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Original Research

The Acute Effects of TENS on Heart Rate Variability in Trained and Untrained Young Individuals.

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Purpose: Limited prior data have suggested a frequency dependent effect of transcutaneous electrical stimulation (TENS) on heart rate variability (HRV) and autonomic activity in healthy and hypertensive adults. The purpose of this study was to examine the acute effects of TENS on autonomically controlled variables of heart rate variability (HRV), heart rate (HR), and R-R interval, and furthermore, to compare effects between cardio-endurance trained and untrained adults.
Methods: 18 young adults (23.75±1.91years) were assigned to trained or untrained groups based on criteria for recreationally active individuals from the American College of Sports Medicine. Autonomic parameters were monitored by infrared-photoplethysmography before, during, and after administration of high and low frequency TENS over two separate periods. A mixed-model ANOVA was used to assess differences between and within groups.
Results: Significant effects were found with the trained group having lower HR (p=0.001), higher HRV (p=0.025), and longer R-R intervals (p=0.001) than the untrained group, regardless of time or frequency of TENS. However, no significant frequency dependent effects were found in either subject group.
Conclusions: The results of this study do not support prior reports of an acute effect of TENS on HRV or autonomic activity but do support exercise training as the most influential factor for improving autonomic function and regulation.

Keywords: TENS, Heart Rate, Autonomic

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1. Introduction

The Centers for Disease Control and Prevention (CDC) reported heart disease to be the leading cause of death in the U.S. in 2018 and heart disease remains a primary health concern for Americans.[1] The autonomic nervous system (ANS) influences heart health through regulation of the parasympathetic and sympathetic divisions. With increased activity of the sympathetic nervous system (SNS) and decreased parasympathetic nervous system (PSNS) activity, there is greater association with cardiovascular disorders and mortality.[2] Pharmacological management of these autonomic driven cardiovascular disorders is a treatment option, but does not come without risk. Alternatively, transcutaneous electrical nerve stimulation (TENS) has been suggested as a non-pharmacological and non-invasive means to reduce SNS activity while increasing parasympathetic activity, thereby inducing an autonomic state that may promote heart health and longevity.[3,4]

TENS is most commonly used as an electrophysical agent for pain modulation. However, from limited reports in healthy and hypertensive subjects, TENS has been shown to influence ANS activity by decreasing sympathetic activity and increasing parasympathetic activity.[4-8] Compared to other electrophysical agents, TENS may induce a significant effect on the balance of the ANS.[4-6,8] More specifically, low frequency TENS (≤10 pulses per second) decreased sympathetic activity and increased parasympathetic activity,[4,6] whereas high frequency TENS (≥50 pulses per second) has shown mixed results and needs further investigation. To date, there persists a lack of consensus and understanding regarding the potential use of TENS for modulating ANS activity.

Blood pressure and heart rate have been used as measures of the effects of TENS on ANS activity.[6,7] More recently, heart rate variability (HRV) has become of particular interest, as high HRV is associated with a decreased risk of cardiovascular disorders and mortality.[9] HRV is the variability of time between consecutive heartbeats, as measured by the time between successive R-waves of the QRS complex on a standard electrocardiogram—commonly termed the R-R interval. A higher HRV is characterized by decreased sympathetic and increased parasympathetic tone. Data from healthy subjects, as well as some unhealthy populations, suggest that HRV can be increased and maintained as an adaptation to regular exercise (e.g. high-frequency exercise training).[10-12] However, individuals incapable of performing regular exercise may not be able to achieve these exercise-induced adaptations in HRV. In these populations, TENS may provide an alternative method for eliciting an increase in HRV and its associated alteration in ANS activity

To date, the effect of TENS on HRV has only been studied in healthy individuals or individuals with hypertension.[3-8] No identifiable studies have examined the effects of TENS on HRV in cardio-endurance trained and untrained individuals. Studies investigating HRV in cardio-endurance trained individuals appear to be lacking altogether, despite the population's seemingly greater propensity for high HRV and increased PSNS tone when compared to untrained individuals.[4,8] Accordingly, cardio-endurance trained individuals make a good model from which to study HRV and the ability of TENS to influence autonomic regulation. Therefore, this study sought to examine the acute effects of TENS on HRV in cardio-endurance trained adults versus untrained adults. It was hypothesized that TENS would show a greater effect on HRV in trained versus untrained adults due to previous exercise-induced adaptations in trained adults.

2. Materials and Methods

Design

This quantitative, single-session experimental study used a mixed model design to assess the acute effects of high and low frequency TENS on the autonomically controlled variables HRV, HR, and R-R interval within and between groups: endurance trained individuals and untrained individuals. Infrared-photo plethysmography was used to measure HRV before, during, and after TENS. Infrared photo plethysmography is the measurement of blood flow through an infrared light source that converts to a pulse signal and is similar to the mechanisms of pulse oximetry. Application of high or low frequency TENS was randomized by order of entry into the study.

Participants

Based on effect sizes from previous studies[4,6], G*Power Analysis was used to determine a sample size of 7-8 participants per group for an estimated effect size of 0.8. Inclusion criteria included an age range of 18 to 30 years old. Participants were excluded if they had any known neurological or cardiac conditions involving the ANS or were currently taking any prescribed medication(s) that were considered para-/sympathomimetics or -lytics (e.g. beta-blockers). Individuals were also excluded if they were knowingly pregnant, self-identified as a regular smoker or tobacco user, or had consumed alcohol the day of testing. Because obesity has been shown to increase sympathetic nervous system activity, participants with a BMI >30 were also excluded.[13,14]

Participants were stratified as trained versus untrained following established and widely recognized criteria based on standards of the American College of Sports Medicine (ACSM).[15] Per ACSM guidelines, participants were included in the cardio-endurance trained group if they were recreationally active at least 30 minutes, 3 days a week, for at least the last 3 months.[15] Participants were included in the non-trained group if they classified as sedentary (i.e. light activity less than 3 times per week). Participants were excluded if they were recreationally active, but did not participate in cardio-endurance type exercise.

Instrumentation

Prior to arrival at the testing lab, participants were told to refrain from consuming any dietary or non-prescriptive sympathetic stimulants the day of testing (e.g. caffeine or energy drinks). The independent variables of height, weight, gender, and age were collected before the application of TENS. Subjects were placed in a Magstim Therapy Chair which was used specifically for its highly modifiable features that allowed for individualized adjustments for comfort (Figure 1). Consistent with previous literature[4,6], TENS electrodes were placed paravertebrally on thoracic spinal levels 1 through 7 using two standard self-adhesive 2 x 3.5” electrodes (Figure 2).

Figure 1. Participant Testing Position

Figure 2. Paravertebral Ganglionar Placement of Electrodes

HRV, HR, and R-R interval, were obtained before, during, and after the administration of TENS using the CorSense® Heart Rate Variability Monitor (Elite HRV LLC), (Figure 3). This commercially available device calculates HRV from heart rate R-R interval data gathered using the CorSense digital finger monitor. The CorSense has been shown to have high correlation with traditional EKG-based measurements of the dependent variables (r=0.99-1.00).[16] In order to collect data, the participant's fingertip was placed in the plethysmography device which was synced via Bluetooth® to the investigator's laptop for real-time data acquisition. All subjects maintained this position throughout the data collection period.

Figure 3. CorSense® Heart Rate Variability Monitor

Intervention

While comfortably seated, participants were instructed to remain quiet while continuing to breathe at a normal, comfortable rate. They were instructed not to talk or interact with investigators during administration of the intervention. TENS was administered using a clinical multi-waveform stimulator (Vectra Genisys, Chattanooga Group, Hixon, TN). Each participant received one session of high frequency (100pps/200μsec) and one session of low frequency (10 pps/200μsec) TENS with a washout period of no stimulation in between. TENS frequency was randomized by order of entry, alternating between high frequency and low frequency TENS.

Data collection was initiated during a 5-minute rest condition without TENS stimulation. Thereafter, data was recorded while either high or low frequency TENS was applied continuously for five minutes at a strong intensity, but without causing visible or palpable muscle contraction. Thereafter, TENS was turned off while data continued to be recorded for another five-minute period after the initial TENS frequency. Following a 10min washout period of no stimulation or data collection, these procedures were repeated using the alternate frequency. Data was again collected in 5-minute sessions: before, during, and after stimulation.

Data Analysis

Data were analyzed using the statistical package 'RStudio' version 1.3.1093. Initially, a 3-way repeated measures ANOVA (2x2x3) was used to look for interactions between TENS Frequency (High/Low), Activity Level (Trained/Untrained), and Time (Pre-Intervention/During Intervention/Post-Intervention) across the variables of interest— HRV, HR, R-R. Two-way (2x2) ANOVAs were thereafter used to assess for two-way interactions in the variables of interest.

The following tests were then completed to further identify significant differences: 1-way ANOVA was conducted for HR x activity level (trained/untrained), 1-way ANOVA was conducted for R-R interval x activity level (trained/untrained), non-Parametric Kruskal Test was conducted for HRV x time (during intervention and post-intervention).

3. Results

A total of 16 individuals participated in this study; 8 individuals that met inclusion criteria for cardio-endurance trained were assigned to the trained group and 8 participants that did not meet the criteria were assigned to the untrained group (Table 1). There were no significant 3-way or 2-way interactions between TENS frequency (high/low), time (before/during/after), and group (trained/untrained). Only the main effect of group was significant for the following variables: HRV ($F=4.99$, $p=0.034$), R-R interval ($F=13.305$, $p<0.001$) and HR ($F=13.421$, $p<0.001$). Trained subjects showed significantly greater values within each time period for HRV (before $p=0.031$; during $p=0.018$; and after $p=0.025$) and R-R interval (before $p<0.001$; during $p<0.001$, after: $p=0.001$). In contrast, HR was significantly lower in the trained group at each time period (before $p<0.001$; during $p<0.001$; after $p=0.001$). (Table 2).

4. Discussion

Limited data from two previous studies have suggested frequency dependent influences on autonomic regulation of the cardiovascular system with TENS. [4,6] Stein et al[4] and

Sartori et al[6] reported a decrease in sympathetic and increase in parasympathetic activity (i.e. increased HRV) following low frequency TENS while in contrast, high frequency TENS resulted in increased sympathetic activity (i.e. increased diastolic blood pressure) in cardiovascular-healthy adults[4] and hypertensive adults[6]. However, no previous study has compared frequency dependent effects of TENS on autonomic regulation in endurance trained versus untrained subjects. Given the known effects of exercise training on autonomically regulated HR and HRV, this study aimed to repeat the procedures of Stein et al. but in untrained versus trained healthy adults. Using this model, this study could attempt to confirm earlier findings in healthy untrained adults while providing novel information from trained adults.

In contrast to previous reports from Stein et al[4] and Sartori et al[6], our findings suggest neither high nor low frequency TENS had significant acute effects on HRV, R-R interval, or HR in healthy adults. Differences in these autonomic variables were more associated with training status of subjects than by the acute effects of TENS, regardless of frequency. The findings of this study do not support earlier reports of frequency dependent effects of TENS on HRV, R-R interval, or HR. Rather, these findings continue to support the role of exercise training on HRV, R-R interval, and HR. To increase HRV and decrease HR, exercise training appears to be more effective than TENS.

Stein et al[4] and Sartori et al[6] are the only two studies to date that have used the paravertebral ganglionar region for the application of TENS when examining autonomic influence and are, therefore, the most appropriate to contrast with our findings. Our study's methods were derived from those used by Stein et al[4] including subjects, electrode location, and stimulus parameters.

While the findings of the present study are appropriate for comparison to previous reports of frequency-dependent effects of TENS on HR and HRV several points of differentiation should be addressed. Stein et al.[4], conducted their testing over 2 consecutive days with the TENS treatment lasting 30 minutes. The present study conducted all TENS treatment within a single session. The potential therefore exists that these factors could explain the differences seen within the results of Stein et al., and the sedentary group of the current study. The administration of TENS varies greatly depending on area of focus (e.g., pain science vs cardiovascular) with no clear consensus within the literature as to a dosage of TENS within and across the various areas of potential focus. This may be considered as positive or negative as the literature base seeks to identify appropriate methodology to employ TENS based on the intended goal. Therefore, the potential exists that 5 minutes of continuous TENS may not be sufficient to elicit a detectable difference, even within multiple frequency modalities. At a minimum however, this study provides additional evidence to be considered when trying to establish a dosage for the use of TENS.

One strength of the present study is that it included aerobic trained individuals who are known for having more robust cardiovascular adaptations than their sedentary untrained counterparts. Thus it may be suggested that a shorter TENS exposure may elicit similar effects within this population.[17] While Stein et al.[4] used 30 minutes of TENS, longer stimulation times present the potential for a sensory habituation.[18] This is commonly seen within the pain literature as longer stimulation times require that the stimulation be modified in order to maintain an appropriate analgesic effect. Accordingly, it may be suggested that TENS has an accumulative effect hence why, in various disciplines, TENS is recommended multiple times a week to induce the desired effect. It is possible therefore that the use of a one-day protocol may not be sufficient to elicit autonomic adaptations in response to TENS. The present study however sought only to identify the acute effects of TENS and therefore only utilized a single session.

The present study found significant differences in HR, HRV, and R-R intervals between trained and untrained participants. The trained group demonstrated lower HR and longer R-R intervals for pre, during, and post TENS applications as compared to the untrained group. Additionally, HRV was significantly higher for the trained group for pre, during, and post TENS applications. These results do not reflect any influence of TENS, regardless of frequency, but rather support known exercise-induced adaptations in autonomically control of the cardiovascular system.

Although the results in this study did not support previous reports of frequency-dependent effects of TENS on HR, HRV, and R-R intervals in healthy adults, significant differences found among these variables in the present study were associated mainly with training status of the participants. Lower HR among the trained group in all categories (pre/during/post) can be explained by cardiovascular adaptations to exercise mediated by increased vagal tone. Higher HRV found in the trained group can also be attributed to cardiovascular adaptations to exercise, as a high HRV is characterized by a reduction in sympathetic tone (i.e. sustained low HR) and developed through consistent participation in cardiovascular exercise.[10-12] Finally, the R-R interval was also longer in the trained group as compared to the untrained group; R-R intervals lengthen relatively as HR slows down, which, in this case, can again be attributed to the trained group's consistent participation in cardiovascular exercise. Therefore, the findings of the present study support the role of exercise training as the main determinant of significant change in HR, HRV, and R-R intervals and, therefore, overall autonomic nervous system modulation.

5. Conclusion

Neither high nor low frequency TENS demonstrated significant acute effects on HRV, R-R interval, or HR in healthy trained and untrained adults. Despite limited previous reports of frequency dependent effects on autonomically controlled parameters, the present study does not identify such effects. Differences in HRV, HR, and R-R interval were more associated with exercise training status of subjects than by the acute effects of TENS, regardless of frequency.

Table 1: Demographics.

	Trained	**Untrained**
Gender	5F/3M	6F/2M
Age (years)	24.25 (2.38)	23.25 (1.28)
Height (inches)	66.08 (3.30)	65.61 (2.69)
Weight (pounds)	155.44 (25.30)	162.50 (42.91)

Mean (Standard Deviation); F = females; M = males
No significant differences

Table 2: HR, HRV, and R-R intervals of the trained and untrained groups in pre-TENS application, during TENS, and post-TENS

Variable	Time	Untrained (Mean ± 95% CI)	Trained (Mean ± 95% CI)	Degrees of Free-dom	F statistic	P-value
HR						
	Pre	79 ± 5.8	64.6 ± 5.16	1,30	15.71	P < 0.001
	During	78.2 ± 5.6	64.1 ± 5.74	1,30	14.07	P < 0.001
	Post	77.9 ± 6.12	64.9 ± 5.03	1,30	12.24	P = 0.001
HRV						
	Pre	60.5 ± 2.86	64.9 ± 3.03	1,30	5.154	P = 0.031
Non - Parametric	*During*	59.8 ± 3.02	64.4 ± 3.32	1	χ^2 (1) = 5.58	P = 0.018
Non - Parametric	*Post*	59.2 ± 3.15	63.6 ± 3.16	1	χ^2 (1) = 5.05	P = 0.025
R-R Interval						
	Pre	773 ± 55.6	949 ± 77.6	1,30	15.39	P < 0.001
	During	779 ± 53.1	960 ± 88.2	1,30	14.05	P < 0.001
	Post	781 ± 48.9	949 ± 90.4	1,30	12.22	P = 0.001

Pre = measured before transcutaneous electrical nerve stimulation (TENS) application, during = measured during TENS application, post = measured after TENS application; HR = heart rate; HRV = heart rate variability.

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