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Boris Kryzhanovsky
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Advances in Neural Computation, Machine Learning, and Cognitive Research

Selected Papers from the XIX International Conference on Neuroinformatics, October 2–6, 2017, Moscow, Russia

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Complexity of Heart Rate During More and Less Differentiated Behaviors

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Abstract. Autonomic nervous system is the main way for the brain–body coordination, of which mode can be evaluated by dynamics of heart rate variability (HRV). HRV analysis is used for evaluation of different psychological states (stress, arousal, cognitive control etc.), which can be considered as characteristics of behavior that formed at different stages of ontogeny. We investigated whether HRV differs between the early-formed (less differentiated) behavior and the later-formed (more differentiated) behavior. Heart rate was recorded in 33 healthy subjects (mathematical specialists). Participants performed two tests which included sentences with mathematical terms and sentences with common current used words. They had to add one missing word in each sentence. Sample entropy as a measure quantifying the complexity of time series was used to analyze HRV. Complexity of heart rate was significantly higher in the mathematical test performance when participants actualized the later-formed behavior.

Keywords: Autonomic nervous system · Complexity of heart rate · Different stages of ontogeny · Behavioral complexity · Sample entropy

1 Introduction

Physiological supporting of behavior includes activation of different linked neurons groups and optimization of physiological processes. As a rule traditionally in the conserved approach internal bodily states are ignored in the searching of the neural basis of behavior. Such mental functions as perceptions, thoughts, feelings etc. are for the most part considered in isolation from the physiological state of the body. A mechanistic understanding of distinct interoceptive pathways, which can influence brain functions, leads to the impossibility of considering the behavior at the whole organism level [1]. Therefore the current main task is forming of the system approach for describing of behavior from psychophysiology perspective.

Autonomic nervous system takes part in subserving of behavior. Studies of autonomic psychophysiology are beginning to have a big part in the current field of neuroscience. As an example, the fundamental association between bodily changes and emotions was founded by James and Lange at 19 century. Since that time a lot off studies with electrical stimulation in animals have demonstrated the coupling of visceral responses to cortical regions, which include cingulate, insular [2], visual [3] and

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somatosensory [4] regions. It means that not only the nucleus of the solitary tract, ventrolateral medulla, parabrachial nucleus and hypothalamus but also many cortex regions take part in the brain–body cooperation (processing of visceral information). Experimental researches into the mechanisms through which visceral afferent information is represented within the brain haven't shown clearly how visceral signals shape human behavior yet. The majority of visceral signals that shape behavior are unnoticed despite there is anatomical and experimental information about the representation and influence of the visceral state in brain processes.

In this way describing principles through which human behavior and experience is coloured by internal bodily signals Benarroch [5] showed the central autonomic network (CAN), which included different structures of the central and the autonomic nervous system. The main statement of the theory is the CAN is an integral component of an internal regulation system through which the brain controls visceromotor, neuroendocrine, pain, and behavioral responses essential for survival (for goal-directed behavior supporting).

Heart rate variability can be considered as a tool for measurement of autonomic nervous system activity. Heart rate variability (HRV) is the variation over time of heart beat intervals (the periods between consecutive heartbeats), which depends on such physiological processes as autonomic neural regulation, thermoregulation, breathing etc. [6]. HRV is thought to reflect the heart's ability to adapt to changing behaviour and can be considered as an indicator of central-peripheral neural feedback and central nervous system – autonomic nervous system integration. Therefore HRV was used in the current study as a noninvasive tool for assessing the activities of the autonomic nervous system.

It is shown that HRV associated with a diverse range of processes, including affective and attention regulation, cognitive functions (such as working memory, sustained attention, behavioral inhibition, general mental flexibility) [7]. These processes can be considered as characteristics of behavior formed at different stages of ontogeny.

From the system-evolutionary theory [8] perspective, a new behavior is sub-served by co-activation of specialized neurons groups that had emerged in learning. The result of learning is a functional system that is a set of brain and body elements activity for providing efficient interaction with the environment [9]. Formation of new systems during development results in growing complexity and differentiation of organism–environment relations. They are becoming more detailed and specific. Consequently, the structure of behavior becomes more complex and differentiated during development [10]. In this way ontogenetic development can be considered as the process of increasing differentiation along with the number of learnt behavioral functional systems [11].

Therefore we investigated whether HRV in the early-formed behavior ("old") differs from HRV in the later-formed ("new") behavior. Basing on the fact that usually "old" behavior is less complicated than "new" behavior [12] we hypothesized that heart rate complexity would be higher at "new" behavior performing.

2 Materials and Methods

The experiment was approved by the Ethics Committee of the Institute of Psychology of Russian Academy of Science. Prior to the experiment, all subjects signed an informed consent form stating that participation was voluntary and that they could withdraw from the study at any moment.

Thirty-three healthy subjects (28 men, median = 27.78 years, range 23–37 years) participated.

Participants did not suffer from any self-reported respiratory, cardiac diseases, epilepsy, psychiatric disorder, or any minor or major illness. All participants were professional mathematicians and had work experience (Median = 4.84 years).

The linguistic task was used for modeling behaviors formed at different stages of ontogeny because language acquisition, as part of individual development, can be considered as learning to achieve adaptive results [13, 14].

The experimental task was to add one missing word in the sentence. The sentences (N = 64) were divided into 2 groups by age of acquisition of words. The first group of sentences (N = 32) included sentences with mathematical terms. Subjects had known these terms from University studying (from the age of 18–19 years). The example is “A normal is a vector that is perpendicular to a given object”. These sentences included later-acquired words and made actual a “new” behavior. The second group of sentences (N = 32) included sentences with commonly used words. Subjects had known these words from childhood (from the age of 5–6 years). The example is “Plasticine is a material for modeling figures”. These sentences included early-acquired words and made actual an “old” behavior. The sentences in both groups were equal in the linguistic estimations, such as the quantity of words, syllables, letters and Fog’s index.

The sentences were performed individually on a standard computer. The order of sentences was random without repetition in each group.

The ECG was obtained using the wireless device HxM BT by Zephyr Technology and the developed software complex. The plastic electrodes were filled with electrolyte and placed on the thorax across the heart, they were located in I and II chest leads. Batch data transmission from the sensor to the mobile device was done through the wireless protocol Bluetooth. Realization of communication, data transmission and storage was performed in the mobile device by the original software “HR-Reader” [15]. “HR-Reader” program medium provided on-line visualization of the registered signal for the record control. The signal was sampled at 400 Hz. The inter-beat intervals (IBI) were extracted from ECG through the threshold algorithm.

The time domain indexes of HRV used in the analysis were the mean (HR, ms) and standard deviation (SDNN, ms) of IBI. These indexes closely reflect all nervous regulatory inputs to the heart.

For estimation of heart rate complexity we used the sample entropy (SampEn) as a set of measures of system complexity reporting on similarity in time series. SampEn was chosen because it is successfully applied to relatively short and noisy data and it is largely independent of record length and displays relative consistency under circumstances. SampEn (m, r, N) is precisely the negative natural logarithm of the conditional probability that two sequences similar for m points remain similar at the next point, where self-matches are not included in calculating the probability [16]. The parameter N is the length of the time series, m is the length of sequences to be compared; r is the tolerance for accepting matches. Thus a low value of SampEn reflects a high degree of regularity. SampEn is independent on the record length and displays relative consistency under circumstances. The parameters m and r were fixed: m = 2, r = 0.5*SDNN.

We calculated HR, SDNN and SampEn for series of IBI individually during performance of the task with mathematical words and the task with commonly used words.

Normality of variables was tested in Shapiro–Wilk's test (W-test). HRV data of two conditions (performing tasks with mathematical or commonly used words) were tested in Wilcoxon signed-rank test. We used non-parametric test because the majority of variables didn't have the normal distribution. Statistical analyses for all measures were accomplished with Statistica 10.

3 Results

We compared to time domain indexes (HR and SDNN) and non-linear index (SampEn) of HRV between two periods: performing the task with mathematical words and performing the task with commonly used words, using non-parametric Wilcoxon signed rank test.

Values of heart rate (HR) and of the standard deviation of heart rate (SDNN) did not significantly differ between two conditions (Tables 1 and 2).

Table 1. Description statistics (median, lower and upper quartiles) and the results of Shapiro–Wilk's test of HRV parameters in task performing with sentences with mathematical words (MW) and sentences with commonly used words (CW).

Statistics	SamEn CW	SampEn MW	SDNN CW	SDNN MW	HR CW	HR MW
Median	0.65	0.72	56.72	58.92	789.64	781.35
Lower quartile	0.51	0.62	44.67	45.48	734.11	708.86
Upper quartile	0.77	0.79	76.48	76.88	922.31	907.13
Median	0.65	0.72	56.72	58.92	789.64	781.35

Table 2. The distributions of the medians of HRV parameters in two types tasks performing were compared using Wilcoxon signed-rank test.

Variables	T	Z	p
SampEn	82.00	2.37	0.01*
SDNN	128.00	1.21	0.22
HR	132.00	0.65	0.49

*Significant level.

Heart rate complexity (SampEn) was significantly higher in the performing the task with mathematical terms than performing the task with commonly used words (Tables 1 and 2).

4 Conclusion

The aim of the current study was to examine the relationship between the system supporting of behavior and complexity of heart rate. It was shown that the early-formed behavior, which realized less differentiated organism–environment relationships, was corresponded with less complexity of heart rate than the latter-formed behavior, which realized more differentiated organism–environment relations.

It was shown that neuronal subserving of the latter-formed behavior includes more neuronal systems [17]. As an example, the acute effect of alcohol on the ERPs related to the use of knowledge and experiences acquired at the early stages of individual development was less than at the later stages [18]. Therefore we can suppose that during later formed behavior the central-autonomic network has to realize more nonstationary activity which demands many different changes in the activity of the heart and other parts of the organism. It leads to lack of regularity of heart rate and to the increase of complexity (Fig. 1).

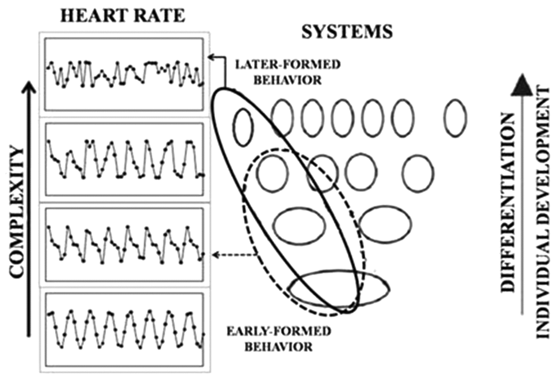

Fig. 1. The correlation between complexity of heart rate and degree of differentiation of behaviors formed at different stages of individual development. The small ovals depict functional systems formed at different stages of individual development. Groups of ovals connected by the line illustrate the combination of functional systems that provide realization of behavior: full line - later-formed behavior, dashed line - early-formed behavior.

It is important that HR was the same in both conditions. It means that these different modes of heart activity, which were seen in the results, cannot be explained through the different intensity of cognitive load, which demands different quantity of internal recourses during early- and latter-formed behaviors.

The main output of the study is that the system subserving of behavior is reflected not only in the brain activity but also in the body activity. Functional systems, which subserve behavior, are not only neuron systems. They also include different parts of the body, which change their activity in cooperation with the brain for an optimal achievement of results.

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References

1. Critchley, H.D., Harrison, N.A.: Visceral influences on brain and behavior. Neuron **77**, 624–638 (2013)
2. Bagaev, V., Aleksandrov, V.: Visceral-related area in the rat insular cortex. Auton. Neurosci. Basic Clin. **125**, 16–21 (2006)
3. Pigarev, I.N., Bagaev, V.A., Levichkina, E.V., Fedorov, G.O., Busigina, I.I.: Cortical visual areas process intestinal information during slow-wave sleep. Neurogastroenterol. Motil. **25**, e268–e169 (2013)
4. Brüggemann, J., Shi, T., Apkarian, A.V.: Viscero-somatic neurons in the primary somatosensory cortex (SI) of the squirrel monkey. Brain Res. **756**, 297–300 (1997)
5. Benarroch, E.E.: The central autonomic network—functional organization, dysfunction, and perspective. Mayo Clinic Proc. **68**(10), 988–1001 (1993)
6. Acharya, U.R., Joseph, K.P., Choo, N.K., Jasjit, M.L., Suri, S.: Heart rate variability: a review. Med. Biol. Eng. Comput. **44**, 1031–1051 (2006)
7. Matthews, S.C., Paulus, M.P., Simmons, A.N., Nelesen, R.A., Dimsdale, J.E.: Functional subdivisions within anterior cingulate cortex and their relationship to autonomic nervous system function. NeuroImage **22**, 1151–1156 (2004)
8. Shvyrkov, V.B.: Behavior specialization and the system-selection hypothesis of learning. In: Human Memory and Cognitive Capabilities, pp. 599–611. Elsevier, Amsterdam (1986)
9. Anokhin, P.K.: Biology and neurophysiology of the conditioned reflex and its role in adaptive behavior: scientific and translation. In: Corson, S.A., Dartau, P.-R., Epp, J., Kirilcuk, V. (eds.) (Transl.), 98 pp. Pergamon Press, New York (1974)
10. Edelman, G.M.: Naturalizing consciousness: a theoretical framework. PNAS **100**, 5520–5524 (2003)
11. Alexandrov, Y.I.: Physiological Significance of the Activity of Central and Peripheral Neurons in Behavior, 426 pp. Science, Moscow (1989)
12. Lewin, K.: Action research and minority problems. In: Lewin, G.W. (ed.) Resolving Social Conflicts, 412 pp. Harper & Row, New York (1946)
13. Maturana, H.R.: Biology of cognition. BCL Report No. 90, pp. 5–58. University of Illinois, Urbana (1970)
14. Kolbeneva, M.G., Alexandrov, Y.I.: Mental reactivation and pleasantness judgment of experience related to vision, hearing, skin sensations, taste and olfaction. PLoS ONE **11**(7), e0159036 (2016). doi:10.1371/journal.pone.0159036
15. Runova, E.V., Grigoreva, V.N., Bakhchina, A.V., Parin, S.B., Shishalov, I.S., Kozhevnikov, V.V., Necrasova, M.M., Karatushina, D.I., Grigorieva, K.A., Polevaya, S.A.: Vegetative correlates of conscious representation of emotional stress. CTM **4**, 69–77 (2013)
16. Richman, J.S., Moorman, J.R.: Physiological time-series analysis using approximate entropy and sample entropy. Am. J. Physiol. Heart Circ. Physiol. **278**, H2039–H2049 (2000)

17. Yu, I.A., Grinchenko, V.G., Shevchenko, D.G., Averkin, R.G., Matz, V.N., Laukka, S., Korpusova, A.V.: A subset of cingulate cortical neurons is specifically activated during alcohol-acquisition behavior. Acta Physiol. Scand. **171**, 87–97 (2001)
18. Yu, I.A., Sams, M., Lavikainen, J., Reinikainen, K., Naatanen, R.: Differential effects of alcohol on the cortical processing of foreign and native language. Int. J. Psychophysiol. **28**, 1–10 (1998)