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Feasibility, safety, and effects of a step training program in community-dwelling older adults with mild-to-moderate dementia: a feasibility wait-list controlled trial

Authors

Wayne Lap Sun **CHAN** [1]

Jae Qi Jing **LIU** [1]

Freddy Man Hin **LAM** [1]

Daphne Sze Ki **CHEUNG** [2,3,4]

Affiliations

[1] Department of Rehabilitation Sciences, The Hong Kong Polytechnic University, Hong Kong

[2] School of Nursing and Midwifery, Deakin University, Australia

[3] Alfred Health, Australia

[4] School of Nursing, The Hong Kong Polytechnic University, Hong Kong

Corresponding author

Dr. Wayne L. S. CHAN,

Department of Rehabilitation Sciences,

ST 505, 5/F, Ng Wing Hong Building,

The Hong Kong Polytechnic University

Email: wayne.ls.chan@polyu.edu.hk

Office number: +852 2766 6742

Abstract

Background

Stepping performance is a strong determinant of falls in older adults. Step training has been shown to be effective in improving fall-related outcomes in healthy older adults. However, step training has not been investigated in older adults with dementia.

Objective

This study evaluates the feasibility, safety, and effects of a step training program in community-dwelling older adults with mild-to-moderate dementia.

Methods

Participants were assigned to either a step training group or a wait-list control group. The step training group performed two 40-minute exercise sessions per week, each consisting of a 5-minute warm-up, 30 minutes of stepping exercises, and a 5-minute cool-down, for 12 weeks. The control group received usual care during this time. The training involved repeatedly stepping onto specific targets on a plastic mat. The exercise intensity was progressed by increasing stepping distance and task complexity once participants could accurately complete the required steps. Feasibility, assessed as the percentage of participants completing the 12-week follow-up, safety, defined as the incidence of adverse events, and clinical outcomes were assessed.

Results

Forty-seven participants (84%) completed the 12-week assessment. No adverse events were recorded. Significant improvements in choice stepping reaction time (p = .038), maximum step length [left leg backward stepping (p = .046) and side stepping (p = .020)], and alternate stepping time (p = .002) were found in the step training group compared to the control group.

Conclusions

The step training program was feasible, safe, and potentially effective in improving the stepping performance of older adults with mild-to-moderate dementia.

Keywords

Alzheimer's disease, Exercise, Balance, Falls, Cognitive training

Introduction

Falls are very common among older adults with dementia. Research indicates that up to 90% of older adults with dementia experience at least one fall each year [1]. The incidence of falls in this population is 2 to 3 times higher than that of healthy older adults [1,2]. Furthermore, falls in older adults with dementia are more likely to result in serious complications, such as hip fractures, repeated hospitalization, and early death [3]. Exercise is considered a key component of fall prevention strategies for older adults living in the community [4]. However, the effectiveness of exercise in reducing the occurrence of falls among community-dwelling older adults with dementia is still uncertain [5,6].

Stepping performance is one of the determinants of fall risk in older adults. Trips and slips are common triggers of falls during walking [7]. Older adults tend to take a step to widen the base of support to maintain an upright position when they lose balance [8]. This stepping response can be initiated (i) voluntarily when the balance disturbance is anticipated (known as volitional stepping) or (ii) reactively when an unexpected perturbation elicits a loss of balance (known as reactive stepping) [9]. In addition to recovering from balance disturbances, older adults are also required to adjust their step height, width, and position in response to changes in the environment, such as uneven ground, dark environment, and slippery surfaces, to ensure safety during walking [10,11]. Previous studies have found that poor performance in both volitional and reactive stepping is associated with a higher risk of falls among older adults [12]. Therefore, volitional and reactive stepping performance has to be addressed to reduce fall risk in older populations.

Volitional stepping requires anticipatory postural adjustments that help maintain the center of mass within the base of support during the single-leg stance phase [8]. The performance of volitional stepping in older adults is influenced by both their sensorimotor function, such as muscle strength and dynamic balance, as well as cognitive function, including attentional control and executive function [13]. Older adults must process somatosensory information and execute appropriate stepping responses at the same time during volitional stepping [14]. As a result, older adults need to rely heavily on their cognitive resources, particularly executive functions, to manage volitional stepping.

The cognitive demand for volitional stepping is even higher when the environment is more challenging [15] or when cognitive function in older adults is impaired [16]. Previous studies have indicated that older adults with cognitive impairment and a high risk of falls demonstrate poor performance in volitional stepping [17]. While older adults with dementia are more likely to experience reduced performance in volitional stepping, leading to an increased risk of falls, it remains unclear how to effectively improve volitional stepping performance in this population to prevent fall-related complications.

Step training has become an increasingly popular approach for improving balance and preventing falls in older adults. Recent studies have shown that volitional step training, often seen as taking steps repeatedly onto specific targets and avoiding distracting targets, reduces falls in healthy older adults [12,18]. Volitional step training has also improved fall-related outcomes (e.g., reaction time) and cognitive function (e.g., dual-task ability) in healthy older adults [19–21]. Despite the positive effects of volitional step training in healthy older adults, the feasibility and safety of such step training have not been investigated in older adults with dementia. It remains unknown whether older adults with dementia are physically and cognitively capable of performing stepping exercises. The ability of step training to improve the stepping performance and fall-related outcomes of older adults with dementia has yet to be investigated.

This feasibility trial aimed to evaluate the feasibility and safety of a step training program specifically designed for community-dwelling older adults with mild-to-moderate dementia. We also examined the potential effects of the program on stepping performance and various fall-related clinical outcomes, including general mobility, walking speed, lower limb muscle strength, balance, global cognition, and daily functioning in this population.

Methods

Study Design

This study was a pilot quasi-experimental, wait-list controlled trial conducted in accordance with the Declaration of Helsinki. Prior to data collection, approval was obtained from the Institutional Review Board of the Hong Kong Polytechnic University and the participating organisations. Written informed consent was sought from study participants and their main caregivers before the baseline assessment. The protocol of this pilot trial was registered on ClinicalTrials.gov (NCT04296123). In this paper, we adhered to the Consolidated Standards of Reporting Trials and guidelines for reporting non-randomised pilot trials [22,23].

Participants

The participants were recruited from local community centres and day care centres for older adults from September 2019 to July 2023. Individuals were eligible if they (i) were 65 years of age or older, (ii) had a physician's diagnosis of dementia or a score below the cut-off on the Hong Kong version of the Montreal Cognitive Assessment (a score of 10 – 18 indicates mild dementia, and a score of 5 – 9 indicates moderate dementia) [24], (iii) were able to walk 10 m independently without any walking aid or with a walking stick; and (iv) had a main caregiver to provide informed consent and valid personal information. Potential candidates were excluded if they (i) were unable to participate in the step training program due to unstable or severe musculoskeletal, cardiopulmonary, or neurological conditions; (ii) were unable to communicate due to substantial visual or hearing impairment; or (iii) had a recent hospitalisation in the past 30 days.

After completing the baseline assessment, participants were assigned to either the step training or the wait-list control group. This feasibility study took place during the COVID-19 pandemic, which led to periodic postponements of participant recruitment, assessment, and intervention due to physical distancing measures. To address this unexpected challenge, all the participants were initially enrolled in the step training program. If physical distancing measures were anticipated to be enforced after the program began, participants were then moved to the wait-list control group. Once the physical distancing measures were lifted, the same step training program was provided to those participants.

Intervention

The step training program included 40-minute exercise sessions held twice a week for a duration of 12 weeks. The participants in the step training group performed exercises under the supervision of an exercise instructor. Each session began with a 5-minute flexibility warm-up, followed by 30 minutes of stepping exercises, and concluded with a 5-minute cool-down. During the stepping exercises, the participants stood on designated standing panels at the centre of a non-slip plastic mat. The instructor stood next to the participants and provided a series of verbal instructions and asked the participants to (1) use one foot to step onto a specific stepping panel secured on the plastic mat and (2) return the stepping foot to the standing panel (see Figure 1).

The step training program consisted of three phases: (i) getting familiar, (ii) increasing complexity, and (iii) consolidating skills (see Figure 2).

In Phase 1, the participants used one foot to step on single-colored panels located in a designated area of a plastic mat (e.g., the upper quadrant). If the participants completed ten target steps accurately, the exercise intensity was increased through the following sequence: (a) increasing the stepping distance gradually from 90% to 110% of their step length measured by the Maximum Step Length Test (see "Clinical outcomes"), (b) increasing the stepping area steadily from one-fourth of the mat to the entire mat, and (c) randomly alternating between using the left or right foot. Once these progressions were completed, the number of stepping panel colours gradually increased until reaching four colours.

In Phase 2, the intensity was further increased by introducing four cognitively challenging stepping tasks: (i) counting numbers (stepping on numbers in either forward or backward sequences), (ii) memorising numbers (stepping on a series of numbers provided by the instructor), (iii) colored shapes (stepping on specific shapes of certain colors), and (iv) animals (stepping on pictures of specific animals). After completing all the tasks in Phase 2, the participants progressed to Phase 3, which aimed to consolidate their stepping and cognitive skills. The tasks in Phase 3 included: (i) coordination (bilaterally or alternatively moving their upper limbs while stepping), (ii) calculation (performing simple addition or subtraction and stepping on the correct number), (iii) alternate colors and numbers (stepping on a series of numbers in forward or backward order with alternating colors), and (iv) blind stepping (memorising the locations of different numbers and stepping on concealed numbers). The number of steps taken and the type of stepping tasks achieved by the participants were recorded in each session.

The participants were required to wear non-slip shoes, comfortable clothing, and corrective eyewear (if applicable) for each exercise session. A minimum of three minutes of rest was provided in the middle of each session. The participants were encouraged to report any discomfort experienced during the stepping exercises. The instructor underwent a one-day workshop organized by the principal investigator, a registered physiotherapist with over ten years of experience working with older adults with dementia. This training covered several topics, including (i) effective communication with older adults with dementia, (ii) recording participants' performance, (iii) adjusting exercise intensity for individual participants, and (iv) ensuring safety throughout the step training program.

The participants in the wait-list control group continued to receive usual health and social services provided by the participating community and daycare centres for the first 12 weeks. After completing the 12-week assessment, they received the same step training program.

Outcome measures

A research assistant assessed the participants' characteristics and outcome measures at baseline and after 12 weeks. The assessor was not blinded to the group allocations. The following personal characteristics of the participants were recorded at baseline: age, sex, years of education, body mass index, history of falls in the past six months, use of walking aids, past medical history, and medications.

Feasibility

The feasibility of the step training program was evaluated based on retention and adherence rates. To determine the retention rate, we calculated the percentages of participants who completed the 12-week assessment in both groups. Adherence rate to the step training program was assessed by examining the percentage of exercise sessions completed by participants in the step training group. Additionally, we calculated the mean number of steps taken by the participants in each exercise session and recorded the maximum exercise intensity achieved by the participants at the end of the program.

Achieving 70% or above in both retention and adherence rates was considered satisfactory [25], indicating that a future definitive trial is warranted.

Safety

The safety of the step training program was assessed by monitoring the number of adverse events reported during the 12 weeks of training. The participants and their main caregivers were asked to report any adverse events (e.g., dizziness, excessive pain, or falls) experienced during or after each exercise session. The exercise instructor also documented any adverse events that occurred during the training.

A future definitive trial is indicated if less than 10% of the participants and their main caregivers in the step training reported any adverse events.

Clinical outcomes

Measures of stepping performance, physical and cognitive function, and functional abilities were used to assess the clinical outcomes of the participants. The participants' stepping performance was evaluated using (i) the Four Square Step Test [26], (ii) the Choice Stepping Reaction Time Test [27], (iii) the Maximum Step Length Test [28], and (iv) the Alternate Step Test [29].

Additionally, the 2-Minute Walk Test was used to evaluate general mobility [30], while the 10-meter Walk Test measured walking speed [30]. The 30-second Sit-To-Stand test was used to evaluate lower limb muscle strength [31,32], and the Berg Balance Scale assessed dynamic balance [33,34]. To evaluate the global cognition, delayed memory recall, and daily functioning of the participants, the Montreal Cognitive Assessment [35] and the Chinese version of the Disability Assessment for Dementia [36,37] were used, respectively.

Sample size calculation

We hypothesized that the step training program would have a moderate effect on the stepping performance of the participants. To determine the necessary sample size for the study, a priori power analysis was conducted. The power (1 – β) was set at 95%, the alpha level was set at .05, and the effect size (Cohen's *f*) was estimated to be 0.25. This analysis indicated that a total of 210 participants would be needed for a definitive trial. To conduct a pilot trial, we estimated that 15% of the total required participants for the definitive trial would be sufficient [38]. After adjusting for a projected 25% attrition rate in the definitive trial, we aimed to recruit 42 participants for this feasibility trial.

Statistical analysis

The characteristics of the participants and the feasibility and safety outcomes were presented using descriptive statistics. For categorical outcomes (e.g., sex, number of falls, and number of adverse events), raw counts were provided. Percentages were used to present retention and adherence outcomes. Means and standard deviations were reported for continuous outcomes (e.g., age, body mass index, the HK-MoCA, and the HK-MoCA delayed recall). Comparisons of the participants' characteristics and clinical outcomes at baseline between the two groups (step training and wait-list control) were conducted using independent t-tests. To compare clinical outcomes while controlling for covariates (age, body mass index, and the baseline scores of the Alternate Step Test and Berg Balance Scale), a repeated measures two-way analysis of covariance was employed, with time (baseline and 12-week) as a within-group factor and group (step training and wait-list control groups) as a between-group factor. An intention-to-treat approach using the Last Observation Carried Forward method (i.e., imputing missing clinical outcome values at 12 weeks with the baseline values) was adopted in the analysis. Effect sizes were calculated using partial eta-squared values (η^2) from the analysis of covariance. The effect sizes were classified as small ($\eta^2 = 0.01$), medium ($\eta^2 = 0.06$), or large ($\eta^2 = 0.14$) [39]. Post hoc analyses with Bonferroni corrections were performed to determine the within-group and between-group differences. The statistical analyses were performed using SPSS version 28.0 (IBM Corp.), with significance set at $p < .05$.

Results

Baseline characteristics

Table 1 displays the baseline characteristics and clinical outcomes of the participants. The mean age of the participants was 80.8 years (6.6), and the mean Montreal Cognitive Assessment score was 10.89 (5.22). Eight (14%) participants have had a fall in the past year. The participants in the step training group performed significantly slower in the Alternate Step Test ($p = .012$) and had lower Berg Balance Scale scores ($p = .007$) compared to those in the wait-list control group.

Feasibility

Twenty-two participants (85%) in the step training group and 25 participants (83%) in the wait-list control group completed the 12-week assessment (Figure 3). Eleven participants withdrew from the study primarily due to the COVID-19 pandemic (e.g., physical distancing measures), personal matters, and health conditions unrelated to the intervention.

The mean number of sessions completed by the participants in the step training group was 17.95 (5.60). The mean adherence rate among the participants was 74% (24%). On average, the participants in the step training group performed 93.65 (28.32) steps per exercise session. At the end of week 12, 20 participants (91%) in the step training group reached Phase 3 of the step training program, while the remaining 2 participants entered Phase 2 at the end of the program.

Safety

The exercise instructor, the participants, and the main caregivers did not report any adverse events throughout the 12 weeks.

Clinical outcomes

Table 2 presents the clinical outcomes of the step training and wait-list control groups at the baseline and 12 weeks. There were significant ‘time x group’ interactions in the Choice Stepping Reaction Time Test (p = .038), the Maximum Step Length Test for left leg backward stepping (p = .046) and side stepping (p = .020), and the Alternate Step Test (p = .002), indicating that the step training group had significant improvements in the choice stepping reaction time, maximum step length on the backward and side stepping of left leg, and alternate stepping speed. No significant interactions were observed in other clinical outcomes. Post hoc analyses showed that the step training group had significant improvements in the Four Square Step Test (p = .027), Choice Stepping Reaction Time Test (p = .024), Maximum Step Length Test for left leg backward stepping (p = .029) and sideway stepping (p = .021), and right leg sideway stepping (p = .014), and Alternate Step Test (p = .010) over the 12 weeks. The 2-Minute Walk Test (p = .025), the planning and organization subscore (p = .026) and the total score of the Disability Assessment for Dementia (p = .039) were significantly better in the step training group compared to the wait-list control group at 12 weeks. Supplementary material shows the figures of the clinical outcomes in the two groups at the baseline and 12 weeks.

Discussion

The results of this pilot trial demonstrate that the step training program is generally feasible and safe for older adults with mild-to-moderate dementia living in the community. The high retention and adherence of the participants and the minimal adverse events associated with the program meet our predetermined criteria for a definitive trial. Moreover, we observed significant improvements in choice stepping reaction time, maximum step length, and alternate stepping performance in the step training group compared to the wait-list control group. These preliminary findings suggest that our step training program may effectively enhance the stepping performance of older adults with mild-to-moderate dementia.

Over 80% of the participants in the step training group completed the step training program at 12 weeks. This retention rate is similar to other step training programs conducted on older populations, which typically achieve retention rates between 75 and 100% [18–21]. Moreover, the adherence rate of our participants to the step training program was over 70%. Adherence rates to step training programs can vary across different studies; some studies reported that only 20% to 50% of older adults met the minimum adherence rates in various step training programs [18,19]. Our adherence rates are similar to those of other exercise interventions targeting older adults with dementia [25]. Additionally, over 90% of the participants successfully completed the first two phases and progressed to the final phase of the program. These findings indicate that older adults with mild-to-moderate dementia are willing and capable of participating in our carefully designed step training program.

We did not receive any reports of adverse events during this feasibility trial. While we observed that some participants experienced balance disturbances during the stepping exercise, none of these issues resulted in falls or injuries. Our findings align with previous studies, which indicated that less than 10% of older adults reported minor adverse events, such as short-term joint pain in their lower limbs, associated with step training [18–20]. The safety measures implemented in our step training program, such as the one-on-one supervision, training provided to the instructor, and clear instructions given to the participants and their main caregivers, may have contributed to the low incidence of adverse events in this study.

We also found a significant improvement in stepping performance, with a moderate to large effect ($\eta^2 = 0.08 – 0.17$) in the step training group compared to the wait-list control group. Specifically, our program improved both the simple stepping, which relies primarily on sensorimotor function such as muscle power and weight shifting) and choice stepping performances, which requires cognitive input such as divided attention and inhibitory responses, in older adults with dementia. These results are consistent with prior research showing that step training significantly improved stepping performances in older adults [40] and people with neurological conditions [41,42]. However, our preliminary results contrast with a recent study that exhibited a significant reduction in falls but no changes in stepping performance among older adults who completed a comprehensive step training program [18]. The positive effects of our step training program on stepping performance are likely due to the cognitive tasks incorporated in the training and the program's resemblance to the stepping tasks encountered in daily life [12]. Nevertheless, further studies are necessary to identify the mechanisms and potential mediators that contribute to the beneficial effects of step training on falls and related outcomes in older adults with dementia.

We did not observe any significant improvements in other physical and cognitive clinical outcomes. This was anticipated, as this feasibility trial lacked sufficient power to identify meaningful changes in these outcomes. Furthermore, our step training program involved both cognitive and motor components, which may have diluted the effects on specific physical and cognitive outcomes compared to other programs focused solely on physical exercise and cognitive training. Previous studies on community-dwelling older adults have documented the beneficial effects of step training on physical performance such as reaction time, gait, balance, and lower limb muscle strength, as well as cognitive outcomes such as executive function and dual-task ability [19–21,40]. Future studies using larger sample sizes and more rigorous study designs will be necessary to determine whether step training effectively improves the physical and cognitive function of older adults with dementia.

We identified several limitations of this study. This feasibility trial used a non-randomised design. The group allocation of the participants was primarily influenced by the changes in the COVID-19 pandemic. Consequently, measured and unmeasured confounders may be unevenly distributed between groups, resulting in selection bias. Moreover, the outcome assessor and exercise instructor were not blinded to the group allocation. Lack of assessor blinding can lead to detection bias in outcome measurement, which could either inflate or attenuate apparent between-group effects. For future studies, concealed randomization and blinded outcome measurements should be considered to strengthen the internal validity. The sample size was too small to provide sufficient power to evaluate the effects of our step training program on various clinical outcomes. The participants were community-dwelling individuals with mild to moderate dementia who were capable of walking independently. Our findings may not be generalisable to older adults with severe dementia, those residing in other settings (e.g., residential aged care facilities), or those who have significant mobility limitations and require manual assistance to walk. While stepping performance was used as a proxy for fall risk in this study, we recognize that it does not directly capture the incidence of falls. To more accurately assess the effectiveness of the step training program, future trials should include actual fall rates as a primary outcome. Furthermore, we only evaluated the participants' global cognition using a composite cognitive measure (the Montreal Cognitive Assessment). Future research should include assessments that specifically target different cognitive domains (e.g., working memory, set-shifting ability, visuospatial orientation) to better understand the potential effects of the step training program on cognitive function in older adults with dementia.

To conclude, the step training program is both feasible and safe for older adults with mild-to-moderate dementia who live in the community. It may also be effective in improving their stepping performance. These findings suggest that future studies using larger samples and more stringent study designs (e.g., randomised controlled trials with assessor blinding) and incorporating more sensitive outcome measures to detect changes in cognitive function are warranted.

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Authors contributions

Wayne Chan (Conceptualization; Methodology; Formal analysis; Investigation; Writing - Original Draft; Writing - Review & Editing; Supervision; Project administration; Funding acquisition); Jae Liu (Formal analysis; Investigation; Writing - Review & Editing; Project administration); Freddy Lam (Conceptualization; Methodology; Writing - Review & Editing; Supervision; Project administration); Daphne Cheung (Conceptualization; Methodology; Writing - Review & Editing; Supervision; Project administration).

Ethical considerations

Prior to data collection, ethical approval was obtained from the Institutional Review Board of the Hong Kong Polytechnic University and the participating organizations.

Consent for publication

Written informed consent was sought from study participants and their main caregivers before the baseline assessment.

Declaration of conflicting interests

The authors declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

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Data availability statement

The data supporting the findings of this study are available on request from the corresponding author. The data are not publicly available due to privacy or ethical restrictions.

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Table 1. Characteristics at baseline.

Characteristics	**Step training (n=26)**	**Wait-list control (n=30)**	***P* value^**
Age, years, mean (SD)	81.5 (6.2)	80.2 (7.0)	.46
Education, years, mean (SD)	5.6 (4.9)	4.9 (3.5)	.53
Female sex, n (%)	18 (69)	19 (63)	.64
Body mass index, kg/m^2, mean (SD)	22.64 (2.67)	23.43 (3.18)	.32
Number of falls in the past six months, mean (SD)	0.2 (0.5)	0.2 (0.6)	.83
Having a history of falls in the past six months, n (%)	4 (15)	4 (13)	.83
Use of walking stick, n (%)	7 (27)	8 (31)	.59
Hypertension, n (%)	20 (77)	25 (83)	.55
Type 2 diabetes, n (%)	9 (35)	5 (17)	.12
Hyperlipidemia, n (%)	6 (23)	5 (17)	.55
FSST, seconds, mean (SD)	28.88 (11.80)	37.64 (23.89)	.096
CSRTT, seconds, mean (SD)	109.75 (74.37)	88.58 (52.97)	.22
MSLT – left forward, cm, mean (SD)	48.91 (10.04)	51.82 (13.55)	.37
MSLT – left backward, cm, mean (SD)	34.41 (11.74)	38.12 (13.66)	.29
MSLT – left sideways, cm, mean (SD)	39.60 (11.20)	43.71 (15.00)	.26
MSLT – right forward, cm, mean (SD)	48.06 (12.30)	51.41 (13.27)	.33
MSLT – right backward, cm, mean (SD)	34.54 (12.41)	41.43 (14.50)	.063
MSLT – right sideways, cm, mean (SD)	39.03 (12.61)	43.03 (15.27)	.30
AST, seconds, mean (SD)	43.82 (23.69)	30.15 (15.40)	.012
HK-MoCA (0 – 30)[§], score, mean (SD)	10.41 (4.82)	11.30 (5.59)	.53
HK-MoCA delayed recall (0-5)[§], score, mean (SD)	0.56 (1.41)	0.25 (0.45)	.32
2MWT, m, mean (SD)	85.42 (26.75)	77.86 (25.56)	.28
10mWT, m/s, mean (SD)	0.93 (0.32)	0.77 (0.32)	.074
30STS, repetitions, mean (SD)	7.73 (3.39)	8.80 (2.86)	.21
BBS (0 – 56)[§], score, mean (SD)	48.81 (3.86)	45.03 (5.82)	.007

CDAD – initiation (0 – 100)§, score, mean (SD)	62.55 (9.92)	60.41 (14.00)	.52
CDAD – planning and organization (0 – 100)§, score, mean (SD)	56.93 (13.40)	53.12 (19.05)	.40
CDAD – effective performance (0 – 100)§, score, mean (SD)	56.99 (11.59)	55.93 (19.13)	.81
CDAD – total (0 – 100)§, score, mean (SD)	58.75 (11.38)	56.51 (16.62)	.57

FSST, Four Square Step Test; CSRTT, Choice Stepping Reaction Time Test; MSLT, Maximum Step Length Test; AST, Alternate Step Test; HK-MoCA, Hong Kong version of the Montreal Cognitive Assessment; CDAD, Chinese version of the Disability Assessment for Dementia; 2MWT, 2-Minute Walk Test; 10mWT, 10-meter Walk Test; 30STS, 30-second Sit-To-Stand test; BBS, Berg Balance Scale.
§ Parentheses contain score ranges, where a higher score indicates a better performance in the test.
^ Chi-squared and independent t-tests were used to compare characteristics between the step training and wait-list control groups.

Table 2. Comparison of clinical outcomes within and between groups.

Outcome measures	Groups	Baseline	After 12 weeks	Interaction *p*-value^	Partial eta squared (η^2)	Post hoc analyses (within-group)#		Post hoc analyses (between-group)#	
		Adjusted mean (SD)				***Groups***	***p*-value**	***Time***	***p*-value**
FSST, seconds	Step training (n=26)	25.35 (18.13)	31.67 (24.49)	.33	0.02	Step training	.027	Baseline	.006
	Wait-list control (n=30)	40.70 (17.86)	42.94 (24.13)			Wait-list control	.38	After 12 weeks	.12
CSRTT, seconds	Step training (n=26)	105.38 (69.55)	85.14 (65.09)	.038	0.08	Step training	.024	Baseline	.53
	Wait-list control (n=30)	92.37 (68.53)	99.62 (64.14)			Wait-list control	.37	After 12 weeks	.45
MSLT – left forward, cm	Step training (n=26)	49.63 (12.19)	50.09 (13.35)	.76	0.00	Step training	.82	Baseline	.66
	Wait-list control (n=30)	51.19 (12.01)	50.77 (13.16)			Wait-list control	.82	After 12 weeks	.86
MSLT – left backward, cm	Step training (n=26)	36.27 (13.43)	41.63 (15.05)	.046	0.08	Step training	.029	Baseline	.95
	Wait-list control (n=30)	36.51 (13.23)	34.63 (14.83)			Wait-list control	.39	After 12 weeks	.12
MSLT – left sideways, cm	Step training (n=26)	40.81 (13.24)	45.36 (14.04)	.020	0.10	Step training	.021	Baseline	.64
	Wait-list control (n=30)	42.66 (13.05)	40.33 (13.84)			Wait-list control	.19	After 12 weeks	.23
MSLT – right forward, cm	Step training (n=26)	49.65 (13.59)	49.46 (12.28)	.94	0.00	Step training	.92	Baseline	.92
	Wait-list control (n=30)	50.04 (13.39)	49.64 (12.10)			Wait-list control	.82	After 12 weeks	.96
MSLT – right backward, cm	Step training (n=26)	37.96 (13.31)	42.88 (14.98)	.15	0.04	Step training	.085	Baseline	.90
	Wait-list control (n=30)	38.47 (13.11)	37.22 (14.76)			Wait-list control	.63	After 12 weeks	.20
MSLT – right sideways, cm	Step training (n=26)	40.85 (13.70)	44.95 (14.11)	.096	0.05	Step training	.014	Baseline	.88

	Wait-list control (n=30)	41.45 (13.50)	41.46 (13.91)			Wait-list control	.99	After 12 weeks	.40
AST, seconds	Step training (n=26)	47.27 (19.46)	40.93 (19.03)	.002	0.17	Step training	.010	Baseline	<.001
	Wait-list control (n=30)	27.16 (19.33)	31.78 (18.91)			Wait-list control	.041	After 12 weeks	.091
HK-MoCA (0-30)§, score	Step training (n=26)	11.04 (5.88)	11.41 (6.75)	.30	0.02	Step training	.62	Baseline	.87
	Wait-list control (n=30)	10.76 (5.79)	9.98 (6.65)			Wait-list control	.26	After 12 weeks	.47
HK-MoCA delayed recall (0-5)§, score	Step training (n=26)	0.71 (0.29)	0.87 (0.37)	.80	0.00	Step training	.61	Baseline	.17
	Wait-list control (n=30)	0.05 (0.34)	0.34 (0.43)			Wait-list control	.43	After 12 weeks	.38
2MWT, m	Step training (n=26)	88.10 (24.74)	88.03 (24.63)	.40	0.01	Step training	.98	Baseline	.088
	Wait-list control (n=30)	75.54 (24.37)	71.46 (24.28)			Wait-list control	.16	After 12 weeks	.025
10mWT, m/s	Step training (n=26)	0.91 (0.34)	0.83 (0.34)	.97	0.00	Step training	.24	Baseline	.24
	Wait-list control (n=30)	0.79 (0.33)	0.71 (0.33)			Wait-list control	.18	After 12 weeks	.23
30STS, repetitions	Step training (n=26)	8.40 (2.73)	7.85 (2.91)	.93	0.00	Step training	.20	Baseline	.82
	Wait-list control (n=30)	8.22 (2.69)	7.73 (2.86)			Wait-list control	.21	After 12 weeks	.88
BBS (0-56)§, score	Step training (n=26)	49.67 (4.88)	48.86 (5.34)	.66	0.00	Step training	.32	Baseline	<.001
	Wait-list control (n=30)	44.29 (4.85)	43.98 (5.32)			Wait-list control	.69	After 12 weeks	.002
CDAD – initiation (0-100)§, score	Step training (n=26)	64.46 (13.49)	67.65 (18.08)	.28	0.02	Step training	.30	Baseline	.15
	Wait-list control (n=30)	58.76 (13.29)	57.05 (17.81)			Wait-list control	.54	After 12 weeks	.050
CDAD – planning and	Step training (n=26)	60.65 (18.44)	64.38 (21.35)	.43	0.01	Step training	.22	Baseline	.051

organization (0-100)§, score	Wait-list control (n=30)	49.90 (18.17)	50.07 (21.04)			Wait-list control	.95	After 12 weeks	.026
CDAD – effective performance (0-100)§, score	Step training (n=26)	59.86 (17.99)	60.06 (21.25)	.53	0.01	Step training	.95	Baseline	.23
	Wait-list control (n=30)	53.45 (17.73)	50.63 (20.95)			Wait-list control	.34	After 12 weeks	.14
CDAD – total (0-100)§, score	Step training (n=26)	61.67 (16.01)	64.45 (18.66)	.33	0.02	Step training	.30	Baseline	.11
	Wait-list control (n=30)	53.99 (15.77)	52.91 (18.38)			Wait-list control	.66	After 12 weeks	.039

FSST, Four Square Step Test; CSRTT, Choice Stepping Reaction Time Test; MSLT, Maximum Step Length Test; AST, Alternate Step Test; HK-MoCA, Hong Kong version of the Montreal Cognitive Assessment; CDAD, Chinese version of the Disability Assessment for Dementia; 2MWT, 2-Minute Walk Test; 10mWT, 10-meter Walk Test; 30STS, 30-second Sit-To-Stand test; BBS, Berg Balance Scale.

§ Parentheses contain score ranges, where a higher score indicates a better performance in the test.

^ Repeated measure two-way ANCOVA was used to compare the outcomes between the step training and wait-list control groups after controlling for age, body mass index, and the performances in the AST and BBS at baseline.

Post hoc analyses with Bonferroni corrections were performed to compare the outcomes between baseline and 12 weeks in the step training and wait-list control groups (within-group) and between step training and wait-list control groups at baseline and 12 weeks (between-group).

Figure 1. A scene of a participant receiving the step training under the supervision of an exercise instructor.

Figure 2. The step training program.

Increase in intensity and complexity

Phase 1: Getting familiar

Panel colors	Stepping foot	Stepping area	Stepping distance
1 color	Left or right foot only	Upper/ lower quadrant	90% of maximum step length
2 colors	Random left or right foot	Left/right half	100% of maximum step length
3 colors		Upper/ lower half	110% of maximum step length
4 colors		Whole mat	

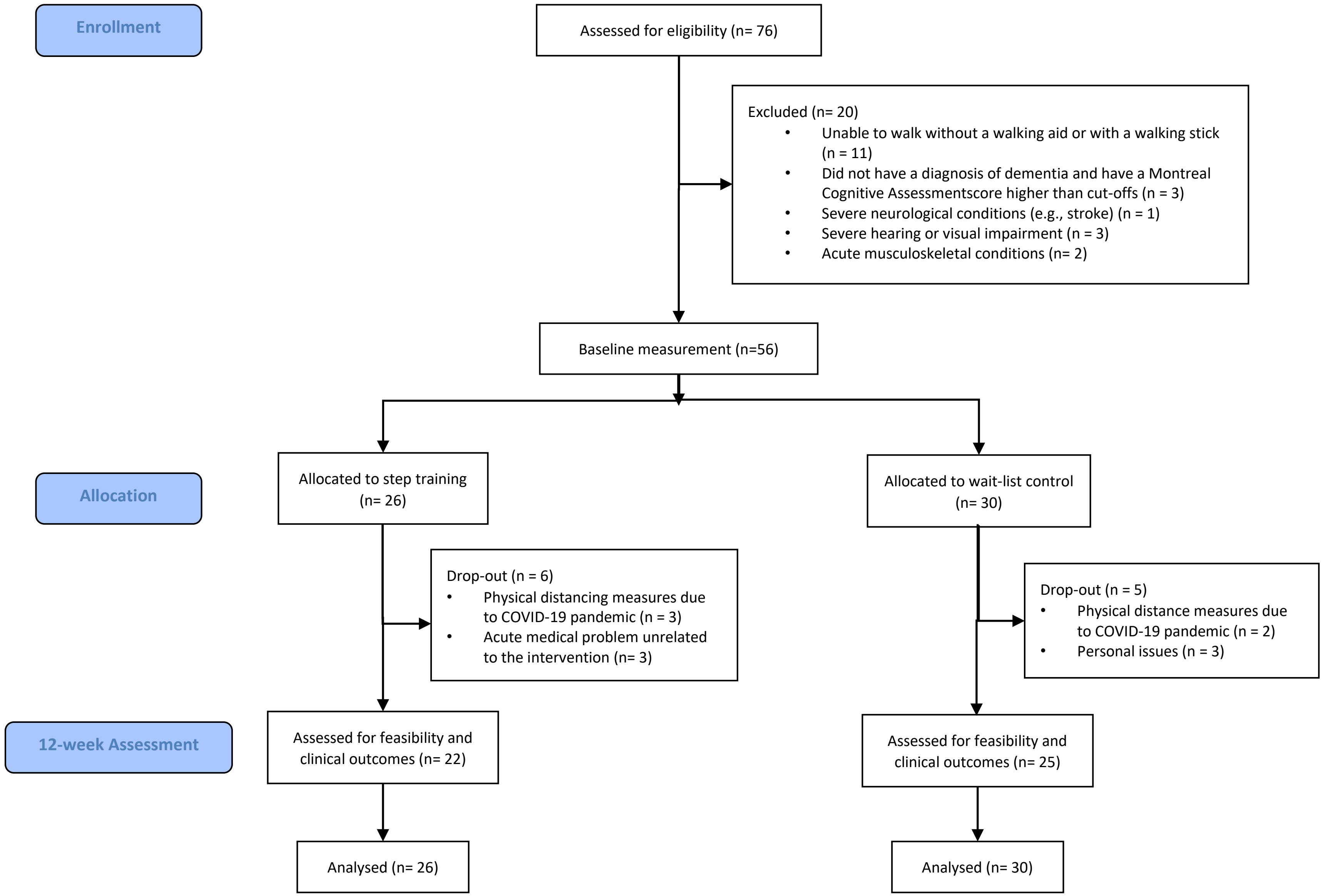
Phase 2: Increasing complexity

Counting numbers	Memorizing numbers	Colored shapes	Animals
1 – 10 forward	2 numbers	1 shape x 1 color	1 type
1 – 20 forward	3 numbers	2 shapes x 1 color	2 types
1 – 10 backward	4 numbers	1 shape x 2 colors	3 types
1 – 20 backward	5 numbers	2 shapes x 2 colors	4 types

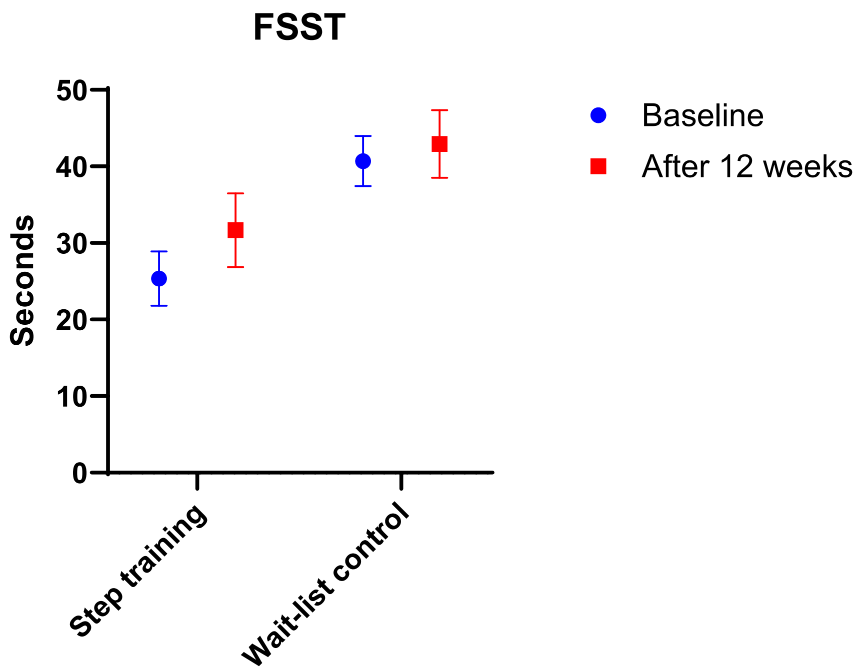
Phase 3: Consolidating skills

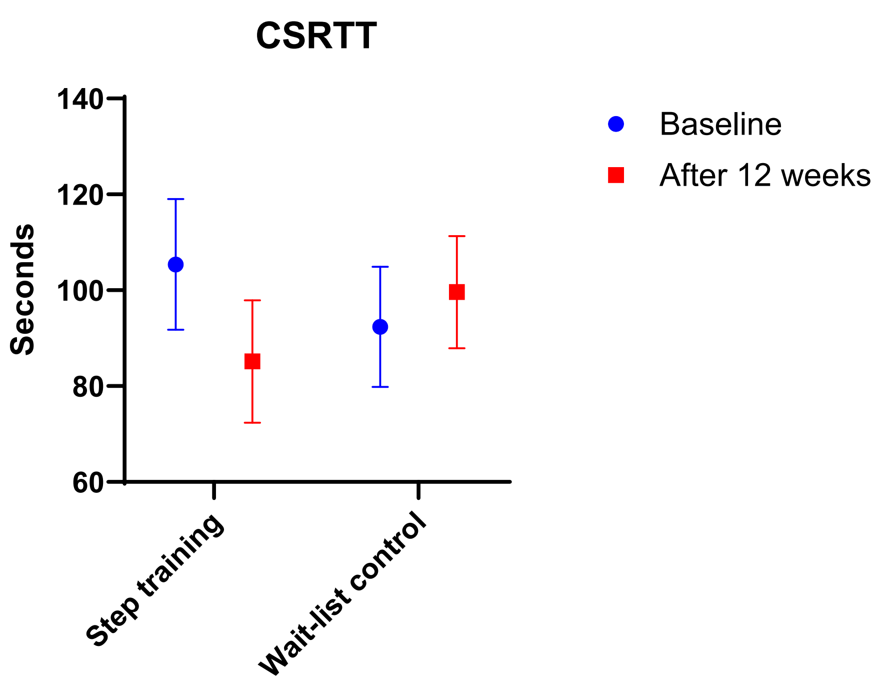
Coordination	Calculation	Alternate colors and numbers	Blind stepping
Bilateral upper limb movements	Addition (single digit)	1 – 10 forward x 2 alternate colors	4 numbers
Alternative upper limb movements	Addition (double digits)	1 – 20 forward x 2 alternate colors	6 numbers
	Subtraction (single digit)	1 – 10 backward x 2 alternate colors	8 numbers
	Subtraction (double digits)	1 – 20 backward x 2 alternate colors	

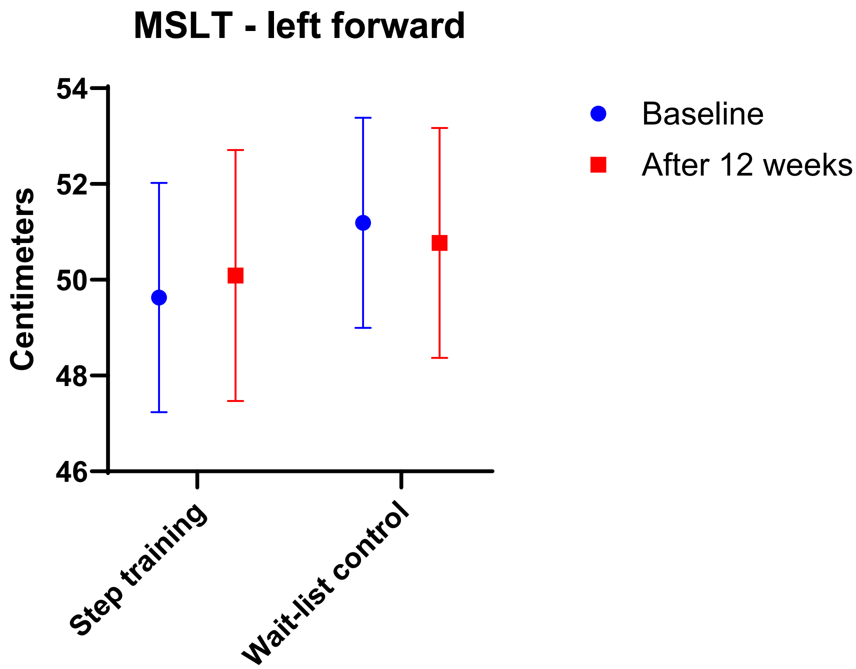
Figure 3. Flow diagram of the feasibility study.

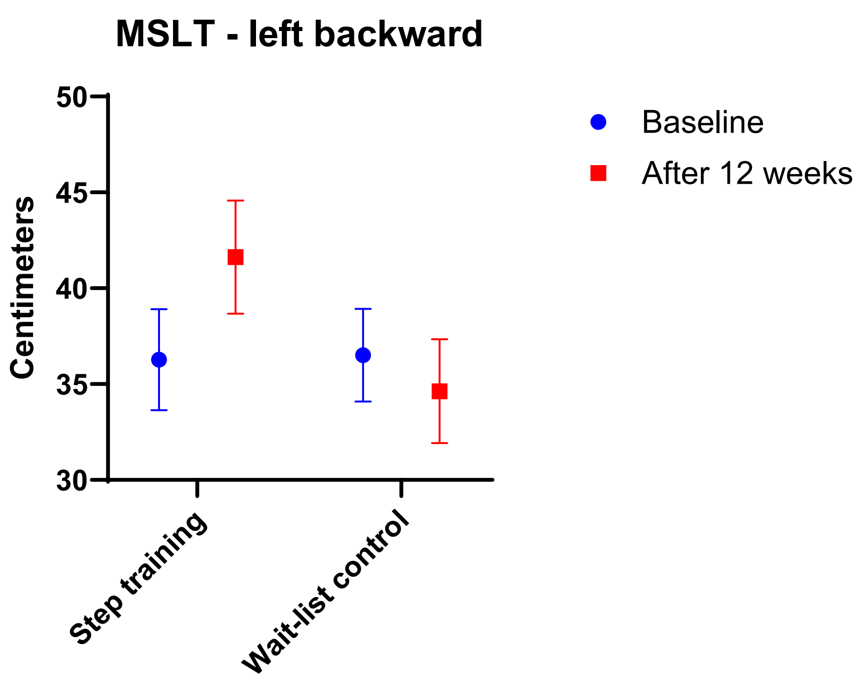


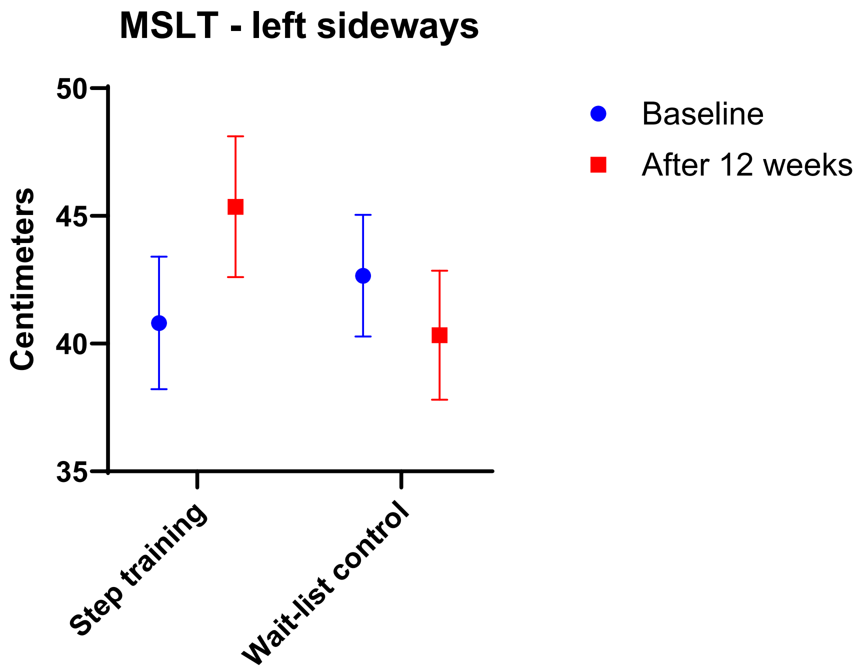
Supplementary figures. Clinical outcomes of step training and wait-list control groups at baseline and 12 weeks.

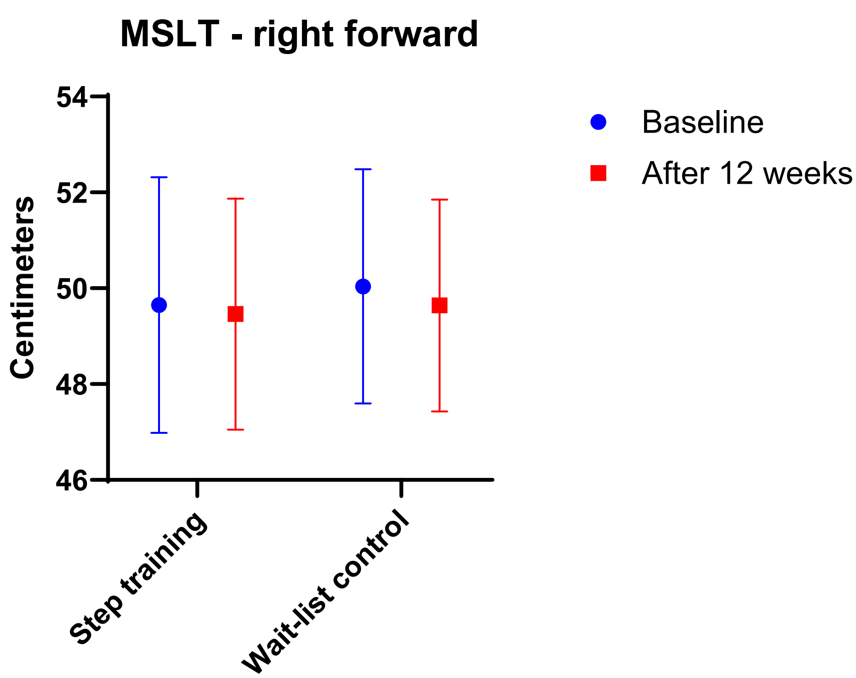


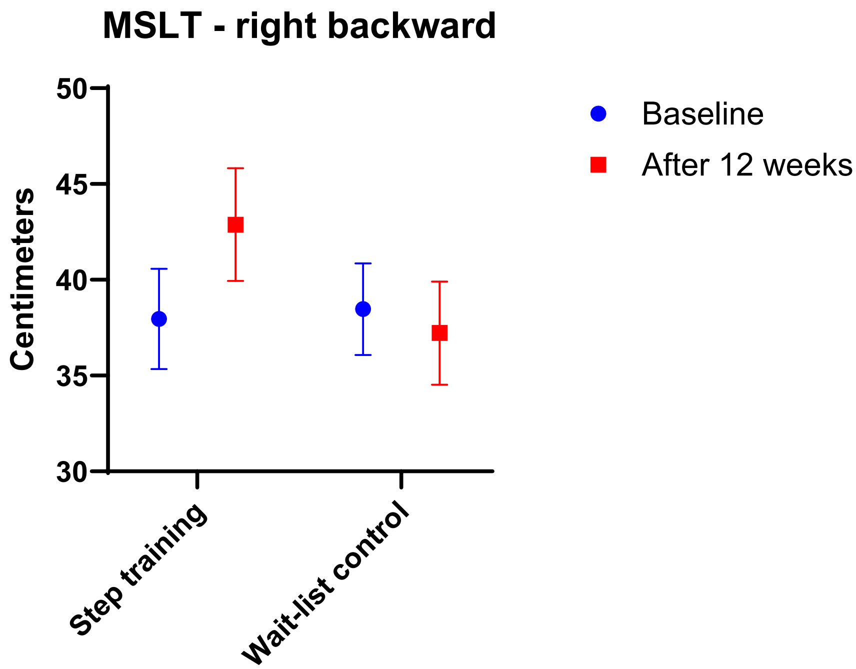


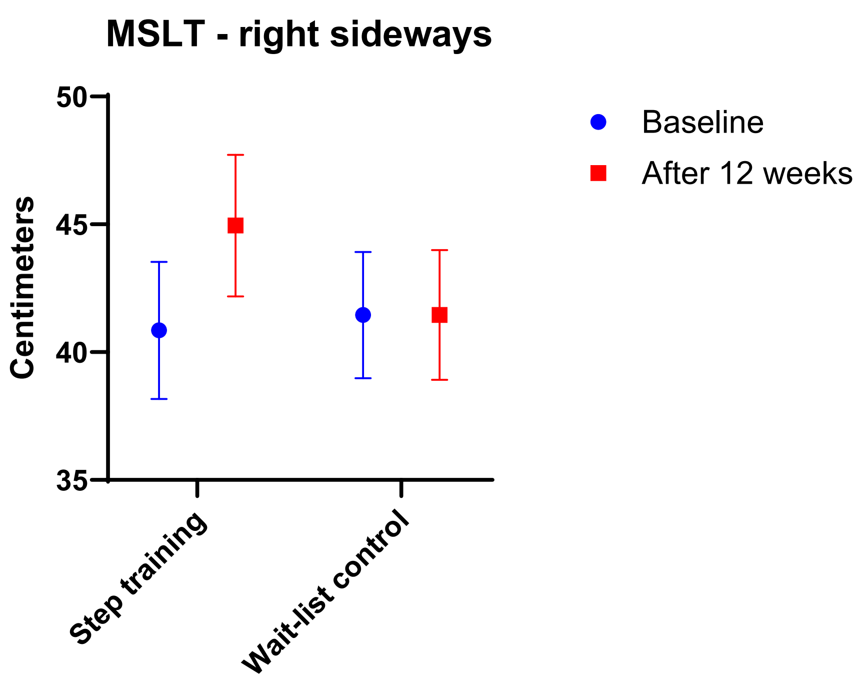

MSLT - left forward
54
52
50
48
46
Centimeters
Step training
Wait-list control
Baseline
After 12 weeks

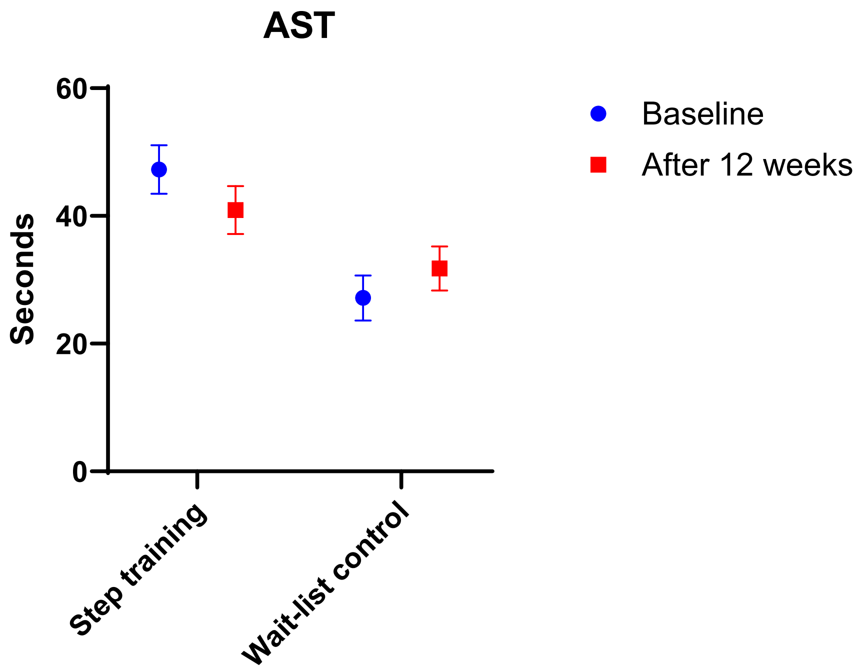

MSLT - left backward
50
45
40
35
30
Centimeters
Step training
Wait-list control
Baseline
After 12 weeks

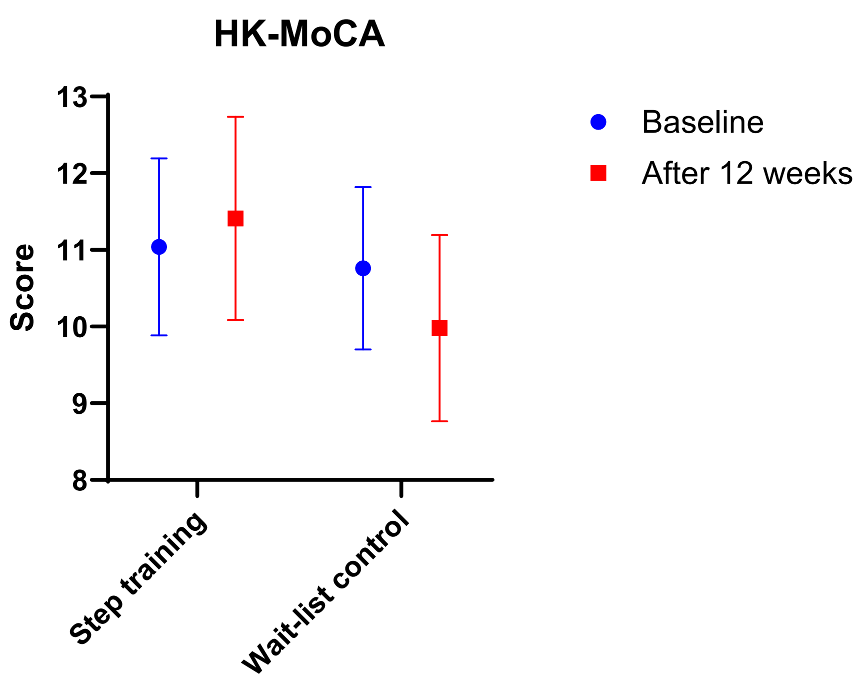

MSLT - left sideways
Centimeters
50
45
40
35
Step training
Wait-list control
Baseline
After 12 weeks

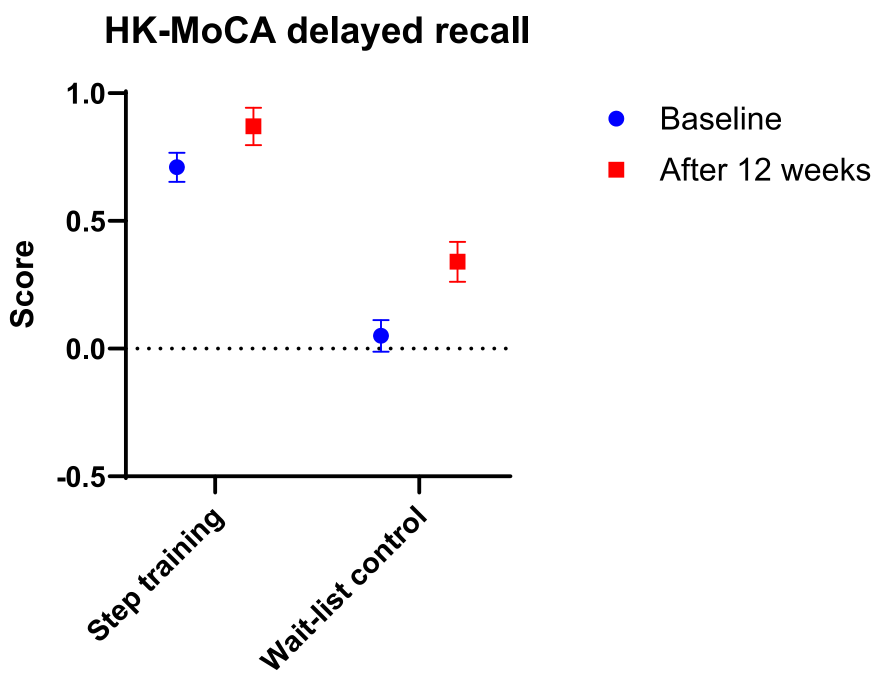

MSLT - right forward
Centimeters
54
52
50
48
46
Step training
Wait-list control
Baseline
After 12 weeks

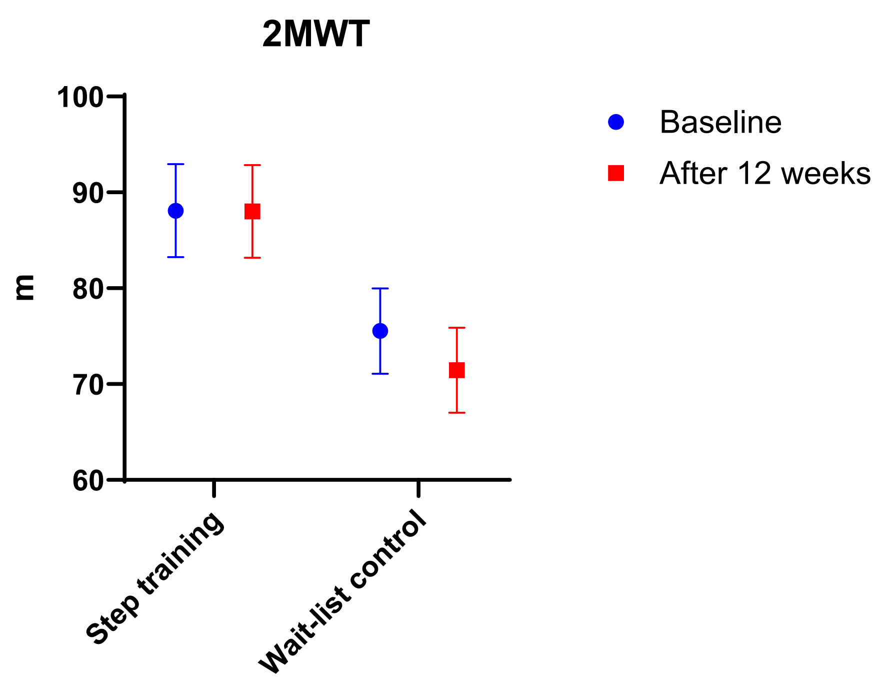

MSLT - right backward
Centimeters
50
45
40
35
30
Step training
Wait-list control
Baseline
After 12 weeks

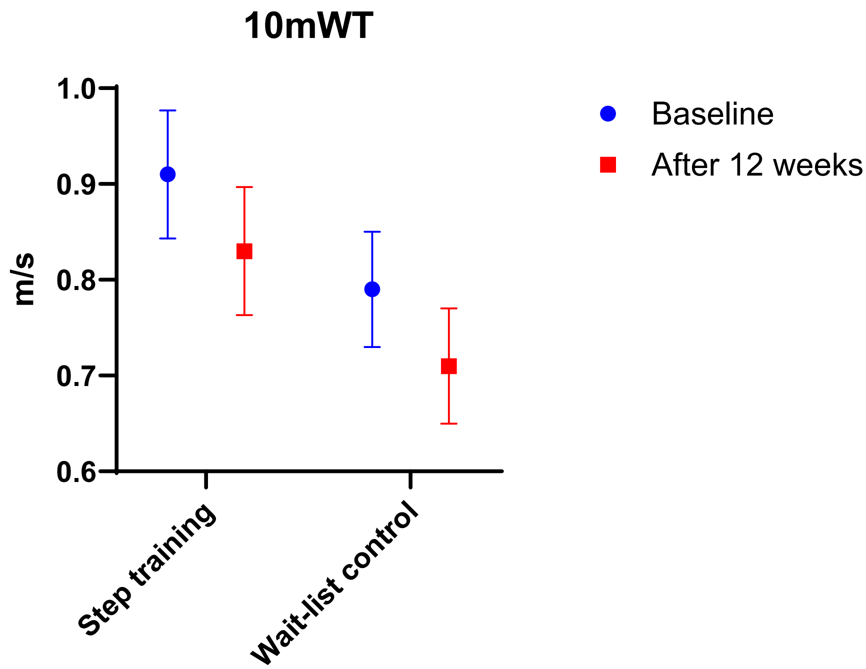

MSLT - right sideways
Centimeters
50
45
40
35
Step training
Wait-list control
Baseline
After 12 weeks

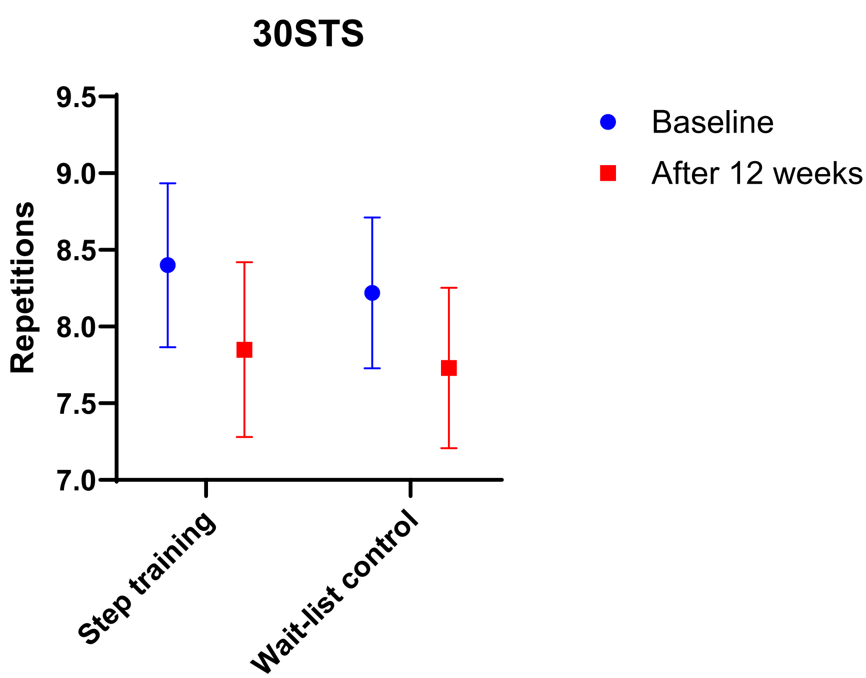

AST
60
40
20
0
Seconds
Step training
Wait-list control
Baseline
After 12 weeks

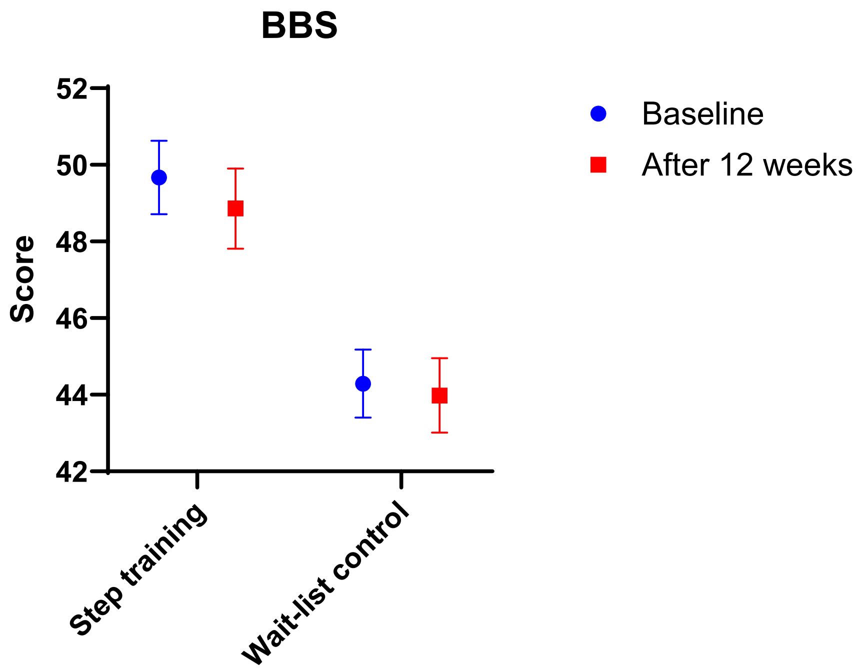

HK-MoCA
13
12
11
10
9
8
Score
Step training
Wait-list control
Baseline
After 12 weeks

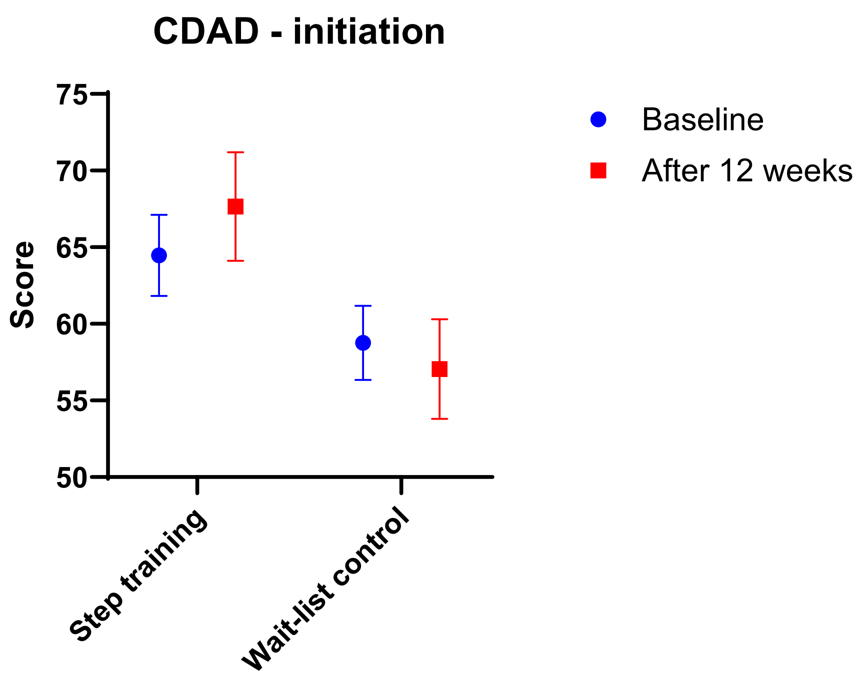

HK-MoCA delayed recall
1.0
0.5
0.0
-0.5
Score
Step training
Wait-list control
Baseline
After 12 weeks

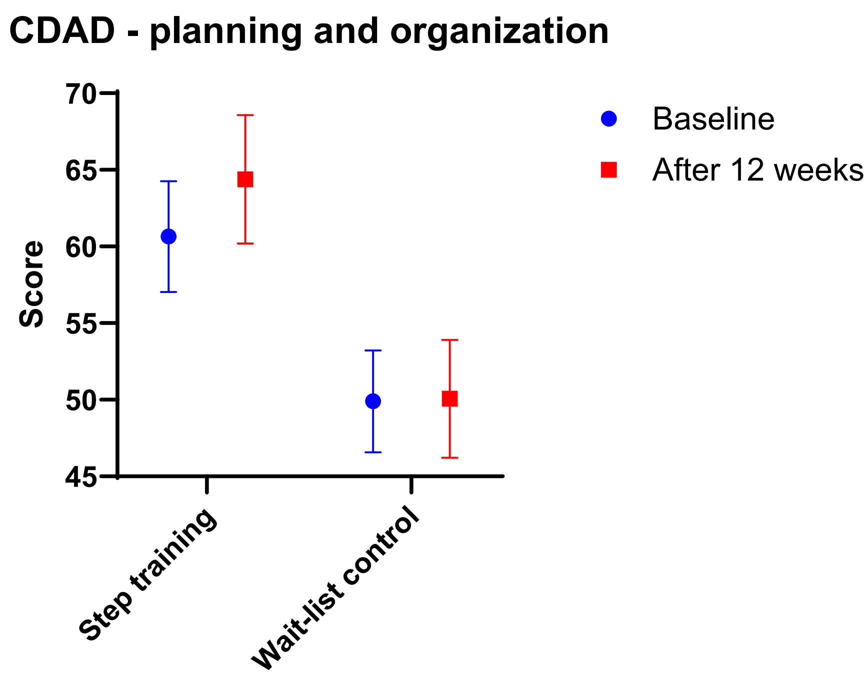

2MWT
100
90
80
70
60
m
Step training
Wait-list control
Baseline
After 12 weeks


10mWT
1.0
0.9
0.8
0.7
0.6
m/s
Step training
Wait-list control
Baseline
After 12 weeks

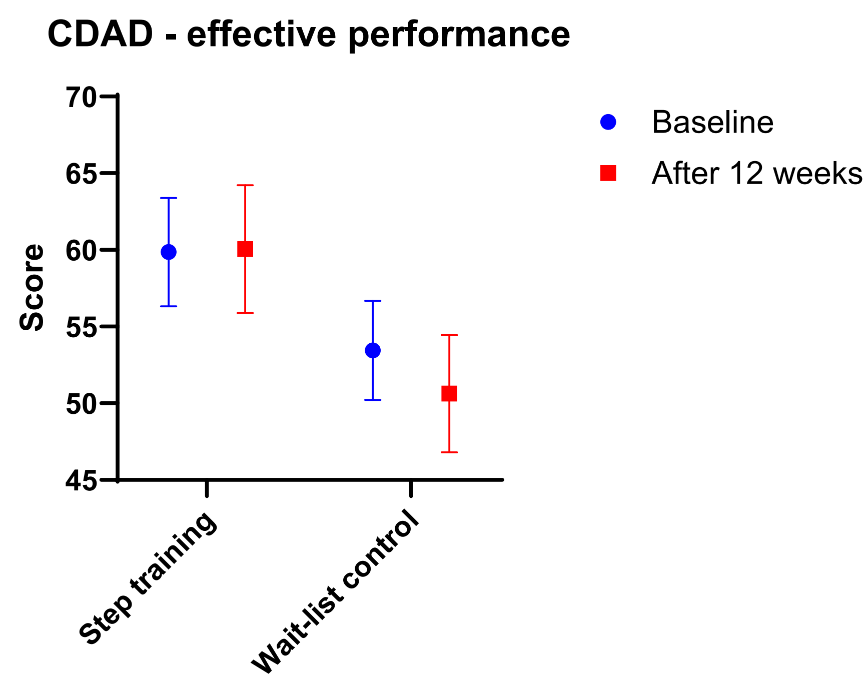

30STS
9.5
9.0
8.5
8.0
7.5
7.0
Repetitions
Step training
Wait-list control
Baseline
After 12 weeks


BBS
Score
52
50
48
46
44
42
Step training
Wait-list control
Baseline
After 12 weeks

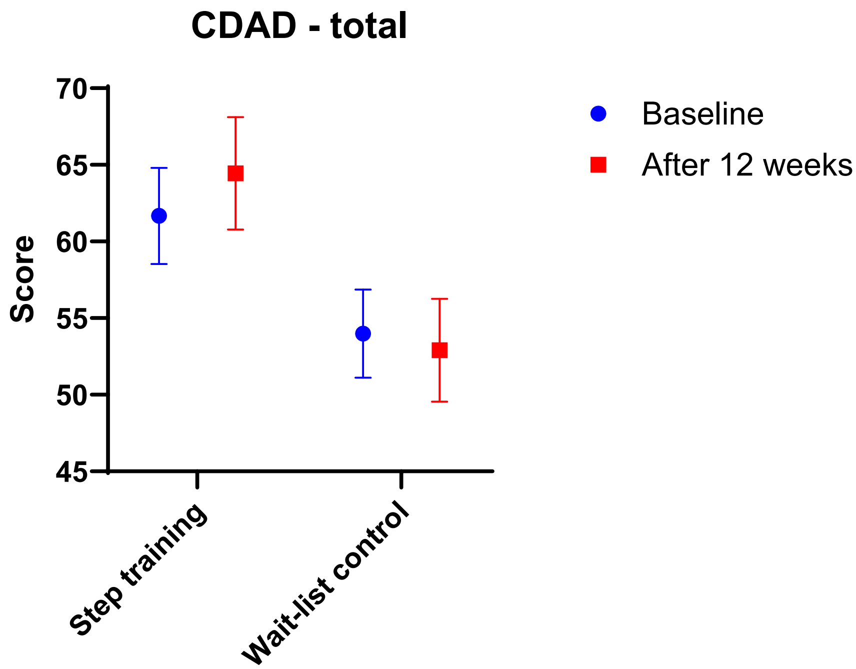

CDAD - initiation
Score
75
70
65
60
55
50
Step training
Wait-list control
Baseline
After 12 weeks



CDAD - planning and organization
Score
70
65
60
55
50
45
Step training
Wait-list control
Baseline
After 12 weeks



CDAD - effective performance
Score
70
65
60
55
50
45
Step training
Wait-list control
Baseline
After 12 weeks



FSST, Four Square Step Test; CSRTT, Choice Stepping Reaction Time Test; MSLT, Maximum Step Length Test; AST, Alternate Step Test; HK-MoCA, Hong Kong version of the Montreal Cognitive Assessment; CDAD, Chinese version of the Disability Assessment for Dementia; 2MWT, 2-Minute Walk Test; 10mWT, 10-meter Walk Test; 30STS, 30-second Sit-To-Stand test; BBS, Berg Balance Scale.