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EFFECTS OF TAI CHI EXERCISE ON ATTENTION IN HEALTHY ELDERLY SUBJECTS AS MEASURED BY NEAR-INFRARED SPECTROSCOPY DURING THE STROOP TASK

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Abstract : **Background:** To our knowledge, there is no study that has examined the effect of Tai Chi exercise (Tai Chi) on attention function using functional brain imaging methodologies. Recent developments in near-infrared spectroscopy (NIRS) have enabled non-invasive clarification of brain functions by measurement of hemoglobin concentrations as cerebral blood volume. So, in the present study, we examined the effects of Tai Chi in the healthy elderly as measured by NIRS during the Stroop task. **Methods:** Twelve healthy elderly subjects participated in the present study after giving consent. The relative concentrations of oxyhemoglobin (oxy-Hb) were measured with frontal probes every 0.1 sec during the Stroop color-word task, using 24-channel NIRS machines. **Results:** The Stroop task scores after the Tai Chi term were significantly higher than those before the Tai Chi term. There were no significant differences in the mean oxy-Hb changes between the conditions before and after Tai Chi. **Conclusions:** Our study suggested that Tai Chi promoted attention function in healthy elderly subjects, and maintained oxy-Hb concentration changes in healthy elderly subjects.

Key words: Tai Chi, near-infrared spectroscopy, Stroop task, attention function, prefrontal function

INTRODUCTION

Tai Chi exercise, often called Tai Chi, has been regarded as both the highest form of martial arts[1] and an important regimen,[2] and for these reasons it has enjoyed growing popularity not only in the Far East but also in many Western countries. Tai Chi is viewed as a way of life that maintains or restores health, and it is a powerful centering activity in which an individual learns control over some bodily functions and quiets the mind.[3),4)] We also previously examined the effects of Tai Chi on healthy elderly volunteers using a General Health Questionnaire (GHQ)[5] and reported that significant time-by-group interactions were found in the GHQ total score and

severe depression score.Tai Chi is therefore related to improvement in the GHQ score among the elderly.[6]

Tai Chi could also be recommended as a mental training method to ameliorate cognitive functions, especially attention function.[7] However, to our knowledge, there is no study that has examined the effect of Tai Chi on attention function using functional brain imaging methodologies. Functional brain imaging methodologies, such as positron emission tomography (PET), single photon emission computed tomography (SPECT), and functional magnetic resonance imaging (fMRI) have the disadvantage of requiring large apparatuses, which prevents their use in a bedside setting for diagnostic and treatment purposes. Furthermore, these functional brain imaging methodologies do not offer high time resolution. By contrast, multi-channel near-infrared spectroscopy (NIRS) systems have recently been developed to allow non-invasive and bedside functional mapping of the cerebral cortex, with a high time resolution.[8),9),10)] We already reported the prefrontal dysfunction in Attention-Deficit/Hyperactivity Disorder as measured by NIRS with a Stroop task.[11)]

To our knowledge, there is no study that has examined the effect of Tai Chi using NIRS and the Stroop task. Therefore, we examined two points in the present study: (1) whether attention function in healthy elderly subjects estimated using the Stroop task data is changed by Tai Chi; and (2) whether attention function in healthy elderly subjects estimated using the oxyhemoglobin (oxy-Hb) change measured by NIRS is changed by Tai Chi. We therefore examined the effects of Tai Chi on attention function in healthy elderly subjects as measured by NIRS during the Stroop task.

METHODS

Study design

This pilot study was a prospective clinical trial to evaluate the psychological effects of Tai Chi for the healthy elderly using NIRS and the Stroop task. This study was approved by the Institutional Review Board of Nara Medical University. Written informed consent was obtained from all subjects before the study.

Study setting and population

The participants were voluntarily recruited using posters. We excluded participants that were under 60 years old, had a psychiatric and/or physical medical history, or had already experienced Tai Chi. The present study enrolled 12 healthy participants. They consisted of 4 males and 8 females. All subjects were Japanese and right-handed. Their mean age was 64.25 (SD: 3.14; range: 60-68) years. The number of correct answers in the Stroop color-word task and the oxy-Hb increase in NIRS were estimated for the subjects both before and after the Tai Chi exercise term at the same time of day (10:00-11:00 a.m.). The subjects were made to participate in Tai Chi exercise as soon as possible after baseline NIRS using the Stroop task.

Tai Chi

The Tai Chi program[12] was based on 24-style. Participants were made to perform 100-minute Tai Chi sessions once a week for about 6 months (their mean term of Tai Chi: 6.83; SD: 1.59; range: 5-10 months) by the Tai Chi expert (W.W). Each session included the following: (1) 30 minutes of warm-up and a review of Tai Chi principles, (2) 60 minutes of Tai Chi practice, and (3) 10 minutes of cooling down.

The Stroop color-word task

We reproduced the Stroop task according to the method previously described.[13] The Stroop task consisted of two pages stapled together. Each page had 100 items presented as 5 columns of 20 items. The items on the first page were the color words RED, GREEN, and BLUE in black ink. The items on the second page were the words RED, GREEN, and BLUE printed in red, green, or blue ink, with the limitation that the word and ink could not match. The items were randomly distributed on the two pages, except that no item could occur twice in succession within a column.

Before the task, the examiners instructed the subjects as follows: "These are tests of how quickly you can read the words on the first page, and the colors on the second page. After we say 'begin,' you are to read down the columns, starting with the first one, saying the words/colors to yourself as quickly as you can. After you finish the first column, go on to the next and so on. After you have read the first page for 45 seconds, we will turn the page. Please repeat this procedure for the second page"

We combined those two pages and made the Stroop color-word task simple and easy so that the subjects could understand it easily. The Stroop color-word task encompassed the first page (p1) and the second page (p2). The Stroop color-word task consisted of a 45-sec p1 task and a 45-sec p2 task (the color-word task first time), a 45-sec p1 task and a 45-sec p2 task (the color-word task second time), a 45-sec p1 task and a 45-sec p2 task (the color-word task third time), and a 45-sec p1 task. We made the 45-sec p1 task the baseline task. We also counted the number of correct answers each time. We named them as follows: Number of correct answers in Stroop color-word task first time (SCWC-1), second time (SCWC-2), and third time (SCWC-3).

NIRS measurements

The oxy-Hb increase and deoxyhemoglobin (deoxy-Hb) decrease in NIRS have been shown to reflect cortical activation. In animal studies, oxy-Hb is the most sensitive indicator of rCBF because the direction of change in deoxy-Hb is determined by the degree of changes in venous blood oxygenation and volume.[14] Therefore, we decided to focus on changes in oxy-Hb. In this study, oxy-Hb was measured with a 24-channel NIRS machine (Hitachi ETG-100, Hitachi Medical Corporation, Tokyo, Japan) at 2 wavelengths of near-infrared light (760 and 840nm), whose absorption was measured. Oxy-Hb was calculated as previously described.[15] The interprobe distance of the machine was 3.0 cm, and it was determined that the machine measures points 2-3 cm beneath the scalp, i.e., the surface of the cerebral cortices.[16,17]

The NIRS probes were placed on the subject's frontal regions, and arranged to measure the relative concentrations of Hb changes at 24 measurement points in an 8 × 8 cm area, with the

lowest probes positioned along the Fp1-Fp2 line according to the international 10/20 system used in electroencephalography. The absorption of near-infrared light was measured with a time resolution of 0.1 sec. The obtained data were analyzed using the "integral mode": the pre-task baseline was determined as the mean across 10 sec just before the task period; the post-task baseline was determined as the mean across 25 sec after the task period; and linear fitting was performed on the data between the 2 baselines. Moving average methods were used to exclude short-term motion artifacts in the analyzed data (moving average window: 5 sec).

We tried to exclude motion artifacts by closely monitoring artifact-evoking body movements, such as neck movements, strong biting, and blinking (identified as most influential in the preliminary artifact-evoking study), and by instructing the subjects to avoid these movements during the NIRS measurements.

Statistical analyses

Statistical comparison of subject characteristics before and after the Tai Chi exercise term was performed using a two-tailed paired t test. Data analyses were conducted using Topo Signal Processing type-G version 2.05 (Hitachi Medical Corporation, Tokyo, Japan). OT-A4 version 1.63K (Hitachi Medical Corporation, Tokyo, Japan) was used for overlap display of the grand average waveforms in both before and after conditions in Fig. 1 and was used to calculate the mean oxy-Hb measurements in Table 2. SPSS 17.0 J for Windows (SPSS, Tokyo, Japan) was used for statistical analysis.

RESULTS

Stroop task scores before and after the Tai Chi exercise term

As shown in Table 1, the SCWC-1, and SCWC-2 after the Tai Chi term were significantly higher than those before the Tai Chi term. And the SCWC-3 after the Tai Chi term tended to be high compared with those before the Tai Chi term.

NIRS data of the subjects during the Stroop color-word task

The grand average waveforms of oxy-Hb concentration changes during the Stroop color-word task in both before and after conditions can be seen in Fig. 1. The grand average waveform of oxy-Hb concentration change in both conditions (before and after the Tai Chi term) did not change much during the task period. The mean oxy-Hb measurements from the pre-task to post-task period in all 24 channels can be seen in Table 2. From the pre-task to post-task period, there were no significant differences between the two conditions in regard to the mean oxy-Hb changes.

DISCUSSION

Until now, there have been few reports examining the effects of Tai Chi on attention function in healthy elderly subjects. Our previous study examined the effect of Tai Chi exercise on a major depressive patient using the Hamilton Rating Scale for Depression (HAM-D)[18] and

event-related potentials (ERPs) as an objective measure. We suggested that Tai Chi could be recommended as a mental training method to ameliorate not only depressive symptoms but also cognitive function, especially attention function.[19] However, the study was just a case report. Studies with large samples are needed to examine the effects of Tai Chi on attention function.

In the present study, we therefore examined the effects of Tai Chi on attention function in healthy elderly subjects as measured by NIRS during the Stroop task. The Stroop task is well known as a gold standard task to measure attention.[20),21)] The Stroop interference effect occurs when subjects are required to name a colored word printed in an incongruent color. Therefore, the Stroop task is thought to be appropriate to manipulate attention demand.20) Our findings about the Stroop task (as shown in Table 2) indicated that Tai Chi exercise promoted attention function in healthy elderly subjects. Nakaaki et al.[22)] indicated that subjects with Alzheimer's disease performed poorly in the event-based prospective memory task under the incorrect-color condition in the Stroop task in comparison with healthy elderly subjects. Because it promoted attention function in healthy elderly subjects, Tai Chi may also promote attention function in subjects with Alzheimer's disease.

To our knowledge, no study has examined the effect of Tai Chi on the elderly using NIRS. Therefore, our report, examining the potential benefits of Tai Chi, is a useful study. We regret that there were no significant differences between the conditions before and after Tai Chi in terms of oxy-Hb concentration changes in all channels. These results might have been obtained for several reasons. One of these is that the term of Tai Chi exercise was too short. If the term was longer, oxy-Hb concentration changes might occur. Another possible reason is the character of NIRS. NIRS only measured the Hb concentration of changes on the surface of the cerebral cortices. Therefore, it might not pick up the effect of Tai Chi exercise on frontal function. In any case, our findings about NIRS (as shown in Table 3 and Fig. 1), indicated that Tai Chi exercise maintained oxy-Hb concentration changes in healthy elderly subjects.

Our study had two major limitations. First, the sample size was small. Second, we had no control over subjects who performed other exercise or no exercise during the same term. Future studies with large samples and control subjects as measured by NIRS are required to determine whether attention function in healthy elderly subjects was ameliorated by Tai Chi exercise. Furthermore, NIRS has disadvantages compared with other methodologies.[10)] The main disadvantage of NIRS is that it enables measurement of Hb concentration changes only as relative values, not as absolute values. We performed a Stroop task that had the first page as the base task to overcome these potential problems. We also measured Hb concentration changes from the activation task to the base task and performed the task 3 times to average out potential accidental changes and prevent the subjects from becoming tired.

In conclusion, our study suggested that Tai Chi exercise promoted attention function in healthy elderly subjects, and suggested that Tai Chi exercise maintained oxy-Hb concentration changes in healthy elderly subjects.

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REFERENCES

1) **Gu, LX.**: Techniques of Tai Chi Chuan. Shanghai Education Press, Shanghai, 1982.
2) **Hu, YZ.**: Qigong and setting-up exercises. People Hygiene Press, Beijing, 1963.
3) **Cheng, J.**: Tai Chi Chuan: a slow dance for health. Phys Sportsmed 27: 109-110, 1999.
4) **Galante, L.**: Tai Chi: The supreme ultimate. Samuel Weiser Inc, York Beach, Maine, 1981.
5) **Goldberg, D.P.**: Manual of the General Health Questionnaire. Neer-Nelson, England, 1978.
6) **Wang, W., Sawada, M., Noriyama, Y., Arita, K., Ota, T. and Kishimoto, T.**: Effects of Qigong in Tai Chi the elderly using General Health Questionnaire (GHQ). J Nara Med Association 60: 159-165, 2009.
7) **Liu, Y., Mimura, K., Wang, L. and Ikuda, K.**: Physiological benefits of 24-style taijiquan exercise in middle-aged women. J Physiol Anthropol Appl Human Sci 22: 219-225, 2003.
8) **Koizumi, H., Yamashita, Y., Maki, A., Yamamoto, T., Ito, Y., Itagaki, H. and Kennan, R.**: Higher-order brain function analysis by transcranial dynamic NIRS imaging. J Biomed Opt 4: 403-413, 1999.
9) **Maki, A., Yamashita, Y., Ito, Y., Watanabe, E., Mayanagi, Y. and Koizumi, H.**: Spatial and temporal analysis of human motor activity using non-invasive NIR topography. Med Phys 22: 1997-2005, 1995.
10) **Yamashita, Y., Maki, A. and Koizumi, H.**: Near-infrared topographic measurement system: Imaging of absorbers localized in a scattering medium. Rev Sci Instrum 67: 730-732, 1996.
11) **Negoro, H., Sawada, M., Iida, J., Ota, T., Tanaka, S. and Kishimoto, T.**: Prefrontal Dysfunction in Attention-Deficit/Hyperactivity Disorder as Measured by Near-Infrared Spectroscopy. Child Psychiatry Hum Dev 41: 193-203, 2010.
12) **China Sports**: Simplified 'Taijiquan', 2nd edn. China Publications Center, Beijing, 1983.
13) **Goldman, C.J.**: A Group Version of the Stroop Color and Word Test. J Pers Assess 39: 386-388, 1975.
14) **Hoshi, Y., Kobayashi, N. and Tamura, M.**: Interpretation of near-infrared spectroscopy signals: A study with a newly developed perfused rat brain model. J Appl Physiol 90: 1657-1662, 2001.
15) **Schweitzer, J.B., Faber, T.L., Grafton, S.T., Tune, L.E., Hoffman, J.M. and Kilts, C.D.**: Alterations in the functional anatomy of working memory in adult attention deficit hyperactivity disorder. Am J Psychiatry 157: 278-280, 2000.
16) **Hock, C., Villringer, K., Müller-Spahn, F., Wenzel, R., Heekeren, H., Schuh-Hofer, S., Hofmann, M., Minoshima, S., Schwaiger, M., Dirnagl, U. and Villringer, A.**: Decrease in parietal cerebral hemoglobin oxygenation during performance of a verbal fluency task in patients with Alzheimer's disease monitored by means of near-infrared spectroscopy (NIRS)-correlation with simultaneous rCBF-PET measurements. Brain Res 755: 293-303, 1997.
17) **Toronov, V., Webb, A., Choi, J.H., Wolf, M., Michalos, A., Gratton, E. and Hueber, D.**: Investigation of human brain hemodynamics by simultaneous near-infrared spectroscopy and functional magnetic resonance imaging. Med Phys 28: 521-527, 2001.
18) **Hamilton, M.**: A rating scale for depression. J Neurol Neurosurg Psychiatry 23: 56-62, 1960.
19) **Wang, W., Sawada, M., Ikeshita, K., Negoro, H. and Kishimoto, T.**: Treatment effects of Tai Chi exercise

in a patient with major depression using mismatch negativity (MMN) and early negative difference (Nde). J Nara Med Association 59: 163-166, 2008.

20) **Kingma, A., La Heij, W., Fasotti, L. and Eling, P.**: Stroop interference and disorders of selective attention. Neuropsychologia 34: 273-281, 1996.

21) **Spieler, D.H., Balota, D.A, and Faust, M.E.**: Stroop performance in healthy younger and older adults and in individuals with dementia of the Alzheimer's type. J Exp Psychol Hum Percept Perform 22: 461-479, 1996.

22) **Nakaaki, S., Watanabe, H., Nakamura, H., Yoshida, S., Matui, T., Kinoshita, Y. and Furukawa, T.**: The Influence of the Stroop Interference Effect on an Event-based Prospective Memory Task in Alzheimer's Disease Patients. Psychogeriatrics 2: 120-126, 2002.

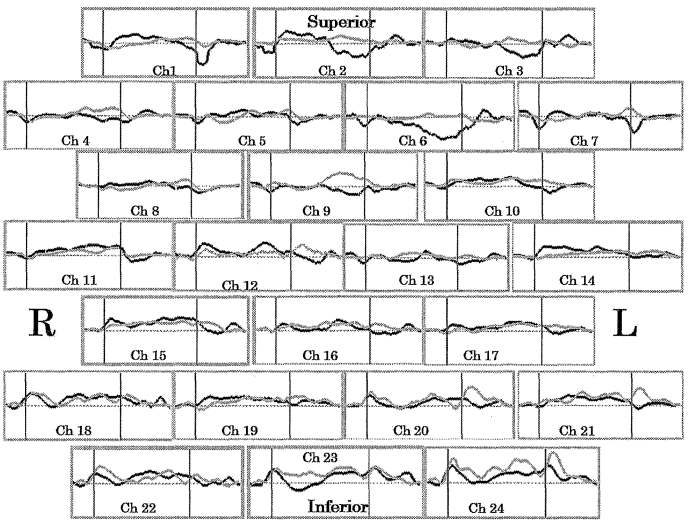

Fig. 1. Grand average waveforms of oxyhemoglobin (oxy-Hb) concentration changes during the Stroop color-word task before and after Tai Chi exercise. The grand average waveform of oxy-Hb before Tai Chi exercise is the gray line, and that after Tai Chi exercise is the black line. The task was carried out between the first and second vertical lines.

Table 1. Stroop task scores before and after Tai Chi

	Before Tai Chi		After Tai Chi		
	Mean	SD	Mean	SD	P value
SCWC-1	29.7500	11.74831	35.9167	10.31731	.037**
SCWC-2	36.9167	11.31739	41.9167	8.12917	.045**
SCWC-3	38.0833	13.21472	42.1667	9.55209	.067*

* $P < 0.1$ ** $P < 0.05$

SCWC-1, Number of correct answers in Stroop color-word task first time; SCWC-2, Number of correct answers in Stroop color-word task second time; SCWC-3, Number of correct answers in Stroop color-word task third time.

Table 2. Mean oxyhemoglobin (oxy-Hb) measurements from pre-task to post-task period in 24 channels

	before Tai Chi		after Tai Chi		
	mean(mMmm)	SD(mMmm)	mean(mMmm)	SD(mMmm)	p value
Ch1	.0007	.04682	−.0045	.09002	.877
Ch2	.0199	.03991	−.0058	.08606	.381
Ch3	.0052	.04305	−.0087	.06812	.481
Ch4	.0126	.05635	−.0068	.03744	.319
Ch5	−.0006	.05316	.0035	.03034	.792
Ch6	−.0075	.06341	−.0539	.10160	.172
Ch7	−.0004	.05650	−.0115	.04139	.650
Ch8	−.0079	.06796	−.0033	.03860	.863
Ch9	.0239	.04503	−.0175	.06439	.142
Ch10	.0251	.05019	.0158	.05944	.642
Ch11	.0058	.04612	.0239	.04015	.153
Ch12	.0146	.10982	.0286	.03905	.765
Ch13	.0130	.04972	−.0070	.04842	.358
Ch14	.0205	.04747	.0320	.02491	.534
Ch15	.0493	.06950	.0441	.05313	.813
Ch16	.0301	.06484	.0140	.04893	.378
Ch17	.0230	.05057	.0225	.04497	.974
Ch18	.0391	.04845	.0392	.05950	.997
Ch19	.0325	.07732	.0332	.04541	.983
Ch20	.0430	.06937	.0197	.03395	.261
Ch21	.0493	.07065	.0268	.05499	.313
Ch22	.0376	.06587	.0357	.04957	.941
Ch23	.0571	.08363	.0318	.07542	.542
Ch24	.0877	.09817	.0460	.04257	.144