Improving Sleep Quality in Older Adults with Moderate Sleep Complaints: A Randomized Controlled Trial of Tai Chi Chih

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Study Objectives: To determine the efficacy of a novel behavioral intervention, Tai Chi Chih, to promote sleep quality in older adults with moderate sleep complaints.

Design: Randomized controlled trial with 16 weeks of teaching followed by practice and assessment 9 weeks later. The main outcome measure was sleep quality, as assessed by the Pittsburgh Sleep Quality Index (PSQI).

Setting: General community at 2 sites in the US between 2001 and 2005.

Participants: Volunteer sample of 112 healthy older adults, aged 59 to 86 years.

Intervention: Random allocation to Tai Chi Chih or health education for 25 weeks.

Results: Among adults with moderate sleep complaints, as defined by PSQI global score of 5 or greater, subjects in the Tai Chi Chih condition were more likely to achieve a treatment response, as defined by PSQI less than 5, compared to those in health education ($P < 0.05$). Subjects in the Tai Chi Chih condition with poor sleep quality also showed significant improvements in PSQI global score ($P < 0.001$) as well as in the sleep parameters of rated sleep quality ($P < 0.05$), habitual sleep efficiency ($P < 0.05$), sleep duration ($P < 0.01$), and sleep disturbance ($P < 0.01$).

Conclusions: Tai Chi Chih can be considered a useful nonpharmacologic approach to improve sleep quality in older adults with moderate complaints and, thereby, has the potential to ameliorate sleep complaints possibly before syndromal insomnia develops.

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Keywords: Insomnia, aging, treatment

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POOR SLEEP QUALITY CONSTITUTES ONE OF THE MOST COMMON DIFFICULTIES FACING OLDER ADULTS, WITH 58% REPORTING SLEEPING DIFFICULTIES at least a few nights per week.[1,2] However, sleep problems remain untreated in up to 85% of people,[3] and, among those who receive treatment, sedative-hypnotic medications remain the treatment of choice.[4] Unfortunately, such pharmacologic management may have particularly deleterious effects in older adults, including daytime confusion, drowsiness, falls and fractures, and adverse interactions with other medications.[5-7]

Behavioral interventions such as cognitive behavioral therapy are among the most widely used nonpharmacologic alternatives for the treatment of insomnia.[8,9] Cognitive behavioral therapy achieves robust improvements of insomnia, as compared with pharmacotherapy,[10,11] and a recent meta-analysis concluded that various behavioral treatments, including cognitive behavioral and relaxation therapies, were equally effective in older adults with chronic insomnia.[9] However, most available studies have examined patients with syndromal insomnia and largely ignored the relatively large segment of the older adult population with moderate sleep complaints, who are not yet at a threshold of insomnia diagnosis (e.g., absence of daytime clinical impairment).

Older adults with insomnia symptoms are at substantial risk for developing syndromal insomnia, as well as depression, anxiety, and pain problems.[12] Hence, preventive treatments that target moderate sleep complaints have the potential to reduce the onset of multiple morbidities in older adults,[12] in addition to forestalling the onset of clinical insomnia in this at risk population. Unfortunately, resources that deliver cognitive behavioral therapy (e.g., highly trained clinicians) may be neither practical nor cost effective in usual care settings, especially for delivery to older adults with moderate sleep complaints but without syndromal insomnia. Moreover, older adults are increasingly seeking lifestyle interventions that are aligned with health promotion, rather than disease treatment.

Among health professionals and the general public, it is generally thought that physical exercise may enhance sleep quality. Indeed, such recommendations are often integrated into education programs to promote good sleep practices and sleep hygiene. Surprisingly, however, only 2 randomized controlled clinical trials have directly evaluated the efficacy of moderate-intensity exercise on self-rated quality of sleep in older adults. One study by King et al[13] demonstrated that 16 weeks of community-based exercise training (i.e., endurance training, brisk walking, and stationary cycling) was superior to a wait-listed control condition on measures of sleep quality, as assessed by the Pittsburgh Sleep Quality Index (PSQI), in a sedentary volunteer sample of adults older than 50 years of age. However, such an aerobic exercise prescription might not be well-tolerated in an elderly population, who have age-related physical limitations. The other study by Li et al[14] compared 2 forms of exercise, Tai Chi versus stretching, on PSQI outcomes in older

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adults and demonstrated greater benefit of Tai Chi, as compared with stretching exercise, on sleep-quality outcomes, although this study did not include a nontreatment control group.

Given the potential benefits of relaxation therapies as well as aerobic exercise on insomnia symptoms, we hypothesized that Tai Chi, a slow-moving meditation,[13] might have a positive impact on sleep quality. Among elderly who often have age-related limitations in their ability to tolerate even moderate-intensity exercise, Tai Chi Chih (TCC) is particularly attractive for use; it is a westernized and standardized version of Tai Chi, consisting of 20 simple and separate moves. We and others have previously demonstrated that the administration of TCC for 16 weeks improves measures of physical and emotional health functioning in older adults.[14-16]

The present study was a randomized controlled trial conducted in part to evaluate the short-term clinical efficacy of TCC versus health education (HE) control on measures of self-reported sleep quality. This study was part a clinical trial designed to evaluate the effect of TCC versus HE on herpes zoster risk and on health behaviors, including sleep quality in older adults. The effect of TCC on herpes zoster risk has been previously reported.[16] During subject recruitment, subjects were informed that the study aimed to evaluate the effects of TCC versus HE on "health and well-being." Hence, older adults were recruited without disclosure of the aim to examine sleep quality, which minimizes the possibility of reporting bias on measures of subjective sleep outcomes. Furthermore, given the design of the clinical trial, we enrolled subjects with and without sleep complaints. Subjects without sleep complaints were also included in the analyses, given limited empiric data on the effects of TCC on behavior measures and evidence that this practice can increase energy and vitality measures.[17] In contrast with previous research on TCC and self-reported sleep quality,[17] a nonexercise, nontreatment control group was used. We compared changes in sleep quality after 16 weeks of the teaching phase of the intervention and 9 weeks later at a follow-up assessment.

MATERIALS AND METHODS

Design Overview

This randomized, controlled clinical trial allocated older adults to receive either TCC or HE (active control intervention) in a 1:1 ratio between 2001 and 2005. From 2001-2002, the study was conducted in San Diego, and, from 2002- 2005, the study was performed in Los Angeles following relocation of the study investigator (MRI). HE was selected as the control condition, as we deemed it a higher priority to determine in this initial study whether TCC has an active clinical benefit that is independent of nonspecific treatment factors (e.g., expectation, group support, attention), rather than comparing this approach with isolated treatment components such as relaxation, exercise, or meditation. Participants were recruited through newspaper advertisements that stated the aim of the study as comparing the effects of TCC versus HE on "health and well-being in older adults." No additional information about the study hypothesis or about evaluation of sleep quality was provided. Hence, participants were blinded to the study objectives and outcomes for self-rated sleep quality.

Setting and Participants

Inclusion criteria were that participants be: (1) 59 years or older and (2) in self-reported good health. The following exclusion criteria were any acute current illness that might interfere with interpretation of the study; presence of a current major psychiatric disorder including syndromal insomnia; alcohol intake greater than 3 drinks per day; and/or unwillingness to adhere to study protocol or ongoing participation in Tai Chi. Subjects who reported significant daytime clinical impairment secondary to insomnia symptoms and/or regular use of sleep-related prescription medications were excluded, given the study objective to evaluate older adults with moderate sleep complaints who are not yet at the threshold of syndromal insomnia.

Procedures

Participants who responded to the advertisement (N = 189) underwent 2 assessment phases before they were included. A 15-mintue telephone interview by a trained project coordinator ensured that participants fulfilled the screening eligibility criteria. The second eligibility-assessment phase included an interview to obtain a medical history and current medication use, followed by administration of the Structured Clinical Interview for DSM-IV diagnoses to rule out the presence a current psychiatric disorder.[18] Specific queries were also used to screen for the presence of insomnia symptoms (e.g., difficulty initiating sleep, maintaining sleep, early morning awakening, or "nonrestful" sleep). To determine the presence of clinical impairment (e.g., DSM-IV syndromal insomnia) that would exclude subjects from the study, other queries asked whether insomnia symptoms interfered with daytime functioning (e.g., symptoms of fatigue, depression, or poor concentration due to sleep problems that interfered with daily activities) or whether subjects were regularly using sleep-related prescriptions medications.

Randomization and Interventions

Randomization was performed using a computer-generated schedule independent of treatment personnel. Allocation concealment was implemented using sealed, sequentially numbered boxes that were identical in appearance for the 2 treatment groups. All study personnel in contact with the participants were unaware of the randomization sequence. A total of 112 participants aged 59 to 86 years were enrolled and randomly assigned to TCC (n= 59) or HE (n = 53) (Figure 1; San Diego, n = 40; Los Angeles, n = 72).

Subjects received either 16 weeks of teaching of TCC or HE administered to groups of 7 to 10 persons. TCC sessions lasted 40 minutes and were given 3 times per week for a total 120 minutes of weekly instruction. HE was allocated an identical amount of 120 minutes of weekly instruction. The rationale communicated to subjects was that TCC is a health-management intervention that incorporates meditation and repetitive physical activity to promote "well-being in aging," whereas HE aims to promote healthy behaviors and well-being by providing knowledge about health management. For TCC, objectives and learning activities related to the specific set of 20 exercises employed were identified according to a therapist

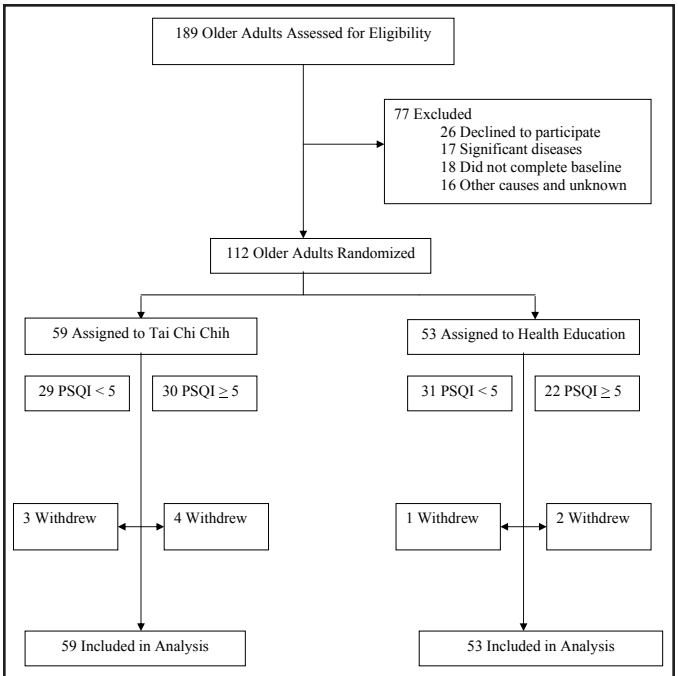

Figure 1—Participant flow and distribution of subjects in study.

manual[19] with verification of skills attainment and weekly supervision by master's level TCC instructors. All TCC instructors had undergone certification as such by the national TCC association, and there was no site effect or teacher effect on the results. Individual exercises were taught weekly in a graduated manner with acquisition of the full set of 20 exercises after 16 weeks of instruction. The HE intervention involved 16 didactic presentations on a series of health-related themes, which were provided by a physician (MRI) or licensed clinical psychologist (SJM) with group discussion, as previously described.[20] Two sessions in the HE intervention specifically included information about sleep and sleep hygiene, and other sessions provided information about the health benefits of exercise and relaxation. Sessions on sleep hygiene provided knowledge about sleep practices (e.g., regular sleep-wake activity schedule, using bed for sleep, refraining from alcohol and from caffeine, exercising in the morning). We assessed treatment credibility and expectation for change after the second treatment session using a 5-point likert scale.[21]

Outcomes and Follow-Up

Assessments were administered at baseline (i.e., before the intervention), at 16 weeks (i.e., after completion of the teaching phase of the intervention), and at 25 weeks follow-up (i.e., 9 weeks after learning acquisition of TCC and practice of the full set of 20 exercises). The primary outcome variable was self-rated sleep quality, as measured by the PSQI, a widely used, 19-item, self-report questionnaire that measures sleep disturbances.[22, 23] According to scoring guidelines, 19 items of the PSQI are used to generate 7 sleep component scores (range of possible subscale scores, 0-3): subjective sleep quality, sleep latency (i.e., time needed to fall asleep), sleep duration (number of hours of actual sleep per night), habitual sleep efficiency (i.e., total sleep time divided by time in bed, converted to a score 0-3), sleep disturbances (e.g., waking up in the middle of the night and the like), use of sleeping medications, and daytime dysfunction (e.g., having difficulty staying awake during the day.) The sum of these component scores yields a global score (range, 0-21), with a score cutoff of greater than 5 indicating clinical sleep impairment [22,23] with a high sensitivity (98.7%) and specificity (84.4%) in identifying insomnia.[24] The PSQI has favorable psychometric properties, with internal consistency reliability ranging from 0.80 to 0.83, test-retest reliability from 0.85 to 0.87, and convergent validity with other self-report measures of sleep and sleep logs.[22,23] The Beck Depression Inventory was used to assess severity of depressive symptoms.[25] Participants were also monitored for use of other treatments and TCC practice time using daily practice diaries during the 16-week intervention phase and the 9-week follow-up. Finally, given that TCC incorporates a component of physical activity, average weekly metabolic equivalents were determined over the course of the trial using previously described procedures.[26]

Statistical Analysis

The primary question of interest concerns the benefit of TCC versus HE in healthy older adults who evidence moderate sleep-quality complaints, as defined by the PSQI global score cutpoint of 5. Hence, the sample was stratified into groups with "good" sleep quality (i.e., PSQI global score < 5) versus those with "poor" sleep quality (i.e., PSQI global score ≥ 5). Improvement in sleep quality in the latter group was the key criterion for determining sample-size requirement. Based on prior meta-analytic findings,[9] in which the mean treatment effect was 0.76, we estimated that the enrollment of 28 per treatment group among those with poor sleep would provide the study with a statistical power of 80% ($\alpha = 0.05$) to detect significant improvements in sleep quality. Because it was expected that approximately 50% of the sample would have poor sleep, the overall target sample size was set at 112. Comparison of treatment groups stratified by sleep quality at entry was performed using analyses of variance.

The primary outcome was defined by the PSQI global score threshold less than 5 among the participants with poor sleep quality; Fisher exact test was used for comparison of numbers of participants who achieved this threshold value of PSQI global score at 25 weeks. A number needed to treat value was calculated for the use of TCC to achieve this treatment threshold compared with the HE condition.[27] We posited that benefit would be found at 25 weeks: after subjects had learned TCC (e.g., during the teaching phase of the 16-week intervention) and after an interval for practice of TCC. Achievement of this treatment threshold at both 16 weeks and 25 weeks were analyzed. All PSQI and Beck Depression Inventory score data were normally distributed, and the general effects of the intervention over time were assessed using a mixed-models group (TCC versus HE) × PSQI score (PSQI global score < 5 versus PSQI global score ≥ 5) × time (baseline, week 16, and week 25) repeated-measures analysis of variance and covariance for PSQI global score and PSQI component scores, with adjustment for multiple comparisons. Because depressive symptoms are often associated with poor sleep quality, additional analyses covaried for severity of such symptoms using the Beck Depression Inventory. Secondary analyses of

Table 1—Baseline Characteristics of the Study Participants

	Tai Chi Chih		Health Education		
	PSQI < 5 (n = 29)	PSQI ≥ 5 (n = 30)	PSQI < 5 (n = 31)	PSQI ≥ 5 (n = 22)	P value
Age, y[a]	69.6 (6.3)	69.7 (6.1)	69.8 (7.6)	70.7 (7.5)	0.94
Women[b]	19 (65.5)	22 (73.3)	16 (51.6)	14 (63.6)	0.36
Non-White[b]	2 (6.9)	9 (30.0)	6 (19.4)	4 (18.2)	0.93
Married[b]	15 (51.7)	13 (43.3)	17 (54.8)	13 (59.1)	0.70
Education, y[a]	16.7 (2.5)	16.6 (2.3)	16.2 (2.3)	15.3 (2.7)	0.16
Annual income, $[a,c]	62.3 (39.7)	48.5 (30.5)	72.5 (51.9)	52.4 (39.5)	0.18
BDI score[a]	3.8 (3.4)	6.0 (4.8)	2.6 (3.1)	7.5 (4.4)	0.001
Physical activity, metabolic equivalents/wk[a]	251.3 (26.9)	259.3 (25.5)	258.5 (30.6)	249.8 (20.5)	0.43

[a]Data presented as mean (SD).
[b]Data presented as number (%).
[c]Annual income is × 1000.
PSQI refers to Pittsburgh Sleep Quality Index; BDI, Beck Depression Inventory.

PSQI scores included a covariate if (a) there was a significant difference in a background variable between the 2 treatment groups and (b) the background variable was significantly related to the PSQI scores. For time effects from baseline to week 25, linear growth-curve estimates were generated to evaluate growth curve slopes in the 2 treatment groups who had poor sleep quality. Growth-curve analyses provide an estimate of linear rate of change for the 2 treatment groups. Greater improvements in PSQI scores over time (i.e., a greater linear rate of change) were hypothesized for the TCC group who had poor sleep quality at baseline. All analyses used an intention to treat approach.

RESULTS

Characteristics of the Study Subjects

As shown in Table 1, the intervention groups stratified by PSQI global scores were similar in age, sex, ethnicity, marital status, education level, annual income, and average weekly physical activity. Severity of depression scores was higher in the treatment groups who had poor sleep quality (PSQI global scores ≥ 5) as compared with those with good sleep quality (PSQI global scores < 5), but the TCC and HE intervention groups did not differ. Among subjects with poor sleep quality, about one third were taking over-the-counter sleep-related medications, as compared with no use in those subjects with good sleep quality; the TCC and HE intervention groups did not differ. Finally, subjects had little medical morbidity and reported, on average, the use of fewer than 2 medication types; medications to treat hypertension, heart disease, and respiratory illness were the 3 most commonly reported classes of medications used. There was no discernible association between any of the clinical demographic variables and sleep-quality responses in the TCC or the HE group.

Adherence to Intervention

Of 112 subjects allocated to the intervention, 102 persons (91%) completed the intervention and were followed to 25 weeks (Figure 1). Of the 7 withdrawals in TCC, 6 withdrew due to the difficulties with time commitments and/or transportation, and 1 did not like the class. Of the 3 withdrawals in HE, 2 withdrew due to difficulties with the time commitment, and 1 dropped due to health problems. Attendance at treatment sessions was high; TCC participants attended 83% of the classes, and HE subjects attended 80% of all sessions.

The 2 intervention groups perceived the treatments as equally credible, with subjects in the TCC and HE groups reporting a similar level of confidence, respectively, that "TCC would be successful in improving health in older adults" or that "HE would be successful in improving health in older adults" (P = 0.56). In addition, participants in the TCC and HE were equally "confident in recommending TCC (or HE) to a friend" (P =0.96).

There were no adverse events associated with either intervention. No participant reported use of other behavioral or complementary medicine practices during the course of the intervention.

Primary Outcome Measure

The primary outcome of interest was the proportion of participants achieving a PSQI global score of less than 5 at week 25 (i.e., after the 16-week teaching phase in which participants had learned the 20 different movements of TCC and then practiced the full set for 9 weeks). Among the participants who entered the study with sleep impairment (i.e., PSQI ≥ 5), 19 of 30 (63%) in the TCC group achieved a PSQI global score of less than 5, whereas, in the HE control group, only 7 of 22 (32%) had achieved this threshold at week 25 ($\chi^2 = 5.0$, $P < 0.05$). At 16 weeks, immediately after completion of the teaching phase of the intervention, a similar benefit was observed although this did not reach statistical significance ($\chi^2 = 2.3$, $P = 0.13$) Among participants who entered the study with PSQI scores less than 5, scores remained low and did not change.

Secondary Outcome Measures

Secondary outcomes measures were change in PSQI global score and the 7 component scores of the PSQI over the 25 weeks (Table 2). Significant time-by-group interactions were

Table 2—PSQI Sleep Quality Across 3 Assessment Points

	Tai Chi Chih PSQI < 5 (n = 29)	Tai Chi Chih PSQI ≥ 5 (n = 30)	Health Education PSQI < 5 (n = 31)	Health Education PSQI ≥ 5 (n = 22)	Time Effect		Time × Group	
					F	P	F	P
Global Sleep Quality					10.0	0.002	20.7	0.0001*
Baseline	2.96 (0.85)	6.67 (1.54)	2.52 (1.18)	8.18 (3.25)				
Posttreatment	3.38 (2.46)	5.13 (3.00)	2.56 (1.85)	6.31 (3.68)				
Follow-up	3.43 (1.82)	4.87 (2.30)	2.54 (2.22)	6.97 (3.59)				
Sleep Quality					0.5	0.49	6.2	0.02*
Baseline	0.50 (0.51)	1.10 (0.56)	0.39 (0.56)	1.23 (0.75)				
Posttreatment	0.62 (0.62)	0.69 (0.62)	0.48 (0.57)	1.14 (0.73)				
Follow-up	0.62 (0.56)	0.81 (0.49)	0.43 (0.69)	1.10 (0.62)				
Sleep latency					18.1	0.0001	2.8	0.1
Baseline	0.43 (0.63)	1.27 (0.78)	0.26 (0.44)	1.50 (0.91)				
Posttreatment	0.41 (0.57)	0.87 (0.92)	0.11 (0.32)	1.31 (1.01)				
Follow-up	0.29 (0.46)	0.87 (0.81)	0.14 (0.36)	1.20 (0.89)				
Habitual sleep efficiency					0.1	0.95	5.8	0.02*
Baseline	0.07 (0.26)	0.73 (0.78)	0.23 (0.43)	0.73 (0.94)				
Posttreatment	0.21 (0.49)	0.48 (0.73)	0.30 (0.67)	0.56 (0.96)				
Follow-up	0.33 (0.48)	0.43 (0.79)	0.29 (0.46)	0.63 (0.76)				
Sleep Duration					4.1	0.05	8.2	0.005*
Baseline	0.18 (0.39)	0.67 (0.76)	0.32 (0.54)	1.32 (0.84)				
Posttreatment	0.31 (0.54)	0.54 (0.65)	0.34 (0.72)	1.19 (0.81)				
Follow-up	0.28 (0.53)	0.54 (0.71)	0.31 (0.66)	0.86 (0.79)				
Sleep Disturbance					2.8	0.1	7.1	0.009*
Baseline	1.23 (0.43)	1.60 (0.56)	0.87 (0.56)	1.45 (0.74)				
Posttreatment	1.14 (0.52)	1.35 (0.65)	0.89 (0.51)	1.00 (0.52)				
Follow-up	1.19 (0.48)	1.30 (0.63)	1.00 (0.54)	1.35 (0.59)				
Use of Sleep Meds					0.04	0.8	2.7	0.1
Baseline	0.00 (0.00)	0.47 (0.86)	0.00 (0.00)	0.91 (1.23)				
Posttreatment	0.14 (0.44)	0.22 (0.42)	0.11 (0.32)	1.00 (1.26)				
Follow-up	0.14 (0.45)	0.65 (1.11)	0.18 (0.61)	0.69 (1.25)				
Daytime Dysfunction					10.8	0.002	2.4	0.14
Baseline	0.61 (0.74)	0.83 (0.59)	0.42 (0.50)	1.05 (0.65)				
Posttreatment	0.55 (0.69)	0.57 (0.59)	0.33 (0.48)	0.50 (0.52)				
Follow-up	0.57 (0.63)	0.70 (0.56)	0.25 (0.52)	0.80 (0.70)				

Data are presented as mean (SD). Posttreatment assessment took place at week 16; follow-up was at week 25. PSQI refers to Pittsburgh Sleep Quality Index. *As indicated in the text, the Tai Chi Chih PSQI ≥ 5 group changed differently over time as compared to the other groups.

found for PSQI global score ($P < 0.001$; Figure 2) and 4 PSQI component subscales, including sleep quality ($P < 0.05$;), habitual sleep efficiency ($P < 0.05$), sleep duration ($P < 0.01$), and sleep disturbance ($P < 0.01$). Among the participants who entered the study with poor sleep quality, improvements were found in the TCC group relative to the HE group. For PSQI global score, the 2 groups with poor sleep quality showed similar rates of decrease until 16 weeks, whereas the TCC group continued to improve, and the HE group worsened at 25 weeks (Figure 2). Among participants who had good sleep quality at entry, baseline PSQI scores were low and were unchanged, remaining similarly low in both treatment groups during the 25 weeks. There were no significant time-by-group interactions for the component subscales sleep latency, daytime dysfunction, and use of sleep medications. These results were unchanged when analyses covaried for Beck Depression Inventory scores at baseline. Finally, to protect against Type I error, a Simes correction for correlated multiple comparisons was imposed in the testing of interaction on the PSQI global and component scores. With a family error rate of $P = 0.05$, interactions for time by group were found for PSQI global score and component subscales sleep quality, habitual sleep efficiency, sleep duration, and sleep disturbance.

TCC showed a within-group effect size of 1.2 for overall sleep quality, which is comparable to the effect size of 0.91 for all types of behavioral interventions on self-reported sleep outcomes in older adults,[9] although future studies are needed to make that empiric comparison. The estimated number needed to treat for TCC to achieve the threshold of PSQI scores less than 5 is 4 (95% confidence interval 1.74 to 18.19).

Growth-curve analyses investigated the differential treatment responses among the participants with poor sleep quality by estimating the linear rate of change, focusing on PSQI global score. The rate of improvement in PSQI global score was greater in the TCC group (-0.080 PSQI global score per week; 95% confidence interval -0.111 to -0.048; $P < 0.001$) than in the HE group (-0.055 PSQI global score per week; 95% confidence interval -0.103 to -0.077; $P = 0.25$). At baseline, both groups displayed similar severity of sleep impairment in the moderate range of severity. At 25 weeks, the TCC group showed a mean PSQI global score below the threshold for clinical sleep impairment, but the HE group continued to show elevated scores.

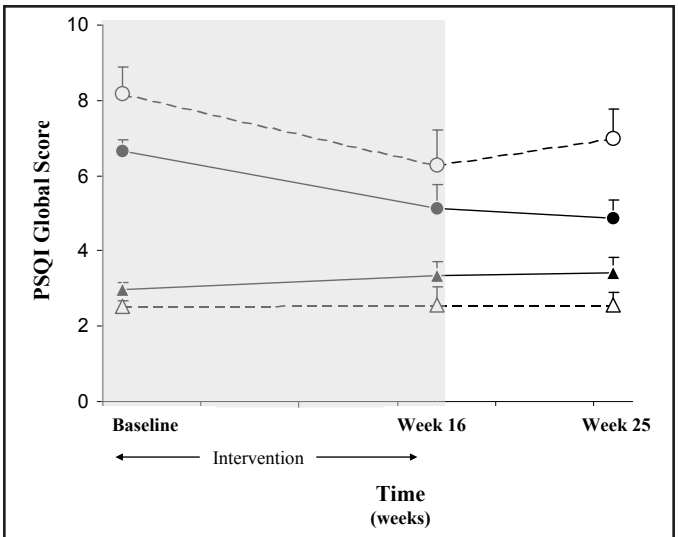

Figure 2—Changes in Pittsburgh Sleep Quality Index (PSQI) global score from baseline (preintervention) to postintervention (16 weeks) and follow-up (25 weeks) in older adults. Health education, PSQI ≥ 5 (○) ; Tai Chi Chih, PSQI ≥ 5 (●); Health Education, PSQI < 5 (**Δ**) ; Tai Chi Chih, PSQI < 5 (▲). The shaded area indicates the duration of the intervention from baseline to week 16.

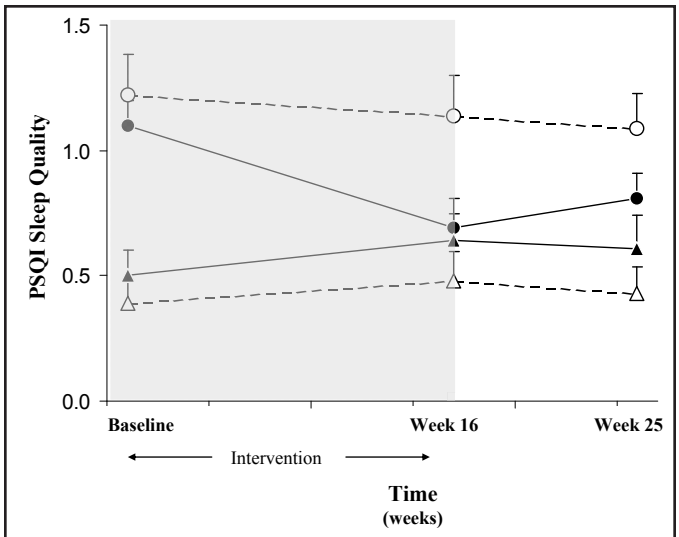

Figure 3—Changes in Pittsburgh Sleep Quality Index (PSQI) sleep-quality component score from baseline (preintervention) to postintervention (16 weeks) and follow-up (25 weeks) in older adults. Health education, PSQI ≥ 5 (○) ; Tai Chi Chih, PSQI ≥ 5 (●); Health Education, PSQI < 5 (**Δ**) ; Tai Chi Chih, PSQI < 5 (▲). The shaded area indicates the duration of the intervention from baseline to week 16.

Evaluation of TCC-relevant Variables Potential Influence on Sleep Outcomes

Over the course of the intervention period, TCC participants showed a significant increase in the number of minutes of at-home TCC practice per week, from 111 ± 61 minutes at week 8 to 213 ± 146 minutes at week 16 ($P < 0.001$). In addition, all TCC participants (100%) maintained this practice after completion of the intervention sessions (i.e., during the follow-up period), averaging 161.8 ± 88.2 minutes per week over the 9 weeks follow-up. The average cumulative at-home practice of TCC totaled 3595 ± 2065 minutes at week 25. Finally, subjects were asked whether they would consider further participation in TCC after completion of the study; using a 5-point Likert scale from 1 "not at all" to 5 "extremely likely", average scores were 4.2 ± 1.3. Despite such adherence and increases in TCC practice, overall physical activity, as measured by metabolic equivalents expended per week, did not change over the course of the trial in either group ($P = 0.64$), which suggests that participants in the TCC group substituted the practice of TCC for other aerobic activity.

Severity of depressive symptoms showed an overall time effect ($P < 0.001$). However, both intervention groups stratified by PSQI scores showed similar rates of improvement in depression scores, and there was no significant time-by-group interaction. Importantly, decreases of depression scores were not related to the differential improvement of PSQI scores in the TCC group relative to HE.

DISCUSSION

The present findings show that TCC training is related to improvements in self-rated sleep quality among older adults who report moderate severity of sleep complaints. As compared with HE controls, a greater proportion of TCC participants achieved a treatment threshold as defined by a PSQI score less than 5, which was evident 9 weeks after completion of the training. Improvements in self-reported sleep were consistently found in 4 of the 7 components of the PSQI, including sleep quality, sleep efficiency, sleep duration, and sleep disturbance. No change was found for measures of sleep latency, daytime disturbance or sleeping medications over the course of the treatment trial; at entry, subjects reported minimal daytime disturbances and/or use of sleeping aids.

TCC achieved a rate of treatment response for poor sleep quality that is comparable to levels achieved by other behavioral treatments of insomnia.[28,29] In addition, the magnitude of benefit achieved with TCC is comparable to pharmacologic treatments. For example, for TCC to achieve a threshold of PSQI less than 5, the number of patients needed to be treated was 4, which is comparable to the number of older adults patients needed to be treated with paroxetine to prevent a recurrence of depression.[30] In contrast, the number of patients needed to be treated with statins to prevent another myocardial infarction is reported to be 21.[31]

In a prior study, Tai Chi was also found to promote improvements in measures of sleep quality. However the magnitude of these treatment effects cannot be determined because 2 experimental groups were used, without inclusion of a nontreatment control group.[17] Moreover, in contrast with the present work, this prior study targeted older adults with and without sleep complaints and provided information about the study's purpose, which might lead to reporting bias for subjective PSQI measures.[17]

This study has several strengths, including sample size, randomization procedures, blinding of subjects to study outcome (i.e., sleep quality), and good adherence to the intervention. Nevertheless, conclusions from this study are constrained by several limitations. First, sampling of older adults with higher

social status and income may have influenced the high levels of treatment adherence. Second, it would have been useful to obtain objective measures of sleep using polysomnography, since few insomnia-treatment studies in older adults have examined both aspects.[9] Nevertheless, the PSQI shows a high sensitivity (98.7%) in identifying insomnia in older adults,[24] and perceptual aspects of sleep quality motivate physician visits, use of pharmacologic sleep aids, and other forms of medical utilization. However, without polysomnography, it is not known whether this sample included subjects with sleep-disordered breathing, nocturnal myoclonus, or another sleep disorder. Furthermore, because exclusion of subjects with syndromal insomnia relied on screening questions about daytime impairment, it is possible that some subjects with insomnia symptoms were included who also had DSM-IV chronic insomnia. Third, the study would have benefited from a longer-term follow-up, which could have assessed adherence to practice of TCC and maintenance of improvements in sleep quality.

The mechanisms underlying these relationships require further investigation. The current study was not designed to answer questions related to the array of physiologic, psychological, and behavioral variables that could serve to mediate TCC effects on sleep quality. Whereas depressive and anxiety symptoms may cooccur with sleep disturbance,[5] declines in depressive-symptom severity were found in both intervention conditions, indicating that changes in depressive symptoms did not mediate the differential improvement in sleep quality in the TCC group. Similarly, because overall physical-energy expenditures did not change in the TCC group, improvements in sleep appear to be independent of the physical-activity component of TCC, consistent with the findings reported by Li et al.[17] However, TCC movements are performed slowly and gently with diaphragmatic breathing and relaxation, and its performance decreases sympathetic output.[32] Given that sympathetic arousal mechanisms, which are increased in older adults,[33] are thought to perpetuate insomnia,[34,35] we speculate that declines in sympathovagal balance may drive improvements in sleep quality over the course of the intervention trial. Interestingly, the benefits of TCC emerged after participants had learned the 20 separate movements of TCC and were then able to practice the full set for 9 weeks. Together, these findings suggest a temporal progression of benefit in which TCC impacts arousal mechanisms, followed by improvements in sleep. In contrast, the HE group worsened during the follow-up period, indicating that education aspects of this intervention (e.g., sleep hygiene) have benefit but do not seem to have lasting effects.

Despite the high prevalence of sleep difficulties in community-dwelling, healthy, older adults, few treatments focus on improving sleep quality in those with moderate impairments, who are not yet at a threshold of syndromal insomnia. Such preventative approaches may forestall the onset and progression of insomnia complaints to clinical severity, which might also have implications for depression risk as well as the onset of role impairments in older adults.[12,36-39] Whereas cognitive behavioral therapy is known to be effective in the treatment of syndromal insomnia,[9] such approaches are not widely available for clinical practice and remain underused, due in part to their necessary delivery by highly trained clinicians. TCC is easy to implement in community settings and is very well suited for older adults who may have physical limitations. Moreover, study participants valued TCC training, as evidenced by their adherence and ongoing practice during follow-up. In conclusion, TCC can be considered a useful nonpharmacologic approach to improve sleep quality in older adults with moderate complaints and, thereby, has the potential to ameliorate sleep complaints, possibly before syndromal insomnia develops.

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REFERENCES

1. National Sleep Foundation. Sleep in America Poll; 2002.
2. Ohayon MM. Epidemiology of insomnia: what we know and what we still need to learn. Sleep Med Rev 2002;6:97-111.
3. Mellinger GD, Balter MB, Uhlenhuth EH. Insomnia and its treatment. prevalence and correlates. Arch Gen Psychiatry 1985;42:225-32.
4. Morin C, Kwentus J. Behavioral and pharmacological treatment of insomnia. Ann Behav Med 1988;10:91-99.
5. National Institutes of Health State of the Science Conference Statement: Manifestations and management of chronic in adults. Sleep 2005;28:1049-1058.
6. Kupfer DJ, Reynolds CF, 3rd. Management of insomnia. N Engl J Med 1997;336:341-6.
7. Glass J, Lanctot KL, Herrmann N, Sproule BA, Busto UE. Sedative hypnotics in older people with insomnia: meta-analysis of risks and benefits. BMJ 2005;331:1169.
8. Morin CM, Culbert JP, Schwartz SM. Nonpharmacological interventions for insomnia: a meta-analysis of treatment efficacy. Am J Psychiatry 1994;151:1172-1180.
9. Irwin MR, Cole JC, Nicassio PM. Comparative meta-analysis of behavioral interventions for insomnia and their efficacy in middle-aged adults and in older adults 55+ years of age. Health Psychol 2006;25:3-14.
10. Sivertsen B, Omvik S, Pallesen S et al. Cognitive behavioral therapy vs zopiclone for treatment of chronic primary insomnia in older adults: a randomized controlled trial. JAMA 2006;295:2851-8.
11. Jacobs GD, Pace-Schott EF, Stickgold R, Otto MW. Cognitive behavior therapy and pharmacotherapy for insomnia: a randomized controlled trial and direct comparison. Arch Intern Med 2004;164:1888-96.

12. Morphy H, Dunn KM, Lewis M, Boardman HF, Croft PR. Epidemiology of insomnia: a longitudinal study in a UK population. Sleep 2007;30:274-80.
13. Wang C, Collet JP, Lau J. The effect of Tai Chi on health outcomes in patients with chronic conditions: a systematic review. Arch Intern Med 2004;164:493-501.
14. Irwin MR, Olmstead R, Oxman MO. Augmenting immune responses to varicella zoster virus in older adults: a randomized controlled trial of Tai Chi. J Am Geriatr Soc 2007;55: 511-517.
15. Li F, Harmer P, McAuley E et al. An evaluation of the effects of Tai Chi exercise on physical function among older persons: a randomized controlled trial. Ann Behav Med 2001;23:139-46.
16. Irwin MR, Pike JL, Cole JC, Oxman MN. Effects of a behavioral intervention, Tai Chi Chih, on varicella-zoster virus specific immunity and health functioning in older adults. Psychosom Med 2003;65:824-30.
17. Li F, Fisher KJ, Harmer P, Irbe D, Tearse R, Weimer C. Tai Chi and self-rated quality of sleep and daytime sleepiness in older adults: a randomized controlled trial. J Am Geratr Soc 2004;52:892-900.
18. First MB, Spitzer RL, Gibbon M, Williams JB. Structured Clinical Interview for DSM-IV Axis I Disorders - Patient Edition, Version 2.0. New York, NY: New York State Psychiatric Institute; 1996.
19. Stone JF. Tai Chi Chih, Joy Through Movement. Boston, MA: Good Karma Publishing, Incorporated; 1996.
20. Nicassio P, Greenberg MA. The effectiveness of cognitive-behavioral and psychoeducational interventions in the management of arthritis. I. In: Weisman MH, Weinblatt M, Louie J, eds. Treatment of Rheumatic Diseases, 2nd ed. Orlando, FL: William Saunders; 2001:147-161.
21. Borkovec T, Nau SD. Credibility of analogue therapy rationales. Journal of Behavior Therapy and Experimental Psychiatry 1972;3:257-260.
22. Buysse DJ, Reynolds CF, 3rd, Monk TH, Berman SR, Kupfer DJ. The Pittsburgh Sleep Quality Index: a new instrument for psychiatric practice and research. Psychiatry Res 1989;28:193-213.
23. Cole JC, Motivala SJ, Buysse DJ, Oxman MN, Levin MJ, Irwin MR. Validation of a 3-factor scoring model for the Pittsburgh Sleep Quality Index in older adults. Sleep 2006;29:112-6.
24. Backhaus J, Junghanns K, Broocks A, Riemann D, Hohagen F. Test-retest reliability and validity of the Pittsburgh Sleep Quality Index in primary insomnia. J Psychosom Res 2002;53:737-740.
25. Steer RA, Rissmiller DJ, Beck AT. Use of the Beck Depression Inventory-II with depressed geriatric inpatients. Behav Res Ther 2000;38:311-318.
26. Sallis JF, Haskell WL, Wood PD et al. Physical activity assessment methodology in the Five-City Project. Am J Epidemiol 1985;121:91-106.
27. Laupacis A, Sackett D, Roberts R. An assessment of clinically useful measures of the consequences of treatment. N Engl J Med 1988;318:1728-1733.
28. Levitt H, Wood A, Moul DE et al. A pilot study of subjective daytime alertness and mood in primary insomnia participants using ecological momentary assessment. Behav Sleep Med 2004;2:113-31.
29. Edinger JD, Sampson WS. A primary care "friendly" cognitive behavioral insomnia therapy. Sleep 2003;26:177-82.
30. Reynolds CF, 3rd, Dew MA, Pollock BG et al. Maintenance treatment of major depression in old age. N Engl J Med 2006;354:1130-8.
31. Evidence based drug therapy: do statins have a role in primary prevention? Therapeutics Initiative Web site. http:/www.ti.ubc.ca/PDF/48.pdf. Accessed April 18, 2008.
32. Motivala SJ, Sollers J, Thayer J, Irwin MR. Tai chi chih acutely decreases sympathetic nervous system activity in older adults. J Gerontol A Biol Sci Med Sci 2006;61:1177-80.
33. Irwin M, Brown M, Patterson T, Hauger R, Mascovich A, Grant I. Neuropeptide Y and natural killer cell activity: findings in depression and Alzheimer caregiver stress. FASEB J 1991;5:3100-3107.
34. Bonnet MH, Arand DL. Heart rate variability in insomniacs and matched normal sleepers. Psychosom Med 1998;60:610-5.
35. Irwin MR, Valladares EM, Motivala S, Thayer JF, Ehlers CL. Association between nocturnal vagal tone and sleep depth, sleep quality, and fatigue in alcohol dependence. Psychosom Med 2006;68:159-66.
36. Motivala SJ, Levin MJ, Oxman MN, Irwin MR. Impairments in health functioning and sleep quality in older adults with a history of depression. J Am Geriatr Soc 2006;54:1184-91.
37. Roberts RE, Shema SJ, Kaplan GA, Strawbridge WJ. Sleep complaints and depression in an aging cohort: A prospective perspective. Am J Psychiatry 2000;157:81-8.
38. Cole MG, Dendukuri N. Risk factors for depression among elderly community subjects: a systematic review and meta-analysis. Am J Psychiatry 2003;160:1147-56.
39. Roth T, Jaeger S, Jin R, Kalsekar A, Stang PE, Kessler RC. Sleep problems, comorbid mental disorders, and role functioning in the national comorbidity survey replication. Biol Psychiatry 2006;60:1364-71.