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Original Article

Heart rate reduction and autonomic response in young adults following different vagal maneuvers

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Objective: Vagal maneuvers can cause a bradycardiac response with a reciprocal increase in parasympathetic outflow and reduction of sympathetic tone. Heart rate variability (HRV) analysis is useful in the evaluation of the autonomic nervous system. The present study investigated the magnitude of heart rate (HR) reduction and autonomic response in healthy young adults following three vagal maneuvers: carotid sinus massage (CSM), the cold face test (CFT), and the Valsalva maneuver (VM).
Materials and Methods: A prospective study was conducted in 50 healthy volunteers between 21 and 35 years old who completed CSM, the CFT, and the VM in random order. Before and after each test, the RR intervals were recorded by electrocardiography for 5 min to analyze variability in the time and frequency domains, and to monitor changes in the HR, blood pressure (BP), and body temperature (BT).
Results: After each test, HR, BP, and BT significantly decreased compared with values at rest (all p values < 0.05). The mean HR during CSM, the CFT, and the VM significantly decreased by 4.0%, 3.2%, and 2.3%, respectively, revealing that CSM most potently induced HR reduction. Significantly increased variance of the RR (VAR) indicated that CSM, the CFT, and the VM induced cardiac autonomic function ($p = 0.001$, $p = 0.009$, and $p = 0.009$, respectively). Although not all of these changes were statistically significant, increased power of the normalized low-frequency component (LF%), decreased power of the normalized high-frequency component (HF%), and an increased LF/HF ratio suggested relative sympathetic enhancement. Only the VM had significant effects on sympathovagal balance in the LF%, HF%, and LF/HF ($p = 0.006$, $p = 0.004$, and $p = 0.006$, respectively).
Conclusion: Of the three maneuvers, CSM had the greatest effects on HR reduction, while only the VM had significant effects on sympathovagal modulation. Although accurate assessment of vagal activity was not available from spectral analysis of HRV, the increases in VAR, LF%, and LF/HF, and decrease in HF% observed in this study suggest that increases in cardiac autonomic activities and sympathetic dominance occur as compensatory responses to HR reduction in a 5-min window following vagal maneuvers. More research is required to determine whether CSM is a superior initial nonpharmacologic treatment for supraventricular tachyarrhythmia in a young population if there are no contraindications.

1. Introduction

Various physical maneuvers can elicit autonomic responses. Carotid sinus massage (CSM), the cold face test (CFT), and the Valsalva maneuver (VM) evoke vagal bradycardia and are safe and effective clinical applications for the evaluation and treatment of supraventricular tachyarrhythmia. CSM can be used to diagnose syncope induced by a hyperreactive carotid sinus [1]. The VM can test hemodynamic integrity and has been used to screen for diabetic peripheral neuropathy [2]. The CFT, which can activate the peripheral sympathetic and cardiac parasympathetic nerve systems and induce peripheral vascular constriction and bradycardia, is suitable for noncooperative pediatric patients [3].

Measuring beat-to-beat variations in the heart rate (heart rate variability [HRV]) is a useful method of evaluating autonomic nervous system (ANS) balance in various fields of the human

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sciences and physiological anthropology [4,5]. Physicians utilize a variety of commercial HRV analyzers for research and for clinical investigation of the heart. Time domain analysis, obtained from continuous electrocardiogram (ECG) recordings of each R wave interval (RR), and the variance of the RR (VAR), provides estimates of overall ANS activity [4]. Frequency domain analysis is another method of assessing periodicity in the ECG and sympathetic and parasympathetic nervous system regulation of the heart [6]. By viewing 5-min ECG recordings under physiologically stable conditions, at least two distinct regions of heart rate (HR) fluctuations can be determined. The high frequencies (HF) of HRV associate with parasympathetic regulation, and the low frequencies (LF) associate with both sympathetic and parasympathetic activities [4,6]. Frequency domain analysis of HRV can therefore quantify the autonomic neural balance of the heart in various physiological situations.

It is well known that the cardiac ANS controls HR or beat-to-beat fluctuations in the HR, and multiple studies have demonstrated the relative magnitudes of bradycardia in vagal reflexes [7–11]. However, no previous study has compared the effects of different vagal maneuvers on HRV. The aim of the present study was, therefore, to noninvasively investigate the magnitude of HR reduction and the cardiac autonomic response using spectral analysis of HRV in a 5-min window following CSM, CFT, and VM in young, healthy adults.

2. Material and methods

2.1. Study participants

This prospective study enrolled young, healthy volunteers aged between 21 and 35 years for investigations of cardiac vagal reflexes at the study hospital. Participants were excluded if they took any anticholinergic, antihypertensive, or antiarrhythmic medications, had a medical history of arrhythmia, transient ischemic attack or stroke, or had a carotid artery bruit on auscultation (Fig. 1). On the day of the experiment, all participants were instructed not to drink alcohol or coffee, smoke, or consume any spicy food. Informed consents were obtained from all participants. The study protocol was reviewed and approved by the Institutional Human Investigations Committee and the Institutional Review Board of the study hospital.

2.2. Experimental protocol

Between 8:00 and 11:00 AM, after a light breakfast, the study participants stayed in a quiet room with a temperature of 25 °C. They relaxed in a supine position and were required to keep their eyes open to prevent falling asleep, and to breathe normally for 10 min. ECG electrodes were placed on both wrists, and recordings were taken from lead I for 5 min. The technician noted any loose electrodes or changes in the participants' positions. Three vagal maneuvers were performed in random order. Body temperature (BT), cuff arterial blood pressure (BP), and HRV were recorded during rest and immediately after each test. The interval between each test was 2 min, allowing the HR and HRV to return to baseline [9–12]. Participants were instructed to maintain stable breathing. One trained technician performed all procedures.

For CSM, the supine participants turned their heads to the left and maintained stable breathing. The technician compressed the right side of the neck near the thyroid cartilage with gentle vertical pressure for 15 s. For the CFT, cold wet towels (around 1 °C) were applied to faces (including the forehead, cheeks, nose, mouth, and jaw) of the supine participants. They were required to hold their

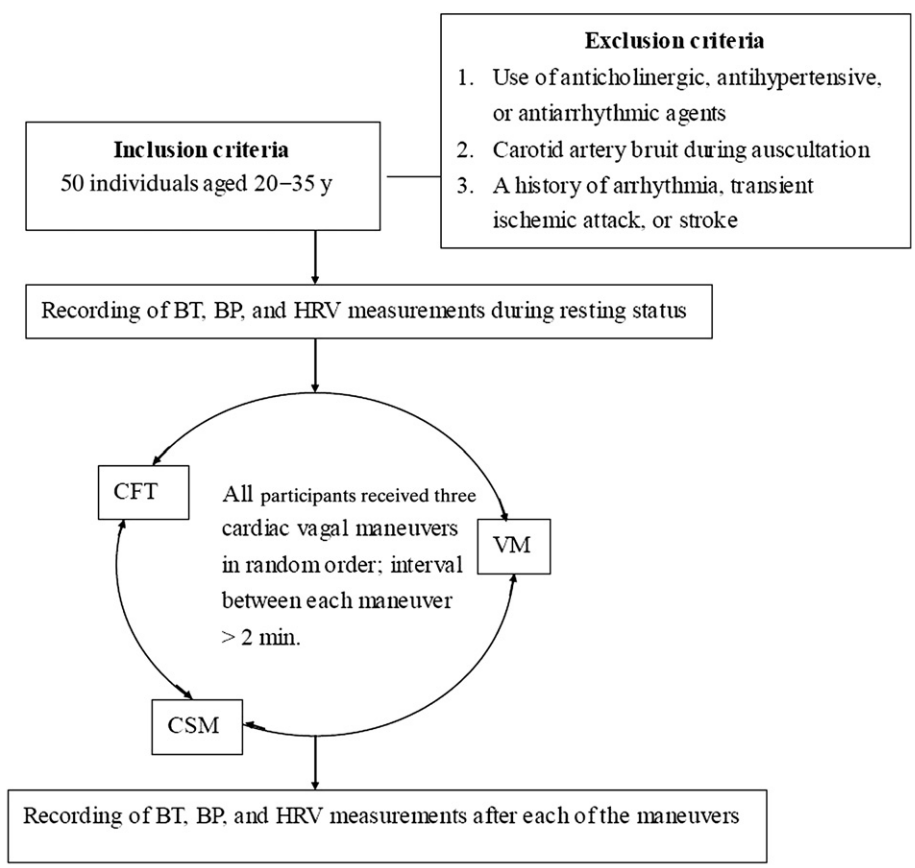

Fig. 1. Study protocol. BP = cuff blood pressure measured in the right upper arm; BT = body temperature measured in the right ear; CFT = cold face test; CSM = carotid sinus massage of the right carotid sinus; HRV = heart rate variability measured by an HRV analyzer; VM = Valsalva maneuver.

breath for 15 s and then the wet towel was removed. The oculocardiac reflex is vagally mediated, and therefore, application of the cold compress to the region of the eyes was avoided.

For the VM, participants exhaled into a mercury manometer against a pressure of 40 mmHg for 15 s, and then returned to normal respiration. Prior to and after each test, BT was measured using an electronic ear thermometer (ThermoScan PRO 4000, Welch Allyn, Skaneateles, NY, USA) placed in each participant's right ear. A standard cuff (12 × 24 cm) sphygmomanometer (MAXNIBP CAS 740, CAS Medical Systems Inc., Branford, CT, USA) measured the BP in the right upper arm (Fig. 1).

2.3. Calculation of heart rate variability

Heart rate variability analysis was performed on RR data extracted from 5-min ECG recordings on an HRV analyzer (SS1C, Enjoy Research Inc., Taipei, Taiwan) [13–15]. HRV was analyzed in both the time and frequency domains. The time domain analysis was obtained from the RR and VAR of the natural logarithm to achieve normal distribution [13]. The HR value was reflected by the mean RR; the higher the RR, the slower the HR. The frequency domain was analyzed using a fast Fourier transform algorithm. The powers of the very low frequency (VLF) band (< 0.04 Hz), LF band (0.04–0.15 Hz), and HF band (> 0.15–0.4 Hz) were calculated as the area under the portion of the curve relative to each component. The powers of the HF, LF, and LF/HF ratio were considered representative of parasympathetic regulation, sympathetic control with parasympathetic components, and sympathovagal balance, respectively. Very low frequency data were not collected because of the poor accuracy of VLF measures from 512 heartbeats. The LF% was calculated using LF/(total power − VLF) × 100, and the HF% from HF/(total power − VLF) × 100 [4,13].

2.4. Statistical analysis

All data from continuous variables were reported as mean ± standard deviation (SD), except when otherwise specified. The differences in heart rate reduction with the three maneuvers were analyzed by the χ^2 test. Measurements of BT, BP, and HRV components before and after the three techniques (CSM, CFT, and VM) were compared using repeated analysis of variance, and then a post-hoc test with the least significant difference was applied to assess the significance of differences between each test. Results were considered statistically significant if the p value was < 0.05 (two-tailed). All statistical analyses were performed using SPSS version 15 under the Windows XP operating system (SPSS Inc., Chicago, IL, USA).

3. Results

Participants included 25 men and 25 women, with a mean age of 27.22 ± 3.37 years. All participants completed the procedures without developing symptomatic hypotension. The resting BT, cuff systolic BP and diastolic BP were 36.4 ± 0.4 °C, 118.6 ± 13.2 mmHg, and 72.2 ± 8.4 mmHg, respectively, for all participants. Table 1 shows the time domain analysis of HRV (VAR) and frequency domain analysis (HF%, LF% and LF/HF) during rest for all participants. Table 2 displays the differences in variables in the 5-min window following each vagal maneuver and at rest. The mean HR post-CSM, post-CFT, and post-VM significantly decreased by 4.0%, 3.2%, and 2.3%, respectively ($p < 0.001$), indicating that CSM had the most potent effects on the magnitude of HR reduction. There were also significant decreases in the HR, BP, and BT and significant increases in the VAR between rest and each of the tests. A significantly increased VAR indicated that cardiac autonomic function was induced following vagal maneuvers. However, significant effects on the LF%, HF%, and LF/HF ratio in the frequency domain analysis ($p = 0.006$, $p = 0.004$, and $p = 0.006$, respectively) were only shown post-VM. Table 2 also reveals an increased LF%, lower HF %, and increased LF/HF ratio post-vagal stimulation, although not all of these changes were statistically significant (LF%, HF% and LF/HF post-CSM: $p = 0.064$, $p = 0.06$, and $p = 0.072$; LF%, HF% and LF/HF post-CFT: $p = 0.657$, $p = 0.566$, and $p = 0.635$; LF%, HF% and LF/HF post-VM: $p = 0.006$, $p = 0.004$, and $p = 0.006$, respectively). This indicates that sympathetic arousal was greater than parasympathetic withdrawal in the 5-min window after CSM, the CFT, and the VM.

4. Discussion

The present study analyzed the magnitude of HR reduction and the differences in HRV responses in 50 healthy adults after three vagal maneuvers. CSM induced more bradycardia than the CFT and the VM. In the time domain analysis of HRV, the VAR significantly increased, indicating increases in cardiac autonomic tone. In the frequency domain analysis, the VM had significant effects on sympathovagal balance, but the other maneuvers did not. The HF% decreased and both LF% and LF/HF increased, suggesting sympathetic predominance. We observed compensatory responses to HR reduction in the 5-min window following the three vagal maneuvers. BT and BP also significantly decreased, although the relevance of these observations is not clear.

It is generally accepted that HR reduction after vagal maneuvers reflects parasympathetic function [16–18]. In Table 2, the decreased HR supports elicited vagal tone, causing depression of myocardial contractility [8,18]. However, the present study's results showing increasing LF% and LF/HF, and decreasing HF%, indicate that sympathetic tone dominates parasympathetic outflow under vagal stimulation. The three tests appeared to induce cardiac acceleration instead of HR deceleration. Vagal tone prevails and variations in heart period are largely dependent on vagal modulation [8,19]. However, the vagal effects develop very rapidly, often within one heartbeat and also decay quickly [5]. The effect of the vagal impulse is brief because the sinus node is rich in acetylcholinesterase and acetylcholine can be hydrolyzed in seconds [20]. Conversely, the onset and decay of the sympathetic effects are much more gradual [21]. The rapid parasympathetic effects and gradual sympathetic responses prevented accurate analysis with the HRV analyzer. Limitations in frequency domain analysis requiring a 5-min period of data collection could have been responsible for this difficulty. The data did not suggest timely sympathovagal modulation, but instead compensatory responses to bradycardia following vagal maneuvers.

Despite careful and reproducible quantification of all vagal maneuvers, study procedures could not control some situations,

Table 1
Time and frequency domain analysis of heart rate variability (HRV) indices during resting status in 50 healthy young volunteers.

Variable	BT (°C)	SBP (mmHg)	DBP (mmHg)	HR (1/min)	VAR [ln(ms^2)]	LF% (nu)	HF% (nu)	LF/HF [ln(ratio)]
Rest	36.4 ± 0.4	118.6 ± 13.2	72.2 ± 8.4	68.2 ± 9.5	7.6 ± 0.7	38.5 ± 13.8	44.8 ± 12.6	− 0.2 ± 0.7

Values are presented as mean ± SD. BT = body temperature; DBP = diastolic blood pressure; HF% = normalized high-frequency; LF/HF = ratio of low-frequency to high-frequency power; LF% = normalized low-frequency; SBP = systolic blood pressure; VAR = variance of RR.

Table 2
Comparison of values for body temperature (BT), systolic and diastolic blood pressure (SDP and DSP) and heart rate variability (HRV) following each of the vagal maneuvers.

Variable	ΔBT (°C)	ΔSBP (mmHg)	ΔDBP (mmHg)	ΔHR (1/min)	ΔVAR [ln(ms^2)]	ΔLF% (nu)	ΔHF% (nu)	ΔLF/HF [ln(ratio)]
Post-CSM	− 0.18 ± 0.28*	− 4.72 ± 5.74*	− 3.36 ± 5.62*	− 2.78 ± 3.23*	0.21 ± 0.43*	3.73 ± 13.94	− 3.23 ± 11.88	0.17 ± 0.66
Post-CFT	− 0.12 ± 0.33*	− 6.20 ± 6.41*	− 2.30 ± 5.53*	− 2.20 ± 2.87*	0.16 ± 0.42*	0.92 ± 14.58	− 0.96 ± 11.76	0.05 ± 0.72
Post-VM	− 0.18 ± 0.25*	− 4.34 ± 4.77*	− 1.84 ± 5.25*	− 1.6 ± 2.37*	0.19 ± 0.50*	5.85 ± 14.44*	− 5.17 ± 12.04*	0.29 ± 0.71*

Δ values of each variable from resting status are presented as mean ± SD. * $p < 0.05$ at end-vagal maneuver as compared with resting status (repeated measures analysis of variance test).
CFT = cold face test; CSM = carotid sinus massage; HF% = normalized high-frequency; LF/HF = ratio of low-frequency to high-frequency power; LF% = normalized low-frequency; VAR = variance of RR; VM = Valsalva maneuver.

such as the exact area of facial cooling, exact lung volume when breath-holding, and degree of digital pressure with CSM. However, using the same technician throughout the study and performing the maneuvers in random order minimized these inconsistencies. The relatively small number of study participants was also a limiting factor. Changes in the 50 participants' HR, BP, and BT were significant. However, the spectral components of HRV demonstrated only a nonsignificant trend of change. Different respiratory patterns can alter vagal activity [22]. Although participants were instructed to keep their breathing stable and even, their respiratory frequencies could not be fully controlled.

In summary, we observed significantly decreased HR, BP, and BT in 50 young, healthy individuals following vagal maneuvers. CSM had greater effects on HR reduction than the CFT and the VM. The VM was the most potent stimulator in the frequency domain analysis. Although accurate assessment of parasympathetic activity was not available from spectral analysis of HRV, the increasing VAR, LF% and LF/HF, and decreasing HF% suggest that increases in cardiac autonomic activities and the shifting of autonomic balance to sympathetic dominance occur as compensatory responses to vagal bradycardia. Further research should be carried out to determine whether CSM is a superior initial nonpharmacologic treatment for supraventricular tachyarrhythmia in a young population if there are no contraindications.

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