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Effects Of Tai Chi Training on Attention and Physiological Changes: An EEG Study

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Abstract

This study aimed to determine how 15 weeks of Tai Chi training affected attention and brain waves. Thirty-six university students (mean age = 24.27 years; SD = ±1.054) participated in this experiment. Participants practiced form postures from the first section of form 85 of the traditional Yang style of Tai Chi Chuan. The Frankfurt Attention Inventory (FAIR) was used to assess each participant's level of attention. The sensorimotor rhythm (SMR) power analysis demonstrated that participants in the Tai Chi group show higher SMR power than the control group. This study showed that Tai Chi Chuan increases theta and alpha waves by relaxing the body and mind, as well as through soft and slow movement and deep breathing. It reduces fast beta waves, which stabilizes the brain and improves attention. FAIR results showed that 15 weeks of Tai Chi training improved selective ability, control index, and persistence index. These findings suggested that Tai Chi is an exercise that helps improve attention.

Key words: Electroencephalography, EEG, Sensorimotor Rhythm, SMR, Attention, Tai Chi, Psychophysiological Changes

1. INTRODUCTION

Tai Chi Chuan is a traditional martial art that originated in ancient China. Research has well documented that Tai Chi Chuan's low-intensity form of exercise strengthens the stability of body and mind, increases attention, enhances a sense of balance through slowly paced posture corrections, and reduces tension, stress, depression, anger, fatigue, confusion, and anxiety (Lee et al., 2006; Taylor-Piliae et al., 2006; Wang et al., 2007; Liu et al., 2005; Sani et al., 2023; Yang et al., 2022). Many researchers have recently reported that Tai Chi Chuan improves attention in sports and academic settings (Ma et al., 2023; Hernandez-Reif et al., 2001; Roh & Choi, 2006). For example, Lee et al. (2006) reported that elementary school students' concentration ability increased after practicing 16 weeks of Tai Chi training. Researchers attributed this improvement to the form postures executed during training, which require persistent concentration.

In Yang style Tai Chi training, practitioners direct their attention in one of four ways, depending on whether the movements are offensive or defensive. The four kinds of attention include broad (broadening one's attention to include all of one's environment), narrow (focusing one's attention on the movements), internal

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(paying attention to one's own movements), or external (paying attention to environmental and external cues, such as the results or effects of the opponent's strategy or movements) (Taylor-Piliae & Coull, 2012). This process is known to improve attention. Roh & Choi (2006) have also asserted that Tai Chi Chuan fosters the ability to concentrate on a single task by satisfying the need for activity and relaxing bodily tension.

Chen et al. (2023) have argued that Tai Chi Chuan effectively focuses one's attention and mind and could, therefore, be a useful method of mental discipline in a sports setting. Unlike meditation or the breathing techniques of yoga, which one performs in a still, static posture, Tai Chi Chuan is a form of meditative exercise that requires movement. Thus, its advantage is being available anytime, regardless of location or surroundings. Accordingly, it is a suitable method for improving attention in a sports setting.

Scholars have used the electro-encephalogram (EEG) to determine the psychophysiological effects of Tai Chi, such as cognitive process, anxiety, and attention. According to a study by Wang et al. (2007), Tai Chi Chuan training increases the presence of alpha waves and decreases the presence of beta waves in the brain. A study by Liu et al. (2005) also showed that subjects' alpha wave-derived brainpower is higher after Tai Chi Chuan training. Park et al. (2000) have attributed the increase of the brain's alpha waves during Tai Chi Chuan training to the characteristic movements of Tai Chi Chuan, which focus the mind. Another study by Liu et al. (2003) reported that Tai Chi Chuan training increases the alpha waves in subjects' frontal lobes and decreases the theta waves in their central fissures and occipital lobes. In a notable study on concentration and brainwaves, Koo et al. (2006) asserted that the high-frequency occurrence of alpha waves is the brainwave pattern that most influences the ability to concentrate. As such, many studies on Tai Chi Chun have been conducted in various fields (Tam et al., 2023). However, an extensive literature of review on Tai Chi Chun research revealed several limitations. For example, brain waves are measured after a short period of training. However, due to the nature of Tai Chi training, long-term training may be required to see the effects of Tai Chi training. Therefore, in order to overcome these limitations, it is necessary to study the effects of Tai Chi on attention by examining brain waves after long-term training. In addition, most of the Tai Chi studies have been conducted on exercise and its effects on health (Yang et al., 2022). However, the study examined how it affects cognition, such as attention, using brain waves, not health.

In addition, Kim et al. (2009a) have asserted a close relationship between attention and SMR activity; SMR waves significantly increase as attention grows. Although research on the effect of Tai Chi Chuan on brainwaves and attention is scarce, the study of brainwaves can reveal the effects of Tai Chi Chuan on attention. Thus, this study aimed to determine the change in attention-related brainwave and brain areas after 15 weeks of Tai Chi training. The studies of Lee et al. (2006) and Roh & Choi (2006) are the basis of the present study's hypothesis. Those studies asserted that attention increased due to Tai Chi Chuan training. In addition, the results of a study by Li et al. (2014), which demonstrated a change in alpha waves after Tai Chi Chuan training, also form the basis of the present study's hypothesis. Also, it is hypothesized that after long-term Tai Chi training, attention ability and SMR waves are expected to increase compared to the control group.

2. Method

2.1. Participants

Thirty-six university students, with a mean age of 24.27 years (SD = ±1.054), participated in this experiment. The researcher assigned participants to two experimental conditions: (1) the Tai Chi Chuan group (males = 10, females = 8) or (2) the control group (males = 10, females = 8), through convenience sampling. The experimental group consisted of students taking Tai Chi classes at K university, and the participants in the control group consisted of students taking general liberal arts classes. None of the subjects had experienced any psychophysiological experiments, mental illness, or neurological disorders. All participants gave informed consent. The Institutional Review Board approved this study.

2.2. Task and Apparatus

2.2.1. Tai Chi Chuan Training Program

Participants in the Tai Chi Chun group practiced postures from the first part of form 85 of the traditional Yang style of Tai Chi Chuan for two hours once a week for 15 weeks. The form posture list consists of the following movements: 1) beginning, 2) grasping the bird's bail, 3) single whip, 4) lifting hands, 5) white crane spreading its wings, 6) left knee brushing and pushing, 7) hands strumming Pi Pa, 8) left knee brushing and pushing, 9) right knee brushing and pushing, 10) left knee brushing and pushing, 11) hands strumming Pi Pa, *12) left knee brushing and pushing, 13) stepping forward – parry* and punch, 14) apparent sealing off, and 15) crossing hands. Participants trained for two hours once a week for 15 weeks under the guidance of a Tai Chi expert.

2.2.2. Apparatus

An eight-channel WEEG (Model: LXE5208 -RF, Laxtha Inc) recorded brainwaves. To identify the proper measurement location, we followed the electrode placement suggested by Jasper (1958), with measurements taken from eight scalp sites (eg., area) (Fp1, Fp2, F3, F4, C3, C4, T3, T4). The reference electrode placement was at the right earlobe and the grounding electrode was at the prefrontal central (Fpz). The researcher took measurements to ensure that the scalp resistance at each measurement location was below 5㏀ before official measurement began. The researcher set the EEG sampling rate at 256Hz and deployed a bandpass filter of 0.1 – 100Hz while entering the EEG signal. The study used Telescan 2.9 (Laxtha Inc.) software for the EEG analysis, excluding EEG signals, including EOGs, with a value exceeding ± 100μV. After filtering signals of 1 – 30Hz with a FIR bandpass filter, the researcher epoched the resulting EEG signal at one-second intervals. The study used the Fast Fourier Transform (FFT) to calculate in an epoch the power spectral densities (PSD) of the theta (4 – 7Hz), slow alpha (8 – 9Hz), mid alpha (9 – 11Hz), sensorimotor rhythm (SMR, 12 – 15Hz), beta low (14 – 18Hz), and beta high (19 – 28Hz) frequency ranges.

2.2.3. Frankfurt Attention Inventory (FAIR)

The Frankfurt Attention Inventory (FAIR) determined each participant's attention level before and after the Tai Chi Chuan training. Moosbrugger and Oehlschlägel (1996) developed this diagnostic psychological examination, which Oh et al. (2005) translated and standardized. The FAIR presents the subject with two tests, each containing 320 classification decision test items. The time given for each test is three minutes. The ability index P (selection) on the FAIR attention test correlates with the number of items processed within the regulated test time, reflecting the level of information comprehended within that timeframe.

In the given time, the control index Q (quality) actively describes how efficiently the participant managed and controlled various stimuli that hindered attention in accomplishing the assignment. The "persistence index C" represents the intensity of the attention persistently maintained, expressed as $C = P \times Q$. The persistence index C describes the integrative ability of the function of concentrating. The reliability coefficients of P, Q, and C and the split-half reliabilities of the first and second tests, ranging between .90 and .95, determined this test's reliability.

2.3. Procedure

Upon arriving at the laboratory, the researcher briefed the participant on the experiment's objectives, after which the participant completed a consent form. Participants lightly practiced Tai Chi for 30 minutes. The researcher than applied an electrode cap on the participant for the EEG measures. Injecting gel into the electrodes at eight locations dropped the electric resistance of the scalp to below 5㏀. After stabilizing the EEG signal, the participant sat on a comfortable chair for a baseline for two minutes with eyes open and 2 minutes with eyes closed. Next, the EEG data for a 3-minute period were recorded from eight scalp positions according to the International 10-20 system: Fp1, Fp2, F3, F4, C3, C4, T3, T4 and the participants did not perform any tasks during the testing period. In this study, the baseline was intended to correct for individual differences, noise, and establish a baseline, and only 3 min tests were used as data. Rather than analyzing EEG measurement data over a long period of time, more accurate and reliable results can be obtained by selecting and analyzing only a specific section in a stable state (3 minutes). The total time required for the experiment was approximately 30 minutes.

2.4. Data Analysis

The study used a 2(group) × 8(area) × 2(time) mixed ANOVA to analyze the effects of Tai Chi by utilizing EEG. The FAIR test was conducted using a paired-t test. The dependent variables included the theta power, the alpha power, and the beta power. The dependent variable values were calculated by calculating the mean and standard deviation for the entire area after training. The study used the SPSS 17.0 program for all statistical data analysis, with the statistical significance level at $\alpha = .05$. Post-experimental verification used the Bonferroni test.

3. Results

3.1. FAIR Attention Test

The researcher found and used the Stanine (STN) standard score as the test value for the FAIR attention test.

3.1.1. Selection Ability Index (P)

The analysis of the selection ability index revealed significant main effects for the group: F (1, 34) = 6.8, $p < .05$, $\eta p2 = .164$. The selection ability index (P) was higher for the Tai Chi Chuan group (M = 8.294, SD = 1.687) than the control group (M = 6.824, SD = 1.845). (see Fig. 1). The paired t-test results for the selection ability index showed a statistically significant difference (t = -4.564, $p < .05$) between the pre- (M = 6.51) and post-training results (M = 8.47).

3.1.2. Control Index (Q)

The analysis of the selection ability index revealed significant main effects for the group: F (1, 34) = 5.16, $p < .05$, $\eta p2 = .154$. The control index (Q) was higher for the Tai Chi Chuan group (M = 6.471, SD = 1.281) than the control group (M = 5.647, SD = 1.730) (see Fig. 1). The paired t-test results for the control index showed a statistically significant difference (t = −2.135, $p < .05$) between the pre- (M = 5.34) and post-training results (M = 6.62).

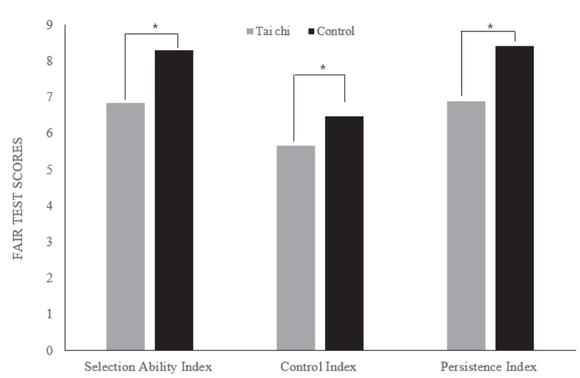

Fig. 1. Changes in attention between the two groups after 15 weeks of Tai chi training

3.1.3. Persistence Index (C)

The analysis of the selection ability index revealed significant main effects for the group: F (1, 34) = 6.94, $p < .05$, $\eta p2 = .171$. The persistence index (C) was higher for the Tai Chi Chuan group (M = 8.412, SD = 1.460) than the control group (M = 6.882, SD = 1.691) (see Fig. 1).

The persistence index results before and after 15 weeks of Tai Chi Chuan training show a statistically significant difference (t = -4.587, $p < .05$) between participants' pre- (M = 6.24) and post-training scores (M = 8.65).

3.2. Theta Power

The analysis of the theta power showed a main effect of group (F (1, 34) = 4.67, $p < .05$, $\eta p2$ = .011 .12), time (F (1, 34) = 39.7, $p < .001$, $\eta p2$ =.53), and area (F (7, 238) = 18.6, $\eta p2$ = .35) (see Fig. 1). The results indicated no significant interactions for time × group (F (1, 34) = 2.05, $p > .05$, $\eta p2$ = .056), area × time (F (7, 238) = 1.62, $p > .05$, $\eta p2$ = .045), and area × time × group (F (7, 238) = .608, $p > .05$, $\eta p2$ = .018). The analysis showed that the Tai Chi Chuan group (M = 19.74, SD = 6.77) exhibited higher theta power than the control group (M = 16.13, SD = 4.77). The time analysis indicated that the theta power in the post-test (M = 22.05, SD = 1.81) was higher than in the pretest (M = 13.82, SD =.846). Post hoc showed that the theta power was higher in areas Fp1, Fp2, F3, F4, C3, and C4 than in areas T3 and T4, in Fp2 than in Fp1, in C4 than in F3, and in F4 than in F3, C3, and C4 (see Fig. 2).

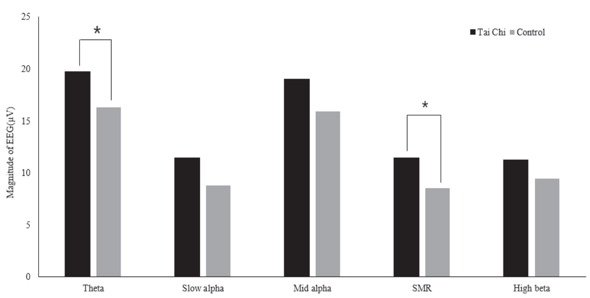

Fig. 2. The magnitude of brain waves in five different frequency bands between Tai Chi and control groups after 15 weeks of training

3.3. Slow Alpha Power

The analysis of the slow alpha power shows a main effect of time (F (1, 34) = 22.16, $p < .05$, $\eta p2$ = .397) and area (F (7, 238) = 17.88, $p < .001$, $\eta p2$ = .344). However, there are no significant main effects for the group (F (1, 34) = .953, $p > .05$, $\eta p2$ = .027). Also, the results showed no significant interactions for group × time (F (1, 34) = 2.59, $p > .05$, $\eta p2$ = .071), group by area (F (7, 238) =1.61, $p > .05$, $\eta p2$ = .136), area by time (F (7, 238) = 1.42, $p > .05$, $\eta p2$ = .198), and area × time × group (F (7, 238) = 1.464, p >. 05, $\eta p2$ = .041). The time analysis indicated that the slow alpha power in the post-test (M = 11.66, SD = 1.41) was higher than in the pretest (M = 8.7, SD = 1.11). The post hoc test showed that the slow alpha power was higher in areas Fp2, F3, F4, C3, and C4 than in areas T3 and T4, in Fp2 than in Fp1, in F3 than in Fp1 and Fp2, in F4 than in F3, and in C4 than in F3 and C3 (see Fig. 2).

3.4. Mid Alpha Power

The analysis of the mid alpha power showed a main effect of area (F (7, 238) = 27.680, $p < .05$, $\eta p2$ = .44) and time (F (1, 34) = 44.1, p < 01, $\eta p2$ = .566), but the study found no group main effect (F (1, 34) = .448, p > 05, $\eta p2$ = .013). The mid alpha power revealed no significant interaction for area by group (F (7, 238) =.984, $p > .05$, $\eta p2$ = 0.03), time by group (F (1, 34) = 2.04, $p > .05$, $\eta p2$ =.056), area by time (F (7, 238) = 1.13, $p > .05$, $\eta p2$ = .032), and area by time by group (F (7, 238) = 2.21, $p > .05$, $\eta p2$ = .061). The post hoc analysis indicated that the mid alpha power was higher in areas Fp2, F3, F4, C3, and C4 than in areas T3 and T4; in Fp2 than in Fp1; in F3 than in Fp1 and Fp2;

in F4 than in F3; and in C4 than in F3 and F4. The time analysis showed that the mid alpha power in the post-test (*M* = 22.2, *SD* = 1.66) on the mid alpha power was significantly higher than that in that of the pretest (*M* = 14.01, *SD* = 1.15) (see Fig. 2).

3.5. Sensorimotor Rhythm (SMR)

The analysis of the SMR power shows a main effect of group (F (1, 34) = 5.16, p < .05, ηp2 = .11), time (F (1, 34) = 22.2, p < .001, ηp2 = .396) (see Fig. 2), and area (F (7, 238) = 15.88, p < .001, ηp2 = .318). There were no significant interactions of group by time (F (1, 34) = 1.96, p > .05, ηp2 = .054), group by area (F (7, 238) =1.42, p > .05, ηp2 = .040), area by time (F (7, 238) = 1.32, p > .05, ηp2 = .035), and area × time × group (F (7, 238) = 1.91, p > .05, ηp2 = .053). The analysis indicated that the Tai Chi Chuan group (*M* = 11.4. *SD* = 4.76) showed a higher SMR power than the control group (*M* = 8.5, *SD* = 3.74). The time analysis showed that the post-test SMR power (*M* =11.25, *SD*=1.5) was higher than the pretest SMR power (*M* = 8.43, *SD* = 1.0). Post hoc analysis indicated that the SMR power was higher in areas C3 and C4 than in areas Fp1, Fp2, F3, and F4 (see Fig. 2).

3.6. Beta High Power

The high beta power analysis showed a main effect of area (F (7, 238) = 6.46, p < .05, ηp2 = .159) and time (F (1, 34) = 8.81, p < .05, ηp2 = .206), but no main effects for group (F (1, 34) = .360, p > .05, ηp2 = .010). Also, the results found no significant interactions for area by group (F (7, 238) = .070, p > .05, ηp2 = .002), time by group (F (1,34) = .393, p > .05, ηp2 = .011), area by time (F (7, 238) = 1.25, p > .05, ηp2 = .012), and area by time by group (F (7, 238) = 1.87, p > .05, ηp2 = .052). Post hoc analysis indicated that the high beta power was lower in areas Fp1 and Fp2 than in areas F4, C4, and T4, and it was higher in areas C4 and T4 than in areas Fp1, Fp2, F3, and C3. The time analysis showed that the high beta power in the post-test (*M* = 11.88, *SD*=1.02) was lower than the one on the pretest (*M* = 9.70, *SD* = .73) (see Fig. 2).

4. Discussion

The study results revealed that post-training P values were higher than pre-training values. The increase in P in this study may be related to the properties of the Tai Chi Chuan form postures. The findings of this study also demonstrated that the P value of the Tai Chi group was higher than that of the control group. It is assumed that these research results may be due to the influence of Tai Chi Chuan style. The form of Tai Chi Chuan used in this study was the first part of the traditional Yang style. This form is a complicated sequential technique composed of slow and uniformly paced movements connected sequentially without breaks. One cannot execute this movement if one is distracted or unfocused. During the 15 weeks of training, the belief is that the subjects experienced an increase in their proficiency, as evidenced by the rise in their ability index (P) while mastering the movements of the first part of the traditional Yang style Tai Chi Chuan form posture and performing the complex exercise. Kim et al. (2016) supported the interpretation of this study by claiming that the postures acquired through Tai Chi training improve the mental attention of participants.

The increase in the Q value noted in this study reflects the characteristics of Tai Chi Chuan, which involves repeated movements and a strict structure. For instance, in the form posture list, the sixth and seventh movements, “Left Brush Knee and Push” and “Hands Strumming Pi Pa,” and then “Right Brush Knee and Push,” come before “Left Brush Knee and Push” and “Hands Strumming Pi Pa,” which repeat as steps ten and eleven. Because the structure repeats complicated movements this way, one could accidentally omit or repeat a movement if they lose focus or are inattentive during training. For subjects to execute the Tai Chi Chuan movements without making a mistake, they need to be able to control the variation and order of the postures within and between movements. When the training time for Tai Chi Chuan extends, participants sometimes execute the movements out of order. In these instances, the assumption is that the C value increases because of the subjects' continuous efforts to execute the movements properly. These study results corroborate the results of Hernandez‑Reif et al. (2001). These researchers found that their subjects' attention levels increased as they spent more time on Tai Chi Chuan training.

The findings of this study demonstrate that participants in the Tai Chi group showed a prominent increase in theta in the frontal lobe and the central fissure compared to the control group. Scholars know that the theta wave reflects internal attention and the state of deep meditation that occurs between sleep and waking (Hutchison, 1996; Cho & Shim, 2005; Malan et al., 2023). In this study, the increased presence of the theta wave after the Tai Chi Chuan training seems to result from the quiet movements of Tai Chi Chuan, also known as "zen in motion," i.e., meditation in motion. The assumption is that the slow pace and relaxed movements of Tai Chi Chuan directed the participants' attention to their internal experiences, producing meditative effects and leading to the presence of theta wave. This finding aligns with Hernandez‑Reif et al. (2001), who observed that practicing Tai Chi Chuan increases the presence of the theta wave in the frontal lobe.

The results of this study demonstrated that the alpha power of the Tai Chi group was found to increase more in the frontal and central regions compared to the control group. The slow alpha power is a more prominent brainwave when the brain is resting or relaxed, especially before falling asleep (Cho & Shim, 2005). This study attributes the increase in the participants' slow alpha waves to the slow movements and breathing practiced during the Tai Chi Chuan training. As practitioners perform Tai Chi Chuan movements, their breathing tends to become shallower and longer initially, gradually transitioning into deep breaths and natural abdominal breathing as the duration of each movement increases. The assumption is that the participants' slow alpha power increased due to the slow, still exercise of Tai Chi Chuan, inducing a relaxed, meditative, and restful state of mind. Guo et al. (2019) observed that while the beta wave increases and the alpha wave decreases during Tai Chi training, the presence of the alpha wave increases sharply, accompanied by a decrease in the beta wave during the rest period after training. Their study showed that the alpha wave was more active in the frontal sites than in the occipital lobe after training, aligning with this study's results.

The sensorimotor rhythm (SMR) power analysis demonstrated that participants in the Tai Chi group had higher SMR power than the control group. Interestingly, there was a significant decrease in the SMR wave after training rather than before, which contradicts the results of past studies. The decrease in the SMR wave was especially prominent in the central fissure area. The SMR wave is a brainwave that acts as a buffer when transitioning from rest to activity or from rest to sleep. In other words, the SMR can occur in the standby state but not in the states of rest, tension, or relaxation and appears only in the sensory-motor cortex (Cho & Shim, 2005; Yoo & Koo, 2008). Scholars have found a close relationship between the SMR wave and concentration (Botrel & Kubler, 2019; Kim et al., 2019; Sterman, 1977). For example, Yoo & Koo (2008) reported that the SMR wave significantly increases when concentration increases. In addition, Cho & Shim (2005) asserted that the SMR wave enables concentration, thus potentially being responsible for concentration.

The present study contradicts the results of these previous studies. Previous studies may have observed an increase in the SMR wave due to the measurement of brainwaves occurring after activities in the motor-sensory cortex had diminished through biofeedback training or imaging. This study's SMR wave decreased significantly because the sensory-motor cortex became active after Tai Chi Chuan training. Studies have demonstrated that the SMR wave becomes active when the sensory-motor areas are at rest and decreases when the sensory-motor areas are activated by actual movements or motor imagery (Yue et al., 2012).

The beta power analysis results show especially conspicuous decreases in areas T3 and T4. The beta high power becomes prominent when the brain conducts relatively complicated inferences, performs information processing activities of a high mental load, or is in a state of mental tension, anxiety, or excitement (Kim et al., 2009b). The beta high wave in this study decreased because the relaxed movements of Tai Chi Chuan lowered the activity level of the cerebrum. This study concurs with the results of studies by Liu et al. (2003), which demonstrated that the alpha wave sharply increases and the beta wave decreases during the rest period after Tai Chi Chuan training (Li et al., 2014; Xue et al., 2014). In this study, the beta power significantly decreased after training, especially in the temporal lobe area. This finding indicates that psychological relaxation suppressed the participant's beta high wave through Tai Chi Chuan training. However, it is considered premature to conclude that the reduced beta wave is due to the Tai Chi movement because there is only a difference in the temporal lobe and there is no difference between groups.

5. Conclusion

Tai Chi Chuan increased the participants' ability index (P), control index quality (Q), and persistence index (C). The slow pace and relaxed movements of Tai Chi Chuan increased the slow and mid alpha powers. The SMR power decreased as the sensory-motor areas became active, and the beta power decreased as the relaxed movements lowered the activity level of the cerebrum. The results of this study show that Tai Chi Chuan enhances stability in the cerebrum and improves attention by boosting theta and alpha waves while reducing beta waves. One achieves this effect through the practice's combination of relaxation techniques, smooth and deliberate movements, and deep breathing exercises. This study has limitations in generalizing the results of the study because the subjects were conveniently sampled. This study also has a limitation in that it did not consider the cultural context. Tai Chi is deeply rooted in Chinese culture, and its effects might be influenced by cultural factors, which are not always accounted for in research conducted in different cultural contexts. The development and use of standardized Tai Chi protocols for further research can improve comparability throughout the study.

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