Heart Rate Variability in the Assessment and Biofeedback Training of Common Mental Health Problems in Children

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ORIGINAL PAPER
SUMMARY
Heart rate variability (HRV) is a measure of the beat-to-beat variations in heart rate related to the work of autonomic nervous system. It may serve as a psychophysiological indicator for arousal, emotional state and stress level. We used this parameter in both the assessment and biofeedback training, for dealing with five groups of common mental health problem in school children (anxious-phobic, somatoform, obsessive-compulsive, attention deficit hyperactivity and conduct disorders). The obtained results were compared with healthy children at the same age. In order to define the four main characteristics of personality (extroversion/introversion, neuroticism/stability, psychopathological traits and honesty) Eysenck Personality Questionnaire was applied. Results showed significantly higher psychopathological traits in ADHD and somatoform group, lower extroversion in somatoform, higher neurotism in OCD and lower lie scores in ADHD and OCD groups. As HRV instrument we used Heart Math Freeze-Framer System. After 15 sessions of training, children from nearby all groups showed improved high and medium HRV which corresponded to the improved clinical outcome. Hereby, the best results were obtained for conduct and anxiety disorder, and the worst for ADHD.

Keywords: mental health problems, children, heart rate variability, biofeedback

1. INTRODUCTION

The cardiac system demonstrates continuous variations in heart rate. In recent research better understanding of the nature of these variations is acquired, postulating that more chaotic heart rates are healthier than the steadier ones.

Heart rate variability (HRV) is a measure of the continuous interplay between sympathetic (SNS) and parasympathetic (PNS) influences on heart rate that yields information about autonomic flexibility and thereby represents the capacity for regulated emotional responding (Appelhans, 2006**)**. HRV is direct psychophysiological measure for arousal, emotional state and stress level. (Andreassi, 2000; Schwartz & Andrasik, 2003).

The starting point of the frequency-based HRV analyses is the fact that the variations in heart rate produced by SNS and PNS activity occur at different speeds, or frequencies. SNS is slow acting and mediated by norepinephrine while PNS influence is fast acting and mediated by acetylcholine.

Since the original report by Wolf et al. (1978) analysis of spontaneous variations of beat-to-beat intervals has become a valuable tool, familiar to clinical cardiologists.

In 1987, Kleiger and coworkers published a pioneering work demonstrating that reduced heart rate variability was capable of identifying a subgroup of subjects with increased cardiac mortality after myocardial infarction and that its predictive value was independent of traditional clinical risk-stratifying factors. It was originally proposed that reduction in HRV might reflect an autonomic imbalance characterized by increased sympathetic and reduced vagal activity. This interpretation was also supported by indirect findings, showing a tendency toward faster heart rates and a smaller day-night heart rate difference observed in these patients.

Two major theories (polyvagal and neurovisceral) causally relate autonomic flexibility, represented by HRV, and the capacity for regulated emotional responding (Appelhans and Luecken, 2006).

Polyvagal theory is based on an evolutionary explanation that the ANS has been developed in stages to deal with changes in the environment and respond effectively. The last component developed, the ventral vagus complex, physically connects with the facial muscles, voice production, and other socially important behaviors, which creates a physical connection between the heart and emotional expression.

Neurovisceral integration theory gives an integrative explanation about evolutionary forces which led to the development of a rapidly responding vagus nerve to support appropriate emotional expression and regulation through connections with the cortex, limbic system, and brainstem. By inhibiting other potential responses through synaptic activity in the brain and vagal activity in the body, the central autonomic network acts as a neurophysiological command center governing cognitive, behavioral, and physiological elements into regulated emotion states.

Both theories presented above are similar in that they (a) specify a critical role for parasympathetically mediated inhibition of autonomic arousal in emotional expression and regulation and (b) maintain that HRV measures are informative about individuals' capacity for this aspect of regulated emotional responding.

Some empirical research with HRV (Coumel, 1991; Dreifus, et all. 1993; Kleiger, 2005) showed that:

- Higher levels of resting HRV have been associated with effective coping strategies
- Attention control is associated with higher HRV
- Low HRV happened to be an independent risk factor for several negative cardiovascular outcomes
- Low HRV is a proxy for underlying cardiovascular disease processes
- Patients with generalized anxiety disorder show lower HRV than controls
- Low HRV has been associated with depression.
- In clinical practice HRV training was used for prevention of cardiac diseases, to control high anxiety, depression and stress level, as well as to evaluate the stages of sleep (Haines, 1987; Kawachi, 1992, 1994, 1995; Agelink, 2002; Song, 2003; Nahshoni, 2004; Siepmann, 2008; Thomas, 2008; Kaniusas, 2008; Swanson, 2009). Sharpley et all (2000) showed increased risk for cardiovascular disease related to rapid and dramatic increase in heart rate reactivity to a stressor task. In a recent study (Ebben, 2009) HRV training was applied for diminishing sleep problems.

The clinical relevance of HRV in pediatrics was first appreciated in 1965 when Hon and Lee noted that fetal distress was preceded by alterations in interbeat intervals before any appreciable change occurred in heart rate itself. Thereafter, HRV training was applied in children with bronchial asthma, heart failures or brain damages (Massin, 1998; Gurjanova, 2008).

Various *measures of heart rate variability* have been proposed, which can roughly be subdivided into time domain and frequency domain (Amara, 1997; Lombardi. 2000).

The calculation of the standard deviation of beat-to-beat intervals (whose square is referred to as variance or mean power) is an example of a *time domain* measure. In other words, the time intervals between heart beats can be statistically analyzed to obtain information about the autonomic nervous system. This approach includes root mean square of the differences between successive heart beat intervals (rMSSD), the number of normal to normal complexes greater than 50 milliseconds (NN50), and the percentage of total number of beats (pNN50).

A common *frequency domain* method is the application of the discrete Fourier transform to the beat-to-beat interval time series. This provides an estimation of the amount of variation at specific frequencies. A similar procedure is used for calculation of EEG spectral power in the assessment of children with ADHD (Pop-Jordanova, 2009). In this context, concerning ECG spectra, several frequency bands of interest have been defined in humans.

The power spectrum of the HR is divided into four main frequency ranges. The ultra low frequency range (ULF) (< 0.003 Hz) is the slowest component and can be measured only in long term (24 hours) recordings. The very low frequency range (VLF) (0.0033 to 0.04 Hz), representing slower changes in heart rate measurable in shorter recordings, is an index of sympathetic activity, while power in the high frequency range (HF) (0.15 to 0.4 Hz), representing quicker changes in heart rate, is primarily due to parasympathetic activity. The intermediate frequency range around the 0.1 Hz region is called the low frequency (LF) band and is often referred to as the bar receptor band, because it reflects the blood pressure feedback signals sent from the heart back to the brain, which also affect the HRV waveform. This band is more complex, as it can reflect a mixture of sympathetic and parasympathetic activity (Schwartz&Andrasik, 2003)

Several factors influence the accuracy and usefulness of the measured HRV components. These include the duration of the recording and the effect of the various physical and physiological changes that occur during the recording period (Pagani, 1986; Friesen, 1990).

As a dynamic marker, HRV appears to be sensitive and responsive to acute stress. As a marker of cumulative life experience, HRV has also been shown to decline with the aging process. In short, HRV appears to be a marker of two processes: (1) frequent activation (short term dips in HRV in response to acute stress), and (2) inadequate response (long-term vagal withdrawal, resulting in the over-activity of the counter-regulatory system).

The aim of this study was to evaluate HRV in the assessment and therapy of some common mental health disorders in children.

2. METHODS

2.1. Participants

Five groups of children have been evaluated: a) children with anxious-phobic symptoms, N = 15, mean age 12.5 ± 2.25 years; b) children with somatoform problems, N =15, mean age 10.92 ± 2.06; c) children with obsessive-compulsive manifestations (OCD), N = 7; mean age 14.5 ± 2.20; d) children with ADHD, N = 10, mean age 10.5 ±.1.80 e) children with conduct disorders (CD), N = 12, mean age 11.5 ± 1.52; and f) control group, N = 15 children, mean age 10.18 ± 1.33. All of examined children (N = 74) were of similar age (ANOVA p= 0.80) which is important for the comparison of obtained results.

The diagnosis is made according ICD-10 classification by the team consisted of pediatrician-psychophysiologist, clinical psychologist and child neurologist. All children were outpatients at the Pediatric Clinic, Faculty of Medicine, Skopje.

2.2. Procedure

In the assessment procedure interviews with parents and children and psychometric evaluation with Eysenck Personality Questionnaire (EPQ) are used. EPQ (Eysenck and Eysenck, 1975; Hathaway, 1965) is used for discriminating four main psychological characteristics of the personality: extroversion/ introversion; neurotic tendencies/ stability; psychopathologic traits/ normal behavior and control lie-scale. Most important for the study was to discriminate extrovert/ introvert children which is significant for mental arousal (Pop-Jordanova and Pop-Jordanov, 2005)

Eysenck Personality Inventory (EPI) is a self-report personality inventory which assumes three basic factors (the two most important being extraversion to introversion and neuroticism). In previous studies we used this instrument for differentiation the personality traits in children with chronic

FIGURE 1. Screenplay for Heart Math Freeze-Framer System

diseases (Pop-Jordanova, 2008), mental anorexia and adiposity (Pop-Jordanova, 2000) as well as somatoform disorders and ADHD (Pop-Jordanova, 2009). For clinical analyses, we developed a computer-based expert system (Pop-Jordanova and Boskovska, 1985). The stability, validity and reliability of scales in EPI and EPQ was confirmed in many studies (Lajunena & Scherler, 1998; Verghese, 1972, Pryke. 1977, Eysenck and Eysenck, 1985, 1986, 1988)

As biofeedback instrumentation we used Heart Math Freeze-Framer System (1998). This relatively simple system is constructed to help in following area: to shift intentionally to more positive emotional state; to help in better problem solving; to maintain general health and physical resilience; to transform the stress into positive relationships and to help in effective dealing with stress. It is supposed that effective emotional regulation depends on being able to flexibly adjust the physiological response to a changing environment.

The patients were sitting in a comfortable chair, in a quiet room, along with the practitioner. The instruction was: be calm, breath deeply and try to think about pleasant situations or persons. After the assessment, 15 training sessions are applied. The dynamic of HRV changes during one whole session for one patient is presented on the Figure 1.

The obtained results were statistically elaborated with: ANOVA for first and last sessions of all groups and Student t-test for differences between groups (Word package Statistics 7). The applied biofeedback system shows heart rate changes during every training session. The duration of all sessions is about 16 minutes and included basic recording and two games (meadow and balloon). Calculated mean values and standard deviations of the first and last session are used for t-test. In addition, the system shows the high, mean and low entertainment level ratio in every session.

Score	Anxious-phobic	CD	ADHD	Somatoform disorders	OCD	Control
P	5.82±2.12 p = 0.27	6.37±2.34 p = 0.34	5.37±1.86 p = 0.004**	8±4.66 p = 0.05*	6.25±2.94 P = 0.3	4.86±2.09
E	14.36± 5.15 p = 0.062	15.25±4.29 p = 0.3	17.75±3.11 p = 0.63	11.2±2.95 p = 0.0004**	14.75±2.27 p = 0.72	17.2±1.42
N	14.45±3.79 p = 0.13	13.62±4.99 p = 55	15.37±2.86 p = 0.11	14.4±4.22 p = 0.11	13±4 p = 0.02*	12.2±3.38
L	14.27±3.0 p = 0.098	12.8±4.0 p = 0.11	11.5±3.39 p = 0.003**	15.3±2.7 p = 0.46	11.5±2.69 p = 0.03*	16.13±2.29
*p<0.05; ** p< 0.005, P= psychopathological traits; E=extroversion; N=neurotic tendencies; L=lie scale						

TABLE 1. Results obtained for EPQ

	SS effect	df effect	ms effect	ss error	df error	ms error	f	P
low first	60,82	34	1,78	13,66	6	2,27	0,78	0,7
medium first	48,48	30	1,61	26	10	2,6	0,62	0,84
high first	41,98	17	2,46	32,5	23	1,41	1,74	0,1
low last	58,82	29	2,02	15,66	11	1,42	1,42	0,27
medium last	61,15	30	2,03	13,33	10	1,33	1,52	0,24
high last	51,07	20	2,55	23,41	20	1,17	2,18	0,044

TABLE 2. ANOVA for low, medium and high HRV, the first and last session

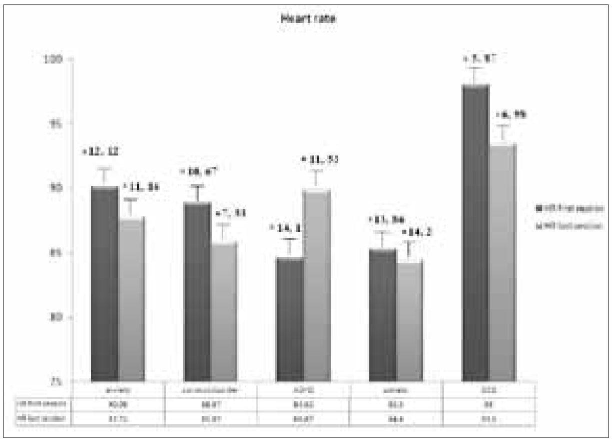

FIGURE 2. Changes of heart rate (first and last session) for different groups

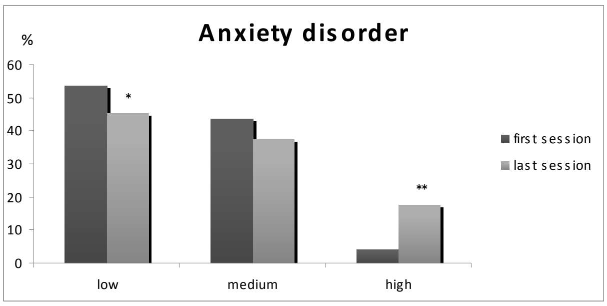

FIGURE 3. HRV spectra for children with anxiety, * p< 0.05; ** p< 0.01

3. RESULTS AND DISCUSSION

Results obtained for EPQ for all group of children are presented on Table 1.

The comparison of EPQ scores between groups showed significant difference in P score between anxious-phobic and ADHD group (p = 00022), and conduct disorder and ADHD (p = 0.03). Children with ADHD and with somatoform problems differ significantly in L scores (p = 0.007) as well as in N scores (p = 0.007).

Generally, all children manifesting some mental health problem showed lower scores for extroversion and higher scores for neuroticism, compared to the control group. It can be supposed that all these children have higher inner mental arousal compared with healthy children. It means that "brain-rate" (spectrum-weighted frequency) is higher in eyes closed than in eyes open condition (Pop-Jordanova and Pop-Jordanov, 2005). This finding is important for the choice of biofeedback modality. Namely, for introvert personalities, manifesting so called "inner arousal" (calculated with brain-rate formula), the application of peripheral biofeedback modalities is a better choice. In this context peripheral biofeedback

Disorder	the zone-accumulated entrainment score
Anxiety	30
Conduct disorders	32,5
ADHD	10,62
Somatoform disorders	20
OCD	20

TABLE 3. Results for zone-accumulated score (%)

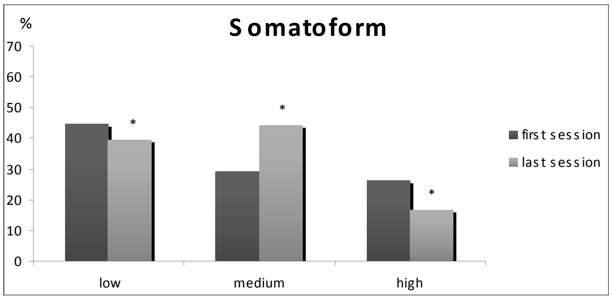

FIGURE 4. HRVspectra in somatoform group, *p< 0.05

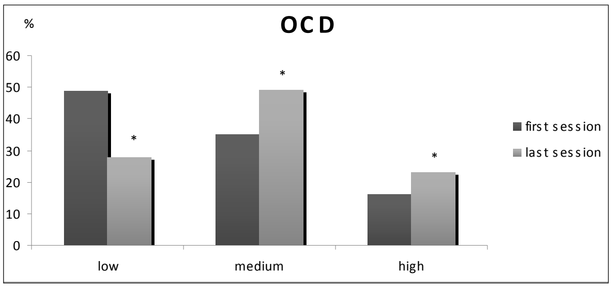

FIGURE 5. HRVspectra in children with obsessive-compulsive disorder, * p< 0.05

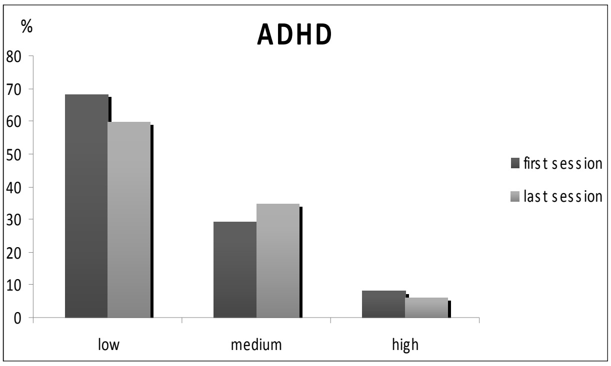

FIGURE 6. HRV spectra for children with ADHD

based on HRV was chosen also for this study. The aim of HRV training is to obtain higher HRV, shifting simultaneously the EEG spectrum toward lower frequency range.

In the following, we present the results obtained with biofeedback HRV in different group of children.

On Figure 2, heart rate for first and last session for different groups is presented. It can be seen that maximal changes are obtained for obsessive-compulsive, conduct disorders and anxiety. It means that with training almost all children, except ADHD group, learned to diminish heart rate.

Anxiety group (Fig. 3) showed very good results concerning HRV; they diminished the low and raised the high HRV scores.

For children with somatoform problems (Fig. 4) it was obtained significant changes in all spectral HRV parameters (low, high and medium, p< 005). From the clinical aspect, only the higher medium HRV is a positive outcome. Children did not succeed to raise the high part of HRV.

Changes of HRV in the OCD group are presented on Figure 5. It is clear that with the training children learned to obtain higher medium and high part of spectra which is important for the clinical outcome.

From Figure 6 it is clear that children with ADHD did not succeeded to change high part of HRV which would be good from the clinical point of view. Simultaneously, some previous studies (Rossier, 2004; Merkel, 2000; Monastra, 2002; Pop-Jordanova, 2009) showed effectiveness of central biofeedback (neurofeedback) in ADHD children. This is in accordance to the pathophysiology of the disorder: deficit of the executive frontal lobe function.

On Figure 7 changes obtained in HRV with the training for conduct disorder are divided in relation to spectra. It is important that we obtained significant improvement of high HRV (p< 0.01) which is very good from the clinical aspect, along with diminishing the low HRV (p <0.01).

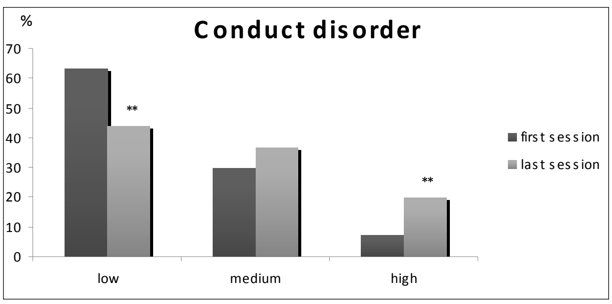

FIGURE 7. HRVspectra in children with conduct disorder, ** p< 0.01

On the Table 2, Analysis of Variance (ANOVA) for the first and last training session concerning low, medium and high HRV for all five groups is presented. As can be seen, only in the high HRV significant difference of variance is obtained. It is in correlation with the clinical outcome.

Not significant correlations between age and low, medium and high HRV have been obtained. In addition, no correlations between age and scores obtained from EPQ were found.

The zone-accumulated entrainment score shows the percentage of successfulness (high HRV) during all training sessions (Table 3). The maximum is 100% which is practically impossible to reach. However, the higher score means more successful changes in long duration of HRV.

The results obtained with biofeedback calculated directly through the instrument happened to be the best in the group with conduct disorder as well as for children with general anxiety (32.5 and 30 respectively), but it is also good for OCD and somatoform disorders. For ADHD group this parameter is minimal. It means that peripheral biofeedback is not a good choice for ADHD children.

In general, this study shows that HRV as a peripheral biofeedback could be good choice especially for introvert children manifesting common mental health problems. The application is non-invasive, has good cost-benefit and the included games are very interesting for children.

4. CONCLUSIONS

All school children with mental health problems we dealed with in this study (anxiety disorders, somatoform, obsessive-compulsive, ADHD, and conduct disorders) showed significant differences in EPQ scores (especially for psychopathological traits, introversion and neurotic tendencies) compared with the healthy ones.

Heart rate data have reflected various physiological states such as biological workload, stress and concentration on tasks, drowsiness and the active state of the autonomic nervous system.

HRV training showed very positive influence concerning the clinical out come, especially for children with conduct and anxious-phobic disorders, but also partially for obsessive-compulsive and somatoform disorders.

HRV training happened to be not too much efficient for ADHD group, whereby EEG biofeedback may be more suitable. This could be explained by the primary role of CNS executive function in ADHD.

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