The Autonomic and Rate Pressure Product Responses of Tai Chi Practitioners

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Abstract

Background: Spectral analysis of autonomic nervous system activity can provide insight into cardiovascular function. Rate pressure product is the parameter often targeted pharmacologically to decrease the incidence of myocardial events. **Aim:** The purpose of this study was to investigate whether or not Tai Chi Chuan practitioners would demonstrate autonomic responses that would be more cardioprotective when compared to non-trained controls. **Materials and Methods:** This was a cross-sectional study that measured the autonomic responses and rate pressure product of 2 groups of subjects; a Tai Chi Chuan trained (n = 13) and non-trained sedentary controls (n = 13) at rest and during 2 stressor phases that simulated functional activities of daily living. **Results:** The Tai Chi group maintained a greater parasympathetic outflow at rest and during the isometric grip stressor phase ($P<0.05$). Sympathetic outflow, systolic blood pressure and rate pressure product were significantly lower in the Tai Chi group at rest, during the isometric grip and standing stressor phases ($P<0.05$). **Conclusion:** Although a cause-and-effect relationship cannot be concluded in this study, the Tai Chi group was able to demonstrate efficiency of the myocardium with suppressed rate pressure product values and autonomic responses that favored parasympathetic outflow. This type of training may complement non-pharmacological anti-hypertensive therapy.

Keywords: Autonomic modulation, Heart rate variability, Myocardial oxygen consumption, Tai Chi

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Introduction

Autonomic modulation is the ability of the autonomic nervous system (ANS) to respond to stimuli, both internal and external, in order to maintain homeostasis. The ANS is responsible for the involuntary regulation of vital body functions. This system is divided into two branches: the parasympathetic (PSNS) and sympathetic nervous system (SNS). Both branches affect heart rate (HR), blood pressure (BP) and the smooth muscle tone of blood vessels. The myocardium is innervated by fibers of both branches. Peripheral blood vessels, on the other hand, are innervated by sympathetic efferents.

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ANS activity can be measured non-invasively through variations in both HR and BP. Spectral analysis of HR variability (HRV) provides information on the autonomic modulation of HR. Specifically, parasympathetic activity is associated with the high frequency band of HRV within the range of 0.15-0.4 Hz. The low frequency band of 0.04-0.15 Hz is modulated by both PSNS and SNS activity.[1] Spectral analysis of BP variability (BPV), as represented by baroreceptor sensitivity (BRS) and the low frequency component of systolic BP (LF_{SBP}), is a non-invasive measure of SNS activity.

Tai Chi Chuan (TCC) is a martial art characterized by its slow, gentle and rhythmic movement patterns. As a method of exercise training, TCC can be practiced to strengthen internal energy (chi) and overall health. It has been the subject of many research studies of motor control, psychological anxiety and cardiovascular function.[2-8] With regard to autonomic physiology, several authors have examined the acute effects of TCC after several weeks of training.[2,5,6] Several studies have examined the acute responses of TCC on HRV.[5,6] These studies were cross-sectional and compared the autonomic modulation of individuals who were trained in Tai Chi with age-matched sedentary controls. During both the studies, measurements were taken before and after Tai Chi training and meditation. As was hypothesized, results were favorable for those who were trained in TCC and meditation as compared to those who were not. A third study compared Tai Chi training with low intensity cardiovascular training. Although this study was longitudinal, the results were inconclusive.[2] None of the above studies controlled for respiratory rate during the measurement of the autonomic variables, which may have affected the validity of their findings.

It is well established that respiratory rates modulate autonomic parameters and, as such, should be controlled for.[9-13] Respiratory depth and frequency have been shown to affect the depolarization of the sinus node and thereby influence cardiac autonomic control. During inspiration, parasympathetic outflow to the SA node is impeded and results in shortening of the R-R interval (cardioacceleration) whereas, during exhalation, this pattern is reversed (cardiodeceleration). In this investigation, respiratory rate was controlled throughout all data collection phases.

The efficiency of the myocardium to perform work can be represented by the myocardial oxygen consumption (MVO_2), which is the most important indicator of the load on the heart.[14-16] Rate pressure product (RPP) is a non-invasive method of estimating MVO_2 and can be calculated by multiplying HR by SBP and dividing by 100 (RPP = [(HR X SBP)/100]).[16] The hemodynamic components of this product, HR and SBP, are modulated by both branches of the ANS. HR is influenced by both the PSNS and SNS, whereas, SBP is only affected by the SNS. RPP is the parameter that is targeted by the pharmacological community in an attempt to decrease the incidence of ischemic events leading to infarctions.

Therefore, the aim of this study was to examine the RPP and autonomic responses of experienced Tai Chi practitioners and non-practitioners, while controlling for respiratory rates. The hypotheses were that the long-term practitioners of TCC would have an attenuated RPP and autonomic modulation favoring parasympathetic output at rest and during physical stressor phases when compared to sedentary-matched controls. This study was cross-sectional in nature.

Materials and Methods

Subjects

Based on statistical calculations from preliminary data of the dependent variables, 80% power at $P<0.05$ required 26 participants. Subjects were divided into a Tai Chi trained group (TCC: $n = 13$) and a sedentary (non-trained) group (NT: $n = 13$). Participants for the experimental group were recruited from classes at a Tai Chi school in Westchester County, New York. Both the experimental and control groups consisted of 6 male and 7 female participants [Table 1]. Subjects in the experimental group were only partaking in Yang style Tai Chi as their form of physical training for a minimum of 2 hours per week and at least 6 months of training. Training sessions consisted of 40 minutes of practice of the TCC form, which is composed of 108 movement patterns. These students were trained by a Tai Chi Master, with over 47 years of training in this art. Subjects for the control group were sedentary individuals, not participating in any form of exercise training and were matched according to age, gender and BMI (body mass index) to the experimental group. Both groups consisted of healthy individuals between 30 and 60 years of age. Before participating in the study, subjects completed a medical history and physical activity questionnaire. In order to be considered for participation, both groups of individuals were required to be non-smokers, and not present a history of hypertension, cardiovascular complications, metabolic disorders or taking any medications that interfere with the functions of the ANS. Participants provided informed written consent and were not excluded based on race, gender or socioeconomic background. This investigation was approved by the Human Studies Committee of the Institutional Review Board of the University.

Initial measurements

Upon entry into the laboratory, subjects were asked to perform a maximal handgrip maneuver using a Jamar hand dynamometer (Jamar hand dynamometer, Sammons Preston, Bolingbrook, IL) to determine their maximum voluntary contraction (MVC) with the dominant hand. Height, weight and training history were also recorded. Subjects were then prepared for the recordings of respiration, electrocardiograms, brachial blood pressures and beat-to-beat blood pressures. Respiration data were obtained using a Respitrace device (Deban Industries, Toledo, OH). Specifically, a temperature probe was placed under the right nostril of

Table 1: Descriptive data for both groups of subjects

	TCC	NT	*P*
Age (years)	42±5	44±5	0.42
BMI	27±4	30±5	0.06
Yrs. Train	2.5±1.7	0	<0.001
Gender	M = 6, F = 7	M = 6, F = 7	NS

TCC = Tai Chi Chuan group, NT = Non-trained, BMI = Body mass index, Yrs. Train = years of training in TCC. Data are presented as mean±SD , NS = Not significant the subject's nose and inspiratory and expiratory airflow were recorded. Cardiac electrical activity and HR were determined with an electrocardiograph recorder (Viatak 414 ECG monitor, Hillsboro, OR). Disposable electrodes were placed on the subject's chest in a V5 configuration. Brachial blood pressure was measured using a Dinamap blood pressure monitor (Dinamap BP monitor model 1846SC, Critikon Inc., Tampa, FL) on the dominant arm. Beat-to-beat finger arteriolar blood pressure was measured using the Finapres photoplethysmograph (Finapres, model 2300 Ohmeda, Louisville, CO). This device was placed on the middle phalanx of the middle finger of the non-dominant hand. In order to minimize the effects of respiration on HR and BPV, subjects were required to maintain a paced breathing rhythm. Subjects breathed at 12 breaths per minute (0.2 Hz) while following the up and down movement of a red LED light box.

After the preparatory phase, subjects rested for 15 minutes while seated in order to equilibrate prior to data collection. Following this resting phase, data were collected for 3 minutes during 3 different phases. Phase 1 (seated rest), phase 2 (sustained isometric contraction) and phase 3 (standing) were carried out in a counterbalanced manner. Between these phases sufficient time was allowed for the subjects' vital signs to return to baseline levels. During seated data collection, the arm with the Finapres rested on a surface that was level with the location of the atria. For the isometric stressor, subjects maintained their seated position with the dynamometer in the hand and resting on their thigh. During this stressor, subjects were asked to maintain a contraction at 30% of their MVC for a total of 3 minutes. Visual feedback was provided by the use of a red mark placed on the appropriate value of the hand dynamometer. For the standing stressor, the subject was instructed to stand up from the seated position. During this phase, the subject's arm, with the attached beat-to-beat blood pressure monitor, was placed at the height of the atria for the entire data collection period.

Frequency domain analyses

Specialized LabView software was created in order to analyze the autonomic parameters being measured. Prior to analyses, the pulse wave signal was inspected for artifact correction and rejection following established procedures.[17-19] The methods used were based on spectral decomposition of the pulse intervals, beat-to-beat blood pressures and respiratory waves.[20] For this research study, the heart period (R-R) was spectrally decomposed as described previously. The high frequency component (msec^2 = power of the area 0.15-0.4 Hz) and low frequency component (msec^2 = power of the area 0.04-0.15 Hz) were considered to be representative of parasympathetic and sympathetic activity, respectively.

Beat-to-beat blood pressures were derived from the continuous blood pressure waveform. For the spectral decomposition, blood pressure peaks were detected with an established peak detection algorithm. The sequence of the systolic peaks was then interpolated to provide a continuous data stream, and the resulting systolic pressure data were used to calculate the power spectra. Power spectra within the 0.04-0.15 Hz range were defined as low-frequency components and were considered to be representative of sympathetic vasomotor activity.[17-19] The very low frequency range (VLF) of 0.0033-0.04 Hz represents a slower modulation of the heart that is influenced by peripheral vasomotor and renin-angiotensin systems. Circadian, neuroendocrine and other rhythms are represented in the ultra-low-frequency (ULF) bandwidth of <0.0033 Hz. Total power (TP) represents all of the variance in HR over a 24-hour period.[1,11,21,22]

Both parasympathetic and sympathetic results are expressed in normalized values and were calculated as LF_{sbp}nu or HF_{RR}nu power = [LF_{sbp} or HF_{RR} / (TP – VLF) × 100]. Spectral analysis of HRV allows for the quantification of parasympathetic (HF) and sympathetic (LF) activity respectively. The ratio of these 2 components of the ANS (LF/HF) is known as sympathovagal balance and represents the predominating outflow of this system.[1,23,24] The ratio is determined by dividing sympathetic power by parasympathetic power. A value less than 1.0 would represent a greater parasympathetic outflow, whereas values greater than 1.0 represent a shift toward increased sympathetic modulation. When LF, which is composed of both LF and HF, is divided by HF, parasympathetic outflow is mathematically factored out. Therefore, this ratio is primarily representative of sympathetic outflow, particularly during stressful events.[25]

Baroreceptor assessment was carried out during the same epochs as the spectral analyses. Specifically, baroreflex sensitivity (alpha index) was the ratio of the square root between the band-pass filtered pulse interval spectral values and filtered SBP spectral values in the frequency region where coherence was >0.5. This method was based on the calculation of the modulus of the transfer function between SBP and pulse interval powers in the low-frequency band (0.04-0.15 Hz).

All data acquisitions and post-acquisition frequency domain analyses were carried out in accordance with the standards put forth by the Task Force on HRV interpretation.[26] All recordings received an anonymous code and all dependent variables were analyzed in a blinded manner.

Statistical analysis

Statistical analysis was performed using statistical analysis software, SPSS 14.0. Descriptive data were expressed as means±standard deviations. Several 2-way (group x stressor) analyses of variance (ANOVA) were performed to determine if differences existed within and between groups with regard to autonomic responses to the experimental conditions. Resting data were compared to the isometric and standing stressors in the following manner: rest vs. isometric grip and rest vs. standing. Significant differences between group means were assessed, during each individual condition of testing, using a 1-way ANOVA for each dependent variable being measured. Statistical significance was set at an alpha level of $P<0.05$.

Results

The autonomic responses for rest, isometric contraction and standing stressors are presented in Table 2. The hemodynamic responses for rest, isometric contraction and standing stressors are presented in Table 3. Vagal modulation, represented by the high-frequency modulation of HRV (HF_{RR}nu), was significantly higher at rest ($P<0.001$) and during the isometric contraction stressor ($P=0.002$) for the TCC group compared to the NT group. Low frequency to high frequency modulation ratio (LF/HF) of HRV, a non-invasive marker of sympathetic modulation, was significantly lower at rest ($P<0.001$) and during the isometric stressor ($P=0.002$) for the TCC group compared to the NT group. Low-frequency modulation of systolic BPV, a non-invasive marker of sympathetic vasomotor modulation, was significantly lower at rest ($P<0.001$), during the isometric contraction ($P<0.001$) and standing stressors ($P < 0.001$) for the TCC group compared to the NT group. As shown in Table 3, RPP and SBP were lower in the TCC group when compared to the NT group during each phase of testing ($P<0.001$). No significant differences were found in BRS (alpha index) during any of the phases between groups.

Discussion

The major finding of this study was that long-term practitioners of Tai Chi demonstrated a significantly lower RPP when compared to sedentary-matched controls. In addition, findings in this study suggest that autonomic mechanisms may be in part responsible for the lowering of the RPP. Specifically, TCC practitioners demonstrated significantly more autonomic modulation favoring parasympathetic outflow at rest and during the stressors. The stressors that were used simulated functional activities of daily living, such as grasping and holding (isometric grip) and positional changes (standing). Each stressor elicited parasympathetic withdrawal and increased sympathetic outflow in both groups. However, the TCC group demonstrated responses that maintained a greater parasympathetic modulation and lesser sympathetic response. Increased parasympathetic tone has previously been demonstrated as being cardioprotective. Decreased HRV, as a result of increased sympathetic tone, has been shown to be unfavorable and can lead to cardiovascular complications.[1,9,24,25] These adaptations are important in that TCC is a form of low impact exercise that can be easily performed by people of all ages. Prior work has shown that aerobic exercise is effective in increasing cardiovascular health by reducing blood pressures, resting HR and increasing HRV.[27,28] TCC requires the

Table 2: Autonomic parameters at rest, during isometric grip and standing phases

	Rest			Isometric grip			Standing		
	TCC	NT	*P*	TCC	NT	*P*	TCC	NT	*P*
HF_{RR}nu ($msec^2$)	63±12	30±8	<0.001	55±18	31±17	0.002	37±23	23±7	0.05
LF_{RR}nu ($msec^2$)	37±12	68±8	<0.001	44±18	67±17	0.002	62±23	76±8	0.05
LF/HF	0.62±0.26	2.77±2.1	<0.001	0.97±0.58	3.17±2.2	0.002	2.93±2.1	4.04±2.4	0.22
Alpha (ms/mmHg)	6.8±1.9	6.9±1.7	0.89	7.3±2.9	5.8±1.9	0.12	6.3±2.1	6.8±2.7	0.56
LF_{SBP}nu ($msec^2$)	48±17	82±10	<0.001	58±13	77±10	<0.001	52±20	85±5	<0.001

TCC = Tai Chi Chuan group, NT = Non-trained, HFRRnu = Normalized high frequency RR interval (parasympathetic), LFRRnu = Normalized low frequency RR interval (sympathetic), LF/HF = Low frequency to high frequency ratio, Alpha = Alpha index (baroreceptor sensitivity), LFSBPnu = Normalized low frequency systolic blood pressure. Data are presented as mean±SD

Table 3: Hemodynamic parameters at rest, during isometric grip and standing phases

	Rest			Isometric grip			Standing		
	TCC	NT	*P*	TCC	NT	*P*	TCC	NT	*P*
RPP	79±10	87±8	0.03	81±14	96±16	0.02	98±14	109±11	0.04
SBP (mmHg)	106±14	127±9	<0.001	111±18	139±13	<0.001	114±18	138±11	<0.001
HR (bpm)	75±7	68±3	0.02	73±10	69±9	0.28	86±9	79±6	0.03

TCC = Tai Chi Chuan group, NT = Non-trained, RPP = Rate pressure product, SBP = Systolic blood pressure, HR = Heart rate. Data are presented as mean±SD individual to perform movement patterns at a slow tempo for extended periods of time. The intensities of this training have been shown to be approximately 6 METS and comparable to low to moderate aerobic exercise of 50-60% of VO_2max.[4,29,30]

The use of TCC as a model of cardiovascular training, without the use of pharmacological intervention, to improve autonomic modulation has not been extensively or thoroughly studied. This may be very relevant considering the new blood pressure classification and suggestions to lower RPP. The major focus of anti-hypertensive treatment is lowering RPP and the modification of associated autonomic mechanisms. The results in this investigation provide suggestive evidence that TCC might be an effective and perhaps preventative non-pharmacological therapy. Specifically, RPP is predicated upon the product of SBP and HR. Moreover, blood pressure is the product of cardiac output and peripheral vascular resistance. Beat-to-beat BPV, obtained using the Finapres, provided insight for sympathetic vasomotor modulation. These values (LF_{sbp}nu) were significantly lower at rest and during each stressor phase in the Tai Chi group. Therefore, since arterioles are heavily innervated by sympathetic fibers, attenuation in sympathetic modulation may have resulted in less of a peripheral resistance. TCC practitioners demonstrated higher parasympathetic modulation during the stressors and these responses may have contributed to a lesser rise in RPP. The consistently lower LF/HF ratio supports the notion that the autonomic balance is preserved better in the TCC practitioners when compared to the non-trained-matched controls.

Respiration has been shown to affect both the frequency domain and hemodynamic parameters of the ANS.[10,12,13,21,23] Respiratory entrainment is a very influential component of autonomic modulation. Previous work has demonstrated that slow breathing of 6 breaths per minute (0.1 Hz) may increase the low-frequency component of the HRV power spectrum.[10] This is a concern that is often unresolved due to large inter-individual differences in respiratory rate. Moreover, TCC includes a conscious control of breathing producing an attenuated respiratory rate.[2,5,6] Spontaneous breathing in this group revealed rates between 6-8 breaths per minute. Controlling respiration rate at 12 breaths per minute may have contributed to the higher HR in the TCC group since this frequency of breathing was faster than they were normally accustomed to. Prior studies on the effects of TCC and autonomic modulations failed to control for respiration, which may have weakened the validity of the results. This study controlled for respiration and as such standardized the data across groups.

Although BRS, as represented by the alpha index, was not shown to be significantly different between groups during any of the conditions of testing, SBP and LF_{SBP}nu were significantly lower in the TCC group during each stressor. Since these components are sympathetically mediated, the attenuated responses further confirm decreased sympathetic activity. One explanation for BRS not being significantly different between groups is that Tai Chi training does not elicit elevated blood pressure responses as compared to other forms of exercise. More recent work has demonstrated an improvement in BRS in patients with coronary artery disease when TCC was used in conjunction with cardiac rehabilitation and pharmacological intervention.[8]

Conclusion

Although a cause-and-effect relationship cannot be made due to the nature of this study, the efficiency of the myocardium, in the TCC group, was demonstrated by suppressed RPP values. This product contains elements of both parasympathetic (HR) and sympathetic (SBP) nervous system activity. Although HR was significantly higher for the TCC group, a lower RPP value can only be attributed to the reduced blood pressure responses. Therefore, results in this investigation appear to suggest that long-term practice of TCC may be effective in lowering RPP and provides additional evidence on some of the autonomic mechanisms responsible for these results. Perhaps, TCC may be an effective adjunct to non-pharmacological anti-hypertensive therapy.

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