The Effect of Tai Chi Quan and Computerized Balance Training on Postural Stability in Older Subjects

Background and Purpose. This study explored whether two exercise programs would affect the ability to minimize postural sway of 72 relatively inactive, older subjects who participated in the Atlanta FICSIT trial. **Subjects.** Subjects were randomly assigned to (1) a computerized balance training group, (2) a tai chi group, or (3) an educational group serving as a control for exercise. Each group consisted of 24 members. **Methods.** All subjects were evaluated under four postural conditions before, immediately after, and 4 months following their respective interventions, each of which was given over 15 weeks. **Results.** Platform balance measures revealed greater stability after training among subjects in the balance training group but little change in stability among subjects in the tai chi and educational group. Subjects in the tai chi group were less afraid of falling after training compared with subjects in other groups with similar covariates. **Conclusion and Discussion.** Unlike computerized balance training, tai chi does not improve measures of postural stability. Because tai chi delayed onset to first or multiple falls in older individuals, this effect does not appear to be associated with measures of enhanced postural stability. Tai chi may gain its success, in part, from promoting confidence without reducing sway rather than primarily facilitating a reduction in sway-based measures. [Wolf SL, Barnhart HX, Ellison GL, et al. The effect of tai chi quan and computerized balance training on postural stability in older subjects. *Phys Ther.* 1997;77:371–381.]

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Many authors[1–4] have noted that exercise is a generic intervention with demonstrated physiological and psychosocial benefits for all age groups, including older individuals with specified chronic conditions. Improvements in muscle strength,[5] muscle mass,[6] cardiovascular status,[7–10] fatigue resistance,[11] and hypertension[12] among older people who exercise are well documented. As facilitators of these improvements, physical therapists seek to regain or maintain maximal independence or prevent dependence for their older clients. These goals are often sought through innovative exercise programs and through precise documentation of physiological changes.

In 1990, the National Institute on Aging initiated the FICSIT (Frailty and Injuries: Cooperative Studies on Intervention Techniques) trials to explore novel interventions designed to have an impact on physiological, behavioral, and environmental dimensions related to frailty or falls in elderly individuals and, in the process, define a common database across sites. The work completed by Fiatarone and colleagues[13] demonstrated that intense strength training improved lower-extremity force by 113% in older nursing home residents compared with a control group with concomitant improvements in gait speed, stair climbing, cross-sectional thigh muscle area, and spontaneous physical activity. Tinetti's group[14] demonstrated that a multifactorial program, including adjustment of medications, home exercise prescription, and behavioral instructions, resulted in a reduction in the numbers of falls among older individuals residing in independent living sites compared with a control group of older people receiving social visits. Wolfson and coworkers[15] showed that a combined strengthening and weight training program had a favorable impact on a variety of balance measures among 110 community-dwelling persons with a mean age of 80 years. When all FICSIT site interventions were grouped into categories by defining the prevailing aspect of each intervention as emphasizing balance, strength, or endurance, those treatments emphasizing a balance component delayed the onset of first falls more than did strength or endurance interventions compared with all control groups across sites.[16] Furthermore, the balance intervention most contributing to this delay was tai chi (TC).

At the Atlanta FICSIT site, the TC intervention for older subjects was compared with computerized balance training (BT) and with a control condition (ED) for subjects who attended weekly educational sessions without changing their exercise routine. We chose to explore these interventions because of our interests in frailty and falls and because of our past interests in using feedback of physiological events to shape movement control.[17,18] These particular interventions present an intriguing contrast. Computerized balance training is an individualized, high-technology procedure, whereas TC is a group activity that promotes socialization and requires no special equipment or space needs.[19] Computerized balance training uses force transducers embedded in platforms that detect and resolve changes in center of mass within three planes.[20–22] Indeed, these devices have been used to train patients with hemiplegia to improve standing balance.[23,24] Our results revealed that TC delayed the onset of first or multiple falls by 47.5% compared with BT or ED and also reduced the subjects' fear of falling.[25]

This finding is relevant because one of the more pervasive objectives of many geriatric therapeutic interventions is to improve or maintain "balance" in order to promote functional independence and eliminate or reduce fall-related events. An important principle underlying this approach is the need to enhance or maintain

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postural stability.[26] Accordingly, the purpose of our study was to explore whether the two training interventions used at the Atlanta FICSIT site actually affected the subjects' ability to minimize postural sway under defined perturbation conditions. This exploration in older individuals is particularly relevant if successful demonstrations of postural stability are viewed as necessary precursors to reductions in falls or diminished fear of falling.

Method

Interventions

Computerized balance training provides feedback to a person who is positioned on a force platform. The resolution of outputs from several force transducers is resolved as a cursor displayed on a monitor placed in front of the subject. Targets can be placed on the screen, and through weight shifts, with or without concurrent movement from the platform on which the individual stands, progressive increases in center of pressure displacement can be explored. In our study, older participants engaged in a 15-week training session, during which they received 1 hour of instruction each week. Training progressed from standing while maintaining a stable center of mass to displacements through greater excursions with targets delineated at appropriate distances. These efforts were undertaken with eyes open and then closed. Training tasks were made more complex by including linear (maximum movement, ±2.54 cm from zero start position; speed, 10–130 seconds per cycle) and angular (maximum movement, 4° toes down and 4° toes up; speed, 4–45 seconds per 4° of tilt) displacements while subjects first maintained a stable center of mass. The subjects would subsequently try to move the cursor into appropriate targets during platform movement. These efforts were made more complex by progressively increasing the range and speed of platform excursions. A more detailed accounting of this intervention is presented elsewhere.[27] Sway data were obtained from the same device with which participants in the BT group were instructed. A device-specific training effect, therefore, could have occurred. At no time, however, did the training regimen include the instruction or task specification used in the evaluation.

Tai chi quan is a martial art that has been used in China for centuries. Within approximately the past 300 years, TC has been adapted as an exercise and practiced in Oriental cultures by people of all age groups, but notably by many older persons. There are 108 "forms" within TC. For the purpose of this study, these forms were synthesized to 10 forms so that the intervention could be successfully completed by cohorts of 12 subjects each over 15 weeks. Each cohort of the TC group met twice a week for 1 hour. The first meeting of the week was to acquaint the group with the form. The second meeting permitted individualized attention to practice and facilitate accurate movement technique. The movement elements contributing to each form became progressively more complex and required gradual increases in head, neck, and trunk rotation, with a simultaneous reduction in base of support.

An ED group was also included as a control for exercise. This group also consisted of two cohorts of 12 members each who met once a week for a 1-hour session over the course of 15 weeks. Meetings were arranged so that a variety of topics were discussed, including polypharmacy, memory loss, bereavement, sleep disturbances, falls, and other issues of importance to each group.

Although the TC group met twice a week in contrast to the weekly meetings of the BT and ED groups, the total contact time with individual participants was the same, that is, approximately 1 hour. At each meeting of the TC group, the instructor would demonstrate and review the movements to be learned. The actual contact time spent explaining and working with subjects in the TC group was comparable to the contact time the clinician experienced with each subject in the BT group each week.

Subjects

To qualify for participation in the Atlanta FICSIT trial, all subjects had to live independently and have access to a central site where all interventions were scheduled. Subjects were at least 70 years of age; free from progressively debilitating processes such as Alzheimer's or Parkinson's disease, metastatic cancer, or severe arthritis; and capable of walking across a room independently or with a cane. All subjects gave informed consent prior to participation.

The Atlanta FICSIT trial consisted of 200 eligible subjects who were randomly assigned to TC, BT, and ED groups. Among these 200 subjects, the last 72 subjects were deliberately recruited from the independent living center at Wesley Woods, a facility about 1.6 km (1 mile) from the Emory University (Atlanta, Ga) campus. For the purposes of this report, we will consider only these 72 subjects, with 24 subjects randomly assigned to each group. The reasons are as follows. First, in contrast to their predecessors in this study, these people tended to be reclusive. They did not participate in activities because of perceived limitations in mobility and were reluctant to leave their rooms other than for meals or some social events. Compared with community-dwelling older subjects who were recruited earlier in the Atlanta FICSIT study and who eagerly sought activities to enhance their lives, these 72 subjects were considerably less active. Second, with few exceptions, complete data sets on force transducer outputs were available for these 72 subjects.

Measurement Equipment

The intent of this study was to examine subtle changes in postural control that might not be detected through the more traditional measures of one-leg or tandem stance times. Accordingly, the Chattecx Balance System™* was selected to acquire postural stability measurements under defined conditions. This device contains two force plates on which an individual stands. Each force plate contains eight transducers that resolve pressure changes into x and y coordinates over 20-second intervals. Several measures can be derived from data storage. The anteroposterior displacement reflects the range of data points gathered in the y axis during efforts at maintaining totally stable posture (COB-Y). Side-to-side displacement reflects the range of data points in the x axis (COB-X). Differences in heel-toe pressure are the differences in voltage values between the posteriorly and anteriorly placed transducers in both planes. The dispersion index reflects the variability or scatter of x and y coordinates and is based on how far the points deviate from the mean center of pressure. For all three measures, the larger the values, the greater will be the displacement, pressure, or sway, respectively. All measures are expressed as voltage resolution of outputs from force transducers that manifest changes in weight distributions.

Measurement Conditions

Subjects were evaluated on the Chattecx Balance System™ before and after interventions as well as at 4-month follow-up. Testing conditions were always sequential and designated as (1) quiet standing, eyes open (condition A), (2) quiet standing, eyes closed (condition B), (3) toes up (angular perturbation of 4° over 4 seconds), eyes open (condition C), and (4) toes up, eyes closed (condition D). In each instance, data were gathered for 20 seconds and each condition was repeated three consecutive times, from which an averaged response was noted.

Data Analysis

Baseline characteristics and preintervention values of balance measures and fear of falling were compared among the three groups. Fisher's Exact chi-square test was used to determine the significance of differences for categorical variables, and the Kruskal-Wallis analysis of variance (F test) was used for continuous variables.[28] For each balance measure (dispersion, COB-X, COB-Y), under each condition, a repeated-measures analysis of covariance (ANCOVA)[29] (two times [postintervention and follow-up] × three groups) was performed to test the overall group effect and the interaction of time and group, where preintervention balance measures and baseline characteristics were used as covariates for adjustment. In addition to the repeated-measures ANCOVA for each of the 12 balance outcome measures, a factor analysis was also undertaken to reduce the number of outcome variables to a fewer number of factor variables.[29] If the factor variables were intuitively reasonable, that is, if the grouping of factors seemed appropriate to better comprehend and interpret the data, the repeated-measures analyses were performed on the factor variables. The Tukey's method was used for pair-wise comparisons. Probability values less than .05 were considered to be significant in these analyses.

To explore the status of fear of falling in relation to balance measures, scales of the four-scale fear-of-falling questionnaire[14] (1=not at all afraid, 2=somewhat afraid, 3=fairly afraid, 4=very afraid) was combined to form a two-scale measure (1=afraid, 0=not afraid). A logistic regression model was developed to assess the odds ratios for fear-of-falling status in terms of time (preintervention, postintervention, and follow-up), group indicators, balance measures (as time-dependent variables), baseline characteristics, the interaction of time and group indicators, and the interaction of group and balance measures. The generalized estimating equation method[30] was used for parameter estimation. The variables selected for model building were baseline covariates that were significant among the three groups, variables that were known risk factors of fear of falling, and all balance measures. The final model retains all variables with probability values less than .20. The probability value of .20 was chosen because the sample size was relatively small for a dichotomous outcome variable and the goal of this analysis was exploratory. The odds ratios were computed from the final model for interpretation. Standardized residuals were examined for goodness of fit. All analyses were performed on subjects who had complete data at all three time periods for platform or fear-of-falling measurements and who had baseline characteristics used in the modeling.

Results

Baseline Characteristics

More than 40 baseline demographic data, including cognitive and quality-of-life variables, were compared among the three groups. Only a few differences among three intervention groups were observed. Table 1 displays the important baseline variables and some selected baseline variables by group. The BT group engaged in fewer volunteer activities than did the other two groups (6 subjects versus 14 subjects in the ED and TC groups, $P<.028$). The ED group had lower scores for both trails A (34.0 versus 47.3 for the BT group and 48.4 for the TC group, $P<.0003$) and trails B (92.9 versus 121.2 for the BT group and 129.1 for the TC group, $P<.00039$) tests. These tests measure visual conceptual and visuomotor

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Table 1.
Baseline Demographic Characteristics[a]

Characteristic	BT (n=24) n (%)	ED (n=24) n (%)	TC (n=24) n (%)	*P*
Age (X̄±SD)	77.7±6.5	75.2±4.9	77.7±5.6	.20
Female	19 (79.2)	22 (91.7)	19 (79.2)	.46
Live alone	12 (50.0)	11 (45.8)	13 (54.2)	.846
Volunteer	6 (25.0)	14 (58.3)	14 (58.3)	.028
MMSE score (X̄±SD)	29.2±1.2	29.3±0.9	29.3±1.0	.90
CES-D score (X̄±SD)	7.5±5.8	8.4±6.8	7.9±5.8	.97
Raw digit-symbol (X̄±SD)	38.1±11.4	45.1±12.9	37.5±8.8	.072
Trails A score (X̄±SD)	47.3±24.9	34.0±12.5	48.8±15.8	.0003
Trails B score (X̄±SD)	121.2±59.9	92.9±35.5	129.1±38.0	.0039
Weight (X̄±SD)	153.2±29.9	147.4±21.6	143.5±25.8	.55
Systolic blood pressure (X̄±SD)	144.5±22.1	141.6±25.9	141.4±21.6	.851
Body mass index (X̄±SD)	26.3±3.7	25.6±3.9	25.4±3.3	.59
Cancer, malignancy, or tumor	15 (62.5)	6 (25.0)	9 (37.5)	.027
Arthritis	17 (70.8)	15 (62.5)	18 (75.0)	.63
Medication for hypertension	13 (54.2)	11 (45.8)	11 (45.8)	.80
Cataract	13 (54.2)	9 (37.5)	14 (58.3)	.31
Fell last year	6 (25.0)	9 (37.5)	15 (62.5)	.027
Fall self-efficacy scale (X̄±SD)	14.8±4.6	13.2±2.7	13.4±3.4	.613

[a] Over 23 additional characteristics were not different at baseline. BT=computerized balance training, ED=education (control), TC=tai chi, MMSE=Mini-Mental State Examination, CES-D=Center for Epidemiological Studies Depression Scale.

tracking abilities.[31] Another behavioral test, the Folstein Mini-Mental State Examination,[31] which measures cognitive mental status, and all other behavioral measures did not detect differences at baseline.

More BT group participants had been treated for cancer (15 subjects versus 6 subjects in the ED group and 9 subjects in the TC group, $P<.027$, chi-square test). Although more TC group participants had fallen within the past year (15 subjects versus 6 subjects in the BT group and 9 subjects in the ED group, $P<.027$), these differences were not reflected in baseline responses on the fear-of-falling questionnaire. Additional baseline data among many other variables, including Instrumental Activities of Daily Living Scale[32] score, Sickness Impact Profile[32] score, sleeping patterns, and alcohol intake, were not different among these groups.

Balance Measures

The factor analysis did not result in meaningful factor variables from the 12 balance measures; that is, these balance measures could not be grouped into identifiable and relevant balance variables. Thus, an ANCOVA for repeated measures for each balance measure was used for reporting. There were some differences in preintervention balance measures among the three groups. For consistency, the repeated-measures ANCOVAs (two times [postintervention and follow-up] × three groups) were all adjusted for preintervention balance measures and baseline characteristics. Tables 2 through 4 show the results for balance measures under the four testing conditions at three time points. There were time and group interactions (column 6 in Tabs. 2–4) for dispersion (condition A) and COB-X (condition C). The overall group effects were seen for the dispersion (conditions C and D), COB-X (condition C), and COB-Y (condition A) measures. The Tukey's pair-wise comparisons showed that these group effects were due mostly to the reduction in force values between the BT and TC groups and between the BT and ED groups.

In summary, the dispersions under conditions C and D were reduced substantially between the preintervention and postintervention evaluations for the BT group (condition C, 21.80 to 13.70; condition D, 35.81 to 26.66) compared with the TC group (condition C, 23.78 to 21.17; condition D, 37.81 to 38.49) and the ED group (condition C, 22.13 to 19.59; condition D, 35.03 to 33.82) ($P<.0001$, Tab. 2). Subjects in the BT group also had increased dispersion from the postintervention evaluation to the 4-month follow-up compared with the ED and TC groups for condition A (BT group, 7.44 to 8.14; ED group, 7.22 to 7.43; TC group, 9.57 to 8.30) ($P=.03$). For the COB-X measure in condition C, there was a greater decrease between the preintervention and postintervention evaluations for the BT group (4.50 to 1.07) than for the TC group (3.87 to 3.04) and the ED group (3.08 to 4.07) ($P=.02$, Tab. 3). Subjects in both the BT and TC groups started to increase the COB-X measure at follow-up, but the magnitude was larger for the TC group (3.04 to 5.40, $P=.0184$, Tab. 3). The BT group also had substantially greater reductions in COB-Y measures for conditions A (5.66 to 1.26) and B (10.75 to 5.14) compared with the TC group (condition A, 3.70 to 3.69; condition B, 12.38 to 12.86) and the ED group (condition A, 5.14 to 4.98; condition B, 12.00 to 11.04)

Table 2.
Dispersion Measures by Condition, Time, and Group[a]

	BT Group (n=16)		ED Group (n=19)		TC Group (n=19)			
Condition/Time[b]	$\bar{X}$	SD	$\bar{X}$	SD	$\bar{X}$	SD	**Group P^c**	**Interaction P^c**
A								
Preintervention	9.37	3.35	7.46	2.06	10.50	5.05	.9891	.0344
Postintervention	7.44	2.46	7.22	2.72	9.57	3.20		
4-month follow-up	8.14	2.59	7.43	1.86	8.30	3.15		
B								
Preintervention	15.49	4.17	12.93	4.21	18.15	5.06	.3118	.0837
Postintervention	13.97	5.70	14.85	5.40	15.42	4.48		
4-month follow-up	16.27	7.25	14.67	8.70	17.76	8.44		
C								
Preintervention	21.80	6.09	22.13	5.77	23.78	6.17	.0001	.2681
Postintervention	13.70	3.89	19.59	3.86	21.17	4.92		
4-month follow-up	14.81	4.19	18.67	18.67	21.19	6.89		
D								
Preintervention	35.81	7.78	35.03	6.59	37.81	5.99	.0001	.4505
Postintervention	26.66	9.06	33.82	6.62	38.49	6.11		
4-month follow-up	27.62	6.96	33.08	6.98	36.69	6.56		

[a] BT=computerized balance training, ED=education (control), TC=tai chi.
[b] A=quiet standing, eyes open; B=quiet standing, eyes closed; C=toes up, eyes open; D=toes up, eyes closed.
[c] Group and interaction probability values were obtained from 2×3 (two time points×three groups) analysis of covariance using preintervention and baseline characteristics as covariates.

Table 3.
Measures of Center of Balance in the X Axis by Condition, Time, and Group[a]

	BT Group (n=16)		ED Group (n=19)		TC Group (n=19)			
Condition/Time[b]	$\bar{X}$	SD	$\bar{X}$	SD	$\bar{X}$	SD	**Group P^c**	**Interaction P^c**
A								
Preintervention	2.67	2.67	2.01	1.68	2.66	2.28	.4637	.5596
Postintervention	1.52	1.12	2.48	2.09	3.42	3.86		
4-month follow-up	1.90	1.85	2.06	1.88	2.69	2.19		
B								
Preintervention	6.98	6.10	5.08	4.96	7.92	6.18	.4986	.9323
Postintervention	3.75	4.16	5.39	4.99	5.40	5.32		
4-month follow-up	5.63	4.27	6.41	5.58	6.78	5.70		
C								
Preintervention	4.50	3.98	3.08	2.06	3.87	3.28	.0220	.0184
Postintervention	1.07	0.62	4.07	3.14	3.04	2.18		
4-month follow-up	1.73	1.95	3.07	2.17	5.40	5.11		
D								
Preintervention	8.18	5.86	5.39	3.31	6.28	5.42	.1890	.83619
Postintervention	6.31	4.63	5.17	3.05	5.34	3.96		
4-month follow-up	7.28	5.88	6.69	3.90	5.64	5.17		

[a] BT=computerized balance training, ED=education (control), TC=tai chi.
[b] A=quiet standing, eyes open; B=quiet standing, eyes closed; C=toes up, eyes open; D=toes up, eyes closed.
[c] Group and interaction probability values were obtained from 2×3 (two time points×three groups) analysis of covariance using preintervention and baseline characteristics as covariates.

(P=.007 and P=.0572, respectively; Tab. 4). Subjects in the TC group tended to show greater dispersion and lateral motion (COB-Y) immediately after the intervention in angular perturbation conditions.

Fear of Falling

Fifty-two subjects had complete data for the fear-of-falling questionnaire and covariate values. Table 5 displays the frequency of fear of falling by group and time. There were no differences in fear-of-falling status

Table 4.
Measures of Center of Balance in the Y Axis by Condition, Time, and Group[a]

Condition/Time[b]	BT Group (n=16) $\bar{X}$	BT Group (n=16) SD	ED Group (n=19) $\bar{X}$	ED Group (n=19) SD	TC Group (n=19) $\bar{X}$	TC Group (n=19) SD	Group P[c]	Interaction P[c]
A								
Preintervention	5.66	4.56	5.14	5.64	3.70	3.22	.0070	.6553
Postintervention	1.26	0.93	4.98	4.07	3.69	4.48		
4-month follow-up	1.86	1.57	4.52	3.36	4.02	3.11		
B								
Preintervention	10.75	6.72	12.00	12.42	12.38	8.82	.0572	.1869
Postintervention	5.14	4.35	11.04	9.79	12.86	7.35		
4-month follow-up	5.70	4.87	6.51	7.22	9.18	7.75		
C								
Preintervention	6.15	5.59	8.24	7.86	5.37	4.68	.3244	.3165
Postintervention	2.29	2.92	6.37	3.62	6.42	6.07		
4-month follow-up	3.71	4.17	4.88	4.74	6.58	8.55		
D								
Preintervention	12.61	8.60	13.38	10.92	9.13	6.19	.5858	.6731
Postintervention	10.87	10.95	12.28	8.26	14.26	7.40		
4-month follow-up	10.91	10.51	10.32	7.41	10.92	6.22		

[a] BT=computerized balance training, ED=education (control), TC=tai chi.

[b] A=quiet standing, eyes open; B=quiet standing, eyes closed; C=toes up, eyes open; D=toes up, eyes closed.

[c] Group and interaction probability values were obtained from 2×3 (two time points×three groups) analysis of covariance using preintervention and baseline characteristics as covariates.

Table 5.
Frequency of Fear of Falling by Group and Time[a]

Time	BT Group (n=17) n (%)	ED Group (n=19) n (%)	TC Group (n=16) n (%)	P
Preintervention	10 (58.8)	11 (57.9)	9 (56.3)	.99
Postintervention	10 (58.8)	13 (68.4)	5 (31.3)	.08
4-month follow-up	10 (58.8)	11 (57.9)	9 (56.3)	.99

[a] BT=computerized balance training, ED=education (control), TC=tai chi.

between the three groups at baseline. Subjects in the TC group appeared to be less afraid immediately after intervention (P=.08); specifically, the responses of the subjects in the BT group did not change, two more responses in the ED group showed greater fear (13 versus 11), and four more responses in the TC group showed less fear (5 versus 9). Subjects in all three groups, however, returned toward preintervention levels by the 4-month follow-up. It should be noted that these probability values may not be real, as the correlations from repeated measurements and differences in baseline characteristics were not adjusted. Application of the logistic regression model, using generalized estimating equations, however, addresses this problem. In addition, the same subject may not have reported being "afraid" to fall at all three time points. Seventy-one percent of the subjects in the BT group reported no change in fear-of-falling status at all three time points, compared with 60% in the ED group and 44% in the TC group (P=.27). The logistic regression model for repeated binary outcomes was used to fit these data, adjusting for covariates, using the generalized estimating equation approach. Table 6 presents the results from the final logistic regression model. There was no lack of fit, as determined by small standardized residuals. Living alone was positively associated with fear of falling (odds ratio=3.865, P=.037). Systolic blood pressure was negatively associated with fear of falling, but the magnitude was small.

To interpret the variable estimates from time-dependent covariates that interacted with each group, odds ratios were calculated by group for various comparisons in Table 7. Subjects in the TC group were less afraid of falling after the intervention compared with subjects in the BT and ED groups who had similar covariates (odds ratio=0.298 and 1.436, respectively; P=.13). The BT and ED groups had increased odds ratios for fear of falling

Table 6.
Logistic Regression Model for Repeated Measures of Fear of Falling Using the Generalized Estimating Equations Approach

Variables[a]	**Estimator**	**Odds Ratio**	**Z Robust Score**	***P***
Baseline covariates				
Live alone	1.352	3.865	2.09	.037
Systolic blood pressure	−0.027	0.973	−2.45	.014
Fall self-efficacy scale	0.166	1.181	1.32	.187
Time-dependent variables and variables with interaction				
COB-X in condition A	−0.310		−2.76	.006
Time 2 (postintervention) indicator	0.362		0.79	.43
Time 3 (4-month follow-up) indicator	0.091		0.18	.86
BT indicator	0.618		0.86	.39
TC indicator	0.037		0.03	.98
TC indicator×time 2 indicator	−1.574		−1.51	.13
TC indicator×time 3 indicator	−0.156		−0.18	.86
COB-Y in condition A	0.221		2.24	.025
COB-Y in condition A×BT indicator	−0.205		−1.61	.11
COB-Y in condition A×TC indicator	0.011		0.08	.94

[a] BT=computerized balance training; ED=education (control); TC=tai chi; COB-X=center of balance in x axis; COB-Y=center of balance in y axis; condition A=quiet standing, eyes open.

Table 7.
Odds Ratios for Fear of Falling for Time-Dependent Variables That Interact With Group[a]

				P	
Variables	**BT Group**	**ED Group**	**TC Group**	**BT Group Versus ED Group**	**TC Group Versus ED Group**
Preintervention	1.0	1.0	1.0		
Postintervention	1.436	1.436	0.298	NS[b]	.13
4-month follow-up	1.095	1.095	0.937	NS	NS
COB-X in condition A at preintervention	1.0	1.0	1.0		
COB-X in condition A at postintervention (one-unit decrease)	1.958	1.958	0.406	NS	.13
COB-X in condition A at 4-month follow-up (one-unit decrease)	1.493	1.493	1.278	NS	NS
COB-Y in condition A at preintervention	1.0	1.0	1.0		
COB-Y in condition A at postintervention[c] (one-unit decrease)	1.413	1.151	0.236	.11	.11
COB-Y in condition A at 4-month follow-up (one-unit decrease)	1.078	0.878	0.743	NS	NS

[a] BT=computerized balance training; ED=education (control); TC=tai chi; COB-X=center of balance in x axis; COB-Y=center of balance in y axis; condition A=quiet standing, eyes open.

[b] P=.08 for BT group versus TC group.

[c] NS=not significant at .2 level.

between the preintervention and postintervention evaluations for 1 unit of reduction in COB-X for force under condition A, but the odds ratio for fear of falling decreased to 0.406 for the TC group. On average, all subjects showed a small reduction in COB-X under condition A (Tab. 3). There was no interaction between COB-X under condition A and treatment group (Tab. 6). The odds ratio for fear of falling was 1.413 times higher immediately after intervention than before intervention for subjects in the BT group with 1 unit of reduction in COB-Y for force under condition A, but the odds ratio was 0.236 lower for the TC group (P=.08). On average, the BT group had 4.4 units of reduction in COB-Y for force under condition A from the preintervention evaluation to the postintervention evaluation, and the TC group had only 0.01 unit of reduction (Tab. 4). Thus, applying the logistic regression model (Tab. 6) yielded an odds ratio for fear of falling that was 1.34 times higher for the BT group but 0.30 times lower for the TC group, on average.

Discussion

The analyses of data for the 72 inactive older subjects selected from the Atlanta FICSIT randomized trial suggest that the 15-week computerized BT improved postural stability, as reflected in platform data output. The improvement in COB-X or COB-Y in condition A was associated with increased fear-of-falling responses in the

BT and ED groups. The 15-week TC practice did not improve postural stability, but might have reduced fear of falling. Our analyses of fear of falling, however, were based on a small sample size and the possibility of a relatively large Type I error. Further investigations are needed to confirm these exploratory findings.

Evaluation of balance often requires the application of more sophisticated clinical and computer-based tests among older individuals, regardless of whether they are active or inactive. This concern is particularly true if subjects do not have documented histories of falls or definitive pathologies contributing to postural instability. This type of evaluation is also necessary to gain insights into innovative interventions developed to reduce falls or attributes of frailty. In our study, the participants were older, represented varying degrees of independence, and participated in nontraditional treatment forms. The interventions lasted only 15 weeks, and at no time did weekly contact exceed 2 hours. We believe, therefore, that the increased stability demonstrated by the BT group is remarkable.

On first glance, these findings may not be surprising. Subjects in the BT group were trained on the same instrument with which they were tested; thus, a high degree of user familiarity was present. This explanation for improved stability is unlikely for several reasons. First, the testing situation was not included as part of the training, and subjects in the BT group were trained to increase sway. Second, if familiarization with instrumentation had been a primary factor for enhanced postural stability, then we would expect that the other two intervention groups would have shown reduced force platform measurements at repeat test intervals (postintervention and 4-month follow-up).

Coogler and Wolf[33] have reported that among 85 elderly adults, those assigned to the control group tested with the same magnitude of postural stability as subjects engaged in a sensory training balance program measured at 1 week and 4 months after completion of training. Yet, in the present study, the TC group in particular showed increased sway at the postintervention evaluation for several conditions. In contrast, Hu and Woollacott[34] studied 24 older subjects, half of whom were given training for 1 hour a day over 10 to 15 days to enhance stability. Follow-up at 1 and 4 weeks after the completion of training indicated that improved stability persisted in five of eight training conditions, as compared with the control subjects. This improvement was attributed to enhanced integration of sensorimotor function within the nervous system rather than to repetition, selected cognitive processing, or improved endurance. Although the intensity of their intervention was comparable to ours, the robustness of their subjects was probably superior, and the duration of follow-up monitoring was four times shorter. Thus, we would expect decay in their performance by 4-month follow-up as well.

Last, it could be argued that the improved stability might be unique to older people or due to increased muscle strength[34] derived from the BT group. This explanation is also unlikely because there were no baseline differences in strength among the groups[25] and similar magnitudes of stability have been demonstrated on a similar instrument after training of a younger group.[36]

The meaning underlying successful efforts to reduce sway should be viewed in a behavioral context. Therefore, changes in fear of falling responses were examined. These data were evaluated by adjusting for different baseline and time-dependent covariates. Although the impact of these interventions did not affect fear of falling profoundly, only the TC group showed some indication of less fear of falling. In addition, if it can be assumed that a change in a response on a fear-of-falling questionnaire over time indicates a change in attitude toward falls, the BT group showed the least change, with 71% of the subjects always indicating the same response, whereas only 44% of the subjects in the TC group gave the same fear responses over time.

The generalized estimating equation approach was used to fit a logistic regression model so that we might further understand the interrelationship between postural measurements and other key variables. As might be anticipated, living alone increased the odds ratio for fear of falling (odds ratio=3.865, Tab. 6), irrespective of group assignment, whereas lower systolic blood pressure readings were weakly associated with fear of falling. When assessing fear of falling by group and time (Tab. 7) after controlling for all other covariates, the limited impact of BT training became apparent. The BT and ED groups showed an odds ratio for fear of falling of 1.436 at the postintervention evaluation, compared with an odds ratio of 0.298 for the TC group. When trained to improve postural stability, the BT group increased the odds ratio for fear of falling by 1.413 at the postintervention evaluation, compared with an odds ratio of 0.236 for the TC group, for one unit of reduction in sway force in the anteroposterior direction during quiet standing (Tab. 7). Conceivably then, TC training, although promoting less fear of falling and greater sway in specific sagittal or coronal planes, may also allow subjects to feel more confident during quiet standing. Alternatively, increasing postural stability, even during the more basic task of quiet standing, following training with a computerized balance device does not ensure a change in fear of falling when other baseline covariates are controlled. Fear of falling is augmented among these subjects.

From these observations, we conclude that computerized BT, as applied in this study, enhanced postural stability measured from a force platform for participants receiving BT. These changes were not manifest in less fear of falling. These observations, when combined with the fact that BT had no impact on other psychosocial variables such as self-mastery,[25] call into question whether enhanced postural stability in older individuals is a necessary or appropriate condition to influence falling events or acquisition of behaviors that would instill confidence to successfully combat unexpected, real-life perturbations. On the other hand, the increased force transducer values noted after the intervention, which were indicative of less stability, were seen in angular perturbation conditions (dispersion and COB-Y) in the TC group. This observation would only strengthen this difference between the BT and TC groups. This difference between the groups, therefore, may have been caused by the combined enhanced stability of the BT group and the reduced stability of the TC group over time. Neither intervention had enough long-term impact on fear-of-falling responses beyond the intervention, because the odds ratios for fear of falling were virtually identical among all three groups at the 4-month follow-up (Tab. 7).

In light of the fact that TC delays onset time for falling in older individuals,[25] the potential importance of this exercise form warrants more detailed scrutiny. We know that TC emphasizes increased total body movement, particularly in rotational planes, with gradual narrowing of base of support.[35,36] Ostensibly, this movement behavior would encourage greater total body displacement capabilities. If our TC practitioners were incorporating these changes into their postural stances, enhanced sway, especially during angular displacements, would be a very real possibility. This behavior could only be manifest with practice and was seen for angular displacements at postintervention and follow-up evaluations for conditions of dispersion and COB-Y. These observations at the very least raise the intriguing notion that reduced falling events seen in TC practitioners may be associated with training to increase rather than decrease postural instability.

The fact that changes in fear-of-falling responses did not persist to follow-up for the TC group may indicate a need for a more intense or longer intervention to maintain a sense of well-being. Determining the validity of these speculations must await measurements taken from a larger sample of TC practitioners, including those who are more "active" than the subjects from which our platform data were taken.

Last, we do not know the influence that the TC instructor may have had on participant adherence with practice between instructional classes, nor do we know about the intensity of practice efforts of subjects in the TC and BT groups between intervention sessions. Approximately 40% of the subjects in the TC group, however, continued to meet weekly for TC practice after completion of the 4-month follow-up, and 30% of these subjects continued to meet weekly for TC practice 2 years after completion of this study.

Future Directions

Tai chi training may be manifest in less postural stability and more sway to dynamic perturbations. The potential value of TC as an exercise regimen should be explored. This study limited TC sessions to 15 weekly meetings covering 10 "forms." This time interval is remarkably narrow when one considers that TC is practiced among older Chinese individuals on a daily basis and becomes an integral activity much earlier in life than when our older subjects first learned this movement form.[37,38] A more detailed and extended training interval should be studied, particularly among relatively healthy elderly individuals, to assess the extent of psychosocial and physical benefits and the degree to which this exercise form is integrated into routine lifestyles. The influence that both the trainers and the practice intensity between sessions may have on these and other outcome measures also needs to be studied. Future efforts will engage several TC or BT instructors so that physiological changes can be related to the instruction. Efforts to accurately monitor intensity of practice between sessions will also be made. In this study, subjects in the TC group were given an information sheet about each form, whereas subjects in the other groups were not given this information. There is no mechanism to retrieve reliable data on the extent to which this variable affected either the "interest" of the subjects in the BT and ED groups or the intensity with which subjects in the TC group practiced.

Equally as important is the need for future investigations to systematically study the impact of a comprehensive TC intervention on the well-being of more frail, older subjects with a defined diagnosis that has immobilizing consequences.

Analyses of the present data set also suggest that computerized BT can reduce sway at rest or during perturbations with defined displacement and speed characteristics. Whether demonstrating greater postural stability is the most efficacious approach is not yet known, because the outcome did not have a favorable impact on fear of falling or other psychosocial variables.[25] Other avenues of investigation to further assess the benefits of computerized BT can be examined. Among these approaches would be (1) extending the treatment interval to greater than 15 hourly sessions, (2) stressing the limits of stability to the point of near falls as a primary treatment strategy, and (3) engaging in more dynamic movements, including progressively narrowed base of support, during the actual training.

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References

1 Stamford BA. Exercise and the elderly. *Exerc Sports Sci Rev.* 1988;16: 241–379.

2 Vallbona C, Baker SB. Physical fitness in the elderly. *Arch Phys Med Rehabil.* 1984;65:194–200.

3 Hurley O. *Safe Therapeutic Exercise for the Frail Elderly: An Introduction.* Albany, NY: Center for the Study of Aging; 1988.

4 Fletcher G, ed. *Exercise and the Practice of Medicine.* 2nd ed. Mount Kisco, NY: Futura Publishing Co Inc; 1988.

5 Fiatarone MA, Marks EC, Ryan ND, et al. High-intensity strength training in nonagenarians. *JAMA.* 1990;263:3029–3034.

6 Grimby G. Physical activity and muscle training in the elderly. *Acta Med Scand Suppl.* 1986;711:233–243.

7 Hawker M. *Geriatrics for Physiotherapists and the Allied Professions.* London, United Kingdom: Faber & Faber Ltd; 1974.

8 Harris R, Frankel LJ. *Guide to Fitness After Fifty.* New York, NY: Plenum Press; 1977.

9 Biegel L. *Physical Fitness and the Older Person.* Rockville, Md: Aspen Publishers Inc; 1984.

10 Shephard RJ. *Physical Activity and Aging.* 2nd ed. Rockville, Md: Aspen Publishers Inc; 1987.

11 Gueldner SH, Spradley J. Outdoor walking lowers fatigue. *Journal of Gerontological Nursing.* 1988;14:6–12.

12 Lowenthal DT, Wheat M, Kuffler LA. Coordinating drug use and exercise in elderly hypertensives. *Geriatrics.* 1988;43:69–80.

13 Fiatarone MA, O'Neill EF, Ryan ND, et al. Exercise training and nutritional supplementation for physical frailty in very elderly people. *N Engl J Med.* 1994;330:1769–1775.

14 Tinetti ME, Baker DI, McAvay G, et al. A multifactorial intervention to reduce the risk of falling among elderly living in the community. *N Engl J Med.* 1994;331:821–827.

15 Wolfson L, Whipple R, Derby C, et al. Balance and strength training in older adults: intervention gains and tai chi maintenance. *J Am Geriatr Soc.* 1996;44:498–506.

16 Province MA, Hadley EC, Hornbrook MC, et al. The effects of exercise on falls in elderly patients. *JAMA.* 1995;273:1341–1347.

17 Wolf SL, LeCraw DE, Barton LA, Jann BB. A comparison of motor copy and targeted feedback training techniques for restitution of upper extremity function among neurologic patients. *Phys Ther.* 1989; 69:719–735.

18 Wolf SL, Segal RL. Downtraining human biceps-brachii spinal stretch reflexes. *J Neurophysiol.* 1996;75:1637–1645.

19 Wolf SL, Kutner NG, Green RC, McNeely E. The FICSIT Trials, Site 5: Emory University and the Wesley Woods Geriatric Center. *J Am Geriatr Soc.* 1993;41:329–332.

20 Nashner LM, McCollum G. The organization of human postural movements: a formal basis and experimental synthesis. *Behavior and Brain Science.* 1085;8:135–172.

21 Murray MP, Seireg AA, Sepic SB. Normal postural stability and steadiness: quantitative assessment. *J Bone Joint Surg [Am.]* 1975;57:510–516.

22 Wolfson L, Whipple R, Amerman P, Kleinberg A. Stressing the postural response: a quantitative method of teaching balance. *J Am Geriatr Soc.* 1986;34:845–850.

23 Hocherman S, Dickstein R. Platform training and postural stability in hemiplegia. *Arch Phys Med Rehabil.* 1984;65:588–592.

24 Winstein CJ, Gardner ER, McNeal DR, et al. Standing balance training: effect on balance and locomotion in hemiparetic adults. *Arch Phys Med Rehabil.* 1989;70:755–762.

25 Wolf SL, Barnhart HX, Kutner NG, et al. Reducing frailty and falls in older persons: an investigation of tai chi and computerized balance training. *J Am Geriatr Soc.* 1996;44:489–497.

26 Patla AE. A framework for understanding mobility problems in the elderly. In: Craik RL, Oatis C, eds. *Gait Analysis: Theory and Application.* St Louis, Mo: Mosby; 1995:436–449.

27 Wolf SL, Coogler CE, Green RC, Xu T. Novel interventions to prevent falls in the elderly. In: Perry HM III, Morley JE, Coe, RM, eds. *Aging and Musculoskeletal Disorders: Concepts, Diagnosis, and Treatment.* New York, NY: Springer Publishing Co Inc; 1993:178–195.

28 Fisher DL, Van Belle G. *Biostatistics: A Methodology for the Health Sciences.* New York, NY: John Wiley & Sons Inc; 1993.

29 Johnson RA, Wichern DW. *Applied Multivariate Statistical Analysis.* Englewood Cliffs, NJ: Prentice-Hall Inc; 1992.

30 Zeger SL, Liang KY. Longitudinal data analysis for discrete and continuous outcomes. *Biometrics.* 1986;42:121–130.

31 Lezak MD. *Neuropsychological Assessment.* 3rd ed. New York, NY: Oxford University Press Inc; 1995:381–384.

32 Buchner DM, Hornbrook MC, Kutner NG, et al. Development of the common data base for the FICSIT trials. *J Am Geriatr Soc.* 1993;41: 297–308.

33 Coogler CE, Wolf SL. Balance training in elderly fallers and non-fallers. *Issues on Aging* (newsletter of the Section on Geriatrics, American Physical Therapy Association). 1996;19:30.

34 Hu M-S, Woollacott MH. Multisensory training of standing balance in older adults, I: postural stability and one-leg stance balance. *J Gerontol.* 1994;49:M52–M61.

35 Wolfson L, Judge J, Whipple R, King M. Strength is a major factor in balance, gait, and the occurrence of falls. *J Gerontol.* 1995;50:M64–M67.

36 Hamman RG, Mekjavic I, Mallinson AI, Longridge NS. Training effects during repeated therapy sessions of balance training using visual feedback. *Arch Phys Med Rehabil.* 1992;73:738–744.

37 Koh TC. Tai chi chaun. *Am J Chin Med.* 1995;9:15–22.

38 *Preliminary Study of Reducing Aging With Taijiquan.* Beijing, People's Republic of China: People's Sports and Exercise Publication; 1983.