire (short form); MET = metabolic equivalent of task; MVPA = moderate-to-vigorous intensity physical activity; IADL = the instrumental activities of daily living; WEMWBS = the Warwick-Edinburgh Mental Wellbeing Scales; EQ-5D-5L = the EuroQoL five-dimension, five- level questionnaire; SF-36 = Short Form Health Survey.					

Table S5-6. mean (SD) outcome measures (adjusted for sex and age) for all participants at week 12

Outcome	Intervention	Control	Estimated mean difference	95% CI	P value
Physical function, n	**28**	**36**			
SPPB S&B items (score /8)	7.02(1.1)	5.60(1.0)	1.42	1.00 - 1.85	**<.0001**

SPPB strength (score /4)	3.24(1.0)	2.45(0.8)	0.79	0.38 - 1.19	**0.0002**
5 reps sit-to-stand time (s)	11.05(3.4)	14.39(3.5)	-3.34	-5.29 - -1.38	**0.0009**
SPPB balance (score)	3.80(0.3)	3.15(0.6)	0.65	0.39 - 0.91	**<.0001**
60-s sit-to-stand (N reps)	29.7(10.0)	24.9(6.7)	4.77	1.36 - 8.18	**0.0065**
Right leg standing balance (s)	32.9(22.7)	26.4(21.9)	6.53	-2.44 - 15.5	0.1523
Left leg standing balance (s)	35.4(23.1)	24.6(20.2)	10.81	2.39 - 19.2	**0.0123**
Physical activity, n	**27**	**36**			
IPAQ score (MET-mins·week^{-1})	2749(2575)	2068(1817)	681	-388 - 1750	0.2104
MVPA time (min·day^{-1})	79.3(112.7)	68.8(76.1)	10.46	-27.3 - 48.3	0.5860
Sedentary time (min·day^{-1})	454(172.7)	413(146.9)	40.7	-42.5 - 124	0.3363

Walking Time (min·day^{-1})	76.3(56.8)	57.2(62.9)	19.07	-9.03 - 47.2	0.1825
IADL (score)	7.82(0.6)	7.87(0.3)	0.05	-0.21 - 0.09	0.4859
Exercise Cognitions, n	**27**	**36**			
Barrier self-efficacy	52.2(22.4)	52.8(21.4)	-0.56	-10.52 - 9.41	0.9125
Competence	18.8(6.6)	17.5(5.5)	1.33	-1.32 - 3.98	0.3238
Habit strength	35.3(21.6)	32.3(19.8)	2.95	-5.66 - 11.6	0.4988
Outcome expectancies	57.2(10.0)	55.6(5.4)	1.62	-1.65 - 4.88	0.3305
Behaviour regulation	33.7(26.6)	28.4(27.5)	5.29	-6.36 - 16.9	0.3706
Health and Wellbeing, n	**27**	**36**			
Vitality	27.6(8.2)	27.1(8.3)	0.46	-2.85 - 3.77	0.7825

Wellbeing (WEMWBS)	53.5(8.9)	51.6(9.9)	1.86	-2.17 - 5.89	0.3624
Satisfaction with life	25.7(7.4)	23.8(7.9)	1.87	-1.37 - 5.11	0.2553
Quality of life (EuroQoL score)	6.98(1.9)	7.17(2.2)	-0.19	-1.10 - 0.73	0.0855
EQ-5D-5L (EQ VAS)	79.6(13.6)	73.3(17.4)	6.25	-0.88 - 13.39	0.6849
Physical health (SF-36)	80.7(16.4)	76.5(19.7)	4.19	-3.38 - 11.76	0.2754
Mental health (SF-36)	80.9(14.8)	77.9(14.7)	2.97	-3.70 - 9.64	0.3799

IPAQ data were processed, cleaned, and analysed in accordance with recommendations outlined in the “Guidelines for Data Processing and Analysis of the International Physical Activity Questionnaire” manual. IPAQ = International Physical Activity Questionnaire (short form); MET = metabolic equivalent of task; MVPA = moderate-to-vigorous intensity physical activity; IADL = the instrumental activities of daily living; WEMWBS = the Warwick-Edinburgh Mental Wellbeing Scales; EQ-5D-5L = the EuroQoL five-dimension, five- level questionnaire; SF-36 = Short Form Health Survey.

Table S5-7. Raw data showing mean (SD) of psychological outcomes at each time point, along with estimated mean differences (EMD), effect sizes (Cohen's d), and p-values between groups. EMD, Cohen's d, and p-values were obtained using linear mixed models adjusted by sex and age for all follow-up measures.

Outcome	Week 0		Week 4					Week 8					Week 12				
	Int	Con	Int	Con	***EMD [95%CI]***	***Cohen's d***	***p value***	Int	Con	***EMD [95%CI]***	***Cohen's d***	***p value***	Int	Con	***EMD [95%CI]***	***Cohen's d***	***p value***
Physical activity, n	**44**	**46**	**30**	**39**				**28**	**36**				**27**	**36**			
IPAQ score (MET-mins·week^{-1})	2161 (1839)	2441 (2162)	2402 (3005)	2894 (1557)	-492 [-1574 - 590]	-0.89	0.371	2784 (3092)	2327 (1555)	457 [-569 - 1482]	0.87	0.381	2749 (2575)	2068 (1817)	681 [-388 - 1750]	1.25	0.2104
MVPA time (min·day^{-1})	73.5 (65.5)	80.2 (89.1)	89.5 (63.1)	83.7 (52.7)	5.77 [-32.7 - 44.2]	0.29	0.767	83.3 (74.6)	72.2 (72.1)	11.08 [-25.3 - 47.4]	0.60	0.548	79.3 (112.7)	68.8 (76.1)	10.46 [-27.3 - 48.3]	0.54	0.5860
Sedentary time (min·day^{-1})	460 (185.9)	430 (202.8)	404 (195.3)	383 (125.7)	21.5 [-63.1 - 106]	0.50	0.617	430 (206.5)	389 (163.2)	41.1 [-39.1 - 121]	1.01	0.313	454 (172.7)	413 (146.9)	40.7 [-42.5 - 124]	0.96	0.3363
Walking Time (min·day^{-1})	60.8 (48.7)	56.5 (34.5)	61.1 (87.6)	80.0 (38.9)	-18.84 [-47.48 - 9.8]	-1.29	0.196	78.0 (89.8)	55.9 (36.7)	22.08 [-4.86 - 49.0]	1.61	0.107	76.3 (56.8)	57.2 (62.9)	19.07 [-9.03 - 47.2]	1.33	0.1825
IADL (score)	7.91 (0.3)	7.95 (0.1)	7.85 (0.4)	7.87 (0.3)	0.02 [-0.17 - 0.14]	0.25	0.825	7.87 (0.6)	7.90 (0.4)	0.03 [-0.18 - 0.12]	0.39	0.690	7.82 (0.6)	7.87 (0.3)	0.05 [-0.21 - 0.09]	0.65	0.4859
Exercise Cognitions, n	**44**	**46**	**30**	**39**				**28**	**36**				**27**	**36**			
Barrier self-efficacy	61.4 (19.6)	57.3 (21.8)	50.1 (21.4)	52.3 (21.6)	-2.19 [-12.27 - 7.88]	-0.43	0.667	49.7 (21.5)	53.7 (21.5)	-3.93 [-13.62 - 5.77]	-0.79	0.424	52.2 (22.4)	52.8 (21.4)	-0.56 [-10.52 - 9.41]	-0.11	0.9125
Competence	19.9 (5.7)	19.9 (5.6)	18.3 (5.8)	18.1 (5.7)	0.19 [-2.48 - 2.87]	0.14	0.885	18.1 (6.0)	17.9 (5.6)	0.19 [-2.40 - 2.78]	0.14	0.883	18.8 (6.6)	17.5 (5.5)	1.33 [-1.32 - 3.98]	0.98	0.3238
Habit strength	32.6 (19.0)	30.4 (17.7)	37.4 (20.7)	31.9 (17.3)	5.51 [-3.15 - 14.2]	1.24	0.210	34.0 (22.3)	30.7 (21.6)	3.26 [-5.25 - 11.8]	0.75	0.450	35.3 (21.6)	32.3 (19.8)	2.95 [-5.66 - 11.6]	0.67	0.4988
Outcome expectancies	59.1 (7.1)	59.1 (4.8)	57.1 (10.1)	57.1 (5.9)	1.72 [-1.61 - 5.04]	1.01	0.309	57.0 (6.4)	57.0 (5.6)	-0.46 [-3.6 - 2.69]	-0.29	0.775	57.2 (10.0)	55.6 (5.4)	1.62 [-1.65 - 4.88]	0.97	0.3305
Behaviour regulation	34.4 (27.8)	30.8 (26.8)	35.5 (24.8)	26.2 (24.8)	9.31 [-2.39 - 21.0]	1.56	0.117	30.4 (28.2)	29.6 (29.3)	0.79 [-10.72 - 12.3]	0.13	0.891	33.7 (26.6)	28.4 (27.5)	5.29 [-6.36 - 16.9]	0.89	0.3706
Health and Wellbeing, n	**44**	**46**	**30**	**39**				**28**	**36**				**27**	**36**			

Vitality	28.3 (7.2)	27.7 (7.0)	27.9 (7.4)	27.2 (7.6)	0.78 [-2.55 - 4.11]	0.46	0.642	28.2 (8.0)	26.3 (8.3)	1.86 [-1.40 - 5.12]	1.12	0.261	27.6 (8.2)	27.1 (8.3)	0.46 [-2.85 - 3.77]	0.27	0.7825
Wellbeing (WEMWBS)	52.3 (8.3)	52.1 (9.1)	54.7 (8.6)	53.7 (9.0)	1.02 [-3.04 - 5.07]	0.49	0.621	53.0 (9.3)	52.9 (9.8)	0.08 [-3.88 - 4.04]	0.04	0.968	53.5 (8.9)	51.6 (9.9)	1.86 [-2.17 - 5.89]	0.90	0.3624
Satisfaction with life	24.6 (6.8)	23.8 (7.6)	23.9 (7.0)	23.5 (7.5)	0.39 [-2.87 - 3.65]	0.23	0.811	24.5 (7.1)	23.8 (6.8)	0.72 [-2.48 - 3.92]	0.44	0.658	25.7 (7.4)	23.8 (7.9)	1.87 [-1.37 - 5.11]	1.13	0.2553
Quality of life (EuroQoL score)	6.46 (1.7)	7.09 (2.0)	6.60 (1.7)	7.10 (1.9)	-0.51 [-1.43 - 0.42]	-1.08	0.283	6.73 (2.1)	7.05 (2.4)	-0.32 [-1.21 - 0.57]	-0.70	0.477	6.98 (1.9)	7.17 (2.2)	-0.19 [-1.10 - 0.73]	-0.41	0.0855
EQ-5D-5L (EQ VAS)	2161 (1839)	74.3 (17.8)	81.1 (15.7)	77.1 (14.9)	3.94 [-3.24 - 11.12]	1.08	0.280	79.2 (16.7)	77.1 (19.8)	2.09 [-4.91 - 9.09]	0.59	0.555	79.6 (13.6)	73.3 (17.4)	6.25 [-0.88 - 13.39]	1.72	0.6849
Physical health (SF-36)	73.5 (65.5)	77.0 (18.2)	81.9 (19.6)	76.6 (19.5)	5.32 [-2.3 - 12.93]	1.37	0.169	78.9 (23.8)	79.1 (18.2)	-0.15 [-7.62 - 7.32]	-0.04	0.968	80.7 (16.4)	76.5 (19.7)	4.19 [-3.38 - 11.76]	1.08	0.2754
Mental health (SF-36)	460 (185.9)	77.4 (14.7)	81.6 (14.3)	79.1 (15.6)	2.45 [-4.29 - 9.17]	0.71	0.474	81.6 (14.8)	78.6 (14.6)	2.96 [-3.57 - 9.50]	0.89	0.371	80.9 (14.8)	77.9 (14.7)	2.97 [-3.70 - 9.64]	0.87	0.3799

Int= intervention group, con= control group.

Supplementary file 5 – subset outcome *Table S5-8. The table shows the mean (SD) outcomes conducted in lab settings for subset participants at each timepoint.*

Lab-based functional outcome	**Intervention group**				**Control group**			
	Week 0	**Week 4**	**Week 8**	**Week 12**	**Week 0**	**Week 4**	**Week 8**	**Week 12**
Lab-based physical function, n	**27**	**22**	**21**	**21**	**22**	**20**	**19**	**19**
SPPB (score)	7.7(0.7)	8.7(4.0)	10.7(1.6)	11.2(1.2)	7.8(0.6)	8.0(2.3)	8.8(1.0)	8.9(1.0)
SPPB strength (score)	1.7(0.5)	2.8(1.1)	3.1(1.3)	3.4(1.0)	1.7(0.5)	2.2(1.0)	2.5(0.8)	2.5(0.7)
5 reps sit-to-stand time (s)	16.5(3.7)	13.0(3.3)	12.3(4.4)	11.5(3.4)	16.4(4.6)	15.5(4.4)	14.2(3.3)	14.1(3.6)
SPPB balance (score)	3.1(0.6)	3.1(1.6)	3.0(1.7)	3.1(1.7)	3.1(0.4)	2.8(1.0)	2.8(1.2)	2.7(1.2)
SPPB gait speed (score)	2.9(0.5)	3.5(0.6)	3.7(0.6)	3.8(0.4)	3.0(0.4)	3.1(0.7)	3.1(0.5)	3.3(0.6)

SPPB 4-metre walk (s)	5.3(0.8)	4.7(0.8)	4.5(0.7)	4.2(0.8)	5.4(0.7)	5.3(0.9)	5.4(0.7)	5.1(0.8)
60-s sit-to-stand (N reps)	21.3(6.8)	23.0(5.5)	24.7(6.8)	25.6(6.2)	20.1(4.7)	20.8(6.7)	22.2(6.5)	22.3(6.1)
Right leg standing balance (s)	30.5(26.2)	31.7(22.3)	34.0(24.1)	34.6(23.7)	20.2(18.5)	15.9(16.7)	18.7(17.3)	16.9(14.4)
Left leg standing balance (s)	30.0(24.3)	46.4(60.4)	35.1(23.2)	33.4(21.3)	21.8(18.1)	23.8(20.0)	23.2(22.1)	18.7(17.3)
Time-up-and-go (s)	10.7(2.7)	10.0(2.4)	9.6(2.4)	8.8(1.7)	11.1(2.0)	11.7(2.1)	10.5(2.1)	10.5(2.1)
Right leg chair sit-and-reach (cm)	-12.8(11.1)	-8.7(9.4)	-6.2(9.3)	-5.4(8.9)	-10.8(11.4)	-7.7(10.5)	-5.6(11.1)	-5.5(9.9)
Left leg chair sit-and-reach (cm)	-12.2(11.1)	-8.1(9.8)	-5.4(9.2)	-5.0(9.0)	-13.3(12.6)	-6.8(10.8)	-4.7(10.4)	-6.3(10.5)
Keiser outcomes, n	**21**	**21**	**21**	**21**	**19**	**19**	**19**	**19**
Peak force of last rep (N)	1034.3(227.2)	1021.2(252.8)	1013.3(229.6)	1123.5(300.1)	1190.9(422.7)	1164.6(432.4)	1185.8(435.1)	1191.2(406.7)

Peak force of last rep/weight	1.5(0.4)	1.5(0.4)	1.5(0.5)	1.6(0.5)	1.6(0.5)	1.6(0.5)	1.6(0.6)	1.6(0.5)
Average force of last rep (N)	867.0(181.7)	868.7(210.9)	851.7(183.0)	963.7(255.8)	996.2(333.6)	979.7(347.2)	996.3(347.8)	1012.2(346.4)
Average force of last rep/weight	1.3(0.4)	1.2(0.3)	1.2(0.4)	1.4(0.4)	1.4(0.4)	1.3(0.4)	1.4(0.5)	1.4(0.5)

Table S5-9. mean (SD) outcome measures (adjusted for sex and age) conducted in the lab for subset lab-based participants at week 4

Outcome	Intervention	Control	Estimated mean difference	95% CI	P value
Lab-based physical function, n	**22**	**20**			
SPPB (score)	11.12(4.0)	8.89(2.3)	2.24	1.57 - 2.90	**<.0001**
SPPB strength (score)	3.38(1.1)	2.51(1.0)	0.87	0.34 - 1.39	**0.0014**
5 reps sit-to-stand time (s)	11.5(3.3)	13.9(4.4)	-2.34	-4.51 - -0.17	**0.0351**
SPPB balance (score)	3.96(1.6)	3.11(1.0)	0.84	0.54 - 1.15	**<.0001**
SPPB gait speed (score)	3.82(0.6)	3.25(0.7)	0.56	0.25 - 0.88	**0.0006**
SPPB 4-metre walk (s)	4.18(0.8)	5.10(0.9)	-0.93	-1.36 - -0.48	**0.0001**
60-s sit-to-stand (N reps)	26.2(5.5)	22.8(6.7)	3.43	-0.22 - 7.08	0.0650

Right leg standing balance (s)	32.3(22.3)	18.2(16.7)	13.64	2.02 - 25.3	**0.0221**
Left leg standing balance (s)	30.6(60.4)	24.8(20.0)	12.35	-5.39 - 30.1	0.1710
Time-up-and-go (s)	8.74(2.4)	10.67(2.1)	-1.94	-3.11 - -0.76	**0.0015**
Right leg chair sit-and-reach (cm)	-7.56(9.4)	-6.32(10.5)	-1.24	-7.24 - 4.75	0.6806
Left leg chair sit-and-reach (cm)	-7.43(9.8)	-6.69(10.8)	-0.74	-6.63 - 5.16	0.8040
Keiser outcomes, n	**21**	**19**			
Peak force of last rep (N)	1258(252.8)	1260(432.4)	-1.75	-170 - 166	0.9834
Peak force of last rep/body mass (N/kg)	17.1(1.0)	16.8(1.0)	0.32	-2.53 - 3.16	0.8227
Average force of last rep (N)	1064(210.9)	1063(347.2)	0.46	-146 - 146	0.9949
Average force of last rep/body mass (N/kg)	14.5(0.8)	14.2(0.8)	0.27	-2.17 - 2.71	0.8254

The Keiser outcomes are sum for peak force and average force of last repetition for right and left legs, and all Keiser data show in the table are translated data (i.e., what the pedals were doing).

Table S5-10. mean (SD) outcome measures (adjusted for sex and age) conducted in the lab for subset lab-based participants at week 8

Outcome	Intervention	Control	Estimated mean difference	95% CI	P value
Lab-based physical function, n	**21**	**19**			
SPPB (score)	10.21(1.6)	8.42(1.0)	1.79	1.13 - 2.45	**<.0001**
SPPB strength (score)	2.85(1.3)	2.21(0.8)	0.64	0.12 - 1.16	**0.0168**
5 reps sit-to-stand time (s)	12.9(4.4)	15.1(3.3)	-2.21	-4.37 - 0.06	**0.0442**
SPPB balance (score)	3.83(1.7)	2.94(1.2)	0.89	0.59 - 1.18	**<.0001**

SPPB gait speed (score)	3.56(0.6)	3.13(0.5)	0.43	0.12 - 0.74	**0.0070**
SPPB 4-metre walk (s)	4.64(0.7)	5.21(0.7)	-0.57	-1.00 - -0.14	**0.0107**
60-s sit-to-stand (N reps)	23.7(6.8)	21.6(6.5)	2.07	-1.56 - 5.69	0.2586
Right leg standing balance (s)	30.3(24.1)	24.3(17.3)	11.65	-0.14 - 23.2	**0.0474**
Left leg standing balance (s)	43.8(23.2)	19.0(22.1)	19.46	2.08 - 36.8	**0.0285**
Time-up-and-go (s)	9.93(2.4)	11.51(2.1)	-1.58	-2.74 - -0.42	**0.0084**
Right leg chair sit-and-reach (cm)	-11.05(9.3)	-8.02(11.1)	-3.03	-8.98 - 2.92	0.3134
Left leg chair sit-and-reach (cm)	-10.83(9.2)	-6.85(10.4)	-3.97	-9.84 - 1.89	0.1804
Keiser outcomes, n	**21**	**19**			
Peak force of last rep (N)	1156(229.6)	1233(435.1)	-77.35	-246 - 90.8	0.3601

Peak force of last rep/body mass (N/kg)	15.7(1.0)	16.3(1.03)	-0.61	-3.45 - 2.24	0.6693
Average force of last rep (N)	969(183.0)	1031(347.8)	-62.01	-208 - 84.0	0.3983
Average force of last rep/body mass (N/kg)	13.2(0.8)	13.7(0.8)	-0.52	-2.96 - 1.93	0.6736
The Keiser outcomes are sum for peak force and average force of last repetition for right and left legs, and all Keiser data show in the table are translated data (i.e., what the pedals were doing).					

Table S5-11. mean (SD) outcome measures (adjusted for sex and age) conducted in the lab for subset lab-based participants at week 12

Outcome	Intervention	Control	Estimated mean difference	95% CI	P value
Lab-based physical function, n	**21**	**19**			

SPPB (score)	10.60(1.2)	8.84(1.0)	1.76	1.10 - 2.43	**<.0001**
SPPB strength (score)	3.14(1.0)	2.56(0.7)	0.58	0.05 - 1.10	**0.0310**
5 reps sit-to-stand time (s)	12.3(3.4)	14.0(3.6)	-1.71	-3.88 - 0.46	0.1202
SPPB balance (score)	3.77(1.7)	3.17(1.2)	0.60	0.29 - 0.91	**0.0002**
SPPB gait speed (score)	3.72(0.4)	3.10(0.6)	0.62	0.31 - 0.94	**0.0001**
SPPB 4-metre walk (s)	4.47(0.8)	5.37(0.8)	-0.90	-1.34 - -0.50	**0.0001**
60-s sit-to-stand (N reps)	25.3(6.2)	22.7(6.1)	2.58	-1.07 - 6.23	0.1630
Right leg standing balance (s)	31.8(23.7)	22.7(14.4)	11.26	-0.36 - 22.9	0.0573
Left leg standing balance (s)	32.3(21.3)	24.9(17.3)	9.58	-8.16 - 27.3	0.2874
Time-up-and-go (s)	9.55(1.7)	10.63(2.1)	-1.09	-2.26 - 0.09	0.0706

Right leg chair sit-and-reach (cm)	-8.37(8.9)	-6.37(9.9)	-2.00	-8.00 - 4.00	0.5082
Left leg chair sit-and-reach (cm)	-7.91(9.0)	-5.04(10.5)	-2.87	-8.77 - 3.03	0.3347
Keiser outcomes, n	**21**	**19**			
Peak force of last rep (N)	1148(300.1)	1254(406.7)	-106.54	-275 - 61.7	0.2092
Peak force of last rep/body mass (N/kg)	15.8(1.0)	16.7(1.0)	-0.94	-3.78 - 1.91	0.5111
Average force of last rep (N)	952(255.8)	1047(346.4)	-95.61	-242 - 50.4	0.1948
Average force of last rep/body mass (N/kg)	13.1(0.8)	14.0(0.8)	-0.93	-3.37 - 1.52	0.4487
The Keiser outcomes are sum for peak force and average force of last repetition for right and left legs, and all Keiser data show in the table are translated data (i.e., what the pedals were doing).					

Supplementary file 6 – TFA survey outcomes

Table S5-12. Acceptability of the intervention scores (mean and SD) based on TFA dimensions.

TFA survey	**Intervention group**		
	Week 4	**Week 8**	**Week 12**
General acceptability	4.37(0.67)	4.62(0.56)	4.64(0.49)
Enjoyment	4.00(0.69)	4.00(0.46)	4.04(0.74)
Burden*	3.57(1.10)	3.52(0.99)	3.64(0.91)
Ethicality	3.63(0.72)	4.14(0.79)	3.86(0.93)
Effectiveness	4.03(0.76)	4.34(0.61)	4.18(0.72)
Opportunity cost*	3.73(1.01)	4.21(0.68)	3.96(0.74)

Self-efficacy	4.10(0.84)	4.31(0.81)	3.96(0.92)
Coherence*	4.40(0.86)	4.52(0.74)	4.36(0.87)
Overall mean	3.98(0.32)	4.21(0.34)	4.08(0.31)

Data are mean(SD).

*indicates ratings were reverse-coded (i.e., higher scores are favourable for all items).

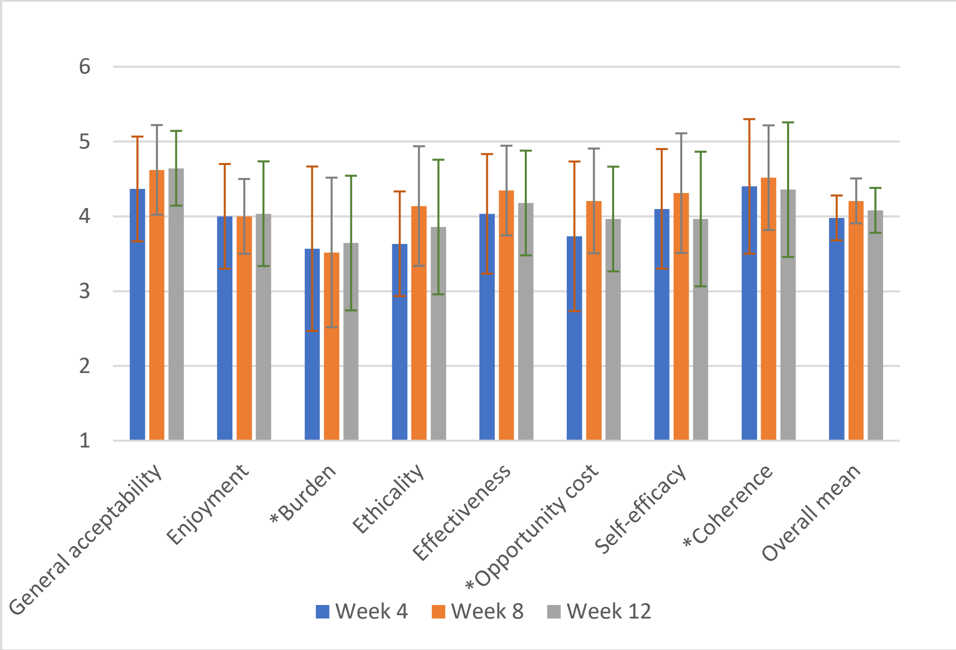


*Figure S5-1. Acceptability of the intervention at different study timepoints. Data are means ± SD. * indicates ratings were reverse-coded (i.e., higher scores are favourable for all items).*

Table S5-13. Participant quotes based on the semi-structured interviews are presented along with individual characteristics [Study ID; age; sex].

TFA domains	Quotes
Overall point of views	*I think the programme is pretty good, very comprehensive. I found it really useful. I think they're good exercises. [ESCTS058; 74yrs; female]* *It was very accessible for me. I've tried exercising before – well, I tried going to classes – I never made it through the class, so this – for me – was much better because I felt I was doing it – it was not too long – so I should be able to manage it most days – so I was really pleased, actually. [ESTCS079; 73yrs, female]* *I thought it was very clearly explained. I thought the videos were excellent. I liked the structure of it. I thought that was really good and very, you know, you kept it quite simple, it's deceptive because it covered a lot. There's a lot of information there, but you did it in a way that made it very accessible… It was enjoyable and it also felt – it felt achievable because the thought of snacking – five minutes. I think it's a very good way…I think it's a very clever way of introducing it. It's very manageable. That's the thing. [ESTCS040; 73yrs; female]*

Affective attitude	**Attitude and feelings** *I've been very grateful, actually, for the opportunity to do them, because I, sort of, mentally thought I should do exercise, and I don't. So, it has motivated me to want to do them. Each day, I always do them... I, kind of, thought, 'This is life changing, in a way.' …somehow, I just got more positive, and now I do feel more positive, actually, about life, really… feeling more energised and positive. [ESTCS059; 78yrs; male]* *Well, it made me move the muscle 'cause I'm housebound. I can't go out and walk without having a pusher or something, so it was a little bit of exercise which I wouldn't have had… It was a feeling of 'A job well done' – you know, you feel pleased with yourself – a sense of achievement. [ESTCS066; 85yrs; male]* *I think 'Energised' – 'Bit powerful' – you know, 'More stable' – 'Pleased to achieve it' – yes – but also, in my body… 'Stronger,' I think, and then perhaps 'More alert' – 'More energised in my mind' – my whole being. [ESTCS060; 68yrs; female]* *I found it interesting, enjoyable and it allowed me to challenge myself on the strength test (Keiser test/1RM)… I definitely felt sense of accomplishment when I beat my records on the strength tests. I really went all out to beat my record and improve the numbers of those I did. [ESTCS034; 71yrs; female]* **Preference**

	The exercises were easier than the Tai-Chi because the Tai-Chi was multi-tasking and I don't think I multi-task very well! Yeah, so I think I preferred snacking because I could do it almost unconsciously. [ESTCS081; 70yrs; female] *I've enjoyed doing the Tai-Chi. The exercise one you could say it's easier in a sense so you can do it more automatically. Whereas the Tai-Chi, you've got to be more, you know, more mindful with it. So yes, it's good. [ESTCS040; 73yrs; female]* *I think learning the Tai Chi, actually, has been the most useful. Because it starts off fairly gently, and you go through, learning all of those different positions has been good… I like the 'Cloud Hand' very much – that's a lovely one to do – and that's quite restful as well. [ESTCS057; 69yrs; female]* *I probably enjoyed the Tai-Chi exercises more. It's more gentle, and I just feel more spiritual and in tune with it, I think. [ESTCS063; 68yrs; female]* *I prefer the Tai-chi, and mentally, I prefer them. But in practice, they are harder, so I know I need to persevere with them more, because they are a little bit more challenging. [ESTCS059; 78yrs; Male]* **Perspectives on exercise programme and its intensities** *The exercises, I soon got up to level three, because I found I was capable of doing… Maybe in the last four weeks, having a different set of exercises just to bring some variety. Maybe to change some of the exercises*

	– or, if I had a bigger range of exercises. Yeah, I feel like some movements are too easy. [ESTCS031, 85yrs, female] *I suppose changing some of the exercises, you know, varying the exercises a little bit so that it didn't get boring because if you do things over and over again, I don't think you do your best because you sort of think – oh well we'll do that one, I know a quick way of doing that. Whereas if you challenge yourself a little bit by changing it, you know, say one week one way of doing it… [ESTCS032; 73yrs; female]* *I think the only thing that's not included in the programme is anything weight bearing for the arms. I know there's the stretching, but it would, I think, be even better if there was a can of baked beans in each hand. [ESTCS055; 76yrs; female]* *I suppose the Tai Chi movements take a bit of time to get your head round and I have looked at the videos and things and all of a sudden it will click and you know what you're doing initially. So I think that's probably why I went up to level three but then I went back down to level two because I knew what I was doing at that point and I hadn't got the mental energy to start something new or to learn a different movement, but that's just because I just wasn't feeling particularly well. [ESTCS082; 72yrs; female]*
Burden	**General burden**

	It wasn't too long, and it didn't take too much effort to do it. But the effort to find a break into the day, and remembering to do it, it was often late in the evening, and I thought, 'Oh, no, I haven't done them yet, I should do them,' but then I didn't. We've been away a couple of times, but otherwise it was fine. [ESCTS051; 69yrs; female] *It didn't really take a lot of time but, sometimes, it was more difficult than others to fit it in, but it didn't take a lot of time. [ESTCS061; 67yrs; female]* **Physical demand** *I found the Ta-Chi snacking slightly more difficult, more challenging... like physically demanding because it's - maybe I'm not so used to that. It's balance, it's newer. [ESTCS049; 71yrs; female]* *I kind of feel I prefer the Tai-chi, and I think that those exercises (exercise snacking) are significantly useful. But I find they're a little bit harder. [ESTCS059; 78yrs; male]* *There's one where we stand on one leg and do it. I think it's to exercise the knees, the kicking. That's fine. It's this bit, the standing on one leg, that's hard. It's just I probably put too much weight on, because I'm not good at standing on one leg, as you know. [ESTCS007; 84yrs; male]* *I think if I'd done it (sit-to-stand) for 30 seconds, that would have been fine. But I think the minute is just too long, and that really, I found that I was putting off doing it because of the whole minute doing it up and down. [ESTCS046; 80yrs; male]*

	The one that I find difficult to do because it's partly balance is this one (the single-leg squat) where you're... it requires a lot of strength as well. That was the most physically taxing for me. [ESCTS014; 81yrs; female] *I think the two most difficult ones were the single-leg lunges – backward lunge – that's difficult – and the Tai Chi one where you have to stand on one leg and put the leg out (the front-heel kick) – that's quite tricky. Well, it is difficult. I like it – I actually quite enjoy that, but it just takes a little while to be able to keep my balance. [ESTCS063; 68yrs; female]* *The level three of the fourth exercise of the Tai-Chi (open Tai-chi), the raising onto your tip toes and then going back onto the heels (calf raise and heel stand). I found that very challenging balance wise. It didn't hurt but I found it very difficult. [ESCTS034; 71yrs; female]* *I have a problem with my trunk, so I found the trunk rotation ones – I knew my limitations, so I never got beyond 'Level Two' on doing the trunk rotation one, and I took that very slowly… [ESTCS018; 68yrs; female]* *For me, the arm ones were quite hard because I've got a bit of autoimmune muscular problem in my arms, so they get very tired. Also I'm not very good at squatting – you know, the single-leg squat… I can't get my knee right down [ESTCS060; 68yrs; female]* **Cognitive and time demand**

	The Tai-chi onces… It's a 'Brain and mind are attached.' also like a…cognitive training. For me to think about moving my arms – kicking my legs at the same time – all of those coordination things was quite difficult. [ESTCS017; 72yrs; male] *I think because with the Tai Chi there was a lot of remembering to sort of – you know I've been doing this and my hands are all over the place. With the exercises you know there was none of that it was just doing the exercises… [ESTCS081; 70yrs; female]* *I think at first, at least, I felt I was getting more out of the exercise bit than out of the tai chi bit. But that's probably because with the tai chi, it took some while before I settled down into what I was doing. I think it's about the right level for you to be able to remember it all without too much trouble. [ESTCS055; 76yrs; female]* *The Tai-Chi exercises like I said, not that they were difficult to perform, but more that they were difficult to memorise and so whereas I could do the Western exercises just from the paper or even remember what to do and do the Western exercises watching the telly, for instance. Whereas the Tai-Chi exercises, I had to more concentrate on and give it my full attention. [ESTCS012; 74yrs; female]* *I think it is about doing things slowly (Tai-chi), you know. I mean, I try like doing mindful things, try all these sorts of things but it is – it has to be a conscious effort for me. [ESTCS040; 73yrs; female]*

Opportunity costs	**General views** *Fairly easy to wedge it in (daily routine), yes. You've got to make a point, because it's something, when you've been around as long as we have been, you settle into a routine, of course you do. You're trying to lever in 20 minutes of something. You say, 'Only 20 minutes.' [ESTCS007; 84yrs; male]* *I just think it's very clever, you know, just say, look five minutes can make a difference and it can make a difference. It does. It has made a difference. You know so I would like give myself a kick up the bum and say oh come on. [ESTCS040; 73yrs; female]* *I tried to do it in a similar time of the day – I tried to make certain that the room was a nice room to do the exercises in. Nothing to distract me – was all quite neat and tidy – I had a drink alongside me – a nice big clock. I actually put the radio on as well to listen to a bit of music while I do it. I made it quite a special event! [ESTCS057; 69yrs; female]* **Reasons of missing out the sessions** *Looking after grandchildren, picking another one up from Uni that sort of thing and time constraints, but usually we manage quite well. [ESTCS032; 73yrs; female]*

	I started off really well, the first month I think I missed out a day, but I have found it difficult sticking to it in this last month. We've been away a bit more, and there's been quite a lot on in the run up to Christmas... [ESTCS051; 69yrs; female] *It wasn't too much time – but, on the days when I was really, really busy… if I don't do it first thing in the morning, I find it difficult, then, to do it later on. I mean, sometimes, I managed it – just depends on… if I was a bit tired that day – I didn't feel very well – or I was very busy over Christmas, and quite stressed. [ECTCS079; 73yrs; female]* **Ideas of enhancing self-discipline** *I think that what we should have done is to have done it regularly at a certain time every day. I think that would have been quite interesting to see whether if we'd done it maybe after breakfast in the morning whether you are less tired. But of course, we have lots of other commitments, so it's a matter of fitting it in with everything else. [ESTCS014; 81yrs; female]* *I did find, when I was busy, that I'd sort of sometimes leave it and think, 'Ooh, gosh – I've gotta do it at some point' or, 'It's probably best if I did it straight thing in the morning, and just before bed – then I know I can manage that.' I'd try and do it at other times in the day – it didn't really work. [ESTCS060; 68yrs; female]*

Perceived effectiveness	**Physical health** *The strength, balance, and also ability to just push yourself that little bit extra, …Yeah – definitely strength in my legs and those arm exercises, I think, are really good… I did notice that my balance was improving. [ESTCS018; 68yrs; female]* *I found the exercise snacking you found this more helpful, yeah. I think it's good for your bones and strengthening your legs. And this is my favourite [waving arms] (multi-dimensional arm raises). I like that. I think because it opens your chest out you know and you're stretching. It helped… like mobility in the shoulders, yes. [ESTCS028; 77yrs; female]* *I could feel it strengthening me, improving my balance and strengthening my arms a little bit, I could feel it strengthen my arms as well as my legs. I found the heel tapping actually more useful than I thought it would be, I could feel I was using those different muscles... I think the ones with the ankle, the tipping, because I don't really stretch those or do that, I mostly stretch my other muscles. [ESTCS051; 69yrs; female]* *It has improved my knees. I could get up and down quite easily before, but sometimes, I would struggle, and I don't find I do anymore. I can get up from kneeling no trouble at all. It's really good. And I think my balance is improving. Some of the exercises near the beginning, I held onto a chair so that I didn't lose my balance, and now I can do it all without a chair. I'm managing to stand on one leg for longer now... I found the ankle*

	exercises very good. I think the ankle exercises are excellent, and really good for your ankles, and so easy to do. There's no excuse for not doing it. [ESTCS053; 78yrs; male] *It helps my legs, my knees and my hips, which I have a problem. I have a walking problem. So, it strengthens them, and I think I feel a bit more capable of doing a bit more walking. I would say that strength wise, certainly. Actually, shoulder and so on has definitely improved, and I do feel more confident in that, in lifting my arms, or doing things. So, it's not a massive change, but it is sufficiently a level of change that it does make my life easier. I feel better even about lifting shopping and stuff, because I feel a bit stronger, and that sort of stuff. [ESTCS058; 74yrs; female]* *This particular one (ankle rotation). I know when I started out, my thigh muscles were very good. My calf muscles were very good. But my ankles were rubbish and I had noticed my ankles have become a lot steadier and a lot stronger just doing these exercises... it was my balance and the ankles that I noticed. [ESTCS034; 71yrs; female]* *I would say, you know, sort of in terms of arthritis and balance. I think my balance, I'm really pleased with my balance. Yes, I think I've really - a lot of the exercises you know, like you know the Tai-Chi one with your feet going round. I really liked the balancing. So I think my balance I feel has really improved a lot and I feel like my joints as well. My knees are improved, I would say my knee joints are improved. In terms of general flexibility definitely. My (upper body) flexibility is really improved. I'd say yes. Considerably really, although I felt my problems was mostly like lower body, you know, my knees and my legs but in fact when I came to do the exercises, and especially the Tai-Chi, that I realised, oh I'm not as flexible. I can't turn round as much as*

	I used to be able to. I'm not as flexible. So that's been really good to be working on that. And some of the knee exercises, you're going up with your knee, you know. That was really helpful because it made me realise my knees had got more range. [ESTCS040; 73yrs; female] **Wellbeing** *It gives you a feeling of wellbeing – that you've done something, and you've started the day well. So, from that point of view, it sort of set a good routine for the day, and I suppose it does make you think about your posture a bit more and how you carry yourself. [ESTCS057; 69yrs; female]* *It was good and it's given me confidence to think that I can improve my physical health you know, even at this advanced age. I can do a little bit each day just to feel more in control and more healthy, you know. [ESTCS045; 69yrs; female]*
Intervention coherence	**General views** *I didn't find them difficult to understand at all but I sometimes find them difficult to do and that was the things where anything, sort of lower squats. [ESTCS040; 73yrs; female]*

	It's quite simple to learn and it's really useful having you doing it on the video. That was very useful. [ESTCS049; 71yrs; female] *it was very useful to have. It was good having a PDF, that was pretty good but when I was watching you and those other two guys doing it, it just cemented it much better into my mind, as to how I was meant to be doing it. [ESTCS051; 69yrs; female]* *No not particularly, as I said, it all goes along with the fact that I wasn't so familiar with the Tai Chi. I think if I'd been familiar with it – the other movements obviously I've been doing one way or another for most of my life, you know, different exercises when I was a child that sort of thing; whereas Tai Chi is a different thing, different element, which was interesting but took more thinking about because I wasn't familiar with it. I'm not saying it was bad, it was just different! [ESTCS032; 73yrs; female]* *I needed to do that because some of the Tai Chi if you follow these instructions, they're very complicated. You've got to watch it on the video… [ESTCS028; 77yrs; female]* *I didn't reach the level three really because I found some of the exercise difficult to even understand, Tai-Chi. [ESTCS045; 69yrs; female]* **Future suggestions**

	I wish you'd gone through it for us, the exercises, because a couple of times, we wondered whether we were doing it right. Make sure we were doing it correctly, that we'd interpreted the words and the video correctly. [ESTCS031; 85yrs; female] *Maybe that's what's missing…at some stage, maybe at the very first time you meet people, to make sure they're doing the exercises correctly. [ESTCS028; 77yrs; female]*
Ethicality	**General views** *I would certainly recommend it to other people – to have a go. I mean, we've just stayed with friends – they are a little bit younger than us but they're not in physically such good shape. They would find some movements really difficult to do. But even if you stuck to the simplest – the first level, it would be a good thing to do… good for some of them… people got a new knee, or something. [ESTCS017; 72yrs; male]* *I mean one of my friends, she's younger than I am anyway but she's enjoying it (another participant) and I live in a place with people over 60 and when I talked about this, they have been interested… [ESTCS028; 77yrs; female]* *It must be very motivating for people who are very sedentary or no confidence and that sort of thing. [ESTCS049; 71yrs; female]*

	Thoughts on remote and lab-based assessments *I found the video call easy, no problem at all. The lab sessions were absolutely fine. In fact, I'd say that's almost the best bit coming over, having an update, an afternoon out, we'll come over and actually see you, and try to give it a good test, and see the progress… an indication like that of improvement is a form of encouragement. You can know if you improve, or not, and you can have something like motivation to keep doing the exercises. [ESTCS007; 84yrs; male]* *My broadband did not work sometimes. But both are fine. I think to do the two are fine but it's good to have a one-to-one session and you're good at sort of encouraging me to go far. [ESTCS028; 77yrs; female]* *I mean, obviously, not being terribly familiar with Zoom calls… you were the first one I've ever done – still getting to grips with it! – but that's actually been quite fast-learning thing. [ESTCS057; 69yrs; female]* *I think it's nice at the lab session to have some kind of feedback, and that is useful. There is a, sort of, sense of… We hope it's progress, but even if it weren't, it would still be useful to have a physical person there to say, 'Perhaps we need to look at this another way, or something.' To have that sort of feedback… [ESTCS059; 78yrs; male]*

Self-efficacy	*I did enjoy it. I'm very glad I did it. It was good and it's given me confidence to think that I can improve my physical health you know, even at this advanced age. [laugh] I can do a little bit each day just to feel more in control and more healthy, you know. [ESTCS045; 69yrs; female]* *The family think we're being very good…I think it's been good. We've talked to our friends about it – been quite proud… [ESTCS017; 72yrs; male]* *It's sort of waking my body and my mind up! (laughs) It's what we need really. Body and mind are intertwined so yeah… If a bus came, I thought – no I can walk, instead of waiting for the bus I walk. If I've got shopping, I'll walk. [ESTCS028; 77yrs; female]* *I shall keep up with the exercises. I think I might go more into the Tai Chi and have a look at that more, rather than sticking rigidly to that, so I might sort of look more into Tai Chi... I think the exercise snacking to start with and then I think looking more into the Tai Chi because I find the Tai Chi interesting. I'm also thinking about going to Pilates. [ESTCS032; 73yrs; female]* *I've certainly improved. I'm gradually doing more of each movement in the time allowed, although that's pretty much plateaued now. We've gradually managed to do more from the start to now. That's a really good achievement, yes. [ESTCS055; 76yrs; female]*

	I feel motivated, and I feel that even on the times when I think, 'Gosh, exercises,' in fact, I still feel motivated. I think, 'I must get them done.' So, it's like tick that box, I need to do it. Really, I suppose, possibly, we should think about doing them twice a day. [ESTCS058; 74yrs; female] *I think, for me, I know I do need to try again to start walking further, and to try to marry that up with breathing to get stronger and more proactive, I suppose, about moving and walking, yes. So, walk to get the paper, because at the moment we drive, or I drive to go and get the paper, but I need to start walking again. I hope that this will give me that strength to be able to do that again. [ESTCS059; 78yrs; male]* *That (Tai-chi snacking) was very calming. I, even, thought of joining a Tai Chi class because it's very doable – and it's very calming. I felt a sense of achievement – yeah – I was glad I was doing it. I wanted to keep it up and still continue doing it… lengthen the sessions – just seeing how well I get on. [ESTCS079; 73yrs; female]*

5.4 Summary

This chapter exploring the efficacy and acceptability of the exercise and Tai-chi snacking showed that the 12-week progressive programme significantly improved lower extremity functions (i.e., strength, balance, and mobility) in older adults who previously scored 2-6 in SPPB strength and balance domains (i.e., mobility impaired). Participants found the programme useful, acceptable, and convenient to fit into their daily routines. Based on the logbooks from participants who completed the intervention, there was an overall high adherence in participation. Participants progressed through different levels of movements, with intensities influencing their progression rate. Indeed, we got valuable information on the timing of the benefits of the intervention. The strength and balance scores of the SPPB consistently favoured the intervention group from week 4 to week 12, confirming sustained effects of the exercise and Tai-chi snacking. The SPPB strength item and 5 reps STS also showed continuous improvement in the intervention group, albeit with varying rates. Similarly, in the lab subset, SPPB scores consistently favoured the intervention group, with significant improvements across all time points, as well as positive effects in outcome measures such as balance, gait speed, and 5 reps STS, although improvement rates varied. As with many exercise interventions in older adults, a large attrition rate of 29% was observed, which reduced our statistical power from a desired 90% to 80%. Participants cited illness symptoms and time constraints (due to various commitments) as the main reasons for missing sessions which were aligned with the findings in the acceptability study (Chapter 3). Establishing a consistent daily routine was suggested by participants to improve adherence. Looking at the qualitative interviews with participants from the intervention group yielded several insights into their experiences with the programme:

i. Affective attitude: participants generally found the programme accessible and convenient to do at home. It was seen as achievable and motivational, despite this, a few found the programme too easy or short.

ii. Burden: both exercise snacking and Tai-chi snacking were seen as requiring physical effort, especially single leg weight bearing and air squat movements. Tai-chi snacking was perceived as more time-consuming and cognitively demanding.

iii. Opportunity costs: participants felt that the programme did not require them to sacrifice other activities and appreciated its short duration (20 minutes per day).

iv. Perceived effectiveness: strength, balance, flexibility, and mobility improvements were noted, and some reported relief from joint stiffness and discomfort. Positively impacts on activities of daily living and overall confidence were also reported.

v. Intervention coherence: most participants found the movements easy to learn, with video instructions being particularly helpful, especially for learning Tai-chi snacking. Suggestions were made for one-off demonstrations or personal training sessions to enhance self-efficacy.

vi. Ethicality: participants believed the programme was attractive and accessible for older adults and could benefit those with various physical activity/fitness levels and health conditions.

vii. Remote and lab assessments: in general, participants had no issues with the remote assessments, finding them feasible and manageable. Some preferred lab-based assessments due to the personal interaction and physical feedback from the researcher.

viii. Self-efficacy: participants experienced increased self-efficacy, and motivation from the programme. They expressed a willingness to continue and even expand their engagement in the programme and other types of exercise.

Recent studies have shown that home-based exercises improved loneliness, depressive symptoms, and quality of life in older adults (Chua et al., 2023, Solis-Navarro et al., 2022). Although our initial analysis did not find statistically significant differences in psychological outcomes, calculating Cohen’s d for these measures revealed varying effect sizes across the components. Several measures demonstrated substantial effect sizes, suggesting a potential trend or signal for an effect (See Table S5.7 in Supplementary file 4). These effect sizes, particularly in IPAQ score, sedentary time, walking time, EQ-5D-5L, SF-36 mental health domain, and exercise habit index across all timepoints, indicated moderate to large effect magnitudes. These results indicate practical significance despite not meeting conventional statistical significance thresholds.

Considering that our study was not powered specifically for health outcomes, a larger sample size or an extended study duration may be necessary to achieve statistical significance and provide a more comprehensive understanding of the impact of improving physical functions through exercise and Tai-chi snacking. Future research could explore the potential longer-term effects of these interventions. Furthermore, a recent systematic review demonstrated that evidence for the impact of home-based exercise programmes on mental health and quality of life in older adults is quite limited (Santos et al., 2023). Accordingly, to comprehensively understand the impact of home-based exercise on psychosocial outcomes in older adults, more research with varied populations needs to be done.

To our knowledge, this is the first study investigating both the effectiveness of an unsupervised home-based exercise-snacking programme with quantitative methods and the acceptability using qualitative study methods. This is also the first prolonged intervention study with *strength-based exercise snacking* combined with *balance-based Tai-chi snacking* movements that were designed with progression and with remote delivery. Study limitations include the specific target population, technology literacy limiting inclusion, constraints on remote assessment of mobility (SPPB gait speed domain), inappropriate mechanistic outcome measures (Keiser leg press machine), and lack of upper body functional tests. Future studies should not only look at the efficacy but also find an appropriate way (instead of using Keiser leg press protocol) to discover the mechanisms of the snacking exercises in pre-frail older adults. Additionally, it would be interesting to explore whether the positive outcomes observed from our unsupervised home-based exercise intervention persist in participants beyond the end of the intervention period. Investigating whether there is correlation between the progression of the exercise and the improvement in physical function to further design the optimal home-based training methods following the periodisation training model (Harris-Love et al., 2017, Moura et al., 2018) could also be considered in future work.

This chapter involving mixed method RCT (quantitative and qualitative evaluation) indicated that 12-week home-based progressive strength and Tai-chi exercise snacking is feasible, acceptable, and efficacious for improving physical functions in pre-frail older adults. This confirms the findings of Chapter 3 and Chapter 4, suggesting that the format is suitable and engaging for older adults, and can be delivered and evaluated remotely in a meaningful way. Indeed, the exercise and Tai-chi snacking programme's low-cost nature and its ease of implementation strengthens its feasibility and acceptability. The findings prompt the need for future studies to explore the broader implications of home-based S&B exercise interventions on long term physical function and health, and extend the research to larger and more diverse samples. Nevertheless, an original part of the proposed doctoral work was to conduct this RCT study in two countries (UK and Taiwan) to understand its impact in older adults from different cultural backgrounds comprehensively and compare the acceptability of the prolonged intervention amongst British and Taiwanese older adults. We aim to finish the study as part of postdoctoral research in the future, comparing the outcomes between UK and Taiwanese participants, and discussing whether and why the effectiveness and the acceptability of this progressive snacking exercise programme varies from British to Taiwanese older adults.

6 Chapter VII – General discussion

General Discussion

The world's population is ageing rapidly, principally due to greater numbers living longer, and so preparing for later life has never been more important. Maintaining functional status and reducing health-related degeneration in older populations is important is crucial for healthy ageing. The concept of applying innovative, acceptable and scalable exercise approaches to enhance physical function and well-being in older adults is a growing area of research interest. The purpose of the work in this thesis focused on exploring the feasibility, acceptability, and efficacy of unsupervised home-based exercises that could overcome typical exercise barriers in older adults.

This chapter summarises the findings presented in this thesis and highlights the key implications and take-home messages. The future development of research is illustrated in Section 6.4, outlining the potential forthcoming applications.

6.1 Summary of findings

This thesis comprised of one systematic review and three research studies, including qualitative and quantitative methods, lab-based and remote settings, investigation of different cultures, and RCT study designs. The thesis began with a systematic review and meta-analysis (Chapter 2) to understand the effectiveness of unsupervised home-based exercises for improving physical function in older adults based on existing literature. This study revealed no significant improvements in physical fitness function when compared to usual care control groups. Limited studies and small sample sizes may have influenced these results. Additionally, the original design to investigate cultural variances through Western and Eastern cultures was undermined by the absence of eligible Mandarin literature. Despite the statistical results and study limitations, this study recognised the potential effects of unsupervised home-based exercises on physical functions in older adults with different health conditions. The following chapter (Chapter 3) explored whether home-based exercise and Tai-chi snacking is acceptable in older adults with varying physical functions (i.e., SPPB 4-8 defined as moderate or SPPB 8-12 defined as high) and investigated cultural differences between older adults with different cultural backgrounds (British and Taiwanese). This study with 1-week short trial was a qualitative investigation involving 63 participants, and the semi-structured interview was based on the Theoretical Framework of Acceptability that accounts for the multiple domains that define the construct and predict engagement. The findings indicated that both exercise and Tai-chi snacking were acceptable in older adults, and little difference was observed between UK and Taiwanese participants. These snacking exercises were deemed suitable for participants within their age groups, although a few Taiwanese female participants cited their busy lifestyles as barriers to engagement, while some of those with higher function had a tendency to find the format tedious.

Subsequently, to understand whether home-based exercise and Tai-chi snacking is feasible and implementable to older adults' daily lives, the following study (Chapter 4) involved a 4 week intervention. In this remote four-arm randomized feasibility study, participants received one of three daily exercise interventions (exercise snacking/ Tai-chi snacking/ combo) or a control condition of direction to the NHS standard exercise guidance during the Covid-19 pandemic. The findings demonstrated increased muscle strength (i.e., sit-to-stand tests) and physical activity levels (except walking time) in all participants, steady exercise cognitions, vitality, life satisfaction, and quality of life scores in all participants, and improved balance scores in snacking exercise groups. The programmes indeed provided older adults who were asked to self-isolated opportunities to remain physically active during Covid-19 lockdowns. Primarily, this remote study illustrated the feasibility of introducing, delivering, and safely assessing the home-based exercise and Tai-chi snacking programmes remotely to older populations.

The home-based snacking exercises were designed to be inclusive, demanding minimal time or equipment. Based on the findings in Chapter 3 and 4, exercise snacking was perceived as easy, uncomplicated, and well-received, whereas Tai-chi snacking was reported to be comparatively complex yet captivating, owing to its sophisticated concepts. This resulted in high levels of adherence to both snacking exercises. However, participants' feedback suggested that cutting down Tai-chi snacking movements and incorporating upper body movements into exercise snacking programme may boost the acceptability. Reshaping certain exercise movements based on participants' varying levels of physical function may enhance programmes manageability and efficacy and extend the applicability to broader populations. To meet different needs of broader populations, creating a progression within the exercise and Tai-chi snacking programme would be beneficial and effective.

Consequently, the three-level progressive exercise and Tai-chi snacking programme with arm and shoulder movements was created. A mixed methods (i.e., qualitative and quantitative) randomised controlled trial investigating the acceptability and efficacy of progressive home-based exercise and Tai-chi snacking on physical functions, general health and mental wellbeing with a specific focus on pre-frail older adults was conducted in the final study (Chapter 5). This study involved an extended intervention period of 12 weeks, aiming to explore whether the consistently high participation rate identified in Chapter 4 would translate into continuous, long-term adherence. To gain a deeper understanding of the intervention's effectiveness, a subset of participants underwent laboratory-based assessments that included more robust physical functional measures. Notably, the intervention group in this study exhibited significant improvements in strength, balance, and mobility compared to the usual care control group. In addition to the observed positive physical effects, it's important to note that plateauing in the improvement of certain measures may be due to practice effect and/or the progressing of exercise in participants reaching ceiling effect, particularly noticed after week 4. While improvements were observed in SPPB, other measures did not exhibit substantial enhancements. This suggests that the snacking exercises might not consistently drive improvement throughout the intervention period. Despite the programme's positive physical effects, no significant differences were observed in psychological outcomes. It's crucial to acknowledge that this study was underpowered for the primary outcome, potentially affecting the statistical power of other measures. Adherence to the exercise and Tai-chi snacking sessions was relatively high, with participants attempting a mean of 90% of the total sessions. However, the limitation in logbook returns (24 out of 28 completers in the intervention group) must be considered. Exploring improved methods to monitor adherence is crucial to understand if the observed plateau resulted from waning adherence over time. Based on the TFA survey and interviews, the exercise and Tai-chi snacking intervention was stated to be acceptable and enjoyable. The programme's acceptability and appropriateness for pre-frail older adults were emphasised, offering a convenient and accessible exercise option for individuals with mobility limitations or restricted access to exercise facilities.

6.2 Take-home messages

The research questions of each chapter in this thesis along with their key findings were outlined as follow:

i. The review provided insights into potential benefits of unsupervised home-based exercises for improving physical functions in older adults, highlighting research gaps, and emphasising the necessity for comprehensive and generalised investigation of unsupervised home-based exercises in future work. (Chapter 2 – systematic review)
ii. The home-based exercise and Tai-chi snacking were perceived acceptable and enjoyable, and not burdensome; however, there was a necessity to adjust the design of the exercise programme (Chapter 3 – qualitative acceptability study).
iii. The unsupervised 4-week fixed home-based exercise and Tai-chi snacking programme was found to be feasible and effective, though its acceptability could have been increased by providing different progressions and adjustments (Chapter 4 – Covid-19 remote study).
iv. The unsupervised 12-week progressive home-based exercise and Tai-chi snacking programme was acceptable and efficacious in enhancing physical functions in pre-frail older adults, with its low-cost nature and easy implementation further boosting its feasibility (Chapter 5 – mixed-method prolonged RCT).

6.3 Contribution to knowledge

As individuals age, they tend to experience a decline in physical activity. Recent research highlighted the importance of designing and promoting innovative interventions aimed at fostering active engagement in physical activities during the later stages of one’s life (de Paula et al., 2023). The overall contribution of this thesis is exploring the potential of home-based exercise and Tai-chi snacking, which is well-suited for the many older adults who do not [wish to] participate in traditional forms of exercise. This novel home-based snacking exercise regime enhanced strength, balance, and mobility in older adults, thereby may have potential in elevating their overall quality of life and exercise cognitions. However, the direct impact on overall quality of life and exercise cognitions requires further investigation.

To date, a limited number of studies have attempted to explore the acceptability of home-based exercise and Tai-chi snacking for older adults and accordingly refine the programme. Moreover, many research inquiries limit themselves to singular settings or countries, with authors often critiquing their findings for lack of generalisability. Investigating the responses of older adults from different cultures, particularly Eastern and Western cultures, considering the distinctive concepts of Western exercise snacking and East-Asian Tai-chi snacking, to home-based exercise and Tai-chi snacking has provided valuable insights. By gaining initial understanding of the suitability of home-based snacking exercises in cross-cultural contexts, I have identified indicators of the acceptance and potential sustainability of these health promotion solutions, although my observations were limited to three days for each snacking exercise. Future research can delve deeper into exploring the long-term sustainability of these exercises.

The mixed method work in this thesis provided not only objective quantitative outcomes but also incorporated subjective experiences and judgments from participants, as assessed through qualitative evaluations. This mixed-method design has equipped researchers, health professionals, and even fitness industries with practical strategies for developing appropriate and effective interventions for older adults. The verified feasibility of remote assessments could offer researchers with cost-effective and reliable online protocols (Benlidayi, 2023, Kohn et al., 2023). Indeed, applying the home-based exercise and Tai-chi snacking programme in practice following the findings of the research in this thesis has the potential to help older adults seeking to enhance or maintain physical functions in building up exercise routines that align with their lifestyles and needs (Huang and Yen, 2023, Newbold et al., 2021). In turn, this could improve the health status and overall quality of life for older populations.

6.4 Limitations and future directions

The work in this thesis provides novel information on: (a) the potential physical function effects of unsupervised home-based exercise interventions, (b) participants' initial perspectives on the acceptability of home-based exercise and Tai-chi snacking programme with different cultural contexts, (c) the intervention feasibility, and (d) the prolonged intervention's effectiveness on overall physical functions and its acceptability in older adults.

However, given the findings of the systematic review (Chapter 2), more evidence is needed to fill in the gaps of knowledge on the effectiveness of unsupervised home-based exercises in all-around older populations. Again, the initial aim to explore cultural differences between Western and Eastern cultures came across difficulties due to the lack of Mandarin literature. Confining the study to English literature could have disregarded non-English publications and their cultural impacts. Small sample size and lack of consistent outcome measures may be influential factors affecting the results. Accordingly, enhancing study designs and methods is crucial.

The short duration of exposure to the snacking protocols (1-week trial) and the study design (with qualitative evaluation only) in Chapter 3 had been addressed in Chapter 4 and 5. Particularly, the initial perspectives of participants regarding home-based exercise and Tai-chi snacking which were explored in Chapter 3 were found to be in line with the acceptability of the extended intervention period discussed in Chapter 4 (4 weeks) and 5 (12 weeks). To gain a deeper understanding of the scientific effects and explore the research topic in generalised, quantitative methods with larger sample sizes were also employed in Chapter 4 and 5, investigating objective outcomes of home-based exercise and Tai-chi snacking and in not only healthy older adults but also pre-frail ones. On the other hand, due to the study's primary focus on establishing feasibility in Chapter 4, no robust statistical analysis was used to investigate the intervention effect. This limitation was addressed in Chapter 5 where a mixed linear model was utilised for analysing the effectiveness on physical functions and psychological exploratory outcomes.

Nevertheless, when studying the effectiveness of home-based exercise and Tai-chi snacking, differences between the nature of the exercises themselves might influence the potential effects on physical functions that they triggered. Therefore, we invited a subset of participants to undergo the 10-rep incremental test (using Keiser leg press machine) for mechanistic outcomes in lab settings in the final randomised controlled trial (Chapter 5). However, the inability of performing leg presses with maximum leg extension velocity in pre-frail older participants prevented us from accurately interpreting mechanistic outcomes. Researchers need to find better and appropriate ways to assess the mechanistic measures with [pre-frail or frail] older adults. Perhaps in the future, researchers could initiate investigations by using motion capture/analysis systems and electromyography to examine the effectiveness of home-based snacking exercises on muscle activation, joint force, and its biomechanics in older adults and further find suitable methods for measuring muscle force, power, and velocity. On the other hand, utilising the study method of Chapter 5 to investigate what and why the effectiveness of home-based exercise and Tai-chi snacking varies from older adults with different cultural backgrounds in future work may bring great insights on implementing these novel home-based exercise interventions into different ethnicities older populations daily routines in practice.

Future research should focus on overcoming the limitations we faced in this thesis, such as participant demographic, target populations, exclusive criteria, issues related to technology literacy, challenges associated with remote assessments, and the sole focusing on lower extremity function only. These factors have potentially limited the generalisability: specifically (a) targeting on healthy older adults and pre-frail older adults without special health conditions, (b) having participants skewed toward females and those with higher education, (c) using the Groningen Frailty Indicator to screen out potential participants (resulting in a 20% exclusion rate) due to concerns about the safety of conducting remote assessments in the remote study, (d) precluding older adults who are not adept at using technology, (e) not assessing mobility via remote assessments, and (f) solely testing lower body functions without including upper body functions, etc. Moreover, the validity of remote assessments and certain mechanistic outcomes was questioned.

Further research is necessary to address these concerns. Exploring methods to engage populations that could be benefitted, such as potentially frail clinical outpatient groups and individuals with lower socioeconomic status who might face technology-related barriers, is important challenges for future investigation. In addition, assessing the programme's long-term effects post-intervention is imperative to better understand whether the research findings can be translated into practice.

6.5 Practical implications

In addition to contributing to the body of knowledge, the findings have practical implications for public health and clinical practitioners who are invested in promoting exercise and improving physical functions and well-being amongst older adults.

i. Targeting lower functioning populations

The suitability of the exercise and Tai-chi snacking programme for individuals with lower physical functions is one practical implication. The programme's safety and engagement factors make it a potential option for enhancing physical activity and well-being in individuals with varying levels of physical function. While the clinical contexts of surgery, strokes, and falls involve specialised and well-evidenced rehabilitation practices, there may be opportunities to explore complementary approaches. Moreover, the programme offers a promising option (due to its progressive nature) for those with musculoskeletal disorders. Clinical practitioners and rehabilitation specialists can consider integrating this approach as a supplementary or complementary element into their rehab plans, tailored to individual needs and combined with existing evidence-based practices to enhance physical recovery and overall well-being in their patients.

ii. General population-level interventions

Public health agencies seeking to implement population-wide interventions can consider the exercise and Tai-chi snacking programme as part of their strategies to promote physical activity in older adults, including those in communities with mild cognitive impairment, lower socioeconomic status, and rural areas. Its accessibility and adaptability make it a feasible and practical option for large-scale health promotion aimed at improving physical functions and quality of life in ageing populations, especially in those diverse and often underserved communities.

iii. Gateway to increased physical activity

The snacking approach could also be seen as a gateway to increased physical activity and improved confidence in engaging in other exercise formats. It benefits individuals in building foundational strength, which is fundamental to all physical activity, as individuals need to be strong enough to stand up and move effectively. It additionally enhances balance, which is the next most important aspect, as sufficient balance is necessary for remaining standing and participating safely in various activities beyond chair-based exercises This programme can be an imperative step in building up the necessary strength and balance for sustained long-term benefits through behaviour change. Practitioners can easily fit this programme into their daily routines to help them further build into more comprehensive exercise habits.

By considering these practical implications and potential contexts, healthcare professionals, rehabilitation specialists, and public health agencies can utilise our research to enhance physical health and mental well-being in older adults while addressing the needs of diverse populations in various healthcare settings.

6.6 Conclusion

This thesis provides a comprehensive exploration of the positive effects of unsupervised home-based exercise interventions on physical functions. Through investigating the feasibility, acceptability, and effectiveness of home-based ‘exercise and Tai-chi snacking', these studies advance our understanding and contribute to the existing knowledge within the field of health promotion and exercise science research. By applying the insights gleaned from these works, researchers and practitioners can enhance and broaden exercise strategies that enable older adults to maintain or improve physical functions and overall quality of life. This can contribute to combating the issues of ageing societies and potentially result in decreased healthcare costs for older adults worldwide.

At the start of this thesis, the idiom 'Sit less, move more' was presented as a driving theme for the research. Over the ensuing chapters it has come to light that 'more' in this sense does not have to be much at all, particularly when the goal is improving physical function. Indeed, just 20 minutes of exercise per day is seemingly sufficient, and often desirable, for older adults with impaired mobility to retrieve or feel the benefits. While this thesis does not answer questions of how sustainable exercise and Tai-chi snacking programmes can be, how it impacts health and wellbeing long-term, nor whether it raises confidence for older adults to participate in more physical activity outside the home, it does demonstrate that there are inexpensive, convenient and empowering exercise solutions that can help everyone stay strong.

7 Bibliography

AN, H.-Y., CHEN, W., WANG, C.-W., YANG, H.-F., HUANG, W.-T. & FAN, S.-Y. 2020. The relationships between physical activity and life satisfaction and happiness among young, middle-aged, and older adults. *International journal of environmental research and public health,* 17**,** 4817.

BAKHSHAYEH, S., SARBAZ, M., KIMIAFAR, K., VAKILIAN, F. & ESLAMI, S. 2019. Barriers to participation in center-based cardiac rehabilitation programs and patients' attitude toward home-based cardiac rehabilitation programs. *Physiotherapy theory and practice*.

BAUMAN, A., MEROM, D., BULL, F. C., BUCHNER, D. M. & FIATARONE SINGH, M. A. 2016. Updating the evidence for physical activity: summative reviews of the epidemiological evidence, prevalence, and interventions to promote "active aging". *The gerontologist,* 56**,** S268-S280.

BEMBEN, D. A., FETTERS, N. L., BEMBEN, M. G., NABAVI, N. & KOH, E. T. 2000. Musculoskeletal responses to high-and low-intensity resistance training in early postmenopausal women. *Medicine & Science in Sports & Exercise,* 32**,** 1949-1957.

BENLIDAYI, I. C. 2023. THE EFFECTS OF EXERCISING ON PSYCHOLOGICAL WELL-BEING IN OLDER ADULTS. *Anti-Aging Eastern Europe,* 2**,** 36-41.

BESWICK, A. D., REES, K., DIEPPE, P., AYIS, S., GOOBERMAN-HILL, R., HORWOOD, J. & EBRAHIM, S. 2008. Complex interventions to improve physical function and maintain independent living in elderly people: a systematic review and meta-analysis. *The Lancet,* 371**,** 725-735.

BOOTH, M. L., OWEN, N., BAUMAN, A., CLAVISI, O. & LESLIE, E. 2000. Social–cognitive and perceived environment influences associated with physical activity in older Australians. *Preventive medicine,* 31**,** 15-22.

BRACH, J. S., SIMONSICK, E. M., KRITCHEVSKY, S., YAFFE, K., NEWMAN, A. B., HEALTH, A. & GROUP, B. C. S. R. 2004. The association between physical function and lifestyle activity and exercise in the health, aging and body composition study. *Journal of the American Geriatrics Society,* 52**,** 502-509.

BRAITHWAITE, R. L., GRIFFIN JR, J. P., STEPHENS, T., MURPHY, F. & MARROW, T. 1998. Perceived exercise barriers and participation in Tai Chi for elderly African American. *American Journal of Health Studies,* 14**,** 169.

BUCKINX, F., AUBERTIN-LEHEUDRE, M., DAOUST, R., HEGG, S., MARTEL, D., MARTEL-THIBAULT, M. & SIROIS, M.-J. 2023. Impacts of Remote Physical Exercises on Functional Status and Mobility among Community-Dwelling Pre-Disabled Seniors during the Covid-19 Lockdown. *The journal of nutrition, health & aging***,** 1-8.

BURTON, E., FARRIER, K., LEWIN, G., PETTIGREW, S., HILL, A.-M., AIREY, P., BAINBRIDGE, L. & HILL, K. D. 2017. Motivators and barriers for older people participating in resistance training: a systematic review. *Journal of aging and physical activity,* 25**,** 311-324.

CARLSTON, D. E. 1983. An environmental explanation for race differences in basketball performance. *Journal of sport and Social Issues,* 7**,** 30-51.

CARNEIRO, N. H., RIBEIRO, A. S., NASCIMENTO, M. A., GOBBO, L. A., SCHOENFELD, B. J., JÚNIOR, A. A., GOBBI, S., OLIVEIRA, A. R. & CYRINO, E. S. 2015. Effects of different resistance training frequencies on flexibility in older women. *Clinical interventions in aging,* 10**,** 531.

CASTAÑO-VERGARA, D. M. & CARDONA-ARANGO, D. 2015. Perception of state of health and associated factors in older adults. *Revista de Salud Pública,* 17**,** 171-183.

CAVILL, N. A. & FOSTER, C. E. 2018. Enablers and barriers to older people's participation in strength and balance activities: A review of reviews. *Journal of Frailty, Sarcopenia and Falls,* 3**,** 105.

CHAABENE, H., PRIESKE, O., HERZ, M., MORAN, J., HÖHNE, J., KLIEGL, R., RAMIREZ-CAMPILLO, R., BEHM, D., HORTOBÁGYI, T. & GRANACHER, U. 2021. Home-based exercise programmes improve physical fitness of healthy older adults: A PRISMA-compliant systematic review and meta-analysis with relevance for COVID-19. *Ageing research reviews,* 67**,** 101265.

CHOI, J. H., MOON, J. S. & SONG, R. 2005. Effects of Sun-style Tai Chi exercise on physical fitness and fall prevention in fall-prone older adults. *Journal of advanced nursing,* 51**,** 150-157.

CHOU, C.-H., HWANG, C.-L. & WU, Y.-T. 2012. Effect of exercise on physical function, daily living activities, and quality of life in the frail older adults: a meta-analysis. *Archives of physical medicine and rehabilitation,* 93**,** 237-244.

CHUA, C. M. S., CHUA, J. Y. X. & SHOREY, S. 2023. Effectiveness of home-based interventions in improving loneliness and social connectedness among older adults: a systematic review and meta-analysis. *Aging & Mental Health***,** 1-10.

DARWESH, A., ELSAYED, E., ABBAS, H., EL-FIKY, A., EL-MARAKBY, A. & ABOELENIN, A. 2014. Balance Deficits in Elderly Population. *Middle East J Sci Res,* 21**,** 1-6.

DE PAULA, D., CROCHEMORE-SILVA, I., GRIEP, R. H., DUNCAN, B. B. & SCHMIDT, M. I. 2023. Accelerometry Measured Movement Behaviors in Middle-Aged and Older Adults: Cross-Sectional Analysis of the ELSA-Brasil Study. *Journal of Physical Activity and Health,* 1**,** 1-10.

DEN OUDEN, M. E., SCHUURMANS, M. J., ARTS, I. E. & VAN DER SCHOUW, Y. T. 2013. Association between physical performance characteristics and independence in activities of daily living in middle-aged and elderly men. *Geriatrics & gerontology international,* 13**,** 274-280.

DESCHENES, M. R. & KRAEMER, W. J. 2002. Performance and physiologic adaptations to resistance training. *American Journal of Physical Medicine & Rehabilitation,* 81**,** S3-S16.

DIEPEVEEN, S., LING, T., SUHRCKE, M., ROLAND, M. & MARTEAU, T. M. 2013. Public acceptability of government intervention to change health-related behaviours: a systematic review and narrative synthesis. *BMC public health,* 13**,** 1-11.

EUN-JUNG, K., SUNG-WON, J., YOUNG-EUN, K., DUN-SOL, G. & SEOK-JUN, Y. 2018. Assessing the impact of aging on burden of disease. *Iranian journal of public health,* 47**,** 33.

FARRELL, L., HOLLINGSWORTH, B., PROPPER, C. & SHIELDS, M. A. 2013. *The socioeconomic gradient in physical inactivity in England*, Citeseer.

FIELD, T. 2011. Tai Chi research review. *Complementary Therapies in Clinical Practice,* 17**,** 141-146.

FLEGAL, K., KISHIYAMA, S., ZAJDEL, D., HAAS, M. & OKEN, B. 2007. Adherence to yoga and exercise interventions in a 6-month clinical trial. *BMC Complementary and Alternative Medicine,* 7**,** 37.

FRANCO, M. R., TONG, A., HOWARD, K., SHERRINGTON, C., FERREIRA, P. H., PINTO, R. Z. & FERREIRA, M. L. 2015. Older people's perspectives on participation in physical activity: a systematic review and thematic synthesis of qualitative literature. *Br J Sports Med,* 49**,** 1268-1276.

FRANCOIS, M. E., BALDI, J. C., MANNING, P. J., LUCAS, S. J. E., HAWLEY, J. A., WILLIAMS, M. J. A. & COTTER, J. D. 2014. 'Exercise snacks' before meals: a novel strategy to improve glycaemic control in individuals with insulin resistance. *Diabetologia,* 57**,** 1437-1445.

FREIBERGER, E., DE VREEDE, P., SCHOENE, D., RYDWIK, E., MUELLER, V., FRÄNDIN, K. & HOPMAN-ROCK, M. 2012. Performance-based physical function in older community-dwelling persons: a systematic review of instruments. *Age and ageing,* 41**,** 712-721.

FURNHAM, A. & NORDLING, R. 1998. Cross-cultural differences in preferences for specific male and female body shapes. *Personality and Individual Differences,* 25**,** 635-648.

FYFE, J. J., DALLA VIA, J., JANSONS, P., SCOTT, D. & DALY, R. M. 2022. Feasibility and acceptability of a remotely delivered, home-based, pragmatic resistance 'exercise snacking'intervention in community-dwelling older adults: a pilot randomised controlled trial. *BMC geriatrics,* 22**,** 1-12.

GEIRSDOTTIR, O. G., ARNARSON, A., BRIEM, K., RAMEL, A., TOMASSON, K., JONSSON, P. & THORSDOTTIR, I. 2012. Physical function predicts improvement in quality of life in elderly Icelanders after 12 weeks of resistance exercise. *The journal of nutrition, health & aging,* 16**,** 62-66.

GHRAM, A., BRIKI, W., MANSOOR, H., AL-MOHANNADI, A. S., LAVIE, C. J. & CHAMARI, K. 2021. Home-based exercise can be beneficial for counteracting sedentary behavior and physical inactivity during the COVID-19 pandemic in older adults. *Postgraduate medicine,* 133**,** 469-480.

GINÉ-GARRIGA, M., ROQUÉ-FÍGULS, M., COLL-PLANAS, L., SITJA-RABERT, M. & SALVÀ, A. 2014. Physical exercise interventions for improving performance-based measures of physical function in community-dwelling, frail older adults: a systematic review and meta-analysis. *Archives of physical medicine and rehabilitation,* 95**,** 753-769. e3.

GLENN, J. M., GRAY, M. & BINNS, A. 2015. The effects of loaded and unloaded high-velocity resistance training on functional fitness among community-dwelling older adults. *Age and ageing,* 44**,** 926-931.

GRYFFIN, P. A., CHEN, W. C., CHANEY, B. H., DODD, V. J. & ROBERTS, B. 2015. Facilitators and barriers to tai chi in an older adult community: a theory-driven Approach. *American Journal of Health Education,* 46**,** 109-118.

GUIZELINI, P. C., DE AGUIAR, R. A., DENADAI, B. S., CAPUTO, F. & GRECO, C. C. 2018. Effect of resistance training on muscle strength and rate of force development in healthy older adults: a systematic review and meta-analysis. *Experimental gerontology,* 102**,** 51-58.

GURALNIK, J. M., SIMONSICK, E. M., FERRUCCI, L., GLYNN, R. J., BERKMAN, L. F., BLAZER, D. G., SCHERR, P. A. & WALLACE, R. B. 1994. A short physical performance battery assessing lower extremity function: association with self-reported disability and prediction of mortality and nursing home admission. *Journal of gerontology,* 49**,** M85-M94.

GYLLENSTEN, A. L., HUI-CHAN, C. W. & TSANG, W. W. 2010. Stability limits, single-leg jump, and body awareness in older Tai Chi practitioners. *Archives of physical medicine and rehabilitation,* 91**,** 215-220.

HACKNEY, M. E. & WOLF, S. L. 2014. Impact of Tai Chi Chu'an practice on balance and mobility in older adults: an integrative review of 20 years of research. *Journal of geriatric physical therapy,* 37**,** 127-135.

HARRIS-LOVE, M. O., SEAMON, B. A., GONZALES, T. I., HERNANDEZ, H. J., PENNINGTON, D. & HOOVER, B. M. 2017. Eccentric exercise program design: a periodization model for rehabilitation applications. *Frontiers in physiology,* 8**,** 112.

HORNE, M., SKELTON, D. A., SPEED, S. & TODD, C. 2013. Perceived barriers to initiating and maintaining physical activity among South Asian and White British adults in their 60s living in the United Kingdom: a qualitative study. *Ethnicity & health,* 18**,** 626-

645.
HUANG, C.-H. & YEN, M. 2023. Applying an Exercise Snack-Based Health Promotion Strategy. *Hu Li Za Zhi,* 70**,** 78-83.
JAKICIC, J. M., WING, R., BUTLER, B. & ROBERTSON, R. 1995. Prescribing exercise in multiple short bouts versus one continuous bout: effects on adherence, cardiorespiratory fitness, and weight loss in overweight women. *International journal of obesity and related metabolic disorders: journal of the International Association for the Study of Obesity,* 19**,** 893-901.
JAKICIC, J. M., WINTERS, C., LANG, W. & WING, R. R. 1999. Effects of intermittent exercise and use of home exercise equipment on adherence, weight loss, and fitness in overweight women: a randomized trial. *Jama,* 282**,** 1554-1560.
JANG, H., CLEMSON, L., LOVARINI, M., WILLIS, K., LORD, S. R. & SHERRINGTON, C. 2016. Cultural influences on exercise participation and fall prevention: a systematic review and narrative synthesis. *Disability and rehabilitation,* 38**,** 724-732.
JETTE, A. M., LACHMAN, M., GIORGETTI, M. M., ASSMANN, S. F., HARRIS, B. A., LEVENSON, C., WERNICK, M. & KREBS, D. 1999. Exercise--it's never too late: the strong-for-life program. *Am J Public Health,* 89**,** 66-72.
KADARIYA, S., GAUTAM, R. & ARO, A. R. 2019. Physical Activity, Mental Health, and Wellbeing among Older Adults in South and Southeast Asia: A Scoping Review. *BioMed Research International,* 2019**,** 6752182.
KALETA, D., POLANSKA, K., DZIANKOWSKA-ZABORSZCZYK, E., HANKE, W. & DRYGAS, W. 2009. Factors influencing self-perception of health status. *Central European journal of public health,* 17**,** 122.
KING, A. C., HASKELL, W. L., YOUNG, D. R., OKA, R. K. & STEFANICK, M. L. 1995. Long-term effects of varying intensities and formats of physical activity on participation rates, fitness, and lipoproteins in men and women aged 50 to 65 years. *Circulation,* 91**,** 2596-2604.
KIS, O., BUCH, A., STERN, N. & MORAN, D. S. 2019. Minimally supervised home-based resistance training and muscle function in older adults: A meta-analysis. *Archives of gerontology and geriatrics,* 84**,** 103909.
KOHN, J. N., LOBO, J. D., TROYER, E. A., WILSON, K. L., ANG, G., WALKER, A. L., PRUITT, C., PUNG, M. A., REDWINE, L. S. & HONG, S. 2023. Tai chi or health education for older adults with hypertension: effects on mental health and psychological resilience to COVID-19. *Aging & Mental Health,* 27**,** 496-504.
KOSHOEDO, S. A., PAUL-EBHOHIMHEN, V. A., JEPSON, R. G. & WATSON, M. C. 2015. Understanding the complex interplay of barriers to physical activity amongst black and minority ethnic groups in the United Kingdom: a qualitative synthesis using meta-ethnography. *BMC public health,* 15**,** 643.
LACROIX, A., KRESSIG, R. W., MUEHLBAUER, T., GSCHWIND, Y. J., PFENNINGER, B., BRUEGGER, O. & GRANACHER, U. 2016. Effects of a supervised versus an unsupervised combined balance and strength training program on balance and muscle power in healthy older adults: a randomized controlled trial. *Gerontology,* 62**,** 275-288.
LAN, C., LAI, J.-S., CHEN, S.-Y. & WONG, M.-K. 1998. 12-month Tai Chi training in the elderly: its effect on health fitness. *Medicine and Science in Sports and Exercise,* 30**,** 345-351.
LAN, C., LAI, J.-S., CHEN, S.-Y. & WONG, M.-K. 2000. Tai Chi Chuan to improve muscular strength and endurance in elderly individuals: a pilot study. *Archives of physical medicine and rehabilitation,* 81**,** 604-607.
LEES, F. D., CLARK, P. G., NIGG, C. R. & NEWMAN, P. 2005. Barriers to exercise behavior

among older adults: a focus-group study. *Journal of aging and physical activity,* 13**,** 23-33.
LI, F., FISHER, K. J., HARMER, P., IRBE, D., TEARSE, R. G. & WEIMER, C. 2004. Tai Chi and self-rated quality of sleep and daytime sleepiness in older adults: a randomized controlled trial. *Journal of the American Geriatrics Society,* 52**,** 892-900.
LIAN, X., ZHANG, Y., LI, X., JING, L., CAIRANG, Z. & GOU, J. 2017. Exploration on the relationship between the elderly osteoporosis and cardiovascular disease risk factors. *Eur Rev Med Pharmacol Sci,* 21**,** 4386-4390.
LIANG, I. J., FRANCOMBE-WEBB, J., MCGUIGAN, P. M., PERKIN, O. J., THOMPSON, D. & WESTERN, M. J. 2023. The acceptability of homebased exercise snacking and Tai-chi snacking amongst high and low function UK and Taiwanese older adults. *Frontiers in Aging,* 4.
LIANG, I. J., PERKIN, O. J., MCGUIGAN, P. M., THOMPSON, D. & WESTERN, M. J. 2021. Feasibility and acceptability of home-based exercise snacking and tai chi snacking delivered remotely to self-isolating older adults during COVID-19. *Journal of aging and physical activity,* 30**,** 33-43.
LIU 2008. 太极拳健身理论论绎. 北京: 北京体育大学出版社.
LIU, S., LI, L., LIU, Z. & GUO, X. 2019. Long-term Tai Chi experience promotes emotional stability and slows gray matter atrophy for elders. *Frontiers in psychology,* 10**,** 91.
LIZAMA-PÉREZ, R., CHIROSA-RÍOS, L. J., CONTRERAS-DÍAZ, G., JEREZ-MAYORGA, D., JIMÉNEZ-LUPIÓN, D. & CHIROSA-RÍOS, I. J. 2023. Effect of sit-to-stand-based training on muscle quality in sedentary adults: a randomized controlled trial. *PeerJ,* 11**,** e15665.
LO, O.-Y., CONBOY, L. A., RUKHADZE, A., GEORGETTI, C., GAGNON, M. M., MANOR, B., LACHMAN, M. E., LIPSITZ, L. A. & WAYNE, P. M. 2020. In the eyes of those who were randomized: Perceptions of disadvantaged older adults in a Tai Chi trial. *The Gerontologist,* 60**,** 672-682.
LUNNEY, J. R., LYNN, J., FOLEY, D. J., LIPSON, S. & GURALNIK, J. M. 2003. Patterns of functional decline at the end of life. *Jama,* 289**,** 2387-2392.
MAK, M. K. & NG, P. L. 2003. Mediolateral sway in single-leg stance is the best discriminator of balance performance for Tai-Chi practitioners. *Archives of physical medicine and rehabilitation,* 84**,** 683-686.
MANAF, H. 2013. Barriers to participation in physical activity and exercise among middle-aged and elderly individuals. *Singapore Med J,* 54**,** 581-586.
MILLER, S. & TAYLOR-PILIAE, R. E. 2018. The association between Tai Chi exercise and safe driving performance among older adults: An observational study. *Journal of sport and health science,* 7**,** 83-94.
MOSCHNY, A., PLATEN, P., KLAAßEN-MIELKE, R., TRAMPISCH, U. & HINRICHS, T. 2011. Barriers to physical activity in older adults in Germany: a cross-sectional study. *International Journal of Behavioral Nutrition and Physical Activity,* 8**,** 121.
MOURA, B. M. D., SAKUGAWA, R. L., ORSSATTO, L. B. D. R., DE LIMA, L. A. P., PINTO, R. S., WALKER, S. & DIEFENTHAELER, F. 2018. Functional capacity improves in-line with neuromuscular performance after 12 weeks of non-linear periodization strength training in the elderly. *Aging Clinical and Experimental Research,* 30**,** 959-968.
MUNIYAPPA, R. & TELLA, S. H. 2018. Osteoporosis and cardiovascular disease in the elderly. *Conn's Handbook of Models for Human Aging.* Elsevier.
MURPHY, M. H., LAHART, I., CARLIN, A. & MURTAGH, E. 2019. The effects of continuous compared to accumulated exercise on health: a meta-analytic review. *Sports Medicine,* 49**,** 1585-1607.
NELSON, M. E., LAYNE, J. E., BERNSTEIN, M. J., NUERNBERGER, A., CASTANEDA, C.,

KALITON, D., HAUSDORFF, J., JUDGE, J. O., BUCHNER, D. M. & ROUBENOFF, R. 2004. The effects of multidimensional home-based exercise on functional performance in elderly people. *The Journals of Gerontology Series A: Biological Sciences and Medical Sciences,* 59**,** M154-M160.

NEWBOLD, J. W., RUDNICKA, A. & COX, A. 2021. Staying active while staying home: The use of physical activity technologies during life disruptions. *Frontiers in Digital Health***,** 145.

NHS 2021. Physical activity guidelines for older adults.

NOWALK, M. P., PRENDERGAST, J. M., BAYLES, C. M., D'AMICO, F. J. & COLVIN, G. C. 2001. A randomized trial of exercise programs among older individuals living in two long-term care facilities: the FallsFREE program. *J Am Geriatr Soc,* 49**,** 859-65.

OIKAWA, S. Y., HOLLOWAY, T. M. & PHILLIPS, S. M. 2019. The impact of step reduction on muscle health in aging: protein and exercise as countermeasures. *Frontiers in nutrition***,** 75.

ORANGE, S. T., MARSHALL, P., MADDEN, L. A. & VINCE, R. V. 2019. Short-Term Training and Detraining Effects of Supervised vs. Unsupervised Resistance Exercise in Aging Adults. *The Journal of Strength & Conditioning Research,* 33**,** 2733-2742.

PAHOR, M., GURALNIK, J. M., AMBROSIUS, W. T., BLAIR, S., BONDS, D. E., CHURCH, T. S., ESPELAND, M. A., FIELDING, R. A., GILL, T. M., GROESSL, E. J., KING, A. C., KRITCHEVSKY, S. B., MANINI, T. M., MCDERMOTT, M. M., MILLER, M. E., NEWMAN, A. B., REJESKI, W. J., SINK, K. M. & WILLIAMSON, J. D. 2014. Effect of structured physical activity on prevention of major mobility disability in older adults: the LIFE study randomized clinical trial. *Jama,* 311**,** 2387-96.

PERKIN, O. J., MCGUIGAN, P. M. & STOKES, K. A. 2019. Exercise Snacking to Improve Muscle Function in Healthy Older Adults: A Pilot Study. *Journal of Aging Research,* 2019**,** 9.

PERSKI, O. & SHORT, C. E. 2021. Acceptability of digital health interventions: embracing the complexity. *Translational behavioral medicine,* 11**,** 1473-1480.

PICORELLI, A. M. A., PEREIRA, L. S. M., PEREIRA, D. S., FELÍCIO, D. & SHERRINGTON, C. 2014. Adherence to exercise programs for older people is influenced by program characteristics and personal factors: a systematic review. *Journal of physiotherapy,* 60**,** 151-156.

PRINCE, M. J., WU, F., GUO, Y., ROBLEDO, L. M. G., O'DONNELL, M., SULLIVAN, R. & YUSUF, S. 2015. The burden of disease in older people and implications for health policy and practice. *The Lancet,* 385**,** 549-562.

RAAB, D., AGRE, J., MCADAM, M. & SMITH, E. 1988. Light resistance and stretching exercise in elderly women: effect upon flexibility. *Archives of Physical Medicine and Rehabilitation,* 69**,** 268-272.

RIBEIRO, R. M., TRIBESS, S., SANTOS, A. S. D., PINTO, L. L. T., RIBEIRO, M. D. C. L., ROZA, L. B. & VIRTUOSO JÚNIOR, J. S. 2015. Barriers to the involvement of the elderly in public services to promote physical activity. *Ciência & Saúde Coletiva,* 20**,** 739-749.

RICHARDSON, D. L., DUNCAN, M. J., CLARKE, N. D., MYERS, T. D. & TALLIS, J. 2021. The influence of COVID-19 measures in the United Kingdom on physical activity levels, perceived physical function and mood in older adults: A survey-based observational study. *Journal of Sports Sciences,* 39**,** 887-899.

SANG 2005. 试述太极拳对老龄化群体身心健康的积极性影响. *首都体育学院学报***,** 114-116.

SANTOS, I. K. D., COBUCCI, R. N., MEDEIROS, J. A. D., ASSIS, G. G. D., MEDEIROS, R. C. D. S. C. D., KNACKFUSS, M. I., CABRAL, B. G. D. A. T., SANTOS, R. V. T. D. & DANTAS, P. M. S. 2023. Home-Based Indoor Physical Activity Programs for Community-Dwelling

Older Adults: A Systematic Review. *Sports Health*, 19417381231175665.
SEKHON, M., CARTWRIGHT, M. & FRANCIS, J. J. 2017. Acceptability of healthcare interventions: an overview of reviews and development of a theoretical framework. *BMC health services research,* 17, 1-13.
SJÖSTEN, N. M., SALONOJA, M., PIIRTOLA, M., VAHLBERG, T. J., ISOAHO, R., HYTTINEN, H. K., AARNIO, P. T. & KIVELÄ, S.-L. 2007. A multifactorial fall prevention programme in the community-dwelling aged: predictors of adherence. *European Journal of Public Health,* 17, 464-470.
SMITH, L., JACOB, L., BUTLER, L., SCHUCH, F., BARNETT, Y., GRABOVAC, I., VERONESE, N., CAPERCHIONE, C., LOPEZ-SANCHEZ, G. F. & MEYER, J. 2020. Prevalence and correlates of physical activity in a sample of UK adults observing social distancing during the COVID-19 pandemic. *BMJ open sport & exercise medicine,* 6, e000850.
SOLIS-NAVARRO, L., GISMERO, A., FERNÁNDEZ-JANÉ, C., TORRES-CASTRO, R., SOLÁ-MADURELL, M., BERGÉ, C., PÉREZ, L. M., ARS, J., MARTÍN-BORRÀS, C. & VILARÓ, J. 2022. Effectiveness of home-based exercise delivered by digital health in older adults: a systematic review and meta-analysis. *Age and ageing,* 51, afac243.
SON, N.-K., RYU, Y. U., JEONG, H.-W., JANG, Y.-H. & KIM, H.-D. 2016. Comparison of 2 different exercise approaches: Tai Chi versus Otago, in community-dwelling older women. *Journal of geriatric physical therapy,* 39, 51-57.
SONG, R., LEE, E.-O., LAM, P. & BAE, S.-C. 2003. Effects of tai chi exercise on pain, balance, muscle strength, and perceived difficulties in physical functioning in older women with osteoarthritis: a randomized clinical trial. *The Journal of Rheumatology,* 30, 2039-2044.
SPARLING, P. B., HOWARD, B. J., DUNSTAN, D. W. & OWEN, N. 2015. Recommendations for physical activity in older adults. *Bmj,* 350, h100.
STATHI, A., GREAVES, C. J., THOMPSON, J. L., WITHALL, J., LADLOW, P., TAYLOR, G., MEDINA-LARA, A., SNOWSILL, T., GRAY, S. & GREEN, C. 2022. Effect of a physical activity and behaviour maintenance programme on functional mobility decline in older adults: the REACT (Retirement in Action) randomised controlled trial. *The Lancet Public Health,* 7, e316-e326.
STRAIN, T., FITZSIMONS, C., KELLY, P. & MUTRIE, N. 2016. The forgotten guidelines: cross-sectional analysis of participation in muscle strengthening and balance & co-ordination activities by adults and older adults in Scotland. *BMC Public Health,* 16, 1108.
STUDENSKI, S., PERERA, S., PATEL, K., ROSANO, C., FAULKNER, K., INZITARI, M., BRACH, J., CHANDLER, J., CAWTHON, P. & CONNOR, E. B. 2011. Gait speed and survival in older adults. *Jama,* 305, 50-58.
SUNGKARAT, S., BORIPUNTAKUL, S., CHATTIPAKORN, N., WATCHARASAKSILP, K. & LORD, S. R. 2017. Effects of Tai Chi on cognition and fall risk in older adults with mild cognitive impairment: a randomized controlled trial. *Journal of the American Geriatrics Society,* 65, 721-727.
TAKARADA, Y. & ISHII, N. 2002. Effects of low-intensity resistance exercise with short interset rest period on muscular function in middle-aged women. *The Journal of Strength & Conditioning Research,* 16, 123-128.
TAMBALIS, K., PANAGIOTAKOS, D. B., KAVOURAS, S. A. & SIDOSSIS, L. S. 2009. Responses of blood lipids to aerobic, resistance, and combined aerobic with resistance exercise training: a systematic review of current evidence. *Angiology,* 60, 614-632.
TAYLOR-PILIAE, R. E., HASKELL, W. L., WATERS, C. M. & FROELICHER, E. S. 2006. Change in perceived psychosocial status following a 12-week Tai Chi exercise programme. *Journal of advanced nursing,* 54, 313-329.

THOMPSON, W. W., ZACK, M. M., KRAHN, G. L., ANDRESEN, E. M. & BARILE, J. P. 2012. Health-related quality of life among older adults with and without functional limitations. *American journal of public health,* 102**,** 496-502.

VELLAS, B., RUBENSTEIN, L., OUSSET, P., FAISANT, C., KOSTEK, V., NOURHASHEMI, F., ALLARD, M. & ALBAREDE, J. 1997. One-leg standing balance and functional status in a population of 512 community-living elderly persons. *Aging Clinical and Experimental Research,* 9**,** 95-98.

WAYNE, P. M., WALSH, J. N., TAYLOR-PILIAE, R. E., WELLS, R. E., PAPP, K. V., DONOVAN, N. J. & YEH, G. Y. 2014. Effect of Tai Chi on cognitive performance in older adults: Systematic review and meta-analysis. *Journal of the American Geriatrics Society,* 62**,** 25-39.

WEINBERG, R., TENENBAUM, G., MCKENZIE, A., JACKSON, S., ANSHEL, M., GROVE, R. & FOGARTY, G. 2000. Motivation for youth participation in sport and physical activity: relationships to culture, self-reported activity levels, and gender. *International Journal of Sport Psychology,* 31**,** 321-346.

WESTERN, M. J., WELSH, T., KEEN, K., BISHOP, V. & PERKIN, O. J. 2023. Exercise snacking to improve physical function in pre-frail older adult memory clinic patients: a 28-day pilot study. *BMC Geriatr,* 23**,** 471.

XU, D., LI, J. & HONG, Y. 2006. Effects of long term Tai Chi practice and jogging exercise on muscle strength and endurance in older people. *British journal of sports medicine,* 40**,** 50-54.

YANG, F.-C., DESAI, A. B., ESFAHANI, P., SOKOLOVSKAYA, T. V. & BARTLETT, D. J. 2022. Effectiveness of Tai Chi for health promotion of older adults: a scoping review of meta-analyses. *American journal of lifestyle medicine,* 16**,** 700-716.

YANG, X. J., HILL, K., MOORE, K., WILLIAMS, S., DOWSON, L., BORSCHMANN, K. & DHARMAGE, S. C. 2011. Balance concerns in the elderly: real or imaginary? *Journal of Clinical Gerontology and Geriatrics,* 2**,** 109-115.

YEH, S., CHUANG, H., LIN, L., HSIAO, C. & ENG, H. 2006. Regular tai chi chuan exercise enhances functional mobility and CD4CD25 regulatory T cells. *British journal of sports medicine,* 40**,** 239-243.