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The Effects of Tai Chi on Sleep Quality in Chinese American Patients With Major Depressive Disorder: A Pilot Study

Yan Ma
Division of Interdisciplinary Medicine and Biotechnology, Beth Israel Deaconess Medical Center, Harvard Medical School, Boston, Massachusetts
Sleep Center Eye Hospital, China Academy of Chinese Medical Sciences, Beijing, China

Alicia Yeung
George Washington University, Washington, DC

Albert C. Yang
Division of Interdisciplinary Medicine and Biotechnology, Beth Israel Deaconess Medical Center, Harvard Medical School, Boston, Massachusetts
Department of Psychiatry, Taipei Veterans General Hospital, Taipei City, Taiwan
School of Medicine, National Yang-Ming University, Taipei City, Taiwan

Chung-Kang Peng
Division of Interdisciplinary Medicine and Biotechnology, Beth Israel Deaconess Medical Center, Harvard Medical School, Boston, Massachusetts

Alisabet Clain, Jonathan Alpert, and Maurizio Fava
Depression Clinical and Research Program, Massachusetts General Hospital, Harvard Medical School, Boston, Massachusetts

Chung-Kang Peng, PhD, is a co-inventor of the sleep spectrogram technique, which is patented and licensed to Embla, Inc. by the Beth Israel Deaconess Medical Center.

Correspondence should be addressed to Yan Ma, Division of Interdisciplinary Medicine and Biotechnology, Beth Israel Deaconess Medical Center, Harvard Medical School, 330 Brookline Ave, Boston, MA 02215. Email: dryan.ma@gmail.com and Albert S. Yeung, Massachusetts General Hospital, Depression Clinical Research Program, 1 Bowdoin Square, 6th Floor, Boston, MA 02114. Email: ayeung@partners.org
Albert S. Yeung
Depression Clinical and Research Program, Massachusetts General Hospital, Harvard Medical School, Boston, Massachusetts
Department of Behavioral Health, South Cove Community Health Center, Boston, Massachusetts

Objective: This pilot study evaluated the effects of Tai Chi training on sleep quality (primary outcomes), and depression and social functioning levels (secondary outcomes) among patients with depression. Participants: Sixteen depressed Chinese patients. Methods: Participants received 1-hr Tai Chi training sessions 2 times per week for 10 weeks. Patients’ subjective sleep quality ratings, objective sleep quality measurements, and depression and social functioning levels were measured before, during, and after the intervention. Results: Sleep quality and depression outcomes improved significantly. Patients reported improved Pittsburgh Sleep Quality Index (PSQI) scores (9.6 ± 3.3 to 6.6 ± 5.2, \( p = 0.016 \)), and cardiopulmonary coupling (CPC) analysis of electrocardiogram (ECG) showed decreased stable sleep onset latency (75.7 ± 100.6 to 20.9 ± 18.0, \( p = 0.014 \)), increased stable sleep percentages (31.5 ± 18.7 to 46.3 ± 16.9, \( p = 0.016 \)), and decreased unstable sleep percentages (45.3 ± 20.1 to 30.6 ± 16.5, \( p = 0.003 \)). Patients also reported decreased Hamilton Rating Scale for Depression (HAM-D-17; 20.1 ± 3.7 to 7.8 ± 5.9, \( p < 0.001 \)) and Beck Depression Inventory (BDI) scores (22.3 ± 9.1 to 11.1 ± 10.6, \( p = 0.006 \)). Significant correlations were found between the changes in subjective sleep assessments \( \Delta \)PSQI and \( \Delta \)HAM-D-17 (\( r = 0.6, p = 0.014 \)), and \( \Delta \)PSQI and \( \Delta \)BDI (\( r = 0.62, p = 0.010 \)). Correlations between changes in objective sleep measurements and changes in depression symptoms were low and not significant. Conclusions: Tai Chi training improved sleep quality and mood symptoms among depressed patients.

Insomnia, a sleep disorder that includes trouble falling asleep, staying asleep, or waking up too early, resulting in daytime impairment, is a common complaint among patients in primary care and behavioral health clinics (Punnoose, Golub, & Burke, 2012). Insomnia is also one of the most common symptoms of major depressive disorder (MDD); (American Psychiatric Association, 2013; Lai et al., 2014; Soehner, Kaplan, & Harvey, 2014). Pretreatment insomnia among patients with depression predicts poorer outcomes of antidepressant treatment (Sung, Wisniewski, Luther, Trivedi, & Rush, 2015). Full recovery or remission from depression should be the goal of depression treatment (Bakish, 2001; Kennedy, 2002) because the presence of residual depressive symptoms is associated with poorer depression outcomes (O’Brien et al., 2011), higher risk of suicide (Agargun et al., 1997; Don Richardson, Cyr, Nelson, Elhai, & Sareen, 2014; Li, Lam, Chan, Yu, & Wing, 2012), and greater risk of recurrent depression (Cole & Dendukuri, 2003; Perlis, Giles, Buysse, Tu, & Kupfer, 1997). As one of the most common residual symptoms in patients treated for depression (Carney, Segal, Edinger, & Krystal, 2007; Kanai et al., 2003; Pigeon et al., 2009), insomnia makes achieving a full recovery difficult (Troxel et al., 2012).

Electroencephalogram (EEG) based polysomnography (PSG) has been the established technology for studying sleep quality. Sleep impairment in patients with MDD is characterized by sleep fragmentation, diminished slow-wave sleep, and altered rapid eye movement (REM) sleep (Cheng et al, 2015; Emslie, Rush, Weinberg, Rintelmann, & Roffwarg, 1990; Kudlow, Cha, Lam, & McIntyre, 2013). However, the use of EEG for sleep monitoring has many limitations.
One issue is that EEG only focuses on brain waves while sleep is a complex physiological process that involves all of the body’s organs and systems (Bianchi & Thomas, 2013). Recent technological advances allow the use of mobile devices to monitor physiological parameters, including electrocardiogram (ECG), in an inexpensive and continuous manner. Cardiopulmonary coupling (CPC) analysis of continuous ECG data has been developed as a convenient alternative to PSG in measuring sleep quality (Thomas et al., 2007; Thomas, Mietus, Peng, & Goldberger, 2005). Yang and colleagues (Yang et al., 2011) compared sleep quality in depressed patients and healthy controls using CPC analysis of sleep measurements and concluded that CPC analysis can be used to quantify sleep quality or stability and to objectively evaluate the severity of insomnia in patients with MDD. These studies have provided the basis for comprehensive assessment of sleep using inexpensive mobile devices in the management of depression.

In the treatment of depression, pharmacological therapies using second-generation antidepressant treatments are the mainstay. However, there are significant side effects associated with antidepressants (Alberti, Chiesa, Andrisano, & Serretti, 2015; Hasnain, Vieweg, & Hollett, 2012; Kikuchi, Suzuki, Uchida, Watanabe, & Mimura, 2013). Cognitive behavioral therapy and mind-body approaches are playing an increasing role in the treatment of depression and insomnia associated with depression (Frame & Alexander, 2013; Geiger-Brown et al., 2014; Watanabe et al., 2015). Tai Chi is a comprehensive mind-body exercise originating from China, which is enjoying growing popularity in the West. It involves mild aerobic exercise, breathing techniques, attentional focus, mindfulness training, relaxation, postural control, along with choreographed movement patterns. According to a 2007 National Health Interview Survey, 2.3 million Americans have practiced Tai Chi in the past 12 months (Clarke, Black, Stussman, Barnes, & Nahin, 2015; Komelski, Miyazaki, & Blieszner, 2012). Preliminary research has shown beneficial effects of Tai Chi on a range of psychological well-being measures including mood, anxiety, general stress management, self-esteem, and quality of life in varied populations (Ma, Sun, & Peng, 2014; Ma, Zhou, Fan, & Sun, 2016). Recent studies have provided growing evidence to suggest the efficacy of Tai Chi for patients with MDD (Cho, 2008; Chou et al., 2004; Lavretsky et al., 2011; Yeung et al., 2012) and those who suffer from sleep disturbances (Field, Diego, Delgado, & Medina, 2013; Irwin et al., 2014; Larkey et al., 2015). To date, there are no studies that specifically evaluate the effects of Tai Chi on quality of sleep among patients with MDD. In this study, we hypothesize that patients’ subjective rating and objective sleep quality from CPC analysis of continuous ECG data will show that Tai Chi improves sleep quality (primary hypothesis) and depression and social functioning (secondary hypothesis) in patients with MDD.

Interested Chinese Americans from a community health center were prescreened for MDD using the Patient Health Questionnaire (PHQ-9). Those with higher scores of PHQ-9 (≥ 10) were interviewed to confirm the diagnosis of MDD. Subjects with Hamilton Rating Scale for Depression (HAM-D-17) (Laenen, Alonso, Molenberghs, Vangeneugden, & Mallinckrodt, 2009; Montgomery & Asberg, 1979) scores between 14 and 24 were selected. These patients were considered to have moderate levels of depression that required intervention. Patients with severe depression (HAM-D-17≥24) were not included in this study due to ethical concerns as Tai Chi is not considered an established treatment for MDD. The primary outcomes were patients’ subjective sleep ratings and objective sleep quality measurements assessed by cardiopulmonary coupling (CPC) (Thomas et al., 2005) analysis of ECG data collected using an ambulatory monitoring device. Secondary outcomes were patients’ depression (measured by HAM-D-17, Clinical Global Impression [CGI] (Guy, 1976), and social functioning (measured by the Short
METHODS

Materials and Study Design

This is a single-group, pre–post assessment of the effects of Tai Chi on sleep quality among patients with depression. This pilot study targeted Chinese patients with MDD. The study was conducted between January 1 and November 30, 2014, at South Cove Community Health Center, a federally funded community health center in Boston, which predominantly serves Chinese Americans.

Inclusion and Exclusion Criteria

Inclusion criteria included (a) self-identification as being of Chinese ethnicity and fluent in Mandarin or Cantonese, (b) 18–65 years of age, (c) satisfy DSM-IV-R criteria for MDD, (d) have a baseline score of 14–24 on the HAM-D-17, and (e) have had no regular (defined as ≥ 3 times per week for ≥ 2 months) Tai Chi training and practice or other forms of mind-body intervention in the past 6 months.

Exclusion criteria included (a) primary psychiatric diagnosis other than MDD, (b) history of psychosis, mania, or severe cluster B personality disorders, active alcohol or substance abuse or dependency disorders in the past 6 months, (c) unstable medical conditions as judged by investigators, (d) usage of or plans to use confounding treatments, including antidepressants and CAM treatments thought to have beneficial effects on mood, such as St. John’s Wort, S-adenosyl methionine (SAMe), omega-3 fatty acids, light therapy, conventional psychotherapy, mind-body interventions (e.g., Qigong, mindfulness training, muscle relaxation training, etc.), (e) current active suicidal or self-injurious potential necessitating immediate treatment, (f) current pregnancy, (g) metallic implants, (h) claustrophobia, and (i) patients who have atrial fibrillation or an implanted pacemaker.

Subject Recruitment

Participants in this study were recruited through advertisement, referral by South Cove’s primary care and mental health clinicians, and routine depression screening at South Cove’s primary care clinics. Since Tai Chi was taught in Chinese languages in this study, only participants who spoke fluent Chinese were enrolled to ensure understanding, and to encourage social interaction and mutual support in class. The study was approved by the Institutional Review Board (IRB) of the Massachusetts General Hospital.

Potential subjects received a phone triage by our bilingual research staff using an IRB-approved protocol that includes both a study-specific phone screen questionnaire and the PHQ-9. If a patient was fluent in Mandarin or Cantonese Chinese, aged 18–65, had not been practicing Tai Chi regularly, and had a PHQ-9 score of 10 or above, the potential subject was scheduled for a screening visit. During the screening visit, a bilingual investigator obtained written consent from the subject, and conducted interviews. Screening visits occurred within
four weeks prior to the start date of the intervention. A psychiatrist interviewed the subject using instruments including the Chinese Bilingual version of the semistructured psychiatric interview (CB-SCID-I/P) to assess the presence of major DSM-IV-R psychiatric disorders (Nietzel & Wakefield, 1996), and the 17-item Hamilton Rating Scale for Depression (HAM-D-17) to determine the eligibility of the patient. A urine pregnancy test was performed on female subjects with child-bearing potential. Female participants who were over 60 years of age and self-reported as being postmenopausal were not required to complete the pregnancy test.

Tai Chi Intervention

Classes were conducted by a Tai Chi master who had more than 25 years of training experience. Tai Chi participants received 1-hr Tai Chi training sessions 2 times per week for 10 weeks. The instructor followed a standardized protocol, which included the first 24 of the traditional 108 movements of Yang-style Tai Chi. Participants were asked to practice Tai Chi at home with an instructional DVD at least 3 times per week and 30 min each time. At the end of 10 weeks, the participants were expected to be able to practice the 24 basic movements on their own. Tai Chi exercise logs were given to participants every week to record practice compliance and adverse events.

Scales and Questionnaires

Outcome measures were assessed at baseline, week 5, and week 10. At each assessment, participants were administered the Hamilton Rating Scale for Depression (HAM-D-17), Beck Depression Inventory (BDI), the Clinical Global Impression–Severity (CGI-S) and Improvement (CGI-I), the Short Form Health Survey (SF-36), the Multidimensional Scale of Perceived Social Support (MSPSS), Mindful Attention Awareness Scale (MAAS), and Pittsburgh Sleep Quality Index (PSQI).

Hamilton Rating Scale for Depression (HAM-D-17)

HAM-D-17 is a clinician-administered interview scale that provides an indication of depression, and acts as a guide to evaluate recovery. It has exhibited well-documented reliability and validity (Laenen et al., 2009; Montgomery & Asberg, 1979). HAM-D-17 assesses the presence and severity of 17 symptoms of depression.

Beck Depression Inventory (BDI)

As a widely used psychometric test for measuring depression severity, BDI (Beck, Steer, Ball, & Ranieri, 1996; Beck, Ward, Mendelson, Mock, & Erbaugh, 1961) contains 21 questions about the subject’s feeling in the previous week. Each question has a set of at least four possible responses, ranging in intensity. A value of 0 to 3 is assigned for each answer, and higher total scores indicate more severe depressive symptoms.

Clinical Global Impression–Severity (CGI-S) and Improvement (CGI-I)

The CGI rating scales are commonly used for symptom severity and treatment response in treatment studies of patients with mental disorders (Guy, 1976). The CGI-S measures the current
condition of the patient, as judged by the clinician, on a scale of 1–7 (higher scores indicate more severe depressive symptoms); and the CGI-I measures the degree of improvement, as judged by the clinician, since the start of treatment on a scale of 1–7 (higher scores indicate worse outcomes).

**Short Form Health Survey (SF-36)**

The Short Form Health Survey (SF-36) (McHorney et al., 1993; Ware et al., 1992) is the most widely used instrument to measure health-related quality of life. SF-36 consists of 36 items in eight scales: physical functioning (10 items), role limitations caused by physical health problems (4 items), role limitations caused by emotional problems (3 items), social functioning (2 items), emotional well-being (5 items), energy and fatigue (4 items), pain (2 items), and general health perceptions (5 items). These eight scales can be aggregated into two summary measures: the physical component score (PCS) and the mental component score (MCS) (Ware, Kosinski, & Keller, 1994). An additional single item assesses change in perceived health. Each scale is directly transformed into a 0–100 scale on the assumption that each question carries equal weight. Lower scores indicate more disability.

**Multidimensional Scale of Perceived Social Support (MSPSS)**

With 4 items for each subscale, the self-administered MSPSS is comprised of 12 items, designed to measure perceptions of social support from family members, friends and significant others (Zimet, Dahlem, Zimet, & Farley, 1988; Zimet, Powell, Farley, Werkman, & Berkoff, 1990). Items are rated on a 7-point Likert Scale (1 = very strongly disagree; 7 = very strongly agree), with higher scores indicating greater levels of perceived support. Confirmatory factor analysis has consistently reported a 3-factor solution: family (MSPSS-FA), friends (MSPSS-FR) and significant others (MSPSS-SO). Internal consistency of the Chinese version is good (Tonsing, Zimet, & Tse, 2012; Zhou et al., 2015).

**Mindful Attention Awareness Scale (MAAS)**

The MAAS is designed to assess open or receptive awareness of and attention to what is taking place in the present. The scale shows strong psychometric properties and has been validated with college students, community samples, cancer patients (Carlson & Brown, 2005), and among Chinese populations (Black, Sussman, Johnson, & Milam, 2012). Correlational, quasi-experimental, and laboratory studies have shown that the MAAS taps into a unique quality of consciousness that is related to, and predictive of, a variety of self-regulation and well-being constructs. The self-report measures are based on 15 items, and the total score is a mean of the 15 items. Higher scores reflect higher levels of dispositional mindfulness. (Brown & Ryan, 2003)

**Pittsburgh Sleep Quality Index (PSQI)**

PSQI was used for subjective sleep assessment, which included multiple sleep-related variables over the preceding month, using Likert and open-ended response formats (Spira et al.,
The PSQI yields seven component scores: subjective sleep quality, sleep latency, sleep duration, habitual sleep efficiency, sleep disturbances, sleep medication, and daytime dysfunction. Component scores range from 0 to 3 and are summed to obtain a global score, which ranges from 0 to 21. Higher scores suggest greater sleep disturbance (Buysse, Reynolds, Monk, Berman, & Kupfer, 1989).

ECG Log and Self-Evaluated Sleep Questions

A brief ECG log and self-evaluated sleep questionnaire was used to record the time when the ECG recording with the ambulatory device (see 2.5 for description) started, and times that participants went to bed at night and rose in the morning. Participants were asked to recall how many times they woke up during the night, and evaluate overall sleep quality.

Data Collection

Subjective sleep quality was assessed by Pittsburgh Sleep Quality Index (PSQI) and a brief sleep log was used to record sleep latency and duration for the studied night. Objective sleep quality was assessed by ECG-based cardiopulmonary coupling (CPC) analysis. ECG recordings were collected by an FDA approved ambulatory electrocardiogram monitor (Dynadx Co.) with a computer-based data acquisition system. All subjects were monitored at home for 24 hr before and after 10 weeks of Tai Chi training. The 24-hr ECG data was analyzed for heart rate variability, which will be reported elsewhere. Only the ECG recordings during sleep at night were extracted for sleep analysis in this study. Sampling rate of ECG monitoring was 200 Hz. All ECG recordings were carefully checked with noise level, artifacts, R peak detection and ectopic beats. Data was discarded if quality level was below 90%.

Cardiopulmonary Coupling Analysis of the ECG Recordings

Cardiopulmonary coupling (CPC) analysis is based on mathematical analysis of the coupling between heart rate variability and the respiratory modulation of QRS waveform on a beat-to-beat basis. Major physiological sleep states derived from CPC analysis include stable sleep (indicated by high-frequency coupling, or HFC), unstable sleep (indicated by low frequency coupling, or LFC), and REM or wakeful states (indicated by very low-frequency coupling, or VLFC) (Thomas et al., 2005). Stable sleep is associated with being healthy, and impaired stable sleep (or increased unstable sleep) is associated with pathological conditions (Thomas et al., 2005).

Statistical Analyses

SPSS 19.0 (IBM SPSS Statistics) was used for statistical analyses in this study. Descriptive statistics were presented as mean ± standard deviation for continuous data, and number (percentage) for categorical data. Comparisons of pre- and postmeasurements of continuous variables were assessed by the nonparametric Wilcoxon Signed Ranks Tests for continuous variables and Fisher Exact Tests for categorical variables, in view of the small sample size.

Spearman’s sign-rank correlation tests for nonparametric data were performed to examine the correlations between changes in subjective sleep assessments using PSQI scores and objective sleep measurements using HFC, LFC, and VLFC, pre and post Tai Chi
training, and changes in depression and functioning (HAMD-17 scores, BDI, CGI-S, CGI-I, SF-36 scores, and Perceived Stress Mindfulness awareness). A $p$ value < 0.05 was considered statistically significant.

RESULTS

Subjects and Demographics

Nineteen depressed patients were screened for this study, and among them, 16 (6 males and 10 females) adult Chinese patients (ages 54.5 ± 11.26 years, range 28--65 years, mean BMI = 23.1 ± 2.9 kg/m²) were enrolled, and 3 patients were excluded due to low levels of depression symptoms (HAM-D-17 score < 14). All participants completed the 10-week Tai Chi training. All of them were able to perform the 24 basic movements after the training. No adverse events were reported. It should be noted that over the course of the study, many participants filled in their exercise logs at the last minute before they were collected at the beginning of each Tai Chi class. Our research team questioned the accuracy of such reporting and decided not to analyze data from the exercise logs.

Subjective Scales and Questionnaire

After the 10-week Tai Chi intervention, both depression outcomes and sleep quality improved significantly (Table 1). For subjective sleep assessments, improved PSQI scores (9.6 ± 3.3 to 6.6 ± 5.2, $p = 0.016$) were reported. For depression outcomes, patients had decreases in HAM-D-17 (20.1 ± 3.7 to 7.8 ± 5.9, $p < 0.001$) and BDI scores (22.3 ± 9.1 to 11.1 ± 10.6, $p = 0.006$). Significant improvements were also found in other clinical measurements including MAAS (3.3 ± 1.0 to 4.4 ± 1.0, $p = 0.006$), CGI-S (4.4 ± 0.8 to 2.3 ± 1.3, $p = 0.001$), CGI-I (4.0 ± 0 to 1.9 ± 1.0, $p = 0.001$), MSPSS-FA (4.6 ± 1.6 to 5.5 ± 1.6, $p = 0.018$), and SF-36-PCS (41.4 ± 9.3 to 47.0 ± 9.8, $p = 0.044$).

CPC-Based Sleep Assessment

Figure 1 illustrates an improvement of objective sleep stability in a depressed patient after Tai Chi training. Changes in objective sleep indices showed that after the 10 weeks of Tai Chi intervention, stable sleep percentage (HPC) increased significantly (31.5 ± 18.7 to 46.3 ± 16.9, $p = 0.016$), and unstable sleep (LFC) percentage (30.0 ± 22.6 to 14.8 ± 16.6, $p = 0.003$) decreased significantly. Stable sleep onset latency (75.7 ± 100.6 to 20.9 ± 18.0, $p = 0.014$) also decreased. No significant change was found in wake or REM sleep percentage (VLFC; 22.1 ± 9.8 to 22.7 ± 7.7, $p = 0.365$) pre and post Tai Chi training (Table 2). Individual changes of outcomes at week 0 and week 10 of Tai Chi intervention are shown in Figure 2.

Correlations of the Changes in Depression Outcomes and Sleep Quality

Significant correlations were found between the changes in subjective sleep assessments and depression outcomes pre and post Tai Chi training (Table 3): \(\Delta\)PSQI and \(\Delta\)HAM-D-17 ($r = 0.6, p = 0.014$), \(\Delta\)PSQI and \(\Delta\)BDI ($r = 0.62, p = 0.010$), \(\Delta\)PSQI and \(\Delta\)CGI-S ($r = 0.618, p = 0.011$), and \(\Delta\)PSQI and \(\Delta\)CGI-I ($r = 0.569, p = 0.021$). However, there were no significant correlations
between changes in objective sleep measurements (stable sleep onset latency [ΔHFC latency]), stable sleep percentage (ΔHFC), unstable sleep percentage (ΔLFC)), and changes in depression outcomes pre and post Tai Chi training. In addition, the correlations between changes in subjective sleep assessments (ΔPSQI) and changes in objective sleep measurements (ΔHFC, ΔLFC) were low and not significant.

### DISCUSSION

In this pilot study, our findings suggest that 10-week Tai Chi training may improve sleep quality in patients with depression, based on patients’ subjective assessments using the PSQI, and the objective sleep measurements using CPC analysis of continuous sleep ECG data measured with an ambulatory electrocardiogram monitor.
Prior studies have reported on the effects of Tai Chi on the treatment of depression (Cho, 2008; Chou et al., 2004; Lavretsky et al., 2011; Yeung et al., 2012). Some previous studies have investigated the effects of Tai Chi on insomnia associated with depression. Field and colleagues (Field et al., 2013) reported that Tai Chi combined with yoga reduced prenatal depression, anxiety, and sleep disturbances, while Larkey and colleagues (Larkey et al., 2015) showed that Tai Chi improved fatigue, but not depression or sleep in breast cancer survivors. This current study, using subjective and objective sleep measurements, has added to these small number of studies to support the potential beneficial effects of Tai Chi on insomnia associated with major depressive disorder.

Currently, pharmacological and cognitive behavioral therapy (CBT) are the mainstay therapies (Ma et al., 2015) for treating insomnia in depressed patients. Due to potential side effects and the risks of dependence on hypnotics, as well as the shortage of well-trained therapists to deliver cognitive behavioral therapy for insomnia (CBT-I) (Deak & Winkelman, 2012), sleep disturbances continue to be a common and distressing symptom in patients with depression. Our findings support that Tai Chi may be a viable option for this population as our results showed that patients who were not Tai Chi practitioners were able to perform the...
24 basic movements after 10 weeks of training. Unlike CBT-I, Tai Chi can be used as a self-management approach for patients with depression to avoid the side effects of antidepressant and hypnotic medications. Tai Chi was shown to be safe (Wayne, Berkowitz, Litrownik, Buring, & Yeh, 2014), even for the elderly and physically frail individuals (Adler & Roberts, 2006; Gillespie et al., 2012). In addition, Tai Chi is relatively cost-effective, and is reported to produce high adherence and enjoyment as an intervention in clinical and community-based studies (Sun & Buys, 2015; Tousignant et al., 2014).

Current objective assessments of sleep quality rely primarily on PSG, while the limitations of PSG have been noted. As a complementary automated technique, cardiopulmonary coupling analysis has been proposed to quantify sleep stability by using single-lead continuous ECG to generate sleep spectrograms (Thomas et al., 2005). In this study, impaired sleep quality, characterized by delayed onset of stable sleep and sleep fragmentation, as well as increased wake or REM and unstable sleep are in line with excessive wakefulness-promoting influences found in depressed patients (Yang et al., 2011).

Sleep is a complex physiological process that involves the function of every system at different levels (Bianchi & Thomas, 2013). CPC incorporates the respiration coupling concept into the analysis to enable the filtering of power spectra due to nonrespiratory induced HR
<table>
<thead>
<tr>
<th>Gender</th>
<th>△HAMD</th>
<th>△BDI</th>
<th>△MAAS</th>
<th>△CGI-S</th>
<th>△CGI-I</th>
<th>△SF-36 -PCS</th>
<th>△SF-36 -MCS</th>
<th>△PSQI</th>
<th>△HFC latency</th>
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<td>0.011</td>
<td>0.062</td>
<td>0.001</td>
<td>0.011</td>
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<td>△BDI</td>
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<td>0.759**</td>
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<tr>
<td>△MAAS</td>
<td>0.617*</td>
<td>-0.514*</td>
<td>-0.686**</td>
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<tr>
<td>△CGI-S</td>
<td>-0.602*</td>
<td>0.925**</td>
<td>0.908**</td>
<td>-0.609*</td>
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<tr>
<td>△CGI-I</td>
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<td>0.925**</td>
<td>0.781**</td>
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<td>△SF-36-PCS</td>
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<td>-0.560*</td>
<td>0.515*</td>
<td>-0.629*</td>
<td>-0.726**</td>
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<tr>
<td>△SF-36-MCS</td>
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<td>-0.742**</td>
<td>-0.800**</td>
<td>0.611*</td>
<td>-0.787**</td>
<td>-0.783**</td>
<td>0.409</td>
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<td>△PSQI</td>
<td>-0.408</td>
<td>0.600*</td>
<td>0.620*</td>
<td>-0.328</td>
<td>0.618*</td>
<td>0.569*</td>
<td>-0.331</td>
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<td>△HFC latency</td>
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<td>0.060*</td>
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<td>-0.046</td>
<td>-0.391</td>
<td>0.205 0.541*</td>
<td>-0.782**</td>
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</table>

**Note.** *p < 0.05, **p < 0.01.

**Note.** Abbreviations: HAM-D-17, Hamilton Rating Scale for Depression; BDI, Beck Depression Inventory; MAAS, Mindful Attention Awareness Scale; CGI-S, Clinical Global Impressions, Severity scale; CGI-I, Clinical Global Impressions, Improvement scale; SF-36, Short Form Health Survey (PCS, Physical Component Summary; MCS, Mental Component Summary); PSQI, Pittsburgh Sleep Quality Index; HFC, high-frequency coupling; LFC, low-frequency coupling.
changes, and to enhance the potential diagnostic utility in clinical applications (Ma & Sun, 2013; Stein & Pu, 2012). Compared to conventional analyses using heart rate variability (Ma & McCraty, 2016), our results based on CPC analyses of ECG data integrated the interlinked physiological processes including autonomic, respiratory, and electrocortical functions, in addition to brain activities. To our knowledge, this is the first study to have examined the impact of Tai Chi practice on depression and sleep disturbances with ECG-based portable objective outcome indicators. CPC-based sleep spectrograms may complement EEG-based techniques for the assessment of sleep stability and quality, and provide low-cost, clinically useful insight into sleep quality in depressed patients, and possibly into the effects of interventions.

In this study, the improvement of patients’ depression and functioning correlated well with their subjective sleep assessment after Tai Chi training, but not with their objective sleep measurements using ECG-based CPC analysis. In addition, the correlations between patients’ subjective and objective assessments of sleep improvement were low, which have been described as sleep discrepancy in previous studies (Kay, Buysse, Germain, Hall, & Monk, 2015; Kay, Dzierzewski, Rowe, & McCrae, 2013; Williams, Kay, Rowe, & McCrae, 2013). The exact reason for such discrepancy is unclear. It is possible that the participants had two distinctive comorbid conditions, depression and insomnia, and the improvement in one condition may not necessarily lead to improvement in the other one. Another possible explanation is that the subjective assessment of sleep disturbance may not reflect a person’s true insomnia; rather it reflects a person’s distress as a result of mood symptoms. Given that sleep disturbances are highly prevalent, portend poorer treatment outcomes, and increase the risk for relapse in depressed populations, understanding the links between sleep quality and depression treatment outcome is critical (Troxel et al., 2012).

Limitations
We would like to acknowledge the following limitations of this study. First, this is a pilot study with a small sample size and no control group in which all subjects received the intervention. While we found significant improvements in subjective and objective sleep measurements, the absence of a control group obviates the possibility of stating definite conclusions regarding the effectiveness of Tai Chi for treating insomnia among depressed patients. It is possible that improvement of sleep quality was due to the passage of time. Some patients might have been motivated to join the study when they were symptomatic and presented with both depression and insomnia. These symptoms may fluctuate and decrease over time. Second, it is unclear if patients’ improvement in the intervention group was a result of Tai Chi or of the social interaction from participating in the study, the establishment of a new structure in life, or the stimulation from and engagement in a new commitment to learn and practice Tai Chi. Future attention-controlled and mechanistic studies might further investigate the differential impacts of Tai Chi and social interaction. Another limitation is the issue of generalizability. As patients in this study were predominantly recent Chinese immigrants, we cannot be sure whether these results would generalize to other populations as there may be cultural beliefs among Chinese Americans which may lead that population to have favorable expectations about the effects of Tai Chi on sleep. Further studies will be needed to examine if Tai Chi is effective for treating insomnia in the mainstream population and in other ethnic minority groups.
CONCLUSION

Tai Chi training resulted in improvement in sleep quality and mood symptoms among patients with depression. Our results showed significant correlations between the changes in subjective sleep measurements and improvement in depression symptoms. The correlations between changes in depression symptoms and changes in objective sleep measurements were low and not significant.

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ORCID

Yan Ma http://orcid.org/0000-0003-1173-2920
Albert Yeung http://orcid.org/0000-0001-8018-998X

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