Heart Rate Variability During a Continuous Performance Test in Children with Problems of Attention

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ABSTRACT

Background: Children with impulsive behavior and poor self-regulation have been shown to have low parasympathetic tone. High vagal tone is associated with attention to novel stimuli.

Objective: To study if Heart Rate Variability, an index of vagal tone, is a mediator of attention.

Method: 77 children who performed a Continuous Performance test (TOVA test) had their EKG recorded for Heart Rate Variability Measurements. Subjects were assigned to groups according to their performance on the TOVA test and a general linear model for repeated measures applied. Pearson Correlations were applied for TOVA scores and HRV Values at four epochs.

Results: No individual correlations were found between Attention Scores and HRV. However, there was a significant group difference showing that good performers had a higher "vagal" tone than poor performers.

Conclusion: The parasympathetic system as measured through HRV is not a mediator of attention. HRV may be an indicator of better health and ability to self regulate.

INTRODUCTION

Heart rate variability (HRV) has received considerable attention as a promising and potentially informative measure of emotional and physical health. Research on HRV has been wide-ranging, encompassing such areas as cardiac diseases, emotional regulation, information processing, optimal performance and social interaction (1-4). The basic underlying concept is that a range of behaviors are dependent on the ability to regulate visceral homeostasis. Specifically, autonomic nervous system flexibility might be a marker of health, whereas a lack of autonomic nervous system adaptation might be a marker or mediator of psychopathology.

Heart rate variability reflects the amount of heart rate fluctuations around the mean heart rate. In general, low HRV frequencies (0.03Hz,-0.15Hz) reflect sympathetic nervous system activity or mixed sympathetic-parasympathetic nervous system activity, while high HRV frequencies (>0.15Hz), or what is termed respiratory sinus arrhythmia (RSA), primarily reflect vagal activity. Kleiger et al. (5) showed that in normal subjects, measures of cardiac autonomic control for quiet resting periods constitute highly stable individual characteristics.

HRV, VAGAL TONE AND BEHAVIOR

High vagal tone is associated with the ability to self-regulate, and with greater behavioral flexibility and adaptability; whereas low vagal tone is associated with poor self-regulation and with a lack of behavioral flexibility (6, 7). For instance, children who have difficulty modulating their “vagal tone” in response to environmental changes also experience difficulty in social interactions, especially those that require reciprocal engagement and disengagement (8). Allen et al. (9) reported that decreased cardiac vagal control is correlated with increased impulse control problems. This finding was only significant in males. In other studies, boys who exhibited high levels of aggression and antisocial behavior showed deficiencies in measures of executive control functions (10) and also deficient vagal modulation of HRV (11). In contrast, children with behavioral inhibition and shyness show evidence of enhanced sympathetic function and higher HRV (12).

High HRV has been associated with attention to novel stimuli (13). Hansen et al. (14), in their study of the effect of vagal tone on performance during a CPT task of sustained...
Attention, found that subjects in their high HRV group had a significantly higher number of correct responses compared to subjects in their low HRV group. High HRV group subjects also had faster reaction times and fewer errors. Further, they found that higher HRV is associated with better performance on working memory tasks.

**ATTENTION, ADHD AND MEASUREMENT OF ATTENTION**

Attention Deficit disorders (ADHD and ADD) are currently reported to be the most prevalent disorders of childhood and also the most studied syndrome in the field of child psychiatry (15). Despite these facts, the pathophysiology of ADHD and ADD is far from being understood.

Precisely which type of neuropsychological impairment is associated with deficits in attention remains controversial, but there is growing evidence that there is a heterogeneity of underlying mechanisms for the ADHD phenotype. Possible explanations include: executive dysfunctions and in particular deficient inhibitory control (16); dysfunction in the distribution of cognitive-energetic resources to meet the changing demands of different situations (17); and motivational dysfunction, an emotional reaction to the imposition of delay, or the failure of an impulsive child to engage successfully with delay rich situations elicits delay aversion (18).

Nigg et al. (19) demonstrated that scores on tests of executive functioning such as CPT, Wisconsin card-sorting test, and the Tower of London are abnormal in only 50% of ADHD subjects, and that the scores may be abnormal in subjects who do not have ADHD. These measures, when taken individually or separately, seem to lack adequate specificity and sensitivity. Among the neuropsychological tasks studied in ADHD research, the continuous performance test is one of the most common, and the derived measure of variability (i.e., reaction time standard deviation) yields the greatest effect size for ADHD (20). The TOVA (Test of Variables of Attention) is one of these continuous performance test and is currently in widespread use in Israel. However, its validity and utility has been questioned as a diagnostic test for ADHD.

None of the subjects received stimulant medication or any other type of medication during the test and for 24-hours prior to the testing. In total, 90 children consented to participate in the study. The TOVA Score is a combination of highly predictive score for attentional problems: Mean response time, D’prime (measure the deterioration of performance over time) and variability. Since the TOVA score of -1.80 is advertised by the developer (22) as a cutoff score for assignment to the ADHD group with 80% specificity, we adopted this score for group assignment. It does not mean, however, that the bad performers had a diagnosis of ADHD or that the good performers did not have a diagnosis of ADHD: a score of less than -1.80 on the TOVA for the “poor performer” group; a score of greater than -1.80 on the TOVA...
for the “good performer” group. Fifty-six children were assigned to the poor-performer TOVA, and 21 children were assigned to the good-performer TOVA group.

EKG data from 13 of the original subjects were rejected because of poor technical quality. Data from the remaining 77 subjects were analyzed. Demographic data are summarized in Table 1. The protocol was accepted by the hospital’s Helsinki review board.

During the administration of the TOVA to the children, the parents were asked to complete a questionnaire that assesses symptoms of ADHD (Conners’ Parent Questionnaire [23]) and the presence of co-morbidity. EKG was measured by three separate electrodes which were placed on the subjects arms; two on the left arm and one on the right arm. A two-minute baseline EKG measurement was recorded.

**THE TOVA TASK**

The visual TOVA is a 21-minute continuous performance test (CPT) in which subjects are instructed to press a button on an electronic micro-switch for every target and inhibit their response for every non-target. Stimuli (targets and non-targets) are presented at the rate of one every two seconds. Each stimulus appears for 100 milliseconds. Subjects are given a three-minute practice trial, followed by the 21-minute test. The 21-minute test consists of four parts. The first two parts include 36 targets and 126 non-targets each, and the second two parts each consist of 126 targets and 36 non-targets, for a total of 648.

Scores recorded on the TOVA include omission errors (failure to press the switch for a target), commission errors (erroneously pressing the switch for non-target), response time for correct responses (time in milliseconds for response after presentation of stimulus), response time variability for correct responses. Scores are recorded for quarters, halves and total performance and are converted from raw scores to standard scores based on normative data for age and gender provided by the test developers (22, 24).

The EKG data were measured by the Thoughttech Procomp Infiniti device and software. A special script was written to collect data from five different time-intervals of the procedure: 1 - baseline; 2 - the first two minutes of the test to measure the HRV adaptation to the task; 3 - the last two minutes of the (low frequency stimuli presentation) “boring” part of the TOVA; 4 - the beginning two minutes of the high frequency stimuli section of the TOVA; 5 - the last two minutes of the TOVA.

**STATISTICAL ANALYSIS**

The IBI (inter-beat interval) data were exported to an Excel file, and artifacts in the data were “cleaned” using a custom-designed program. When an artifact of approximately double the expected IBI value was noted, the program divided the value into two separate beats. When an artifact of approximately half the expected IBI value was noted, the program combined two IBI beats. When a long/high value was followed by a short/low IBI value, the program averaged the two values. Results were analyzed with HRV Analysis Software 1.1 for Windows developed by The Biomedical Signal Analysis Group, Department of Applied Physics, University of Kuopio, Finland. The software is distributed free of charge upon request at http://venda.uku.fi/research/biosignal.

Heart Rate, RRMSSD (root mean square of successive differences), PNN50, very low frequency (VLF), low frequency (LF), high frequency (HF), power mean, and LF/HF-ratio values were obtained from the IBI values.

Scores on the Conners’ questionnaire were summarized into 14 clinical scales.

A general linear model with repeated measures (SPSS) was used where the within-group factor was time and the between-group factor was poor-performer/TOVA versus good-performer/TOVA. Pearson correlations were assessed for relationships between the HRV score and the scores on the Conners’ questionnaire scales or the TOVA scores. Scores on the Connors’ parent scales for both groups and TOVA scores are summarized in Table 2.

**RESULTS**

No statistically significant differences were found for the effect of sex or age on any of the HRV variables. There was an age X omission errors correlation at all four times (O1: .231, p=.03 – O2: .335, p=.00 - O3: .404, p=.00 O4 : .244, p=.03).

At baseline the mean heart-rate of the poor-performer TOVA subjects (89.9+/-.10.7) was slightly higher than the mean heart-rate of the comparison-group/
good-performer (87.8+/-12.3). This difference was not statistically significant (t=-.73, p=.466).

1. Time domain
The measure of PNN50 (the percentage of absolute difference between consecutive IBIs that are greater than 50 ms) shows that the mean reactivity of the good-performer subjects was higher than the mean reactivity for the poor-performer subjects (time effect: F=3.36, p<.01; group effect, F=3.98, p<.049).

Another time domain measure which reflects the parasympathetic component of HRV is RMSSD (root mean square of successive differences between IBIs). On this measure there was a significant overall between-groups effect, collapsed over all five two-minute time intervals [F=7.55, p=.008]. Broken down by two-minute time intervals, the following data were attained: time 1 (t=1.9, p=.053), time 2 (t=2.7, p=.041), time 3 (t=1.4, p=.15), time 4 (t=2.01, p=.047), and time 5 (t=2.19, p=.031). In comparison to the poor-performer, the good-performers showed a decrease in HRV during the boring (low fre-
quency stimulus presentation - time 3) segment of the TOVA, whereas the poor-performer TOVA subjects did not exhibit this variation. At this point during the TOVA (time 3) the earlier difference between the groups disappears. This may well reflect the extra mental effort required and used by children in the good-performer group to attend and accurately respond to the stimuli during this part of the test. Another way of looking at this is that in the boring phase of the CPT, the good-performers are similar to the poor-performers.

2. Frequency domain
On the high frequency (HF) power variable, mean scores in the good-performer group were significantly higher than the poor-performer (between group effect: F=4.0, p=.048). This suggests that there is a lower overall degree of flexibility in the poor-performer TOVA subjects, as their HRV was lower implying that the poor-performer TOVA subjects did not recruit parasympathetic activation throughout the duration of the TOVA. There is a significant time X group interaction \( [F= 2.43, p=.048] \).

On the variable of LF power, the mean score for good performers was higher than the mean for poor performers. This difference did not reach statistical significance (\( F=3.5, p=.065 \)).

**DISCUSSION**
In the present study, autonomic nervous system regulation was assessed via measures of Heart Rate Variability in relation to subjects’ performance on a test of attention (TOVA). The first hypothesis - that HRV fluctuated at different phases of the CPT according to the attentional demands - was confirmed for the “good-performer” subjects. We found a significant group difference in HRV between the good and poor performers: subjects performing well on the TOVA had higher HRV as a group. However, the fact that no significant correlations between individual values of HF and the TOVA scores were found is disturbing. One possible explanation is that HRV is not a direct mediator of attention performance but is a trait marker of better health and adaptation. Therefore it would explain why as a group the better performer on the TOVA had higher HRV but individually it is not the parasympathetic system which mediates the attention. Another explanation would be that the group difference found reflects a type-1 error.

The study’s population sample, as a whole, consisted of children suspected of having an attentional problem. When Connors’ scores for the poor performers and good performers (as groups) were compared, no significant differences were noted suggesting that we had in fact two groups quite similar clinically.

No statistically significant correlations were found between the TOVA scores and the scores on the subscales of the Conners’ Parent Checklist. This seems to confirm that what the Conners’ scores are capturing or measuring and what the TOVA scores are capturing or measuring is not the same dimension of functioning, a finding quite similar to Preston et al. (21).

It is possible that a different attentional task or more
dissimilar groups, i.e., a well defined ADHD group and a non-ADHD control group, would have generated different data. The data from the present study appear to be consistent with Mezzacappa et al. (10) who found that superior or higher performance on tasks of executive functioning (e.g., stop-signal task) was associated with higher RSA. This consistency between the two studies seems to be valid in spite of the fact that the method of data collection during task performance in the present study differed from Mezzacappa et al., who used physiological provocation (standing). Our sample is similar to theirs since they examined a mixed population of children from mainstream and therapeutic schools and did not formally diagnose them.

In contrast, Borger et al. (7) found that ADHD participants had higher HRV than controls. Their study included children with a DSM-III diagnosis of ADHD who had no co-morbidity, and normal controls only. Moreover they examined the 0.10 Hz component as an index of effort allocation whereas the present study used the HF component (0.14 – 0.25 Hz), which reflects more parasympathetic activity. This may account for the different findings.

Within the poor-performer TOVA group, low effort allocation is pronounced in the inattentive sub-type children/participants, and this manifests primarily during the low-frequency (boring) segment of the TOVA test.

These results confirm Porges’ (4) claim that HRV reactivity, linked to vagal recruitment, correlates with increased self-regulation capacities. In the current study, however, children's performance on all of the segments of the TOVA was not correlated with its HRV correlate. This seems to support the caveat stated by Bernstein (25) that psychophysiological relations and biomarkers like RSA are often multi-determined.

It does appear, though, that both the TOVA and HRV are measures of degree of health in children. Moderate flexibility, as measured by HRV scores on the TOVA may be a valid indicator of healthy emotional and psychological functioning in children, and may be a skill worthy of practice.

Follow-up research may further clarify the association between HRV and attention, and rectify some of the limitations in the current study. Future studies should select the control group from a non-clinical sample; examine a clearly defined and diagnosed ADHD group compared with a normal population and include other objective measure of degree of attentiveness .

References