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Evaluating The Effectiveness of Tai Chi Robotic Machine on Enhancing Balance and Reducing Fall Risk in Hong Kong Chinese Older Adults

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Abstract

Background: *Balance impairment is common in the elderly population and is a major contributor to increased fall risk and associated health complications. Studies indicate that Tai Chi is an effective intervention for balance training. This study aimed to examine the effectiveness of the Tai Chi Robotic Machine in enhancing balance and reducing fall risk among Hong Kong Chinese older adults.*

Methods*: 92 Hong Kong Chinese community-dwelling older adults were recruited across the territory. The subjects recruited were randomly allocated to the Tai Chi Robotic (TR) Group (13 males and 42 females, aged 68.66 ± 5.37) and the control group (CG) (18 males and 19 females, aged 67.61 ± 7.49). The TR group received 12 sessions of Tai Chi training via the Tai Chi Robotic Machine (2 sessions per week for 6 weeks), while the CG received no intervention. Assessments were conducted at pre-intervention, post-intervention, and 1-month follow-up. Outcome measures included demographic data, fall history, Aspire Fall Risk Score (FRS), Berg Balance Scale (BBS), Single-Leg-Stand (SLS), self-reported perceived balance, handgrip strength and Short Form 12 Physical and Mental Component Summary (SF-12 PCS & MCS).*

Results: *TR group showed significant post-intervention improvements ($p \leq 0.01$) in Aspire FRS (from 6.69 ± 2.03 to 7.87 ± 1.09); BBS (from 49.51 ± 6.40 to 53.62 ± 3.12); self-reported perceived balance (from 2.20 ± 0.83 to 2.96 ± 0.69). No statistically significant improvements were exhibited in CG. Improvements in the TR group were sustained at 1-month follow-up, indicating maintained effects in balance enhancement relative to the CG.*

Conclusions: *TR group demonstrated effective balance improvements and fall risk reduction compared to CG, showing that the Tai Chi Robotic Machine can serve as an effective modality for balance training, especially among the elderly population in the community.*

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Background

Demographic change towards an aging society has become a long term dilemma in Hong Kong. The World Bank Group (2023) estimated that Hong Kong ranks first globally in life expectancy, which is contributed by a highly-accessible healthcare infrastructure and improved quality of life [1]. With a significant improvement in public health and healthcare standard, a transition towards an aging society can be projected.

With advancement in age, the risk of fall will increase progressively, leading to severe health consequences. Increased risk of osteoporosis and higher fall rates among the elderly population have contributed substantially to the prevalence of fragility fractures. Those who had episodes of fall-related fractures are at an elevated risk for subsequent fractures, which can result in disability or even fatality [2]. Kwok et al. (2012) conducted multiple studies on the association between fall and fractures. The results concluded that vertebral fractures' prevalence was notably high in different parts of Asia, including Hong Kong. Factors including age advancement, balance impairment and mobility limitations were significantly linked to vertebral fractures in Asians [3,4]. In response, fall prevention measures for balance improvement and muscle strengthening are at top priority.

A spectrum of fall prevention campaigns are offered to elderly with different needs, where Tai Chi has been proven to be an effective intervention. Tai Chi is widely favoured among the elderly population, with benefits including improving weight-shifting, endurance and muscle strength. Numerous research supports Tai Chi's effectiveness in improving balance and reducing the risk of falls among older adults [5-7]. These traditional Tai Chi protocols usually involve a Tai Chi Master, with participants engaging in group classes for practice. Considering the time and resource limitations in Hong Kong, consistently organizing such Tai Chi programs on a group basis within community settings presents significant challenges.

Combining modern technologies into traditional Tai Chi training could be an effective alternative with additional advantages. The Tai Chi Robotic Machine is a newly developed gerontechnology product with DEKRA Certification (Report No. 6106609.51QS) for use in Hong Kong. Tai Chi Robotic Machine can provide highly realistic Tai Chi experiences with guided instructions to offer similar physical benefits as conventional practice in enhancing balance and reducing fall risk.

This study aimed to evaluate the effectiveness of the Tai Chi Robotic Machine in enhancing balance and reducing fall risk among community-dwelling Chinese older adults in Hong Kong.

Methods

Ethical Approval

This study was conducted at Tung Wah College in Ho Man Tin District from August 2023 to July 2025. Ethical approval was obtained from the Tung Wah College Research Ethics Committee (Ref. No.: REC2023170), in accordance with the principles outlined in the Declaration of Helsinki. Written informed consent, detailing the study's aims and procedures was obtained from all subjects prior to their enrollment. All collected data and personal information were handled with strict confidentiality to ensure privacy.

Study Design

This study was a cohort study comprising two groups, the intervention group—Tai Chi Robotic (TR) group and the control group (CG). The TR group received 12 sessions of Tai Chi Robotic training, supplemented with fall prevention educational leaflets. The CG only received educational leaflets with no intervention. Three assessments were carried out in the study period, pre-intervention (baseline), post-intervention (following completion of 12 sessions) and post 1-month to evaluate the retention of training effects.

Subjects

All subjects were required to meet the following selection criteria in order to be recruited:

Inclusion Criteria:

- 60 years old or above
- Community-dwelling
- Ambulatory without assistive devices
- Able to attend assessments and intervention

sessions at Tung Wah College
- Capable of providing written informed consent

Exclusion Criteria:
- Diagnosed with severe orthopaedics, neurological, cardiovascular or mental conditions
- History of spinal surgery or bilateral hip replacement
- Diagnosed with malignancy
- Previous Tai Chi practicing experience
- Currently enrolling in other balance interventions

Convenient sampling was used to recruit participants prior to the study's commencement. Recruitment throguh poster and digital mass media were methods used. Subject eligibility was assessed based on the above selection criteria. Random allocation was conducted by an independent surveyor not involved in any other aspect of the study to ensure allocation concealment and minimize potential bias.

Interventions
Subjects in the TR group received Tai Chi training using the Tai Chi Robotic Machine. The machine delivered 8 Chen-style Tai Chi patterns: Small Circle Spiraling, Large Circle Spiraling, Horizontal Push, Outer Push, Forward Rollback, Backwards Rollback, Clockwise Oval and Anti-clockwise Oval, adapted from the techniques of distinguished Tai Chi Master, Master Chow [8]. The duration for practicing each pattern was 3 minutes and a rest interval of 30 seconds was provided between each movement. During the training, subjects were instructed to place their hands on the ball-shaped handle attached on the machine's arm extension. The handle guided their weight-shfting and body movements, which challenged their limit of stability. Training sessions were held twice per week, each for 30 minutes with 12 sessions in total.
In the CG, no Tai Chi training was given to the subjects.

Outcome Measures
Demographic information and outcome measures of subjects were collected at three time points: pre-intervention, post-intervention (following completion of 12 Tai Chi sessions) and post 1-month. The assessment protocol included six key measures:
- **Aspire Fall Risk Score (FRS):** A sensor belt utilizes Bosch SensorTec inertial measurement units to calculate fall risk based on balance, gait and strength through three assessments: the Romberg test, the 6-meter walk test and the sit-to-stand test. Results were rated as the Aspire FRS, generating a score from 1 to 10, where 1 indicates high fall risk and 10 indicates low fall risk [9].
- **Berg Balance Scale (BBS):** Items in BBS use a 5-point scoring system, with a maximum possible score of 56 across 14 different tasks including sitting, standing, transfer, turning and stepping. A cut off score of ≤45 indicates greater fall risk of community-dwelling individuals [10].
- **Single Leg Stance (SLS):** Measures static balance and postural control by standing on one leg with eyes opened for as long as possible. Inability to hold the stance for less than 5 seconds is a predictor of high fall risk, while maintaining it for at least 10 seconds is associated with a lower all-cause mortality rate [11].
- **Self-reported perceived balance:** A subjective outcome indicator for assessing perceived weight-shifting and weight-bearing abilities, comprising a 4-point rating system, with 1 being the least stable and 4 being the most stable. The scale reflects how subjects view their abilities to maintain stability in different daily activities.
- **Handgrip strength:** It assesses the force generated by upper limb muscles during a gripping action, measured with a Jamar dynamometer. Three trials were allowed and the trial with the highest force generated was recorded. Handgrip strength serves as a predictor of future fall risks and is an indicator of overall muscular strength and endurance [12].
- **(6) 12-Item Short Form Survey (SF-12):** A self-reported measurement for quality-of-life covering topics including physical functioning, role limitations, bodily pain, general health, vitality, social functioning and mental health. SF-12 produces two scores: the Physical and Mental Component Summary, with higher values representing better physical and mental health respectively [13].

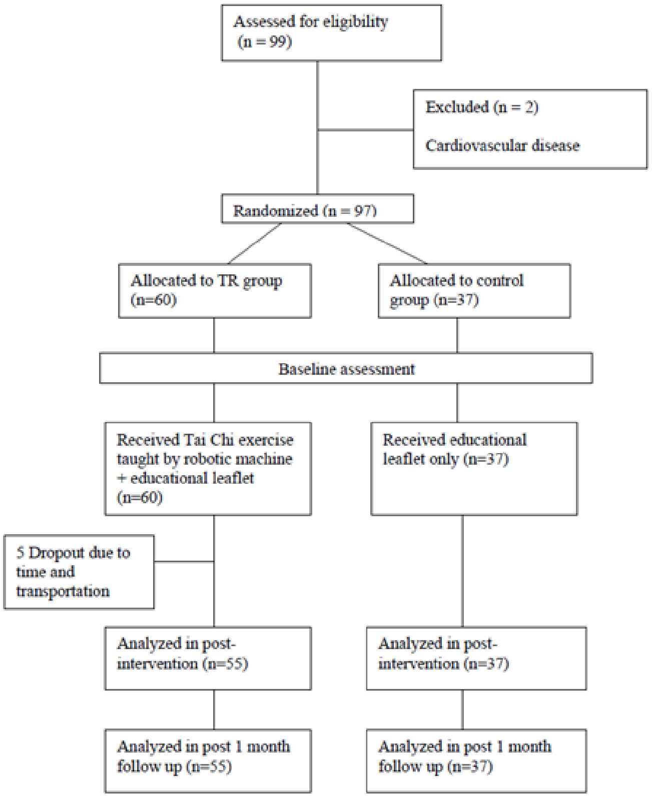
Sample Size Calculation and Statistical Analysis
The formula $N = [(Z\text{-score})^2 \times p \times (1 - p)] / (\text{margin of error})^2 \times DEFF$ was used to calculate the required sample size in the study. Taking into account previous

research on balance training effects of Tai Chi, an estimated moderate effect size of 0.25 was assumed [14]. With a 95% confidence level (Z=1.96), a 5% margin of error and a design effect (DEFF) of 1.2 for potential changes in different factors throughout the study, the minimum sample size was calculated to be 96. Ultimately, 99 participants were recruited and 92 of them completed the study—achieving 95% of the anticipated effective sample size. Statistical analysis was performed utilizing SPSS version 27, with statistical significance set at $p<0.05$.

Results

99 participants were recruited for the study. Before the randomization process, 2 partcipants were excluded because of their cardiovascular conditions, leaving 97 eligible subjects. They were then randomly assigned to the TR group or the CG. Throughout the study period, there were 5 dropouts from the TR group because of scheduling conflicts and transportation difficulties. At the end, 92 subjects finished the whole study and all follow-up assessments (n=55 in TR group; n=37 in CG) (refer Fig. 1).

Figure 1: Consort Diagram of the Study



Demographics

Descriptive data analysis for subjects' demographics, fall episodes within the past 12 months and history of comorbidities was carried out. The mean age in the TR group was 68.66 ± 5.37, while that of the CG was 67.61 ± 7.49. Over the past year, subjects in the TR group reported an average of 0.35 ± 0.58 falls, compared to 0.19 ± 0.70 falls in the CG. The mean number of comorbidities in the TR group and the CG was 1.58 ± 1.61 and 0.92 ± 0.89 respectively (refer Table 1).

Table 1: Demographics of Participants

	Tai Chi Robotic Group (n=55)	Control Group (n=37)
Age (years)	68.66 ± 5.37	67.61 ± 7.49
Male	13 (24%)	18 (49%)
Female	42 (76%)	19 (51%)
Height (cm)	158.33 ± 8.17	160.08 ± 9.44
Weight (kg)	55.63 ± 9.48	60.15 ± 11.51
Number of falls in the past 12 months (times)	0.35 ± 0.58	0.19 ± 0.70
Number of comorbidity (s)	1.58 ± 1.61	0.9 2± 0.89

Note: The values are presented as mean ± SD or number (%)

Aspire Fall Risk Score

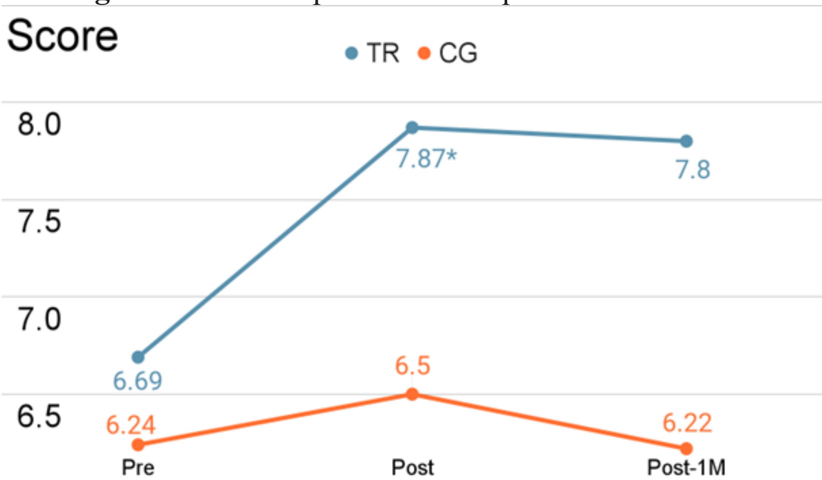
The Aspire FRS in the TR group showed significant improvements from pre-intervention to post-intervention (from 6.69 ± 2.03 to 7.87 ± 1.09) ($p<0.001$), while no significant change was observed in the CG (from 6.24 ± 2.22 to 6.5 ± 2.18) ($p=0.531$). Significant differences were found between the TR and CG groups at both post-intervention and post 1-month assessments, with higher effectiveness shown in the TR group (Table 2). An improving trend for the Aspire FRS was demonstrated in the TR group during the post-intervention phase. It then sustained in the post 1-month follow-up, indicating lasting training effects (refer Fig. 2).

Table 2: Mean Aspire Fall Risk Score

		Tai Chi Robotic Group (n=55)	Control Group (n=37)	Between group p-value
Aspire Fall Risk Score	Pre	6.69 ± 2.03	6.24 ± 2.22	0.320
	Post	7.87 ± 1.09	6.5 ± 2.18	<0.001*
	Post-1M	7.80 ± 1.13	6.22 ± 2.20	<0.001*
	Within group p-value			
	Pre vs Post	<0.001*	0.368	/
	Post vs Post-1M	0.468	0.262	/
	Overall	<0.001*	0.531	/

Note: The values are presented as adjusted mean ± standard deviation.

Figure 2: Line Graph of Mean Aspire Fall Risk Score



Berg Balance Scale

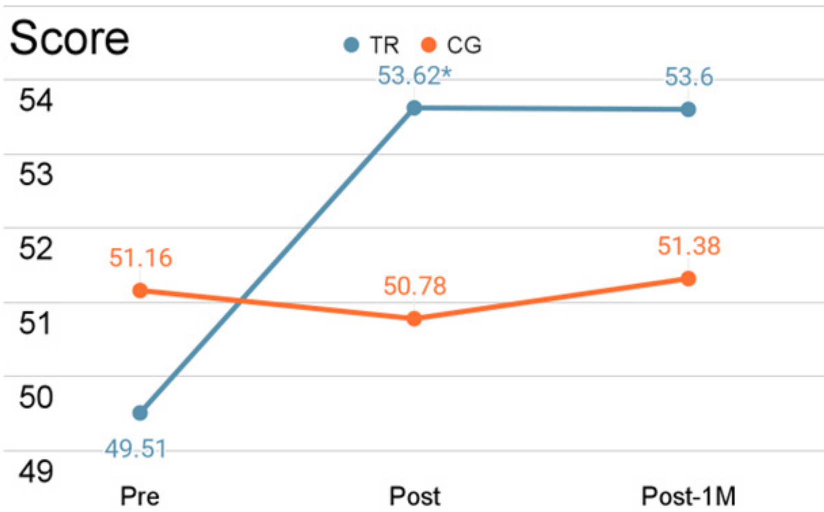
The TR group demonstrated significant increase in BBS score in the post-intervention period (from 49.51 ± 6.40 to 53.62 ± 3.12) (p<0.001), while the CG (from 51.16 ± 5.60 to 50.78 ± 6.01) showed no significant change (p=0.367). Significant differences between the TR group and the CG were observed in post-intervention and 1-month follow-up, with greater improvements in the TR group (refer Table 3). The TR group showed an upward trend, plateauing at the post-intervention period and sustaining in post 1-month, demonstrating long-term training effects (refer Fig. 3).

Table 3: Mean Berg Balance Scale Score

		Tai Chi Robotic Group (n=55)	Control Group (n=37)	Between group p-value
Berg Balance Scale	Pre	49.51 ± 6.40	51.16 ± 5.60	0.205
	Post	53.62 ± 3.12	50.78 ± 6.01	0.004*
	Post-1M	53.60 ± 3.42	51.32 ± 4.74	0.009*
	Within group p-value			
	Pre vs Post	<0.001*	0.306	/
	Post vs Post-1M	0.927	0.140	/
	Overall	<0.001*	0.367	/

Note: The values are presented as adjusted mean ± standard deviation.

Figure 3: Line Graph of Mean Berg Balance Scale Score



Single Leg Stance

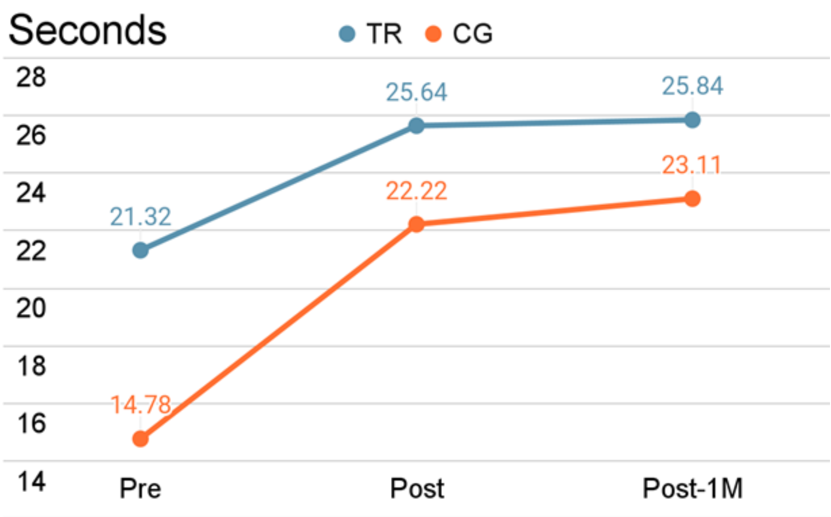
The SLS time in the TR group showed improvement in post-intervention (from 21.32 ± 30.78 to 25.64 ± 2.33). The increase in single leg stance time sustained over the post 1-month assessment relative to pre-intervention, with it demonstrating a slight decreasing trend from post-intervention (from 25.64 ± 2.33 to 25.84 ± 3.09). No statistically significant improvement was recorded at any assessment interval (p=0.100) (refer Table 4). As for the CG, the SLS time showed an increasing trend sustaining from pre-intervention to 1-month follow-up (from 14.78 ± 10.46 to 23.11 ± 3.78), despite showing no statistical significance (p=0.137) (refer Fig. 4).

Table 4: Mean Single Leg Stance Time

		Tai Chi Robotic Group (n=55)	Control Group (n=37)	Between group p-value
Single Leg Stance (secs)	Pre	21.32 ± 30.78	14.78 ± 10.46	0.217
	Post	25.64 ± 2.33	22.22 ± 2.86	0.090
	Post-1M	25.84 ± 3.09	23.11 ± 3.78	0.220
	Within group p-value			
	Pre vs Post	0.022*	0.347	/
	Post vs Post-1M	0.960	0.107	/
	Overall	0.065	0.137	/

Note: The values are presented as adjusted mean ± standard deviation.

Figure 4: Line Graph of Mean Single Leg Stance Time



Self-Reported Perceived Balance

The TR group demonstrated a significant increase in self-reported perceived balance during the post-intervention assessment (from 2.20 ± 0.83 to 2.96 ± 0.69) ($p<0.001$). The improving trend of it also continued through the post 1-month follow-up (from 2.96 ± 0.69 to 3.02 ± 0.71), reflecting sustained training effects (refer Fig. 5). In the CG, the self-reported perceived balance increased from 2.51 ± 0.77 to 2.65 ± 0.75 in the post-intervention period, showing a significant change ($p=0.020$). It then experienced a decrease in the 1-month follow-up assessment (from 2.65 ± 0.75 to 2.59 ± 0.76) (refer Table 5).

Figure 5: Line Graph of Mean Self-Reported Perceived Balance Score

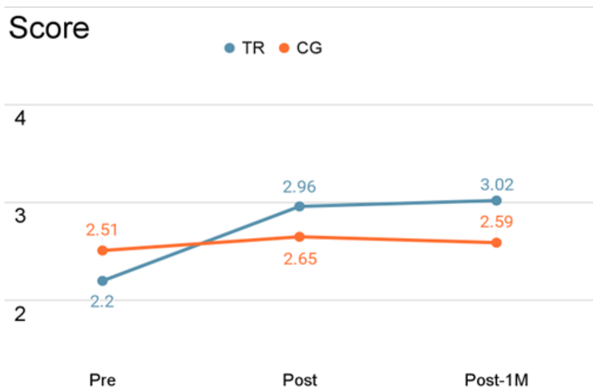


Table 5: Mean Self-Reported Perceived Balance Score

		Tai Chi Robotic Group (n=55)	Control Group (n=37)	Between group p-value
Self- Reported Perceived Balance	Pre	2.20 ± 0.83	2.51 ± 0.77	0.070
	Post	2.96 ± 0.69	2.65 ± 0.75	0.042
	Post-1M	3.02 ± 0.71	2.59 ± 0.76	0.008
	Within group p-value			
	Pre vs Post	<0.001*	0.044*	/
	Post vs Post-1M	0.182	0.160	/
	Overall	<0.001*	0.020	/

Note: The values are presented as adjusted mean ± standard deviation.

Handgrip Strength

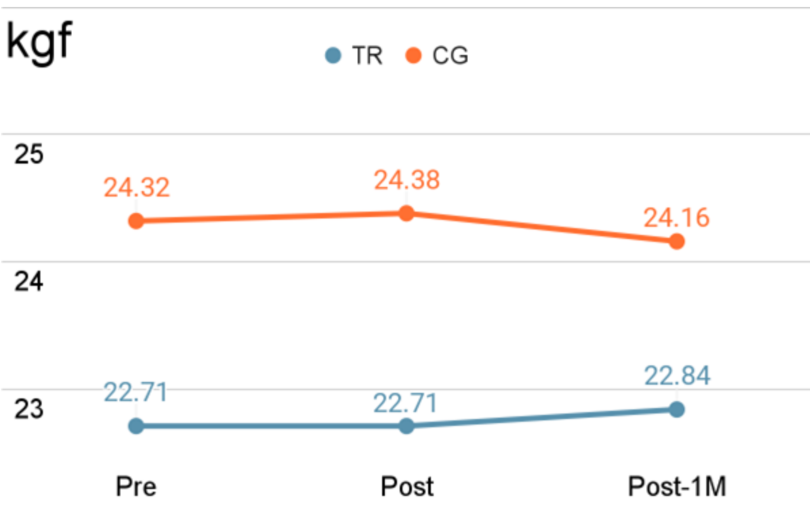
The TR group (from 22.71 ± 8.73 to 22.71 ± 8.19) (p=0.947) and CG (from 24.32 ± 7.57 to 24.38 ± 8.11) (p=0.723) both showed minimal changes in handgrip strength from pre-intervention to post-intervention (refer Table 6). During the 1-month follow-up period, the TR group demonstrated an increasing trend (from 22.71 ± 8.19 to 22.84 ± 8.73), while in contrast, the CG showed a decreasing trend (from 24.38 ± 8.11 to 24.16 ± 7.92) (refer Fig. 6).

Table 6: Mean Handgrip Strength

		Tai Chi Robotic Group (n=55)	Control Group (n=37)	Between group p-value
Handgrip Strength (kgf)	Pre	22.71 ± 8.73	24.32 ± 7.57	0.362
	Post	22.71 ± 8.19	24.38 ± 8.11	0.338
	Post-1M	22.84 ± 8.73	24.16 ± 7.92	0.461
	Within group p-value			
	Pre vs Post	1	0.906	/
	Post vs Post-1M	0.776	0.291	/
	Overall	0.947	0.723	/

Note: The values are presented as adjusted mean ± standard deviation.

Figure 6: Line Graph of Mean Handgrip Strength



SF-12 PCS

The SF-12 PCS score in the TR group showed an improving trend from pre-intervention to post 1-month assessment (from 48.20 ± 7.39 to 49.82 ± 0.697). It demonstrated a sustained improvement, while not being able to reach statistical significance (p=0.074) (refer Fig. 7). The CG did not show any significant changes in SF-12 PCS score throughout the whole study, with the scores from both post-intervention and 1-month follow-up having decreased from baseline (from 50.44 ± 5.93 to 49.64 ± 0.863), also not showing statistical significance (p=0.425) (refer Table 7).

Figure 7: Line Graph of Mean SF-12 PCS Score

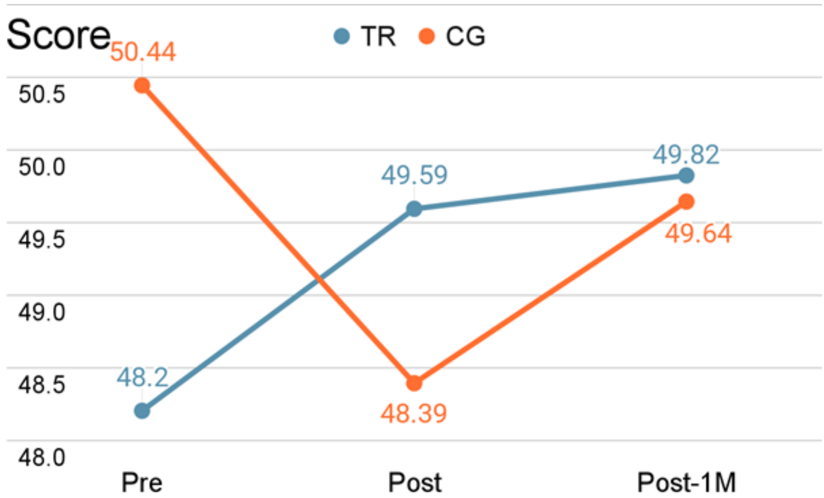


Table 7: Mean SF-12 PCS Score

		Tai Chi Robotic Group (n=55)	Control Group (n=37)	Between group p-value
SF-12 PCS	Pre	48.20 ± 7.39	50.44 ± 5.93	0.126
	Post	49.59 ± 0.633	48.39 ± 0.784	0.744
	Post-1M	49.82 ± 0.697	49.64 ± 0.863	0.411
	Within group p-value			
	Pre vs Post	0.077	0.597	/
	Post vs Post-1M	0.477	0.258	/
	Overall	0.074	0.425	/

Note: The values are presented as adjusted mean ± standard deviation.

SF-12 MCS

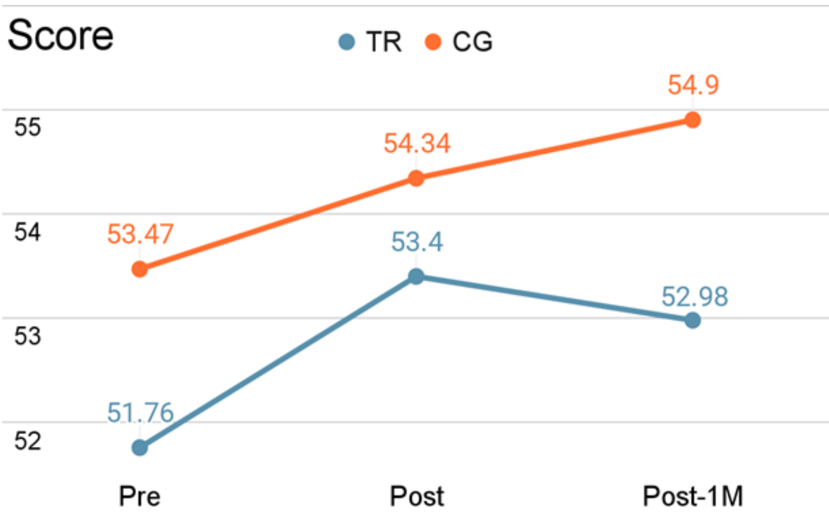
Both the TR group (from 51.76 ± 8.05 to 53.40 ± 6.69) (p=0.127) and the CG (from 53.47 ± 6.68 to 54.34 ± 5.53) (p=0.204) demonstrated an increasing trend of SF-12 MCS score between the pre-intervention and post-intervention period (refer Table 8). This increase was able to sustain during the 1-month follow-up period in the CG (from 54.34 ± 5.53 to 54.90 ± 4.92), while the TR group (from 53.40 ± 6.69 to 52.98 ± 7.31) showed a mild decrease in score in the same time interval (refer Fig. 8).

Table 8: Mean SF-12 MCS Score

		Tai Chi Robotic Group (n=55)	Control Group (n=37)	Between group p-value
SF-12 MCS	Pre	51.76 ± 8.05	53.47 ± 6.68	0.288
	Post	53.40 ± 6.69	54.34 ± 5.53	0.477
	Post-1M	52.98 ± 7.31	54.90 ± 4.92	0.167
	Within group p-value			
	Pre vs Post	0.055	0.300	/
	Post vs Post-1M	0.412	0.288	/
	Overall	0.127	0.204	/

Note: The values are presented as adjusted mean ± standard deviation.

Figure 8: Line Graph of Mean SF-12 MCS Score



Discussion

The TR group exhibited significant improvements in the Aspire FRS, BBS and self-reported perceived balance, with these gains maintained at the 1-month follow-up. These outcomes are consistent with prior studies confirming the benefits of Tai Chi for boosting muscular strength, neuromuscular coordination and minimizing fall risks in elderly populations [15,16]. According to Mao et al. (2024), the progress of balance enhancement stems from the biomechanical principles of Tai Chi, which emphasize controlled weight shifts, postural stability, and lower-body engagement—factors that strengthen joint control and refine equilibrium [17]. Tai Chi exercise is also consistent with the static balance theory, as stated by Zhang et al. (2006), which highlights the importance of the support surface size and the height of the center of gravity in maintaining balance[18]. Consequently, engaging in Tai Chi can improve older adults' skills in controlling their center of gravity and adjusting their posture, thereby enhancing their overall balance. These results validate the Tai Chi Robotic Machine as a promising method for balance training in older adults to decrease their risks of fall.

While the TR group showed marked improvements in most balance-related metrics, no significant changes were detected in SLS performance. This could be attributed to the Tai Chi Robotic's design, which primarily involved stationary, double-leg stances, omitting dynamic single-leg movements commonly found in conventional Tai Chi. The absence of such task-specific exercises may have limited gains in unilateral balance, suggesting that future robotic training programs could be enhanced by integrating more varied postural challenges to target single-leg stability. Both groups also did not demonstrate significant improvements in handgrip strength and SF-12 scores. Tai Chi predominantly focuses on lower-body engagement rather than upper-body strength. While handgrip strength is an indicator for overall muscular fitness, it often requires prolonged training and specific supplementary resistance exercises to demonstrate measurable progress in older adults [19]. Similarly, SF-12 scores may not be able to indicate short-term psychological benefits. Existing literature indicates that such benefits typically emerge after sustained practice[20,21]. Thus, while trends were favorable, an extended period of Tai Chi practice is necessary to detect significant changes in these areas.

Implications

Through delivering standardized training without reliance on a live instructor, the Tai Chi Robotic Machine can mitigate traditional barriers such as cost, scheduling and accessibility, making it well-suited for community and home-based rehabilitation. This is particularly relevant given the increasing need for affordable, technology-driven solutions in aging populations.

Incorporating the Tai Chi Robotic Machine into public health initiatives could expand the reach and generalizability of fall prevention efforts. The Tai Chi Robotic Machine is adjustable to accommodate users of varying body sizes and physical characteristics. This feature enhances its usability across broad anthropometric profiles. By allowing individualized adjustments, the machine supports proper posture and movement alignment. It ensures that subjects can perform the movements within their functional range, thereby maximizing therapeutic benefits. Its adaptability also allows flexible deployment in different settings, including senior care facilities, community hubs and private residences, accommodating older adults with diverse health needs. Enabling home-based use encourages consistent practice, fostering long-term adherence and motivation.

The machine's standardized protocols can ensure consistent training quality. Traditional Tai Chi Masters can vary depending on the instructor's experience, teaching style and interpretation of movements, leading to inconsistencies in training quality and therapeutic outcomes. To eliminate this limitation, the Tai Chi Robotic Machine's delivery of the same movements and styles every time can reduce variability in intervention delivery. This can ensure the quality and consistency of Tai Chi practices for users to achieve desired training effects.

Limitations

Subjects of this study were relatively healthy, community-dwelling seniors with little to no physical impairments, limiting the generalizability of frailer elderly populations. Future studies could focus on older adults with greater mobility challenges, such as those in assisted living facilities, to assess the intervention's efficacy in high-risk groups. Applying the same Tai Chi interventions in these weaker older adults may result in more substantial gains in balance, strength and overall physical performances, leading to more pronounced improvements.

Conclusion

This study demonstrated that the Tai Chi Robotic Machine is an effective intervention for improving balance and reducing fall risk among older adults. These findings support the integration of the Tai Chi Robotic Machine into community and primary healthcare settings for balance training. Its standardized delivery eliminates the need for live Tai Chi instructors, making it particularly valuable in resource-limited environments or for individuals with logistical barriers to attending traditional Tai Chi classes. With Hong Kong facing the challenge of an aging society, rigorous evidence is provided in this study that the Tai Chi Robotic Machine can be an effective and viable method to be utilized in fall prevention. By mitigating fall risks among older adults, subsequent fall-related health consequences can be significantly reduced, as a result, decreasing healthcare expenditures and enhancing overall quality of lives for the elderly.

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