

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

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## 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.

**OBJECTIVES:** 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.

**DESIGN:** Randomised controlled trial.

**SETTING:** Community-dwelling older adults.

**PARTICIPANTS:** 90 older adults with impaired strength and balance were recruited. Participants were randomly allocated to an intervention or waitlist control group.

**INTERVENTION:** A 12-week progressive exercise and Tai-chi snacking programme.

**MEASUREMENTS:** Physical function (the short physical performance battery (SPPB), single-leg balance test and sit-to-stand test) was remotely measured at participants' homes via video calls at baseline, 4-, 8-, and 12-weeks. The self-reported psychological outcomes were also assessed every 4 weeks using online questionnaires. 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 SPPB strength (estimated mean difference in week 4: 1.05; week 8: 0.79; and week 12: 0.79) and balance (estimated mean difference in week 4: 0.71; week 8: 0.57; and week 12: 0.65) at each timepoint compared to control group. Timed-up-and-go (estimated mean difference in week 4: 1.94; week 8: 1.58; and week 12: 1.1) and total SPPB scores (estimated mean difference in week 4: 2.24; week 8: 1.79; and week 12: 1.76) 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 programme is considered to be a beneficial, acceptable and easy implemented physical function intervention.

*Key words:* Pre-frail, progressive home-based exercise, physical function improvement, Tai-chi snacking, exercise snacks.

## 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 (1, 2), reducing risk of falling and fractures (3, 4), and overall improved health and wellbeing (5, 6). In the UK it is recommended that older adults do S&B trainings on at least two days a week to maintain or improve their physical function (7). Unfortunately, very few older adults engage in sufficient S&B exercise to reap these benefits (8-10), with a lack of time, self-efficacy and access to leisure facilities cited as key barriers to participation (11, 12). 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 resistance training sessions at leisure centres or group classes (13). 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 (14, 15). This format of exercise aligns to recent calls for further exploration of 'minimal dose' approaches to exercise for improving strength in older adults (13). 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 (14, 16, 17) as well as clinical populations with mild-cognitive impairment and compromised physical function (18).

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, being both beneficial for physical function, and acting 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 further exercise (17). Participants felt that the exercise snacking programme could alleviate their fear of falling, reduce the possibility of developing dementia, and minimise other health concerns associated with ageing. However, our qualitative feedback also indicated that our exercise snacking programme may be more acceptable with simpler Tai-chi snacking movements, the inclusion of upper body movements, and adjustable levels of difficulty to cater for individual capabilities (17).

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, Simonsick (19)) 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. In addition this study also aimed to assess the acceptability of a prolonged home-based snacking exercise intervention in pre-frail older adults. Therefore, this study 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.

## 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 were completed remotely at baseline, 4 weeks, 8 weeks, and 12 weeks while a sub-group of 40 participants underwent further in-person laboratory-based assessment at the same time-points. 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). The findings were reported in accordance with the Consolidated Standards of Reporting Trials (CONSORT) guidelines (20). A detailed methodology is presented in Supplementary file B.

### *Participant recruitment and randomisation*

University web articles and mailing lists of third-sector ageing organisations in the UK were used to recruit older adults who were 65 years of age or older, could safely undertake and score between 2-6 out of 8 in the strength and balance domains of SPPB, without either section scoring zero, and were not engaging in regular sport or exercise. Eligibility (see supplementary file B1 for full criteria) was ascertained through a preliminary online screening health questionnaire which also gathered participant demographic data, while safety to engage in the intervention and assessment measure was taken determined at a familiarisation session via video call. All eligible participants provided informed consent and were randomised by an independent statistician to either the intervention group, or the control group after baseline assessments were completed.

### *Intervention*

For intervention participants, the 12-week intervention consisted of two bouts of exercise performed each day, one exercise snack [for strength] and one Tai-chi snack [for balance]. Each snack consisted of 5 movements, each performed for one minute with one minute rest in between. Exercise snacks included a bilateral leg exercise, a shoulder exercise, a unilateral leg exercise, an arm exercise, and a plantar flexor exercise (Supplementary File B2). Participants were encouraged to complete as many repetitions as possible of each exercise in that minute. Tai-chi snacking movements included a single leg squat, a trunk rotation, a single leg stand, a hip and knee exercise, and an ankle mobility exercise. Participants were encouraged to complete repetitions of each movement 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.

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 whole 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 a participants' ability to perform a set number of repetitions of a given exercise. Each exercise of the programme could be progressed at its own pace to provide participants with flexibility. Participants were provided with written and video instructions for each exercise (Supplementary file B2), and a logbook to monitor adherence and progression by recording repetitions and level of exercise completed.

### *Control*

Control group participants were asked to continue their normal habitual behaviour and were provided with all intervention materials after their final 12-week assessment.

**Table 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)	13(59)	.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 analyzed using Chi-square tests and unpaired t-tests. \*All randomized participants include 49 lab subset participants.

## Outcomes

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) (16). Participants engaged in the assessment sessions at their homes via video call, using participants' preferred software (e.g., Zoom, Teams, Facetime, WhatsApp). Positioning the camera to capture the participant's entire body in the frame, the researcher evaluated the timed 5 x sit-to-stands and maximum number of 60-second chair stand from a hard-based kitchen chair within a one-minute timeframe. The researcher provided verbal instructions to start and stop the test. Following this, participants performed three SPPB standing balance positions and undertook single-leg balance tests on both legs. These remote assessments followed a previously established, feasible, and safe protocol (16). 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) (19), the timed-up-and-go test (21) and a chair sit-and-reach flexibility test (22). Peak leg press

force was measured on a pneumatic leg press (A420, Keiser®, Fresno, CA). Process measures of exercise cognitions (e.g., exercise self-efficacy and outcome expectancy, motivation) and secondary health and wellbeing measures (e.g., self-reported physical activity, vitality, mental health, quality of life) were also taken at each of the four assessments. Intervention acceptability was measured using a survey (all intervention participants) and interview (subset) who's questions and topic guide were based on the theoretical framework of acceptability (TFA, Sekhon, Cartwright (23)). See supplementary file B1 for full list of measures.

## Statistical analysis

A target sample size of 86 was deemed suitable to detect an effect size of 0.5 in SPPB with 90% power and a significance alpha of 0.05. Considering the 19% drop-out rate in our previous study (16) we aimed for a total sample size of 102. Quantitative data was analysed using R version 4.1.2 (R Core Team 2021, R Foundation for Statistical Computing, Vienna, Austria). Using a linear mixed model for each outcome variable, 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 x Group' was used to understand whether there was any

**Table 2.** 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 at each follow-up assessment. 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	p value	Int	Con	p value	Int	Con	p value	Int	Con	p value		
	Between group EMD [95%CI]			Between group EMD [95%CI]			Between group EMD [95%CI]			Between group EMD [95%CI]				
All participants, n	44	46		28	36		28	36		28	36			
SPPB S&B items (8)	5.24 (0.9)	5.31 (0.8)	7.42 (1.2)	5.68 (0.9)	1.73 [1.31 - 2.16]	<0.01	6.83 (1.3)	5.47 (0.9)	1.36 [0.95 - 1.77]	<0.01	7.02 (1.1)	5.60 (1.0)	1.42 [1.00 - 1.85]	<0.01
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]	<0.01	3.10 (1.2)	2.30 (0.8)	0.79 [0.40 - 1.19]	<0.01	3.24 (1.0)	2.45 (0.8)	0.79 [0.38 - 1.19]	<0.01
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]	<0.01	11.79 (4.2)	15.14 (3.7)	-3.35 [-5.26 - -1.44]	<0.01	11.05 (3.4)	14.39 (3.5)	-3.34 [-5.29 - -1.38]	<0.01
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]	<0.01	3.73 (0.5)	3.17 (0.6)	0.57 [0.32 - 0.82]	<0.01	3.80 (0.3)	3.15 (0.6)	0.65 [0.39 - 0.91]	<0.01
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]	<0.01	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]	<0.01
R 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
L 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]	<0.01	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 total score (/12)	7.7 (0.7)	7.8 (0.6)	10.2 (1.4)	8.0 (2.3)	2.24 [1.57 - 2.90]	<0.01	10.7 (1.6)	8.8 (1.0)	1.79 [1.13 - 2.45]	<0.01	11.2 (1.2)	8.9 (1.0)	1.76 [1.10 - 2.43]	<0.01
SPPB strength (4)	1.7 (0.5)	1.7 (0.5)	2.8 (1.1)	2.2 (1.0)	0.87 [0.34 - 1.39]	0.001	3.1 (1.3)	2.5 (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)	13.0 (3.3)	15.5 (4.4)	-2.3 [-4.5 - -0.2]	0.035	12.3 (4.4)	14.2 (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)	3.1 (1.6)	2.8 (1.0)	0.84 [0.54 - 1.15]	<0.01	3.0 (1.7)	2.8 (1.2)	0.89 [0.59 - 1.18]	<0.01	3.1 (1.7)	2.7 (1.2)	0.6 [0.3 - 0.9]	<0.01
SPPB gait speed (/4)	2.9 (0.5)	3.0 (0.4)	3.5 (0.6)	3.1 (0.7)	0.56 [0.25 - 0.88]	<0.01	3.7 (0.6)	3.1 (0.5)	0.43 [0.12 - 0.74]	0.007	3.8 (0.4)	3.3 (0.6)	0.6 [0.3 - 0.9]	<0.01
SPPB 4-m walk (s)	5.3 (0.8)	5.4 (0.7)	4.7 (0.8)	5.3 (0.9)	-0.93 [-1.36 - -0.48]	<0.01	4.5 (0.7)	5.4 (0.7)	-0.57 [-1 - -0.14]	0.012	4.2 (0.8)	5.1 (0.8)	-0.9 [-1.3 - -0.5]	<0.01
60-s STS (reps)	21.3 (6.8)	20.1 (4.7)	23.0 (5.5)	20.8 (6.7)	3.4 [-0.2 - 7.1]	0.065	24.7 (6.8)	22.2 (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
R leg balance (s)	30.5 (26.2)	20.2 (18.5)	31.7 (22.3)	15.9 (16.7)	13.6 [2.0 - 25.3]	0.022	34.0 (24.1)	28.7 (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
L leg balance (s)	30.0 (24.3)	21.8 (18.1)	34.3 (23.2)	23.8 (20.0)	11.17 [-0.42 - 22.8]	0.058	35.1 (23.2)	23.2 (22.1)	6.23 [-5.23 - -17.7]	0.029	33.4 (21.3)	18.7 (17.3)	8.41 [-3.18 - 20]	0.153
Time-up-and-go (s)	10.7 (2.7)	11.1 (2.0)	10.0 (2.4)	11.7 (2.1)	-1.94 [-3.11 - -0.76]	0.002	9.6 (2.4)	10.5 (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 R (cm)	-12.8 (11.1)	-10.8 (11.4)	-8.7 (9.4)	-7.7 (10.5)	-1.24 [-7.24 - 4.75]	0.681	-6.2 (9.3)	-5.6 (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 L (cm)	-12.2 (11.1)	-13.3 (12.6)	-8.1 (9.8)	-6.8 (10.8)	-0.74 [-6.63 - 5.16]	0.804	-5.4 (9.2)	-4.7 (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)	1.7 (1.0)	1.6 (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.

difference in response over time between groups. Qualitative data were analysed using a deductive framework analysis (24) using the TFA domains as a means to interrogate participants' perspectives on barriers and motivators to participation, future support, and any opportunities to improve the protocol.

## 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 1 indicates the flow of participants through the study. A subset of 49 participants took part in the lab setting assessments, with 40 completing the study. Baseline characteristics for all randomised participants, and lab subset participants are shown in Table 1. No baseline characteristics or functional test scores were different between completing versus withdrawing participants ( $p>0.05$ ) (Supplementary file A1).

### Outcome data

Table 2 presents functional outcomes, with estimated mean differences between groups at all follow-up measures. See Supplementary file A2 for the mean scores of all outcomes at each timepoint (including between-group comparison).

SPPB strength and balance summed scores increased significantly more in the intervention group than in the control group at every timepoint after baseline. Estimated mean difference between groups at week 4 were 1.73[95% CI 1.31-2.16] ( $p<0.0001$ ), at week 8 were 1.36[95% CI 0.95-1.77] ( $p<0.0001$ ), and at week 12 were 1.42[95% CI 1.00-1.85] ( $p<0.0001$ ). Figure 2a shows the changes in SPPB strength and balance summed scores across all timepoints. The 60s STS and stand on left leg increased significantly more in the intervention group than in the control group at every timepoint after baseline assessment, while stand on right leg 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. A post-hoc sensitivity analysis was run to determine if the significant difference in living status between the intervention and control arms had any bearing on the functional outcomes, however no differences in the direction or statistical significance were found when including this variable as a fixed-effect covariate (see Supplementary file A6, Table S12 and S13).

### Subset lab-based physical functional outcomes

Participants in the intervention group significantly increased total SPPB total score at every timepoint compared to baseline versus the control group (Figure 2b). Additionally, the scores of each individual SPPB domain (i.e., strength, balance, and gait speed) were significant improved in the intervention group at these timepoints compared baseline versus the control group (Table 2). 5 reps STS, TUG, and single leg balance on the right leg improved significantly more in the intervention group than in the control group at week-4 and week-8, while ability

to balance on the left leg was significantly increased in the intervention group at week 8 only. No significant differences in improvement were observed between groups for the peak force of Keiser leg press, or in flexibility outcomes. Supplementary file A3 displays the mean scores of lab-based measures at each timepoint.

### Adherence and acceptability

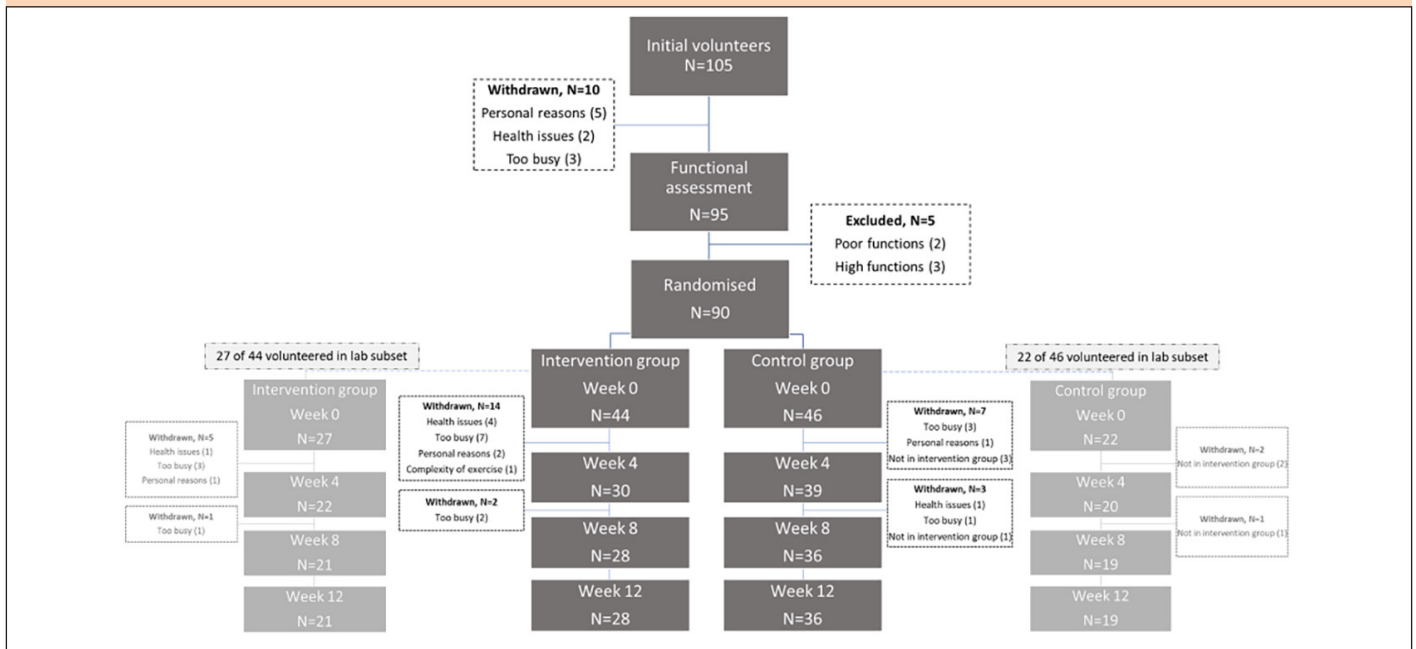
Completed logbooks were available from 24 intervention participants (54% of starters, 86% of completers). These indicated a mean (SD) number of sessions attempted of 77 (10) for the exercise snacking sessions and 75 (10) for the Tai-chi snacking sessions out of a possible 84. Overall adherence was 90% (152 out of 168) for those completing the intervention, with 7 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 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 $\pm$ SD acceptability scores of the exercise and Tai-chi snacking intervention across weeks 4, 8, and 12 were 3.98 $\pm$ 0.32, 4.21 $\pm$ 0.34, and 4.08 $\pm$ 0.31 out of 5 respectively. Supplementary file A4 contains the individual TFA scores at across the intervention.

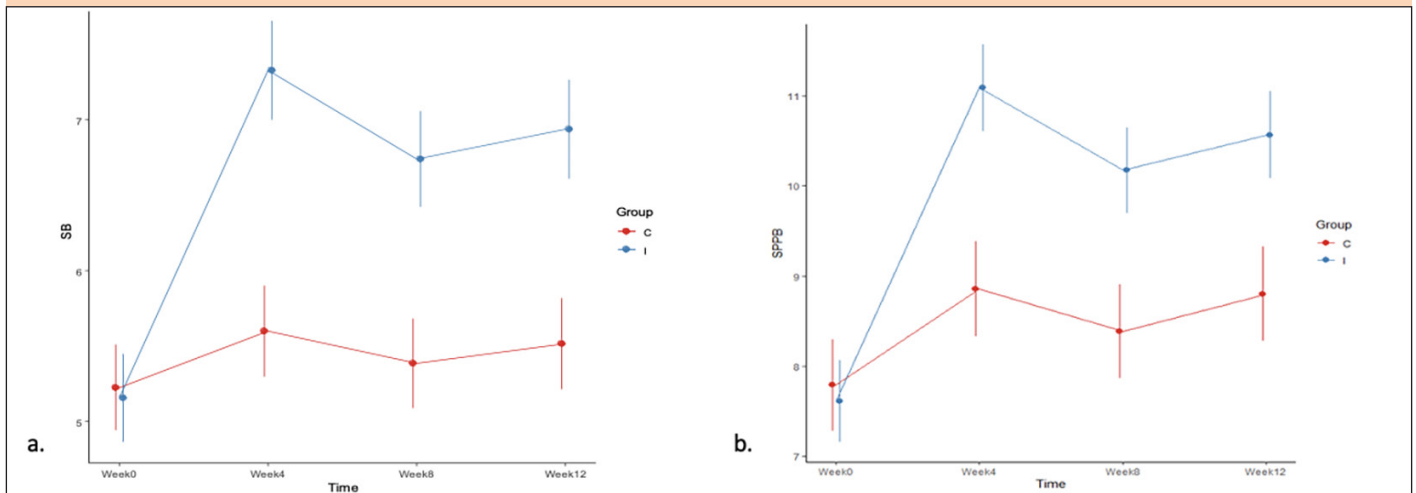
Qualitative data suggests most participants found the programme accessible and convenient to do in their homes and showed a liking for the 'snacking' concept. Specifically, when it comes to participants' feelings towards the intervention (i.e., affective attitude), participants reported a sense of accomplishment and satisfaction after sessions, feeling pleased about being active, 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 more challenging but preferred them due to their relaxing nature. Nevertheless, few participants found the programme too easy and short, expressing a desire for more variety, levels, and intensity options. In general, the exercise and Tai-chi snacking was found to be achievable, enjoyable, and motivational.

Regarding the perceived effort (i.e., burden), participants with poor balance found Tai-chi snacking more physically challenging. Few participants with neuromuscular injury histories found specific movements demanding. For instance, a participant with autoimmune muscular problem reported

**Figure 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



**Figure 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



Statistically significant differences between groups were found at all timepoints as determined by linear mixed model at  $p < 0.05$ .

the upper body movements to be difficult due to , and another participant with a past spinal injury struggled with truck rotation movements Generally most participants found the programme required manageable time and effort. However, Tai-chi snacking was reported as more time-consuming when learning a new exercise format with complex movements which demanded more cognitive effort.

Regarding opportunity costs, participants reported that they did not have to sacrifice doing any activities as the short snacking programme only took 20 minutes per day which is convenient, accessible and easy to imbed in their daily routine. Nonetheless, the primary reasons of skipping the 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 enhance the

adherence and reduce the likelihood of missing exercises.

In terms of perceived benefits, most participants believed the programme improved their physical fitness and mental wellbeing, contributing to a better lifestyle and increased confidence in daily activities. 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 improvements in strength and balance, particularly appreciating the effectiveness of upper body movements for shoulder flexibility. Others mentioned the exercises’ benefits such as strengthened rarely-used muscles, enhanced joint flexibility, and alleviation of knee and hip stiffness.

In terms of the intervention coherence, participants generally found all movements easy to learn and understand, with only one reporting difficulty with level-3 Tai-chi snacking movements. Video instructions were deemed useful and indispensable, especially for learning Tai-chi snacking. Some appreciated having two models in the videos from their age group providing modified exercise movements for better comprehension and motivation. Participants recommended that an initial in-person demonstration or personal training session, along with feedback on their movements, may increase self-efficacy further.

Concerning the programme's ethicality, 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 the programme could benefit sedentary older adults, people lacking confidence on exercising, people with joint or bone injuries, 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 unfamiliar with video calling products enjoyed learning new techniques and appreciated the 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 personally engaged.

Finally, participants reported increased satisfaction, motivation, and noticeable improvements in physical function after doing the programme. These factors increased their self-efficacy for exercising, encouraged more physical activities, and boosted confidence in trying different exercises. Most participants showed willingness to continue and even extend the programme's duration or increase session frequency. Accordingly, while the 12-week progressive exercise and Tai-chi snacking programme was considered effective, it also built-up participants' self-esteem and improved their abilities of managing daily activities and increased their engagement in physical activities. See supplementary file A5 for participant quotes in seven TFA domains.

## Discussion

The 12-week progressive home-based exercise and Tai-chi snacking programme had significant positive effects on physical function, with improvements in the SPPB S&B domains, 5 reps STS, 60s STS, and ability to maintain standing balance on one leg. These improvements were observed in week 4 and sustained until the 12-week intervention period was over.

Significant differences in the SPPB scores between intervention and control groups were observed at all follow-up timepoints in participants who underwent laboratory testing and completed the full battery. For context, previous research has indicated that even small changes in SPPB scores of 0.4-1.5 are clinically meaningful in pre-frail older adults who initially scored less than 9 on the SPPB (25, 26). We also found

significant improvements on 5 reps STS, mobility (TUG), and standing on one leg balance tests and in week 4 and week 8 amongst these participants. Most participants reached the highest level of exercise 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 (16-18). 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; a few participants reported that they habitually put their weight on the same side during exercises. Future instructions should highlight weight balancing and shifting.

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 (27-29). The results align with recent reviews highlighting balance and muscle functions benefits among healthy older adults (30) and improved leg muscle strength and mobility for individuals over 60 (31) through home-based exercises. Comparatively, our study suggests that 10-minutes of daily exercise and tai-chi snacking can be as or more effective in the short term as more complex behavioural interventions (32, 33). 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 participant's 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 (34-36), whereas Tai-chi training could enhance their balance, mobility, and full body relaxation (17, 37-39). 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. Similarly, participants in previous studies reported Tai-chi to be beautiful and refreshing, in contrast to repetitive exercises (37, 38). However, we could not isolate the effectiveness of either approach in this study, as participants did both. Exploring different variations of this programme may determine which

exercise approach is more effective for specific functional outcomes or promoting better engagement, creating opportunity for further tailoring of the intervention to meet individual needs.

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 of continued, 10-minutes daily practice. Additionally, the SPPB strength item (5 reps STS) showed consistently improvement in the intervention group, albeit with a slight decrease over time. Single leg standing balance initially improved but later stabilised. In the lab subset participants, SPPB scores were consistently higher in the intervention group across all time points after baseline, 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 (40-42), 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 being outcomes, which would be worth further scrutinising in larger and longer studies.

Programme adherence was high for those who completed the intervention. Studies have identified self-efficacy and outcome expectancy as key factors for exercise participation (43, 44) although we observed no significant self-reported change in these constructs via questionnaire. 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 align with research showing that enjoyment, satisfaction, and perceived effectiveness have strong correlations to exercise participation (45, 46). 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 the programme's intensity and variability to maintain the adherence (17, 47).

Regarding intervention dropout, most participants withdrew during the first month, reporting busyness and lack of time as primary reasons, consistent with recent studies (48, 49). As the exercise snacking concept and protocol is explicitly designed to overcome participatory barriers of this very nature, one might assume that the provision of more motivational and habit-forming support could be warranted to maximise initial engagement in the intervention. Future research could, for example, explore the use of cognitive strategies such as 'Reframing' exercise (50), or behaviour change techniques

like motivational interviewing, setting graded tasks, instructing on when and where to perform the behaviour and explicit prompting of self-monitoring of outcome (i.e., physical function) that seem pertinent for increasing exercise self-efficacy in older adults (51).

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 (31, 52).

Nevertheless, this study has several limitations. Firstly, many participants were female and highly educated, limiting the generalisability of our findings to populations in lower socioeconomic conditions. It is imperative to find strategies that encourage active participation and retention in male older adults who would benefit from muscle strengthening exercise. Digital literacy is also an issue for many older adults, which the recruitment and digital study procedures did not account for. Secondly, the intervention group had fewer individuals living alone and more married participants which may be the potential impact of this discrepancy on the study outcomes. While our primary focus did not specifically aim to explore differences between those living alone and those married, we acknowledge the potential impact of this discrepancy on the study outcomes. It is worth noting that couples assigned to the intervention group may have unique motivations, and the crucial role of social support for older adult physical activity participation, particularly from family members, is well documented (53). That said, our sensitivity analysis revealed little impact of living status on the physical function results.

Our qualitative interviews revealed that not all couples executed the programmes together, indicating variability in adherence, but larger trials of exercise snacking are warranted to verify the influence of living status. The validity of remote assessments of physical function remains unknown, although conducting functional assessments remotely has been deemed feasible and safe (16). 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. However, a study demonstrated that chair stand and balance test could be substitutes if mobility/gait speed performance assessments are challenging (54). 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 is an important factor to consider when interpreting our results. A baseline characteristic comparison between withdrawers and completers showed no significant differences (Supplementary File A1), suggesting that potential biases related to baseline characteristics were minimised. Given that we did not achieve the desired sample size, conducting further research in larger studies implementing strategies to reduce attrition is essential to verify the findings and ensure the

presently reported effects and acceptability are not an artefact of a survivor bias.

A further consideration on the function outcome is the order of the in-person lab-based and remote assessment sessions. 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 small improvements beyond their usual care. In addition, our exercise programme includes both upper and lower body movements owing to PPI feedback and previous qualitative work (17), 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 to explore any maintenance effect of physical function, exercise cognitions and health.

## 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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*Ethical standards:* Ethical approval for the study was provided by the University of Bath Ethics Approval Committee for Health (REACH reference number: EP 20/21 082).

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