European Journal of Human Movement

OPEN ACCESS

Original Research

Effects of tai chi on cardiovascular responses and stress reduction in prehypertensive subjects: A randomized clinical trial

Touraj Hashemi Nosrat-abad[1], Mansour Bayrami[1], Hossein Namdar[2], Khalil Esmaeilpour[1], Davoud Ezzati[1]*

[1] Department of Psychology, University of Tabriz, Tabriz, Iran.

[2] Cardiovascular Research Center, Tabriz University of Medical Sciences, Tabriz, Iran.

* Correspondence: (Davoud Ezzati) ezzatid@yahoo.com. ORCID ID nº 0000-0002-4344-3595

Received: 20/09/2020; Accepted: 22/04/2021; Published: 31/06/2021

Abstract: Prehypertension seems to be the precursor to hypertension, and using non-pharmacological methods such as tai chi, can reduce blood pressure and its dangerous consequences. Therefore, this study aimed to examine the effects of 8-form Yang-style tai chi on cardiovascular responses and stress reduction in prehypertensive subjects. Sixty prehypertensive men and women aged 25 to 54 years were selected by purposive sampling, and randomly assigned into two experimental groups (15 males and 15 females) and two control groups (15 males and 15 females). Systolic and diastolic blood pressure, and resting heart rate were measured by digital sphygmomanometer and stress was measured using Markham mental pressure inventory. Then, the experimental groups completed tai chi training for 45 minutes, three days per week for 8 weeks, however, the control groups received no intervention. Twenty four hours after completing the training, the dependent variables were re-measured in the study groups. Factorial multivariate analysis of covariance was used for statistical analysis. The results showed that tai chi significantly decreased systolic blood pressure, resting heart rate, and stress in comparison with control group. Our study encourages and supports that a short style of tai chi is an effective way in improving cardiovascular responses and stress in prehypertensive individuals.

Keywords: 8-form Yang-style tai chi, systolic blood pressure, diastolic blood pressure, resting heart rate, stress reduction, prehypertension.

1. Introduction

Hypertension is an important medical and public health issue which places a heavy burden on health care resources and the community (Fisher and Curfman, 2018). It is a chronic medical condition in which the systemic arterial blood pressure (BP) is elevated (Krause, Lovibond, Caulfield, McCormack, & Williams, 2011). Hypertension is a major world health problem and is among the most prevalent chronic conditions (Padmanabhan, Tran, & Dominiczak, 2021). In some countries, seventy percent of adults experience hypertension and it is growing day by day (Kearney, Whelton, Reynolds, Whelton, & He, 2014). Also, more than one billion people worldwide are affected by hypertension (Fisher and Curfman, 2018), and it is estimated that by 2025 this number will reach 1.56 billion (Bell, Twiggs, Olin, & Date, 2015).

According to the seventh report of the joint national committee (JNC-7), prehypertension is defined as a systolic blood pressure (SBP) of 120–139$_{mmHg}$ and/or a diastolic blood pressure (DBP) of 80–89$_{mmHg}$ in 18 years and older adults (Chobanian et al, 2003). In general, the prevalence of hypertension is similar between men and women, except that under the age of 45, it is higher in men than women, and in those over 65, it is higher in women than men (Bell et al, 2015). Deliberately identifying patients as "prehypertensive" needs consideration of too much risk related to increased BP in this range and reminds health care specialists to consider the prevention seriously (Guo et al, 2011). A study showed that the rate of conversion of prehypertension into hypertension over four years was 30% (Vasan, Larson, Leip, Kannel, & Levy, 2001). Factors such as increased age, high body mass, male gender, and stress are related to hypertension and prehypertension (Pitsavos, Chrysohoou, Panagiotakos, Lentzas, & Stefanadis, 2008).

The relationship between stress and hypertension has been thoroughly theorized. Stress as a scientific term, refers to the effect of psychosocial and environmental factors on physical or mental well-being. Therefore, it can be said that stressors and stress responses are distinct phenomena (Eash, 2002). It is broadly accepted that stressors such as challenging stimuli, induce psycho-physiological and behavioural changes (known as stress response) designed to help organisms cope and eventually survive in an environment that is now altered by the presence of stressors (McEven, 1998).

Mental stress and cardiovascular diseases such as hypertension are intertwined (Wong & Nahin, 2003). Therefore, individuals with hypertension and prehypertension, have indicated strong cardiovascular responses to stressful stimuli (Schwartz, Durocher, & Carter, 2011). Despite this hypertensive response being documented, few studies have investigated the mechanisms underlying this response (Wong & Nahin, 2003).

Mental stress continuously induces forearm vasodilation, and evidence suggests that prehypertension blunts this response (Carter, Kupiers, & Ray, 2005). The mechanisms which are in charge of this reaction remain unsolved, although a strong sympathetic neural response has been suggested (Wong & Nahin, 2003).

With the popularity and prevalence of mind-body exercises, the interest in tai chi has increased for people with high blood pressure and stress (Zou et al, 2018; Taylor-Piliae, 2003). Tai chi has origins in ancient Chinese martial arts and combines gentle physical activity with elements of meditation, body awareness, imagery, and attention to breathing (Yeh, Wang, Wayne, & Phillips, 2008).

The dynamics of tai chi emphasize movements in graceful patterns. Besides, tai chi is characterized by deep diaphragmatic breathing, complete weight shifts, moving from deep relaxation to full speed and force, and for balance and whole body connection. However, it should be noted that if some of the movement paths in tai chi are relatively long and the inhaled air is not enough, a "small breath" can be added or the movement can be coordinated with two breaths. However, one should not feel suffocated and should be flexible, because people differ in lung capacity, speed of training and the direction of the limbs, and there will be problems in coordinating breathing and movements (Yang, 2011). Tai chi practitioners claim that one should practice tai chi in a mindful manner and learn the philosophy behind the movements in order to deal with stress effectively (Sandlund & Norlander, 2000).

Some systematic reviews indicate that traditional Chinese exercise such as tai chi can reduce SBP and DBP and can provide benefits for patients with cardiovascular disease and cardiovascular risk factors (Lan, Chen, Wong, & Lai, 2013; Yeh et al, 2008). Other benefits of tai chi include positive mood, increased control of emotional processes, and increased calm and patience and can help reduce stress and prehypertension as one of its consequences (Detert, Derosia, Caravella, & Duquette, 2006).

Essentially, as a primary prevention, intervention can be carried out for prehypertension by the use of proven and safe drugs, or inducing individual behavior changes. Antihypertensive medication is not recommended but should be initiated if life style changes fail to prevent BP from reaching hypertensive levels (Chobanian et al, 2003). Individual behavioural changes are the attractive options because of their inherent "natural" appeal, perceived low cost, simplicity and safety though they may not be sustainable (Albarwani, Al-Siyabi, & Tanira, 2014).

While some studies have investigated the relationship between tai chi with hypertension and stress separately, we have not come across a study that deals with the relationship between tai chi with cardiovascular responses and stress in prehypertensive individuals. Health-based lifestyle changes such as tai chi can be beneficial in lowering BP and mental stress in individuals with prehypertension. Therefore, the purpose of this study was to evaluate the effects of 24 sessions of 8-form Yang-style tai chi training on cardiovascular responses and stress in prehypertensive subjects.

2. Materials and Methods

Subjects — The study population included all prehypertensive males and females in Tabriz-Iran in 2020. Prehypertension was defined as SBP of 120-139mmHg, and/or DBP of 80-89mmHg. Participants signed the consent form and were informed about the anonymity of the data, that the data would be used for research purposes only and that they had the right to refuse or discontinue participation, according to the ethical standards of the Helsinki Declaration of 1983.

Experimental design — To provide the 60 samples required for this randomized controlled study, using purposive sampling method, individuals were enrolled in the study consecutively. Nine subjects were excluded from the study based on exclusion criteria (six people with a conflict program, two people due to the use of anti-anxiety drugs, and 1 person who had previously experienced tai chi training), and 60 prehypertensive males and females (aged=25-54 years) who had the final conditions for inclusion in the study, were randomly assigned into four groups of 15 individuals. Inclusion criteria were as follows: 1- SBP 120 to 139mmHg, and DBP 80 to 89mmHg; 2- Age between 25 to 54 years; 3- Adequate literacy for reading and writing; 4- Ability to attend the sessions. Exclusion criteria were as follows: 1- Sensory-motor disabilities; 2- Use of anxiolytic drugs; 3- Previous tai chi experience. The flowchart presents the process of participant selection and experimental implementation (Figure 1).

Methodology — A digital wrist sphygmomanometer (EmsiG, Model: BW 62) was used to measure subjects' cardiovascular responses. This device is an automated oscillometric BP monitor with standard cuff size range of wrists (13.5-19.5cm) (O'Brien et al, 2002). The advantage of wrist sphygmomanometers is that they are small compared to arm sphygmomanometers, which can be used in obese people, because the diameter of the wrist is slightly affected by obesity. Systematic error due to the hydrostatic effect of the difference in position of the wrist relative to the heart is a possible defect in this type of sphygmomanometer, which can be avoided if the wrist is always at the level of the heart when reading (Ogedegbe and Pickering, 2010). These types of sphygmomanometers have been validated by the European Society of Hypertension (ESH) protocol (O'Brien et al, 2002).

At first, before measuring cardiovascular responses (SBP, DBP, and Resting Heart Rate (RHR)), subjects were asked to sit quietly and without stress for at least 5-10 minutes to eliminate the possible effects of their previous physical activities. Then, the subjects' cardiovascular responses were recorded in the sitting position. Next, subjects were assigned into two experimental groups (n= 30) and two control groups (n=30).

Then, mental pressure inventory was completed by participants. This inventory was developed by Ursula Markham to measure the psychological and emotional pressure caused by environmental stressors with 38 (36 in Persian version) yes-no items which was translated into Persian and adapted to the cultural conditions of Iranian society by Pashasharifi (Sarouni, Jenaabadi, & Pourghaz, 2016). After that, cardiovascular responses recorded as a pre-test. The experimental groups received 24 sessions for 8 weeks (Saturdays, Mondays, and Wednesdays for males; and Sundays, Tuesdays, and Thursdays for females) of 8-form Yang-style tai chi training. All experimental and control groups had the same sleeping/waking times, and in order to have regular sleep, they were advised not to consume caffeinated drinks 4-6 hours before bedtime. Subjects in the tai chi groups were advised to drink adequate amounts of water before, during, and after the intervention sessions, but should not eat from two hours before to two hours after the intervention sessions. Exercises were performed between 8-9 a.m. at a temperature between 21-25°C. The control groups received no intervention. Finally, twenty-four hours after the last session, the mental pressure inventory was completed and cardiovascular responses were recorded as a post-test.

Each tai chi training session consisted of three stages:

1- Warming up: This stage took 10 minutes; in this way, the trainee was initially helped to warm up the limbs to prepare for the stretching exercises. The warm-up included a series of gentle movements of the head to the sides, bending and opening joints such as the knees, elbows, and walking at a slow pace to gradually increase the heart rate. During these exercises, the trainee was asked to focus on his breathing and take slow, deep breaths. Also, the timing of the exhalation should be coordinated with the opening of the joints and the successive contractions and contractions of the muscles so that more oxygen reaches the organs for metabolism (Yang, 2011).
2- Tai chi main and educational movements: This stage took 25 minutes; tai chi main movements are known as form. Forms are interconnected sets of movements that consist of a combination of sitting, steps, hand movements, and so on. In this study, the main exercises of tai chi were 8-form Yang-style (Table 1) which is also known as 10-form Yang-style, but 8-form does not count commencing and closing forms (everydaytaichi.org). Subjects were taught two forms or postures of tai chi per week (totally, 8 forms or postures in the first 4 weeks), and the subsequent sessions were devoted to improving motor function, balance, and focusing on individual movements.
3- Cooling down and recovery: At this stage, for 10 minutes some qigong techniques such as deep breathing and meditation were used to return the body and heart rate to normal.

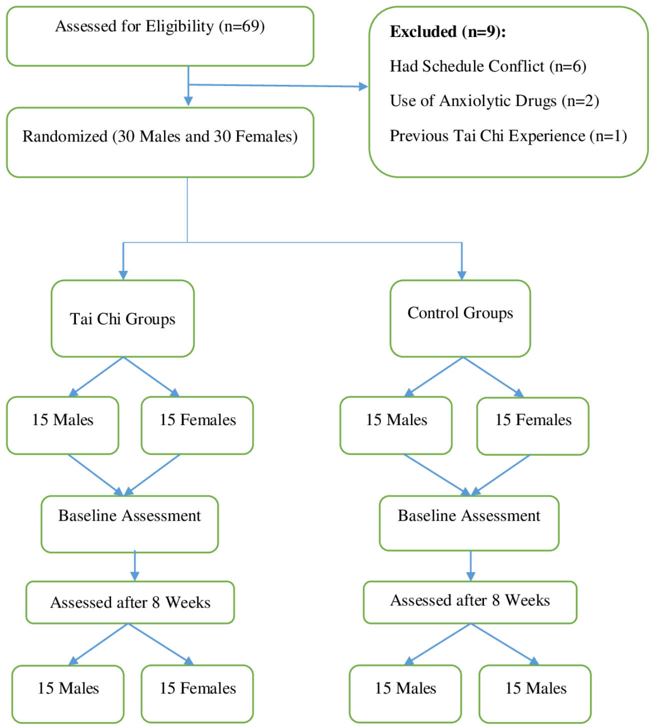

Figure 1. Flowchart of the study

Statistical analysis — This study used IBM SPSS Statistics (version 19, IBM Corporation). All data are presented as

Table 1. Names of the Forms in 8-Form Yang-style Tai Chi

Form	Movement Direction/Number of Repetitions
Commencing Form	Both Hands Rise to Shoulder Level
Curving Back Arms (Repulse Monkey)	Right Hand, then Left Hand
Stepping and Pushing (Brush Knees and Twist Steps)	Left, then Right
Parting the Horse's Mane	Left, then Right
Moving Hands (Wave Hands like Clouds)	Left, then Right
Standing on One Leg (Golden Cock Stands on One Leg)	Left, then Right
Kicking with Leg	Right, then Left
Stepping Sideways and Moving Arms (Grasp Peacock's Tail: Ward off, Rollback, Press, Push)	Right, then left
Crossing Hands or Embrace the Tiger	Right, then Weight Shifts to the Left Leg and Sitting in Back Position
Closing Form	Both Hands Fall to the Side, Right Leg Drawn to the Left.

Table 2. Mean and Standard Deviation of SBP, DBP, RHR, and Stress

		Male		Female	
	Dependent Variables	Baseline	8 Weeks	Baseline	8 Weeks
Tai Chi	SBP(mmHg)	133.80±6.64	125.80±7.00	131.80±5.85	122.53±9.11
	DBP(mmHg)	85.60±3.02	80.93±4.92	84.47±3.14	79.93±3.99
	RHR(bpm)	83.80±9.77	76.67±9.04	80.20±6.55	75.20±4.39
	Stress(pt)	22.67±7.32	15.80±5.60	21.67±6.30	14.07±4.57
Control	SBP(mmHg)	132.07±7.82	132.53±9.32	132.33±4.72	132.94±5.15
	DBP(mmHg)	83.33±7.20	81.00±8.25	82.60±4.72	83.00±4.93
	RHR(bpm)	82.27±12.16	83.60±10.73	80.80±5.66	79.80±7.78
	Stress(pt)	20.07±6.17	20.07±5.77	21.33±4.35	20.60±5.15

SBP: Systolic Blood Pressure; DBP: Diastolic Blood Pressure; RHR: Resting Heart Rate; mmHg: millimeters of mercury;bpm: beats per minute; pt: point Tai chi; N=30 (male=15, female=15) Control; N=30 (male=15, female=15). * Values are presented as mean±SD.

Table 3. Results of Factorial Multivariate Analysis of Covariance of Method† Gender, and SBP, DBP, RHR, and Stress in Prehypertensive Subjects

Source	Value*	F	p	η2
Method	0.411	17.54	0.001**	0.59
Gender	0.956	0.57	0.69	0.04
Method† Gender	0.870	1.84	0.14	0.13
SBP after 8 Weeks		42.48	0.001**	0.45
DBP after 8 Weeks		3.51	0.07	0.06
RHR after 8 Weeks		16.32	0.001**	0.24
Stress after 8 Weeks		58.58	0.001**	0.53

*Values of Wilks' Lambda; ** p<0.001

means and standard deviations. Factorial multivariate analysis of covariance was used for statistical analysis. The pre-test values of SBP, DBP, RHR, and stress were the covariate variables, and gender of participants was the factor of this model. To ensure data normality and to comply with conditions of use of parametric statistics, Kolmogorov Smirnov test was used (p>0.01). Box test was used to verify equality of covariance parameters assumption (p>0.01), and levene's test was used to examine assumption of equality of groups' variances (p>0.01). Analysis of variance interaction effects was used to homogenize the interactive effects of the pretest and independent variables (p>0.01). Also, bartlett's test of sphericity was used for normal correlation of dependent variables (p<0.05). Bonferroni test was used as the post-hoc multiple comparisons. A p-value of <0.05 was considered to be statistically significant.

3. Results

A total of 60 prehypertensive males and females, with a mean age of 39.4±8.9 years old, were included. There were no significant differences between the experimental and control groups in terms of gender and age. Table 2 shows the descriptive statistics of the study groups. In general, in both stages (pre-test and post-test), the experimental groups had a greater decrease in cardiovascular responses and stress than the control groups.

The results of factorial multivariate covariance analysis of groups are presented in table 3. Tai Chi had a significant effect on the weighted mean of SBP, DBP, RHR and stress (wilks lambda= 0.411, F= 17.54, p= 0.001, $\eta 2$= 0.59), but the effect of gender on these variables was not significant, and did not have a moderating role on the effect of tai chi on the cardiovascular responses and stress reduction. Table 3 also shows that there was a significant difference between experimental and control groups in SBP ($p<0.001$), RHR ($p<0.001$), and stress ($p<0.001$) after 8 weeks of tai chi training, but the difference between experimental and control groups in DBP was not significant.

4. Discussion

Tai chi has been used for decades as an exercise for health in a wide variety of people, particularly in the hypertension and prehypertension subjects. Therefore, the present study aimed to evaluate the impact of tai chi on cardiovascular responses and stress in prehypertensive subjects.

According to results of this study, 8weeks of 8-form Yang-style tai chi exercise significantly reduced SBP and RHR in prehypertensive male and female subjects in comparison with control group. Similar cardiovascular responses to tai chi have been reported in a variety of studies. Based on a study, 12 weeks of tai chi exercise program on high–normal hypertensive subjects reduced SBP and DBP significantly (Tsai et al, 2003). In another study of other types of cardiovascular disease such as hypertension and coronary heart disease, the results showed that tai chi lowered BP in the experimental group and may be a major prevention for cardiovascular populations and healthy individuals (Yeh et al, 2008).Other study showed that evaluated hypertensive patients, reported a statistically significant reduction in mean BP after tai chi exercises (Lian et al, 2017).

Tai chi is accompanied by breathing control. Therefore, deep inhalations and exhalations during this exercise increase blood flow in capillaries and arteries throughout the body, and as a result, reduce heart rate and BP (Pan, Zhang, & Tao, 2015). Also, the mechanism of change in BP may be related to reduction of tonic sympathetic nerve activity produced by tai chi training. The reductions on sympathetic drive that follow training are more pronounced in hypertensive patients than in normal individuals and are likely to underline the antihypertensive effect of tai chi (Tsai et al, 2003).

Tai chi as a non-pharmacological intervention can lower BP or prevent hypertension by modifying life style and increase the antihypertensive effect of drugs, and reduce the risk of cardiovascular disease (Wang et al, 2011). Tai chi is also an exercise of aerobic nature that enhances arterial adaptation, and it can be a mechanism of BP reduction (Yeh et al, 2004). Tai chi is associated with benefits such as increased urinary norepinephrine, decreased salivary cortisol, decreased mood disturbance, and increased power feeling that is able to lower BP (Wang et al, 2011).

Some studies have shown that tai chi can reduce RHR. Of 6 studies with HR measured at quiet condition, the pooled result of meta-analysis showed a significant decrease in RHR (Zheng et al, 2015). According to a study, 48 weeks of tai chi program significantly reduced RHR in elderly men and women who were frail (Wolf et al, 2006). Reduction in HR has been accompanied by decreased sympathetic activity in other studies. Sympathetic activity decreased following tai chi but not following slow moving physical activity. Tai chi enhanced vagal modulation and lowered sympathetic activity (Field, 2011). However, an increase in resting parasympathetic tone and a decrease in response to beta-adrenergic stimulation may not be associated with a decrease in RHR after regular exercise or physical activity in humans and may be due to an inherent decrease in heart rate through mechanisms not yet fully understood (Reimers, Knapp, & Reimers, 2018).

The results of this study also showed a significant stress reduction after tai chi exercise in both prehypertensive male and female subjects in comparison with control groups. This result is consistent with previous research showing that tai chi training is able to lower stress, anxiety, and tension (Jin, 1992; Jin, 1989), and increase positive mood states (Jin, 1989). A gender-based study showed that men used mindful exercise (A tai chi type program) to promote mood more than women, while women after mindful exercise showed a greater reduction in mood disturbance (Brown et al, 1995). While this may not indicate a gender difference in the benefits of exercise, it may show that men prefer more intense exercise if they are more stressed than women (Lan et al, 2013).

The role of stress in cardiovascular physiology and the relationship between stress, chronic sympathetic stimulation, and vasoconstriction is well described (Yeh et al, 2008). Sympathetic function, especially noradrenaline secretion, is enhanced by exercise. Therefore, the high level of urinary noradrenaline in tai chi participants indicates this mechanism (Jin, 1992). During moderate physical activity, increased release of noradrenaline from sympathetic nerves may be beneficial to health. Such an increase at this level, could increase lipolysis when working on muscle fibres to oxidize fatty acids released from adipose tissue (Jin, 1992). Tai chi triggers some physiological processes related to physical and emotional pleasure, such as increasing the secretion of serotonin and dopamine (Zou et al, 2018). On the other hand, Cortisol levels, as a stress indicator, decrease in tai chi learners, due to moderate physical load. In this condition, the plasma cortisol levels are reduced, and therefore, salivary cortisol levels increase. This is why during physical activity, peripheral tissues require more cortisol uptake while cortisol secretion is effectively inhibited or slowed (Jin, 1992).

Tai chi as an alternative exercise is recommended for people with prehypertension, because it does not need a specific facility or expensive equipment and can be trained anytime and anywhere, and is easily applicable in the community. Tai chi is also effective for enhancing cardiorespiratory function and other fitness features (Tsai et al, 2003).

5. Practical applications

Further prospective research is needed on the role of meditation-based activities such as tai chi in relation to cortisol and related parameters such as plasma and salivary cortisol levels associated with changes in blood pressure. For example; Future research could examine the effect of tai chi on changing cortisol doses to changes in blood pressure in a variety of hypertensive groups compared with healthy individuals. Also, further prospective research is needed to determine whether tai chi, along with other biological mechanisms, can help reduce stress and high blood pressure.

This study may have a number of limitations. First, the lack of BP holter monitoring on the number of participants, which could provide a clearer picture of changes in BP. Also, some confounding factors, such as the duration and intensity of tai chi training, interactions between subjects and/or the influence of the trainer could influence the rate of cardiovascular responses and stress.

6. Conclusions

In conclusion, we found that 24 sessions of 8-form Yang-style tai chi exercise has the potential to play an important role in reducing BP and stress in prehypertensive subjects and may be a potential exercise paradigm for controlling BP and stress in these individuals.

Supplementary Materials: Research proposal was approved by ethical committee in the Tabriz University of Medical Sciences (Ethics ID: IR.TBZMED.REC. 1398.539), and approved by Iranian Registry of Clinical Trials (IRCT 20200607047679N1).

Funding: This work was supported by the University of Tabriz.

Acknowledgments: This article was extracted from a Ph.D dissertation, registered at the University of Tabriz, and was supported by the University of Tabriz in Tabriz, Iran.

We would like to express our gratitude to all the participants and all those involved in this study. Their support and participation in this study was valuable.

Conflicts of Interest: The authors declare no conflict of interest

References

Albarwani, S., Al-Siyabi, S., & Tanira, M. O. (2014). Prehypertension: Underlying pathology and therapeutic options. *World journal of cardiology,* 6(8), 728-743. https://doi.org/10.4330/wjc.v6.i8.728

Bell, K., Twiggs, J., Olin, B. R., & Date, I. R. (2015). Hypertension: the silent killer: updated JNC-8 guideline recommendations. *Alabama Pharmacy Association,* 334, 4222.

Brown, D. R., Wang, Y., Ward, A. N. N., Ebbeling, C. B., Fortlage, L., Puleo, E., ... & Rippe, J. M. (1995). Chronic psychological effects of exercise and exercise plus cognitive strategies. *Medicine & Science in Sports & Exercise.* 27(5):765–75. PMID: 7674883

Carter, J. R., Kupiers, N. T., & Ray, C. A. (2005). Neurovascular responses to mental stress. *The Journal of physiology, 564(1),* 321–327. https://doi.org/10.1113/jphysiol.2004.079665

Chobanian, A. V., Bakris, G. L., Black, H. R., Cushman, W. C., Green, L. A., Izzo Jr, J. L., ... & Roccella, E. J. (2003). Seventh report of the joint national committee on prevention, detection, evaluation, and treatment of high blood pressure. *Hypertension,* 42(6), 1206-1252. https://doi.org/10.1161/01.HYP.0000107251.49515.c2

Detert, R. A., Derosia, C., Caravella, T., & Duquette, R. D. (2006). Reducing Stress and Enhancing the General Well-Being of Teachers Using T'ai Chi Chih® Movements. *Californian Journal of Health Promotion,* 4(1), 162-173.

Esch, T. (2002). Health in stress: change in the stress concept and its significance for prevention, health and life style. *Gesundheitswesen (Bundesverband der Arzte des Offentlichen Gesundheitsdienstes (Germany)),* 64(2), 73-81. https://doi.org/10.1055/s-2002-20275

Field, T. (2011). Tai Chi research review. *Complementary Therapies in Clinical Practice,* 17(3), 141-146. https://doi.org/10.1016/j.ctcp.2010.10.002

Fisher, N. D., & Curfman, G. (2018). Hypertension—a public health challenge of global proportions. *Jama*, 320(17), 1757-1759.https://doi.org/10.1001/jama.2018.16760

Guo, X., Zou, L., Zhang, X., Li, J., Zheng, L., Sun, Z., ... & Sun, Y. (2011). Prehypertension: a meta-analysis of the epidemiology, risk factors, and predictors of progression. *Texas heart institute journal*, 38(6), 643-652. PMID: 22199424

Video clips of the full set of 8(10) form of Yang-style Tai can be viewed at http://www.everydaytaichi.org/yang-style-10-form.html

Jin, P. (1989). Changes in heart rate, noradrenaline, cortisol and mood during Tai Chi. *Journal of psychosomatic research,* 33(2), 197-206. https://doi.org/10.1016/0022-3999(89)90047-0

Jin, P. (1992). Efficacy of Tai Chi, brisk walking, meditation, and reading in reducing mental and emotional stress. *Journal of psychosomatic research,* 36(4), 361-370. https://doi.org/10.1016/0022 3999(92)90072-a

Kearney, P. M., Whelton, M., Reynolds, K., Whelton, P. K., & He, J. (2004). Worldwide prevalence of hypertension: a systematic review. *Journal of hypertension,* 22(1), 11-19. https://doi.org/10.1097/00004872-200401000-00003

Krause, T., Lovibond, K., Caulfield, M., McCormack, T., & Williams, B. (2011). Management of hypertension: summary of NICE guidance. *British Medical Association,* 25;343:d4891. https://doi.org/ 10.1136/bmj.d4891

Lan, C., Chen, S. Y., Wong, M. K., & Lai, J. S. (2013). Tai chi chuan exercise for patients with cardiovascular disease. *Evidence-Based Complementary and Alternative Medicine,* 2013. https://doi.org/10.1155/2013/983208

Lian, Z., Yang, L., Bian, Y., Zeng, L., Li, M., Sun, Y., & Li, W. (2017). Effects of Tai chi on adults with essential hypertension in China: A systematic review and meta-analysis. *European Journal of Integrative Medicine,* 12, 153-162. https://doi.org/10.1016/j.eujim.2017.05.007

McEwen, B. S. (1998). Protective and damaging effects of stress mediators. *New England journal of medicine,* 338(3), 171-179. https://doi.org/10.1056/NEJM199801153380307

O'Brien, E., Pickering, T., Asmar, R., Myers, M., Parati, G., Staessen, J., ... & Gerin, W. (2002). Working Group on Blood Pressure Monitoring of the European Society of Hypertension International Protocol for validation of blood pressure measuring devices in adults. *Blood pressure monitoring,* 7(1), 3-17. https://doi.org/10.1097/00126097-200202000-00002

Ogedegbe, G., & Pickering, T. (2010). Principles and techniques of blood pressure measurement. *Cardiology clinics,* 28(4), 571-586. https://doi.org/10.1016/j.ccl.2010.07.006

Padmanabhan, S., Tran, T. Q. B., & Dominiczak, A. F. (2021). Artificial intelligence in hypertension: seeing through a glass darkly. *Circulation Research,* 128(7), 1100-1118. https://doi.org/10.1161/CIRCRESAHA.121.318106

Pan, X., Zhang, Y., & Tao, S. (2015). Effects of Tai Chi exercise on blood pressure and plasma levels of nitric oxide, carbon monoxide and hydrogen sulfide in real-world patients with essential hypertension. *Clinical and Experimental Hypertension,* 37(1), 8. https://doi.org/10.3109/10641963.2014.881838

Pitsavos, C., Chrysohoou, C., Panagiotakos, D. B., Lentzas, Y., & Stefanadis, C. (2008). Abdominal obesity and inflammation predicts hypertension among prehypertensive men and women: the ATTICA Study. *Heart and vessels,* 23(2), 96-103. https://doi.org/10.1007/s00380-007-1018-5

Reimers, A. K., Knapp, G., & Reimers, C. D. (2018). Effects of exercise on the resting heart rate: a systematic review and meta-analysis of interventional studies. *Journal of clinical medicine,* 7(12), 503. https://doi.org/10.3390/jcm7120503

Sandlund, E. S., & Norlander, T. (2000). The effects of Tai Chi Chuan relaxation and exercise on stress responses and well-being: an overview of research. *International Journal of Stress Management,* 7(2), 139-149. https://doi.org/10.1023/A:1009536319034

Sarouni, A. S., Jenaabadi, H., & Pourghaz, A. (2016). The Relationship of Mental Pressure with Optimism and Academic Achievement Motivation among Second Grade Male High School Students. *International Education Studies,* 9(8), 127-133. https://doi.org/10.5539/ies.v9n8p127

Schwartz, C. E., Durocher, J. J., & Carter, J. R. (2011). Neurovascular responses to mental stress in prehypertensive humans. *Journal of Applied Physiology,* 110(1), 76-82. https://doi.org/10.1152/japplphysiol.00912.2010

Taylor-Piliae, R. E. (2003). Tai Chi as an adjunct to cardiac rehabilitation exercise training. *Journal of Cardiopulmonary Rehabilitation and Prevention,* 23(2), 90-96. https://doi.org/10.1097/00008483-200303000-00004

Tsai, J. C., Wang, W. H., Chan, P., Lin, L. J., Wang, C. H., Tomlinson, B., ... & Liu, J. C. (2003). The beneficial effects of Tai Chi Chuan on blood pressure and lipid profile and anxiety status in a randomized controlled trial. *The Journal of Alternative & Complementary Medicine,* 9(5), 747-754. https://doi.org/10.1089/107555303322524599

Vasan, R. S., Larson, M. G., Leip, E. P., Kannel, W. B., & Levy, D. (2001). Assessment of frequency of progression to hypertension in non-hypertensive participants in the Framingham Heart Study: a cohort study. *The Lancet,* 358(9294), 1682-1686. https://doi.org/10.1016/S0140-6736(01)06710-1

Wang, Y., Shang, H., Guo, Y., Wu, T, Tian L., Zhang, J., & Wang, W. (2011). Tai Chi for hypertension. *Cochrane Database of Systematic Reviews,* (10). https://doi.org/10.1002/14651858.CD009349

Wolf, S. L., O'Grady, M., Easley, K. A., Guo, Y., Kressig, R. W., & Kutner, M. (2006). The influence of intense Tai Chi training on physical performance and hemodynamic outcomes in transitionally frail, older adults. *The Journals of Gerontology Series A: Biological Sciences and Medical Sciences,* 61(2), 184-189. https://doi.org/10.1093/gerona/61.2.184

Wong, S. S., & Nahin, R. L. (2003). National center for complementary and alternative medicine perspectives for complementary and alternative medicine research in cardiovascular diseases. *Cardiology in review,* 11(2), 94-98. htps://doi.org/10.1097/01.CRD.0000053452.60754.C5

Yang, H. (2011). A Study on How to Breathe Properly When Practicing Tai Chi Chuan. *Higher Education Studies,* 1(1), 64-66. htps://doi.org/10.5539/hes.v1n1p64

Yeh, G. Y., Wang, C., Wayne, P. M., & Phillips, R. S. (2008). The effect of tai chi exercise on blood pressure: a systematic review. *Preventive cardiology,* 11(2), 82-89. htps://doi.org/10.1111/j.1751-7141.2008.07565.x

Yeh, G. Y., Wood, M. J., Lorell, B. H., Stevenson, L. W., Eisenberg, D. M., Wayne, P. M., ... & Davis, R. B. (2004). Effects of tai chi mind-body movement therapy on functional status and exercise capacity in patients with chronic heart failure: a randomized controlled trial. *The American journal of medicine,* 117(8), 541-548. htps://doi.org/10.1016/j.amjmed.2004.04.016

Zheng, G., Li, S., Huang, M., Liu, F., Tao, J., & Chen, L. (2015). The effect of Tai Chi training on cardiorespiratory fitness in healthy adults: a systematic review and meta-analysis. *PloS one,* 10(2), e0117360. htps://doi.org/10.1371/journal.pone.0117360.

Zou, L., Sasaki, J. E., Wei, G. X., Huang, T., Yeung, A. S., Neto, O. B., ... & Hui, S. S. C. (2018). Effects of mind–body exercises (Tai Chi/Yoga) on heart rate variability parameters and perceived stress: A systematic review with meta-analysis of randomized controlled trials. *Journal of Clinical Medicine,* 7(11), 404. htps://doi.org/10.3390/jcm7110404.