JOIN (Jurnal Online Informatika)
Volume 7 No. 1 | June 2022: 46-55
DOI: 10.15575/join.v7i1.809

p-ISSN: 2527-1682
e-ISSN: 2527-9165

Poincaré Plot Method for Physiological Analysis of the Gadget Use Effect on Children Stress Level

Umar Zaky[1], Afwan Anggara[2], Muhammad Zakariyah[3], Ilham Fathullah[4]
[1,2] Department of Information System, University of Technology Yogyakarta, Indonesia
[3,4] Department of Informatics, University of Technology Yogyakarta, Indonesia

Article Info

Article history:

Received August 31, 2021
Revised October 19, 2021
Accepted October 26, 2021
Published June 30, 2022

Keywords:

Children Stress
Gadget
Heart Rate Variability
Poincaré Plot

ABSTRACT

Stress in children can affect the way they think, act, and feel. The habit of using gadgets has several advantages and disadvantages, but there has been no in-depth study of the effect of using gadgets on stress levels in children. This study aims to determine the representation of the physiological condition of using gadgets on stress levels in children. A total of 18 electrocardiogram data were extracted with *poincaré plot* features. This research has found that there is no difference in the level of stress in children between before and after using gadgets in terms of autonomic nervous activity (Sig. > 0.05). However, there is an increase in sympathetic activity that occurs in children even though they have finished using gadgets. Such conditions certainly need to get more attention, especially related to the duration of gadget use and accessible content.

Corresponding Author:

Umar Zaky,
Department of Information System,
University of Technology Yogyakarta,
Jl. Siliwangi, Jombor, Sleman 55285, Yogyakarta, Indonesia
Email: umar.zaky@staff.uty.ac.id

1. INTRODUCTION

Gadget as a result of advanced technological developments allows children to use and even interact easily just by touching the screen. The advantages of gadgets in childhood growth and learning have been widely proven [1] [2]. However, excessive use of gadgets can lead to behavior, development, and learning processes problems [3]. The use of gadgets such as video games may also affect children's development in terms of morality and social development [4].

Social experiences in childhood contribute to the development of the neurological and biological systems [5]. Stressful experiences can alter a child's neurobiology by impairing their health, social competence, and ability to succeed in life. Stress is related to the nervous system which has a role to send signals and respond to potential threatening stress. Chronic stress can trigger the autonomic nervous system to keep working even at rest condition. Naturally, this condition is dangerous for body and mental health.

Current technology allows humans to use sensors that can monitor the activity/performance of a particular organ, such as an electrocardiogram which is capable of recording heart activity. Electrocardiogram (ECG) as a tool for recording the performance of the heart, makes it possible to monitor the activity of the autonomic nervous system. Through this process the stress conditions experienced by a person can be monitored directly.

Stress can be seen from the performance of the autonomic nervous system, which is characterized by increased activity of the sympathetic nervous system and decreased parasympathetic nervous system [6]. Both of these autonomic nervous systems work subconsciously to regulate body conditions. The activity of the autonomic nervous system can be seen through the performance of the heart, by looking at the heart rate variability [7].

Heart rate variability analysis was carried out in recent decades to aid clinical and functional diagnosis [8, 9]. In general, there are two ways to perform HRV analysis, linear and non-linear methods. Linear method involves time domain and the frequency domain. Time domain measures how much HRV was observed during certain periods. Duration of data recording greatly affects time domain value, so that the shorter recording period causes the analysis to be inaccurate [10]. The frequency domain calculates absolute or relative signal strength in the Ultra-Low Frequency (ULF), Very Low Frequency (VLF), Low Frequency (LF), and High Frequency (HF) bands. The duration of the recording period also becomes a limitation for the measurement of this method [11]. Non-linear method measures uncertain and complex series of HRV. One of the non-linear methods that can be used to measure HRV is the Poincaré *Plot*. *The Poincaré plot* was used to identify the response produced by exercise on the treadmill [12], evaluate the effect of driver fatigue on the autonomic nervous system (ANS) [13], and detect apnea [14].

Research among stress and HRV has been conducted by Ahn [15] which developed a stress assessment model using physiological responses generated from electroencephalogram (EEG) and heart rate variability (HRV). The study, which involved 14 subjects, used various EEG and HRV features to allow continuous monitoring of stress. The classification model was developed using Support Vector Machine (SVM). Based on cross-validation results, it was found that the system was able to show the best performance with 87.5% of accuracy.

Daily emotions and chronic work stress at work are also closely related to cardiac autonomic function (HRV vagal activity index) [16]. Effort Reward Imbalance (ERI) questionnaire was used to assess chronic work stress. A total of 19 data were collected to model the neural network of heart rate and HRV information. These results can provide additional information in stress research.

Objective evaluation methods for stress level analysis are important for disease prevention, health promotion, and quality of life improvement. Many wearables are capable of measuring pulse data that reflects stress levels (electrocardiogram). The advent of these devices presents an interesting possibility to monitor a person's stress level in everyday life. This study aims to develop a new method for stress analysis using an electrocardiogram based on the *poincaré plot*, especially for gadget use in children.

This study has a hypothesis that the use of gadgets in children's daily activities has no effect on stress levels. Another objective of this research is to know the physiological condition of the children’s body response through a poincaré *plot*. This research is important considering the many assumptions that gadgets can cause stress in children, but there is not enough evidence to support this assumption in terms of autonomic nervous system activity.

2. METHOD

2.1. Experimental Design

Experimental design serves to provide an overview of the data recording process carried out. The experimental design in ECG recording is designed as shown in Figure 1. Parents/guardians of the subjects who will be involved in this research are given information about the research purposes and the data recording procedures. The research will only be continued if the researcher obtains the consent from parents and the subject. After obtaining approval, an assessment was carried out (subject demographics, body condition interviews and activities prior to recording) and vital sign check (body temperature and blood pressure). After fulfilling predetermined criteria, then proceed with the installation of an ECG recording device (electrode) on the subject. All ECG recordings were performed in the recumbent (baseline) position.

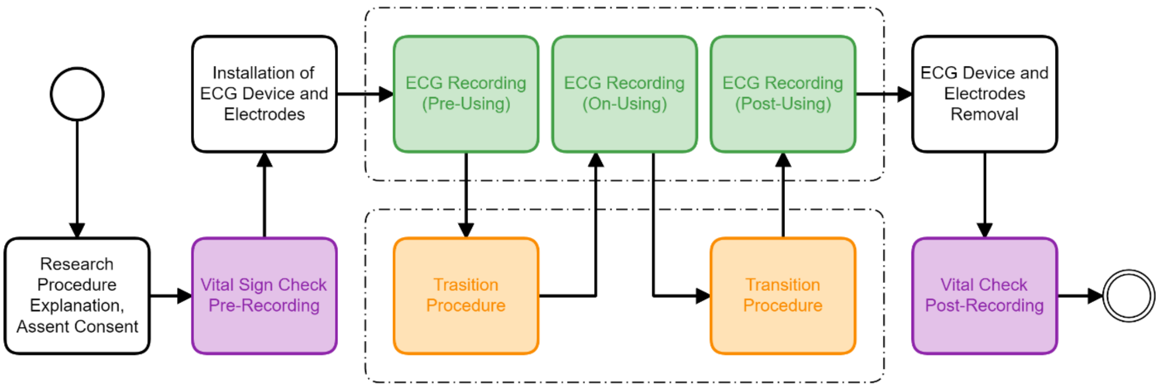


Figure 1. ECG Recording Experimental Design

The first recording (pre-using) was done for 5 minutes when the subject was not using a gadget. After 5 minutes of pre-using recording, subjects were asked to relax for a moment (transition procedure) for 1 minute to prepare for the next recording. Subsequent recording (on-using) was also carried out for 5 minutes, but subjects were asked to start using gadgets such as accessing games, browsing, videos, and others. After completion of the second recording and transition procedure, the last recording is the same as the first recording. The last stage in data collection is removing the ECG recording device and checking the subject's vital signs again.

2.2. Subjects and Data Collection

Data collection is carried out with the specified subject criteria. The subjects were children who were recruited by the researcher sequentially in the Special Region of Yogyakarta. Assent consent was submitted and approved by the parents/guardians of each subject.

The inclusion criteria in this study are: children 5-11 years old, understand and are accustomed to operating gadgets, are willing to take part in the study. The exclusion criteria included: clinically subjects did not experience psychological disorders, did not have a history of heart disease and diabetes mellitus, body mass index > 35.

Data taken from the subject in the form of electrocardiogram recording through the 3 leads electrode. Data is recorded before using gadget (pre-using), during using gadget (on-using), and after using the gadget (post-using). The duration of data recording is 5 minutes in every phase.

2.3. Heart Rate Variability Extraction

Extraction of Heart Rate Variability (HRV) using a poincaré *plot* starts from reading the electrocardiogram (ECG) signal. ECG from the subject has 50 Hz frequency. R-Peaks detection is carried out using the Two Moving Average Algorithm (Figure 2). Two moving average algorithm was chosen because it has proven to be quite good at detecting R-peaks in several medical cases [17].

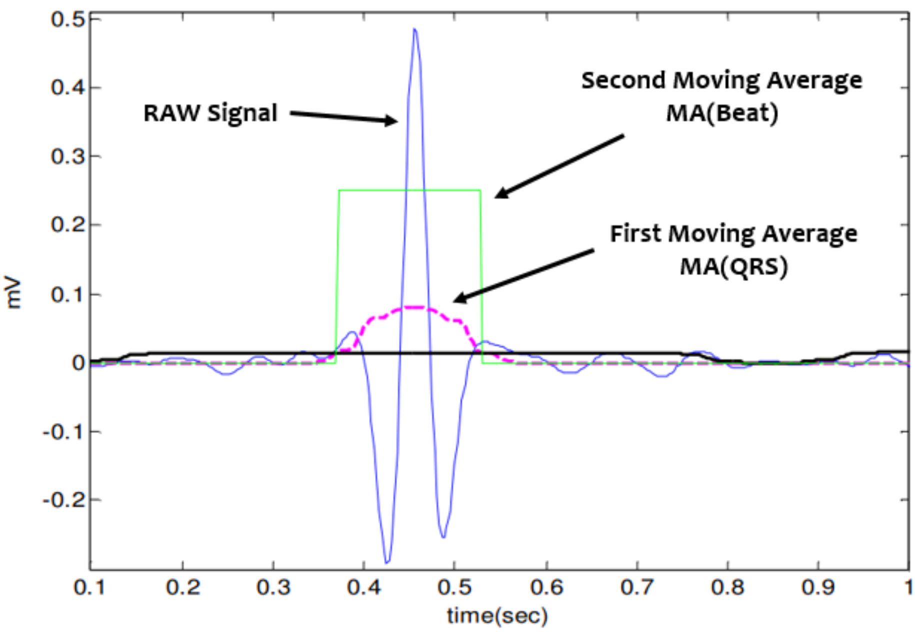


Figure 2. Two Moving Average Algorithm Peak Detection

The Two Moving Average algorithm uses butterworth filtering to filter out frequencies above a predetermined cut-off. Determination of the QRS complex in the ECG signal is carried out using two Moving Window Averages (MWA). The first MWA is used to capture the QRS area by calculating the average of a number of samples. The second MWA aims to capture the complete signal peak. When the amplitude of the first MWA is greater than the amplitude of the second MWA, then part of the signal is selected as the QRS area (QRS block). The maximum absolute value in each QRS block is considered to be the peak of the QRS complex [18].

Each beat has a QRS complex peak (R-Peak), and the results of the ECG data plot and the R-Peak detection results are shown in Figure 3.

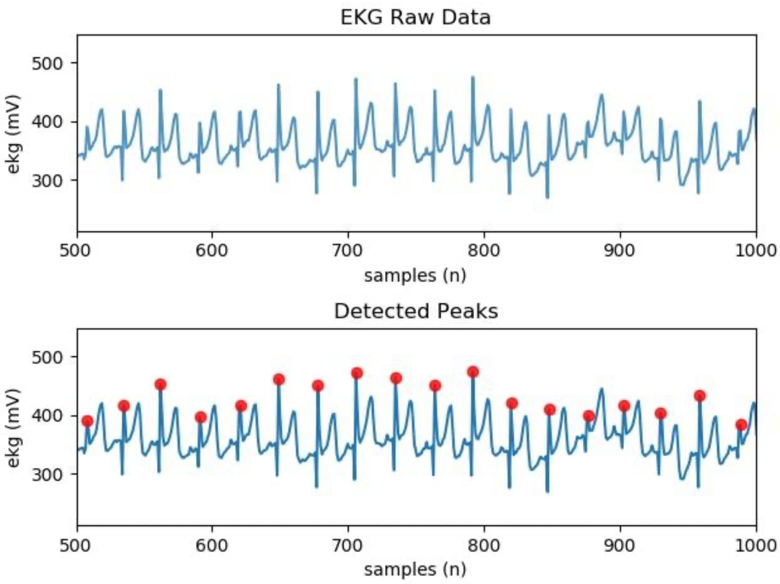


Figure 3. Electrocardiogram Signal Data and
QRS Complex Peaks Detected

After all of the R-Peaks in the ECG signal are obtained, then the interval between adjacent R-Peaks is calculated. Commonly it is called R-R Interval. The results of the R-R Interval plot as shown in Figure 4.

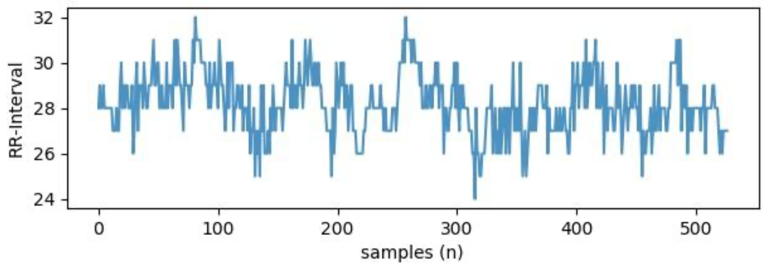


Figure 4. R-R Interval Plot

2.4. *Poincaré Plot* Features

Poincaré plot is a non-linear analysis that serves to determine HRV dynamics. *Poincaré plot* is a representation of a time series where the value of each pair of elements (R-R Interval) consecutively represents a point in the plot [19]. The quantitative analysis of HRV is presented in the form of Poincaré plots. The features in the *Poincaré plot* are Standard Deviation 1 (SD1), Standard Deviation 2 (SD2), SD1/SD2 Ratio, and area of ellipse (S-Region) [20].

Standard Deviation 1 (SD1) is the standard deviation of the variability of the R-R Interval for a moment (short term). SD1 is obtained through Equation (1) below:

$$SD1 = \sqrt{var(x1)} \tag{1}$$

Where var(x1) is the variance of the variable x1. The variable x1 is obtained through the following equation (2):

$$x1 = \frac{\overrightarrow{RR\iota} - \overrightarrow{RR\iota+1}}{\sqrt{2}} \tag{2}$$

Where RRi and RRi+1 are R-R interval vectors defined in Equation (3) and Equation (4), respectively.

$$\overrightarrow{RR_\iota} = (RR_1, RR_2, \dots, RR_{N-1}) \tag{3}$$
$$\overrightarrow{RR_{\iota+1}} = (RR_2, RR_3, \dots, RR_N) \tag{4}$$

Standard Deviation 2 (SD2) is the standard deviation of the long-term R-R Interval variability. SD2 is obtained through Equation (5).

$$SD2 = \sqrt{var(x2)} \quad (5)$$

Where var(x2) is the variance of the variable x2. The variable x2 is obtained through the equation shown in Equation (6).

$$x2 = \frac{\overrightarrow{RRi} + \overrightarrow{RRi+1}}{\sqrt{2}} \quad (6)$$

Where RRi and RRi+1 are R-R interval vectors defined in Equation (3) and Equation (4), respectively.

3. RESULTS AND DISCUSSION

3.1. Subject Demographics

This study has obtained assent consent from the parents of each subject involved in the study. Data collection protocols have also been pursued in accordance with the rules contained in the Declaration of Helsinki regarding research involving human subjects. Subjects in this study are 5 children aged between 5-11 years old. Each child participated more than once to ensure the consistency of the data taken, a total of 18 data were obtained. Table 1 shows the demographics of the subjects included in the study.

Table 1. Research Subject Demographics

Demography	Frequency		Descriptive	
	Total	Percentage	Mean	Std. Deviation
Gender				
Male	3	60%	-	-
Female	2	40%	-	-
Age	-	-	6	1.188
Body Temperature	-	-	36.089	0.374
Blood Pressure				
Diastole	-	-	91.61	8.375
Systole	-	-	62.83	8.631

3.2. *Poincaré Plot* Analysis

The Poincaré plot is described in the form of a scatter plot where the x-axis is the R-R Interval and the y-axis is the R-R Interval after it (R-R Interval+1). Figure 3.4 shows the *poincaré plot* of one subject before using a gadget (left), while using a gadget (middle), and after using a gadget (right).

The center of the data distribution is searched, then the short-term standard deviation 1 (SD1) and long-term standard deviation (SD2) are calculated. The area of the ellipse shows the distribution of the data variability. Area of ellipse is obtained from the product of the coefficient value of phi (π) with SD1 (ellipse width) and SD2 (ellipse length). The blue dots are a representation of all the data, while the area of the ellipse is marked in orange.

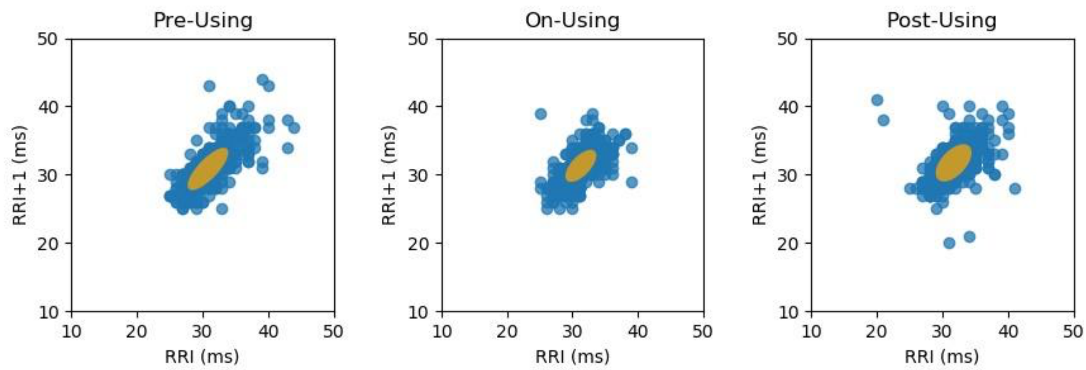
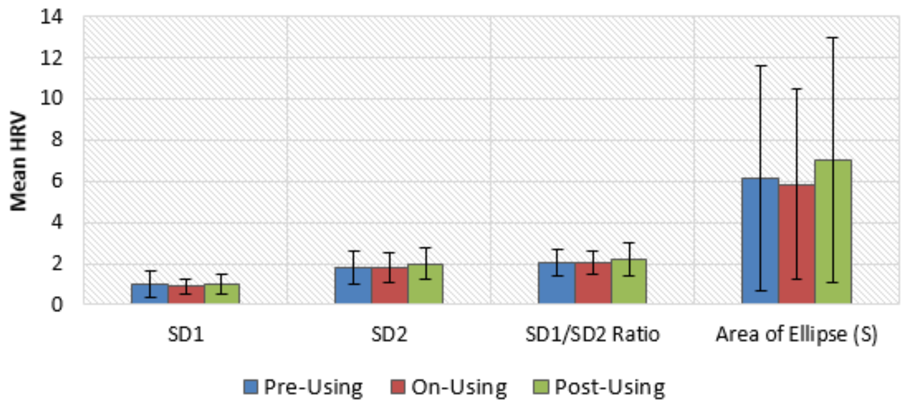


Figure 5. Poincaré Plot Before (Pre-Using), During (On-Using), dan After (Post-Using) Gadget Usage

As shown in Figure 5, data when using the gadget (on-using) tends to have a smaller area of ellipse compared to before (pre-using) and after using the gadget (post-using). In addition, the distribution of the R-R Interval when using gadgets also tends to be more homogeneous.

The next analysis is to perform descriptive statistical tests on the results of the *poincaré plot* feature extraction that has been carried out. This descriptive analysis aims to describe the characteristics of the subject before, during, and after using the gadget. The results of the descriptive statistical test are shown in Figure 6. As shown in the picture, the SD1 parameter when the subject is using the gadget shows a lower average than before and after using the gadget.



Poincaré Plot Features	Pre-Using		On-Using		Post-Using	
	Mean	**Std. Dev.**	**Mean**	**Std. Dev.**	**Mean**	**Std. Dev.**
Standard Deviation1 (SD1)	0.9843	0.6239	0.9063	0.3725	0.9923	0.5002
Standard Deviation2 (SD2)	1.8114	0.7954	1.8178	0.7483	2.0079	0.7924
SD1/SD2 Ratio	2.0239	0.6405	2.0268	0.5594	2.1777	0.8091
Area of Ellipse (S-Region)	6.1734	5.4552	5.8540	4.6196	7.0681	5.9504

Figure 6. Statistics of *Poincaré Plot* Features

3.3. Significance Test

Before conducting a significance test to determine the effect of using gadgets on several HRV parameters, the normality test was first carried out. The normality test was conducted to determine whether the data were normally distributed or not. This is done to determine the significance test to be performed (parametric or non-parametric test). The normality test was carried out using the Shapiro-Wilk Method, because the total data used was less than 50 data. Table 2 shows the results of the overall data normality test.

Table 2. Shapiro-Wilk Normality Test Results

Tests of Normality	**Shapiro-Wilk**		
	Statistic	**df**	**Sig.**
SD1 Pre-Using	0.638	18	**< 0.001****
SD1 On-Using	0.851	18	**0.009***
SD1 Post-Using	0.785	18	**0.001***
SD2 Pre-Using	0.873	18	**0.020***
SD2 On-Using	0.944	18	0.345
SD2 Post-Using	0.953	18	0.471
SD1/SD2 Ratio Pre-Using	0.982	18	0.966
SD1/SD2 Ratio On-Using	0.961	18	0.621
SD1/SD2 Ratio Post-Using	0.859	18	**0.012***
Area of Ellipse Pre-Using	0.752	18	**< 0.001****
Area of Ellipse On-Using	0.839	18	**0.006***
Area of Ellipse Post-Using	0.795	18	**0.001***

** Significant at level 0.05; ** Significant at level 0.001*

Based on the results in Table 2, there is still a significance value that is less than 0.05 (Sig. < 0.05), thus it can be concluded that the data is not normally distributed. Because the data are not normally distributed, the significance test to be carried out is a non-parametric test using the Wilcoxon Method.

The significance test using Wilcoxon rank test was used to determine the effect of the gadget on the *poincaré plot* feature in all subjects. The Wilcoxon Rank Test will test changes in position before and when using the gadget (pre-using to on-using), during using and after using the gadget (on-using to post-using), and before and after using the gadget (pre-using to post-using). The results of the paired t-test are shown in Table 3 below.

Table 3. Significance Test Results

Wilcoxon Signed Ranks Test	Z	Asymp. Sig. (2-tailed)
SD1 Pre Using - SD1 On Using	-0.457	0.647
SD1 On Using - SD1 Post Using	-1.851	0.064
SD1 Pre Using - SD1 Post Using	-1.241	0.215
SD2 Pre Using - SD2 On Using	-0.370	0.711
SD2 On Using - SD2 Post Using	-2.025	**0.043***
SD2 Pre Using - SD2 Post Using	-1.415	0.157
SD1/SD2 Ratio Pre Using - SD1/SD2 Ratio On Using	-0.240	0.811
SD1/SD2 Ratio On Using - SD1/SD2 Ratio Post Using	-0.719	0.472
SD1/SD2 Ratio Pre Using - SD1/SD2 Ratio Post Using	-0.762	0.446
Area of Ellipse Pre Using - Area Ellipse On Using	-0.196	0.845
Area of Ellipse On Using - Area Ellipse Post Using	-2.069	**0.039***
Area of Ellipse Pre Using - Area Ellipse Post Using	-1.372	0.170

** Significant at level 0.05*

Based on the table, with a significance level of 5%, it was found that there were significant differences in the SD2 parameters and the area of ellipse, only when using and after using the gadget (Sig. < 0.05), but other than that there was no significant difference (Sig. > 0.05).

3.4. *Stress Effect on Gadget Use*

The purpose of this study was to determine the effect of using gadgets on stress levels as indicated by autonomic nervous activity. The autonomic nervous system regulates the cardiovascular system which involves heart rate variability (HRV). HRV is one of the health indicators that is useful for measuring changes caused by disease progression, physiological changes, or other pathologies [21, 22]. Disorders of the autonomic nervous system cause fluctuations in heart rate, so HRV analysis can be used to monitor autonomic nervous activity [23, 24].

The Poincaré plot is a popular HRV analysis tool among doctors, because of its ability to visualize HRV dynamics non-linearly [25]. The Poincaré plot has several parameters, including: Standard Deviation 1 (SD1), Standard Deviation 2 (SD2), SD1/SD2 Ratio, and Ellipse Area (S-Region). In general, SD1 is a parasympathetic parameter of the sinus node [26, 27], whereas SD2 is influenced by both parasympathetic and sympathetic nerves [26, 27, 28, 29]. The SD1/SD2 ratio can be used as an indicator for sympathetic nerve activity [29, 11].

Standard Deviation 1 (SD1) and area of ellipse showed similar patterns, specifically when the subject was using the gadget (on-using), the average HRV value was lower than before and after using the gadget. Considering SD1 is a parasympathetic nerve parameter in the autonomic nervous system, it means that the parasympathetic nervous system when using the gadget is not working optimally. The parasympathetic nerves control homeostasis, and are also responsible for "*rest and digest*" functions in the body. Rest and digest function is a condition that aims to heal and regenerate, such as: digesting, detoxifying, eliminating, and building immunity [30, 31]. In patients with diabetes mellitus, lower SD1 indicates weakened parasympathetic regulation caused by disturbances in body health [32]. Although the SD1 value when using the gadget was lower than before and after using the gadget, based on the results of the significance analysis, no significant difference was found. Based on these findings, the use of gadgets does not significantly affect the decrease in parasympathetic activity in the body.

The average SD2 parameter showed an increase when there was a change from before, during, and after using the gadget. The highest SD2 value occurs after using the gadget (post-using). SD2 is a long-term variability that shows both autonomic nervous activity, sympathetic and parasympathetic nerves. However, the SD2 parameter tends to be stronger with sympathetic activity than parasympathetic activity [33]. The significance analysis shows that there is a significant difference in SD2 parameters, only when using the gadget and after using the gadget (SD2 On Using - SD2 Post Using). The difference is not significant between before and after using the gadget (SD2 Pre Using - SD2 Post Using). Thus, the use of gadgets has no effect between before and after using them, but when (on-using) and after using the gadget. If SD2 tends to show sympathetic nervous activity, this study also confirms that a common response to physical and psychological stress is activation of the sympathetic nervous system with inhibition of the parasympathetic nervous system [34].

The SD1/SD2 Ratio parameter shows that there is an increase similar to SD2 parameter. The SD1/SD2 ratio, which is associated with sympathetic nerve activity, shows the highest mean during the post-using condition. In detail, there has been an increase in sympathetic nervous activity before using the gadget to during using the gadget (pre-using to on-using), and from using the gadget to after using the gadget (on-using to post-using). This pattern shows that the use of gadgets can increase sympathetic nerve activity. Sympathetic nervous activity is related to the "*fight or flight"* response. The fight or flight response is a physiological reaction in the body to an event that is perceived as pressure, stress, or threat [35]. Frequent, intense, or inappropriate activation of the fight or flight response has implications for a variety of clinical conditions including most anxiety disorders [36]. However, the increase in sympathetic nerve activity caused by the use of gadgets is not too significant.

Stress is a state of homeostasis that is threatened, after being exposed to adverse extrinsic or intrinsic forces [37]. One of the main pathways activated by stress is the autonomic nervous system [38, 39]. Under normal conditions, the parasympathetic nervous system is activated when a stressful situation is reduced because the autonomic nervous system is highly coordinated to maintain physiological homeostasis [30]. Acute and chronic stress have also been reported to affect the immune system, and increase various inflammatory markers [40, 41].

Poincaré plots describe beat-to-beat behavior in detail. Geometric visualization of the *pointcaré plots* is done by displaying the area of the ellipse at the points in the plot. The points on the caré plot become more dispersed in activity as vagal activity increases, or sympathetic activity decreases [42]. *Poincaré plots* provide information on the R-R interval pattern of the heart, and can even be used to differentiate between heart failure patients and healthy individuals [43], as well as the prognosis of patients with heart failure and patients prone to life-threatening arrhythmias [44, 45]. *Poincaré plots* can reveal abnormalities that are not easily detected by traditional time and frequency domain measurements. Visually, *poincaré plots* are more visible for detecting autonomic changes. Such information indicates that it is important to provide insight into the importance of morphology in *poincaré plots*, especially to relieve stress on the body.

4. CONCLUSION

Poincaré plots can be used to monitor stress on the body, either due to the use of gadgets or other diseases. This research has found that there is no difference in the level of stress in children between before and after using gadgets in terms of autonomic nervous activity. However, there is an increase in sympathetic activity that occurs in children even though they have finished using gadgets. Such conditions certainly need to get more attention, especially related to the duration of gadget use. This study has not limited other factors related to the use of gadgets, such as the content accessed and the duration of using the gadget in a day, so that future research can be done by giving these limits to the subject.

ACKNOWLEDGEMENTS

This research was supported by the Minister of Education through the Penelitian Dosen Pemula Program. We thank our colleagues who provided insight and expertise that greatly assisted the research, although they may not agree with all of the interpretations and conclusions of this paper.

5. REFERENCES

[1] D. N. Sari, "An Analysis of the Impact of the Use of Gadget on Children's Language and Social Development," in *Proceedings of the International Conference of Early Childhood Education (ICECE)*, Padang, 2020.

[2] N. Dubey, "Advantage of Technology Innovation in Education System for Children of Tribal Community," *JUS IMPERATOR,* pp. 1-14, 2019.

[3] M. Keumala, M. Yoestara and Z. Putri, "The Impacts of Gadget and Internet on The Implementation of Character Education on Early Childhood," in *Proceedings of the International Conference on the Roles of Parents in Shaping Children's Characters (ICECED)*, Banda Aceh, 2018.

[4] V. Goswami and D. R. Singh, "Impact of mobile phone addiction on adolescent’s life: A literature review," *International Journal of Home Science,* vol. 2, no. 1, pp. 69-74, 2016.
[5] R. A. Thompson, "Stress and Children Development," *The Future of Children,* vol. 24, no. 1, pp. 41-59, 2014.
[6] E. Won and Y.-K. Kim, "Stress, the Autonomic Nervous System, and the Immune-kynurenine Pathway in the Etiology of Depression," *Current Neuropharmacology,* pp. 665-673, 2016.
[7] J. Dong, "The role of heart rate variability in sports physiology (Review)," *Experimental and Therapeutic Medicine,* pp. 1531-1536, 2016.
[8] N. Montano, A. Porta, C. Cogliati, G. Costantino, E. Tobaldini, K. Casali and F. Iellamo, "Heart rate variability explored in the frequency domain: A tool to investigate the link between heart and behavior," *Neurosci. Biobehav. Rev.,* vol. 33, no. 2, pp. 71-80, 2009.
[9] J. Pumprla, K. Howorka, D. Groves, M. Chester and J. Nolan, "Functional assessment of heart rate variability: Physiological basis and practical applications," *Int. J. Cardiol.,* vol. 84, no. 1, pp. 1-14, 2002.
[10] D. Nunan, G. Sandercock and D. Brodie, "A quantitative systematic review of normal values for short-term heart rate variability in healthy adults," *Pacing Clin. Electrophysiol,* vol. 33, no. 11, pp. 1407-1417, 2010.
[11] F. Shaffer and J. P. Ginsberg, "An Overview of Heart Rate variability Metrics and Norms," *Front. Public Health,* vol. 5, no. 258, 2017.
[12] R. Gomes, L. Vanderlei, D. Garner, M. Santana, L. de Abreu and V. Valenti, "Poincaré plot analysis of ultra-short-term heart rate variability during recovery from exercise in physically active men," *The Journal of Sports Medicine and Physical Fitness,* pp. 998-1005, 2017.
[13] C. Zeng, W. Wang, C. Chen, C. Zhang and B. Cheng, "Poincaré Plot Indices of Heart Rate Variability for Monitoring Driving Fatigue," in *19th COTA International Conference of Transportation Professionals*, Beijing, 2019.
[14] C. González, E. W. Jensen, P. L. Gambús and M. Vallverdú, "Poincaré plot analysis of cerebral blood flow signals: Feature extraction and classification methods for apnea detection," *PLOS ONE,* p. e0208642, 2018.
[15] J. W. Ahn, Y. Ku and H. C. Kim, "A Novel Wearable EEG and ECG Recording System for Stress Assessment," *Sensors,* vol. 19, no. 1991, pp. 1-14, 2019.
[16] A. Uusitalo, T. Mets, K. Martinmäki, S. Mauno, U. Kinnunen and H. Rusko, "Heart rate variability related to effort at work," *Applied Ergonomics,* vol. 42, no. 6, pp. 830-838, 2011.
[17] M. Zakariyah and A. Sahroni, "Komparasi Algoritma Deteksi Puncak QRS Kompleks Elektrokardiogram (EKG) Pada Pasien Penderita Stroke Iskemik," in *Seminar Nasional Informatika Medis (SNIMed)*, Yogyakarta, 2019.
[18] M. Elgendi, M. Jonkman and F. D. Boer, "Frequency Bands Effects on QRS Detection," in *The 3rd International Conference on Bio-inspired Systems and Signal Processing (BIOSIGNALS)*, Valencia, 2010.
[19] M. B. Tayel and E. I. AlSaba, "Poincaré Plot for Heart Rate Variability," *International Journal of Biomedical and Biological Engineering,* vol. 9, no. 9, pp. 708-711, 2015.
[20] L. Claudia, I. Oscar, P. Héctor and V. J. Marco, "Poincaré plot indexes of heart rate variability capture dynamic adaptations after haemodialysis in chronic renal failure patients," *Clinical Physiology & Functional Imaging,* vol. 23, no. 2, pp. 72-80, 2003.
[21] R. Arroyo-Carmona, A. Lopez-Serrano, A. Albarado-Ibanez, F. Mendoza-Lucero, D. Medel-Cajica, R. Lopez-Mayorga and J. Torres-Jácome, "Heart rate variability as early biomarker for the evaluation of diabetes mellitus progress," *Journal Diabetes Research,* vol. 2016, 2016.
[22] U. R. Acharya, O. Faust, S. V. Sree, D. N. Ghista, S. Dua, P. Joseph, V. I. T. Ahamed, N. Janarthanan and T. Tamura, "An integrated diabetic index using heart rate variability signal features for diagnosis of diabetes," *Comput. Methods Biomech. Biomed. Engin.,* vol. 16, no. 2, pp. 222-234, 2013.
[23] B. Sayers, "Analysis of heart rate variability," *Ergonomics,* vol. 16, no. 1, pp. 17-32, 1973.
[24] R. Berger, S. Askelrod, D. Gordon and R. Cohen, "An efficient algorithm for spectral analysis of heart rate variability," *IEEE Trans. Biomed. Eng.,* vol. 33, pp. 900-9004, 1986.
[25] A. H. Khandoker, C. Karmakar, M. Brennan, M. Palaniswami and A. Voss, Poincaré Plot Methods for Heart Rate Variability Analysis, New York: Springer, 2013.

[26] P. Kamen, H. Krum and A. Tonkin, "Poincare plot of heart rate variability allows quantitative display of parasympathetic nervous activity in humans," *Clin. Sci. (Lond),* vol. 91, no. 2, pp. 201-208, 1996.

[27] P. Kamen and A. Tonkin, "Application of the Poincare plot to heart rate variability: a new measure of functional status in heart failure," *Aust. N. Z. J. Med.,* vol. 25, no. 1, pp. 10-29, 1995.

[28] G. De Vito, S. Galloway, M. Nimmo, P. Maas and J. McMurray, "Effects of central sympathetic inhibition on heart rate variability during steady-state exercise in healthy humans," *Clin. Physiol. Funct. Imaging,* vol. 22, no. 1, pp. 32-38, 2002.

[29] M. Tulppo, T. Makikallio, T. Takala, T. Seppanen and H. Huikuri, "Quantitative beat-to-beat analysis of heart rate dynamics during exercise," *Am. J. Physiol.,* vol. 271, no. 1, pp. 244-252, 1996.

[30] L. McCorry, "Physiology of the autonomic nervous system," *Am. J. Pharm. Educ.,* vol. 71, no. 4, p. 78, 2007.

[31] M. Kenney and C. Ganta, "Autonomic nervous system and immune system interactions," *Compr. Physiol.,* vol. 4, no. 3, pp. 1177-1200, 2014.

[32] B. Roy and S. Ghatak, "Nonlinear Methods to Assess Changes in Heart Rate Variability in Type 2 Diabetic Patients," *Arq. Bras. Cardiol.,* vol. 101, no. 4, pp. 317-327, 2013.

[33] S. K. Ghatak and S. Aditya, "Poincaré parameters and principal component analysis of Heart rate variability of subjects with health disorder," arXiv preprint arXiv:1802.10289., New York, 2018.

[34] M. G. Ziegler, "50 - Psychological Stress and the Autonomic Nervous System," in *Primer on the Autonomic Nervous System (Second Edition)*, Academic Press, 2004, pp. 189-190.

[35] M. Schauer and T. Elbert, "Dissociation following traumatic stress," *Journal of Psychology,* vol. 218, pp. 109-127, 2010.

[36] W. B. Cannon, Bodily changes in pain, hunger, fear, and rage, New York: Appleton-Century-Crofts, 1915.

[37] G. Chrousos and P. Gold, "The concepts of stress and stress system disorders. Overview of physical and behavioral homeostasis.," *JAMA,* vol. 267, no. 9, pp. 1244-1252, 1992.

[38] R. Ader, N. Cohen and D. Felten, "Psychoneuroimmunology: interactions between the nervous system and the immune system," *Lancet,* vol. 345, no. 8942, pp. 99-103, 1995.

[39] E. Won and Y.-K. Kim, "Stress, the Autonomic Nervous System, and the Immune-kynurenine Pathway in the Etiology of Depression," *Current Neuropharmacology,* vol. 14, no. 7, pp. 665-673, 2016.

[40] U. Weik, A. Herforth, V. Kolb-Bachofen and R. Deinzer, "Acute stress induces proinflammatory signaling at chronic inflammation sites," *Psychosom. Med.,* vol. 70, no. 8, pp. 906-912, 2008.

[41] M. Maes, C. Song, A. Lin, R. De Jongh, A. Van Gastel, G. Kenis, E. Bosmans, I. De Meester, I. Benoy, H. Neels, P. Demedts, A. Janca, S. Scharpé and R. Smith, "The effects of psychological stress on humans: increased production of pro-inflammatory cytokines and a Th1-like response in stress-induced anxiety," *Cytokine,* vol. 10, no. 4, pp. 313-318, 1998.

[42] C.-H. Hsu, M.-Y. Tsai, G.-S. Huang, T.-C. Lin, K.-P. Chen, S.-T. Ho, L.-Y. Shyu and C.-Y. Li, "Poincaré plot indexes of heart rate variability detect dynamic autonomic modulation during general anesthesia induction," *Acta Anaesthesiologica Taiwanica,* vol. 50, no. 1, pp. 12-18, 2011.

[43] M. Woo, W. Stevenson, D. Moser, R. Trelease and R. Harper, "Patterns of beat-to-beat heart rate variability in advanced heart failure," *Am. Heart J.,* vol. 123, no. 3, pp. 704-710, 1992.

[44] J. Brouwer, D. Van Veldhuisen and A. Man in't Veld, "Prognostic value of heart rate variability during long-term follow-up in patients with mild to moderate heart failure. The Dutch Ibopamine Multicenter Trial Study Group," *J. Am. Coll. Cardiol.,* vol. 28, no. 5, pp. 1183-1189, 1996.

[45] A. Voss, R. Schroeder, S. Truebner, M. Goernig, H. Figulla and A. Schirdewan, "Comparison of nonlinear methods symbolic dynamics, detrended fluctuation, and Poincaré plot analysis in risk stratification in patients with dilated cardiomyopathy," *Chaos,* vol. 17, no. 1, p. 015120, 2007.