Monitoring The Early Physiological Effects of Fitness Regimes Using PPG Signals

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***Abstract*—This paper records a study to investigate the feasibility of using photophlethysmogram (PPG) based system for monitoring the effectiveness of fitness regimes on wellness of working professionals. For this study Yoga was used as the fitness intervention. Although monitoring the health benefits of Yoga over longer periods (eg. 2-3 months) has been performed using various methods, the monitoring of the effect of Yoga over shorter duration (1 to 2 weeks) is difficult and the effect is often not visible in the conventional features considered for PPG analysis. Using PPG signals collected before and after a 12-day program of Yoga sessions, we analyzed the effect of Yoga on the Pulse rate, Pulse harmonics and Heart Rate Variability (HRV). The time and frequency domain characteristics of the PPG signal were analyzed and their variations over the period was evaluated along with the power of the harmonics. We show that short term effect is evident in the harmonics of the PPG signal and some of the key HRV features. The power corresponding to the higher harmonics and 7 of the key HRV features showed good separation between Day 1 and Day 12 with p <0.05.**

***Index Terms*—Fitness Regime, Yoga, PPG, Pulse harmonics, HRV**

I. Introduction

Although the effectiveness of fitness regimes in improving general health is well known, for an individual engaged in a fitness program there is a lack of early feedback on the improvement achived. An early feedback on the improvement could go a long way in improving the stickiness and thereby longer engagement and higher benefits from the fitness regime. We chose to study the effects of Yoga for 2 reasons, a) Yoga claims to have physical as well as mental benefits. b) Our organisation conducts frequent Yoga programs and they are very popular among the staff as compared to other available options.

Yoga, an ancient Indian practice is considered as an effective means of attaining mind-body balance [1]. The technique consists of physical postures and various breathing exercises that are intended to improve muscle flexibility, strength, oxygen absorption, blood circulation and enhance hormonal functions. Apart from this, the Yogic meditation practices is understood to stabilize the autonomic nervous system (ANS). Streeter and others have shown that Yoga can stimulate an under active parasympathetic nervous system and increase the inhibitory action of a hypoactive gamma-aminobutyric acid (GABA) system in brain pathways [2]. The study also suggests that Yoga can be used to explore dynamically the body's stress response and regulatory systems. The other physiological benefits includes resilience towards stress and reduction in risk factors associated with various diseases. Tyagi A and Cohen M in their comprehensive study of 59 literature items involving a total of 2358 participants have concluded that Yoga improves autonomic regulation and enhances vagal dominance and these are reflected in HRV measures [3]. Currently, monitoring of the physiological changes for the effects imposed by Yoga is gaining wide popularity. Efforts in this direction includes the usage of Electroencephalography (EEG) [4], galvanic skin response [5], electroencephalogram and photophlethysmogram (PPG) [6], and so on. However, these studies were targeted at evaluating the effects of Yoga over a longer period (>2 months). Monitoring these effects over a shorter period, for instance a duration of 1-2 weeks is a challenging task. This becomes even more challenging when using low cost devices as they provide data in a lower resolution. To overcome these issues we have used an affordable PPG device for non-invasive monitoring of the effects of Yoga over a short span of 12 days (10 days of Yoga practice with 2 days of rest in the middle).

PPG is basically the measure of optic signal pertaining to blood's arterial volumetric pulsations. Owing to its non-invasive nature and least complexity, it has wide scope in clinical applications. The signal is rich in information related to peripheral oxygen saturation, respiratory and cardiac dynamics and also hypovolemic status [7]. Many metrics based on PPG statistics have been proposed in recent decades - to serve clinical needs, for instance, monitoring the respiratory and the heart rate [7]. As the blood moves outwards from heart to the rest of the tissues and organs, its flow can be influenced by the condition of the muscles, nerves, arterial walls, skin, constituents of blood along with the heart [8].

The rest of the paper is organized as follows. Section II deals with the related work pertaining to the study, section III describes the methodology used, section IV provides details of the experiment, section V discusses the results while the last section provides the conclusions and future road map.

II. Related Work

The usefulness of PPG signals in clinical medicine is widely researched. There have been extensive efforts by different research communities for learning the hidden physiological information inherent in the PPG signal. Our study mainly deals with analyzing the pulse harmonics and HRV of the participants practicing Yoga. Tanuja and Suganthi [6], have reported the effects of Yoga performed by pregnant women

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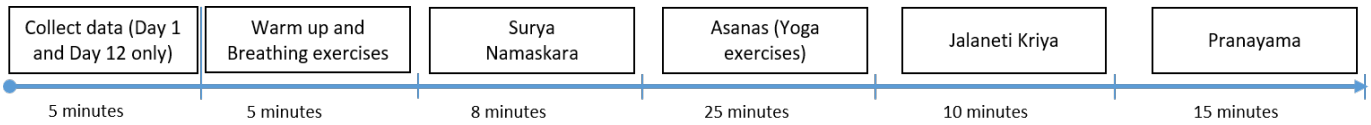

Fig. 1. Sequence diagram of the protocols used for the study

for a duration of eight weeks. They report that with regular practice of Pathangasana, Sisupalasana, Nadi Sudhi, Suga kriya and Aum mantra chanting during pregnancy, reduced heart rate and thus helped in reducing anxiety during and after the labour. Wan-An Lu et al [8] studied the effect of Tai Chi Chuan (TCC) - a traditional form of calisthenics, on the pulse harmonics. It was seen that in the TCC practitioners the power corresponding to the first and the second pulse harmonics increased with respect to the baseline while there was a decrease in the power of fourth pulse harmonics. The increase in power of the second harmonics is attributed to the increase in HR owing to the decreased vascular resistance after performing TCC.

Motivated by the works in [6] and the results of [8] we have extended the analysis up to 12^{th} harmonics to monitor the effect of practicing Yoga for a shorter duration of 12 days.

Fourier transforms has been used exclusively in the analysis of spectral nature of the PPG signals.

III. Methodology

This study aims at examining the effects of Yoga on the arterial pulse wave harmonics and the inter-relation among the pulse harmonics and the autonomic nervous modulation among the Yoga practitioners. For the non "fitness enthusiast", stickiness to health programs have always been a challenge. One of the key reasons for this non-stickiness is the fact that it has not been possible to measure and demonstrate the effectiveness and thereby the health benefits during the initial stages. The main underlying motivation behind this study is to device a mechanism by which we can measure and demonstrate early, the improvement in health of a Yoga practitioner. This section details the methods used and the analysis of the data collected.

As discussed in the introduction section, Yoga has a profound effect on ANS and the related changes be measured using HRV as an acceptable proxy. A standard finger based PPG device was the most appropriate method to collect reliable HRV data in a non-intrusive way from an enterprise. HRV from PPG signal is considered equivalent to that derived from ECG. The details of the study protocol and experiment is given in the subsequent sections.

A. PPG analysis

1) HRV features: Heart rate variability is a phenomenon that corresponds to the variation in the interval between the heartbeats.This can be quantified by making use of time and frequency domain parameters of the HRV signal [9]. While details of the features are available in [9], the parameters used in this study are as follows: (i) *Mean and median NN*: average and median of the NN intervals (N being the peak amplitude), (ii) *SDNN* (iii) *RMSSD* (iv) *nRMSSD* (v) *SDSD* (vi) *NN50*: is the number of pairs of successive NNs which differ by more than 50 ms (vii) *pNN50*: is the proportion of NN50 divided by the total number of NNs (viii) *NN20* (ix) *pNN20* (x) *MAD NN* (xi) *SD1* (xii) *SD2* (xiii) *VLF power*: Power in the very low frequency bin (0.0033–0.04 Hz) (xiv) *LF power*: Power in the low frequency bin (0.04-0.15 Hz) (xv) *HF power*: Power in the high frequency bin (0.15-0.40 Hz) (xvi) *L/H*: ratio of low to high power (xvii) *Total power*: sum of VLF, LF and HF (xviii) *max VLF*: maximum value of VLF (xix) *max LF*: maximum value of LF (xx) *max HF*: maximum value of HF. These HRV features were chosen as they are commonly considered to reflect the changes in the ANS.

2) Pulse harmonics features: Given that the typical PPG signal is a periodic waveform, we estimate its fundamental frequency f_1 as the frequency component with highest magnitude in the spectrum. The n^{th} harmonic is therefore defined as, $f_n = n \times f_1$, where n =1, 2, .., 12. We denote the power of n^{th} harmonic as p_n, respectively. We evaluated upto 12 harmonics and the power corresponding to these frequencies. A total of 18000 pulse signal data points that amounts to 5 minutes of data from the left index finger is used for the power spectral analysis using fast fourier transforms (FFT) [10]. Each FFT bin corresponds to 0.0033 Hz. We excluded the direct current component before the analysis. The major peak in the spectrum located in the vicinity of the heart rate is taken as the fundamental frequency and is termed as f_1. The peaks corresponding to the multiples of the fundamental frequency are identified and termed as the 2^{nd} to the 12^{th} harmonic. Beyond 12, the peaks were found to be very small in order to discern. As the frequency of each harmonic is a multiple of the heart rate which in turn is the fundamental frequency, we used the fundamental frequency f_1 as is and took only the power of the rest of the harmonics.

B. Yoga and Study protocol

Under the guidance of a seasoned Yoga trainer, we organized a 12-Day Yoga (10 Practice days - Monday to Friday and 2 Rest days Saturday and Sunday) session in an Information Technology company in Bangalore, India. The sessions were conducted across 3 locations at different time slots. This ensured that we have the same instructor for all the sessions and some variety in demographics. We collected PPG data for 5 continuous minutes on Day 1 and Day 12 just before the Yoga session started, from participating and consenting volunteers. We also collected PPG data for 5 continuous minutes on Day

1 and Day 12 from a control group of consenting healthy subjects. This was collected when no health programs were being conducted in the organization. We conducted a feedback survey on Day 12 to assess the effectiveness of the Yoga session on the mental and physical health of the individual. We also conducted a feedback survey from the control group to assess their health and Yoga practice, if any.

The Yoga program administered was divided into different sections as shown in Fig. 1 and are elaborated below.

1) Breathing and warm up exercises: . This session is conducted initially for 5 minutes in order to make the participants ready for the Yoga exercises. It consists of hand and ankle stretch, shoulder, wrist and neck exercises, back and front bending with breathing, hip, knee and ankle rotation, complete body stretch, sit ups with breathing and standing jog.

2) Surya Namaskar: Surya Namaskar or Sun Salutation is a sequence of 12 Yoga poses. Besides being a cardiovascular workout, Surya Namaskar is also known to have a positive impact on the body and mind. In our study, the participants performed Surya Namaskar for 8 minutes.

3) Asanas: Asana is basically a posture in which the practioner is seated steady but relaxed [11]. The asanas used for the study are Bhujangasana, Dhanurasana, Shalabhasana, Makarasana, leg raising variations, Jathara Parivartanasana, Baddha Konasana, Ustrasana, Vipareeta bhunamana, Pavanamuktasana, Pashimottanasana, Ardha Padma Paschimottanasana, Utkatasana, Trikonasana, Parivrtta Trikonasana, Virabhadrasana, Adho Mukha Svanasana, Vrikshasana, Matsyasana and Yoga Nidra. This session lasted for 25 minutes.

4) Jala neti kriya: Jala neti kriya is a simple procedure for maintaining nasal hygiene by means of irrigating the nostrils with warm salty water.

5) Pranayama: Prana refers to the universal life force and ayama means to regulate or lengthen. Pranayama means working on the dimension of prana with the help of poses and breathing patterns. The Pranayamas used here are Naadi Suddhi, Kapalabhati, Bhramari, Nadaanusandana (Akara Ukara Makara and Omkara) and cooling pranayamas. This session lasted for 15 minutes.

IV. Experimental procedure

A. Participants

Yoga group : 36 participants (27 females) with mean age 29.7$\pm$ 5.3 years from the company volunteered for the study. The participants for the Yoga program were selected based on their willingness and who did not undergo any surgeries in past 6 months and did not have any heart ailments. Since Yoga claims to produces relative improvements in health benefits irrespective of the current levels, the participants were not filtered or screened for any other ailments.

Control group : 28 healthy participants (11 females) with mean age 25.4$\pm$ 3.2 years from the company volunteered who were devoid of any physical or mental illnesses. We have a lower mean age for this group as we had to ensure that all are healthy subjects. After the data collection survey, we found that 4 participants in the control group were practicing Yoga at least once a week. These 4 participants were eliminated from the analysis, making the control group size to 24 (8 females). Of the remaining, 15 people did some form of exercise (options were None, Lift Weights, Walk, Run, Yoga, Swim, Aerobics, Dance, Play a team sport, Others), once a week, 8 people exercised between 2-5 times a week and one person exercised every day.

A informed consent form was signed by each participant.

B. Data collection

We used SpO2 manager software along with CMS50D+ device provided by Contec [12] to capture PPG data. The signal was acquired from the left index finger. The data was collected before the commencement of the Yoga sessions. This was to ensure that the data is collected when the participant was at rest. We collected PPG data for 5 continuous minutes on Day 1 and Day 12 just before the Yoga session started, from participating and consenting volunteers. The same process was followed for the participants of the control group.

V. Results and discussions

TABLE I
p-VALUE FOR DAY 1 VS. DAY 12 ACROSS PULSE HARMONICS AND HRV FEATURES FOR BOTH GROUPS ($p < 0.05$ ARE IN BOLD)

Pulse Harmonics			**HRV**		
Feature	**Yoga**	**Control**	**Feature**	**Yoga**	**Control**
F1	0.22	0.31	*MeanNN*	0.08	0.33
P1	0.37	0.26	*MedianNN*	0.2	0.37
P2	0.16	0.57	*SDNN*	**0.01**	0.56
P3	0.65	0.29	*RMSSD*	**0.01**	0.56
P4	0.16	0.54	*nRMSSD*	**0.01**	0.53
P5	**0.01**	0.47	*SDSD*	**0.01**	0.56
P6	**0.03**	0.45	*NN50*	0.09	0.93
P7	**0.01**	0.84	*pNN50*	0.07	0.92
P8	**0.01**	0.54	*NN20*	0.47	0.73
P9	**0.0001**	0.83	*pNN20*	0.17	0.62
P10	**0.01**	0.73	*madNN*	**0.04**	0.74
P11	**0.02**	0.41	*SD1*	**0.01**	0.56
P12	**0.01**	0.27	*SD2*	**0.02**	0.6
			VLF	0.36	0.3
			LF	0.31	0.82
			HF	0.3	0.76
			L/H	0.28	0.65
			TP	0.34	0.3
			maxVLF	0.37	0.3
			maxLF	0.29	0.64
			maxHF	0.31	0.85

Table I provides the p-value of the t-test done between the pulse harmonics and HRV features of Day 1 and Day 12 for Yoga and the control groups. It is noticed that the p-value is greater than 0.05 for the control group in both the harmonics as well as HRV features, indicating no major change in physiology during the 12 day period. However, for the Yoga group there is significant change ($p < 0.05$) for the 5th to 12th harmonics and for HRV features SDNN, RMSSD, nRMSSD, SDSD, madNN, SD1 AND $SD2^{O1}$. Studies [13] have established the changes in HRV as a result of changes effected in ANS. Also, Yoga is known [2] to alter ANS response. Hence, the changes we see in HRV parameters

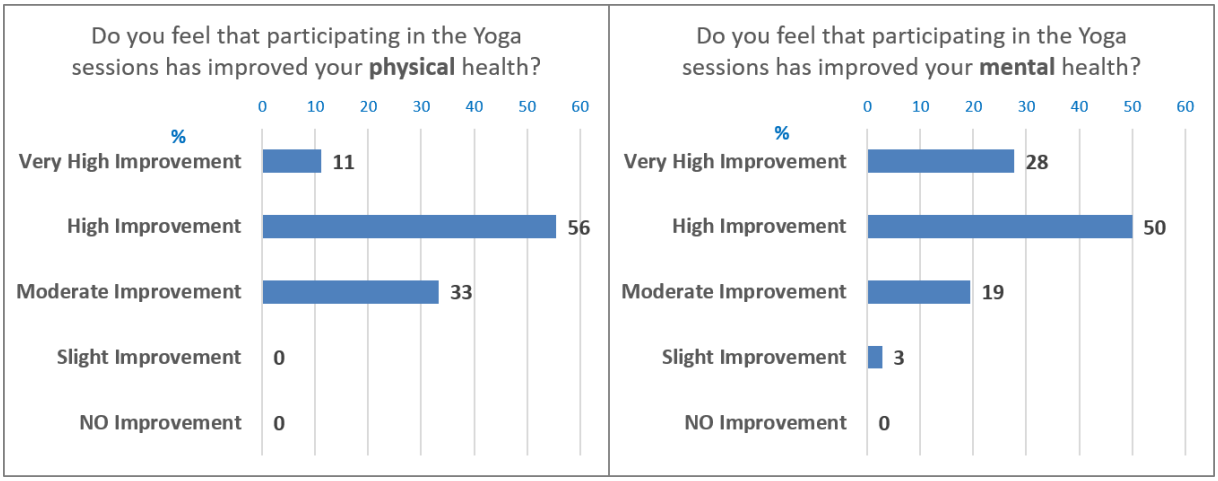

Fig. 2. Survey results from Yoga participants showing improvement in health

can be considered as the effect of the physiological changes brought about by the Yoga session.

Fig. 2 provides the results of the survey conducted on the 12^{th} day for the Yoga participants. Among the participants who completed 8 days or above of the 10 days of Yoga, 97% felt that their mental health has improved moderately or more, while 100% felt that their physical health has improved moderately or more^{O2}. Of the control group participants surveyed, 100% felt that their physical health was moderate or better^{O3}.

Fig. 3 is the graph that denotes the correlation between the pulse harmonics and the frequency domain features of VLF, LF, HF and Total power. It was found that there is a noticeable increase in correlation for the fundamental frequency F1 and harmonics (p1 - p7, except p2) on Day 12 as compared to Day 1, for the subjects who practiced Yoga^{O4}. For example, if we look at the graph in Fig. 3 (A) the correlation between the power of VLF vs. harmonics, it is clear that the line for Yoga Day 1 (legend -x-) is hovering around -0.2 representing a negative correlation with the harmonics p3 to p7 whereas the line for Yoga Day 12 (legend -O-) shows a positive correlation of 0.4 to 0.8 above for the same harmonics. That is, a very low negative correlation before Yoga practice has become a strong positive correlation after practicing Yoga. Secondly, it was noticed that the Day 12 Yoga data pattern correlates well with the healthy subjects pattern^{O5}. Referring to the same example for Fig. 3 (A), we notice that the line for Yoga Day 12 is coinciding with the healthy subjects Day 12 line on most points or is very close. Similar observations were made for maxVLF, maxLF, MaxHF features as well. Fig.4 shows that, for the Yoga group, there is a noticeable increase in correlation of harmonics p3-p7 with medianNN and meanNN^{O6}, while those from p8-p12 has moved from negative correlation to positive correlation when Day 12 is compared to Day 1. As expected F1 correlates completely and negatively for all participants.

There were no changes observed in the control group's pulse harmonics and HRV whereas there is significant change for the Yoga group (observation - O1). Nearly all the Yoga participants have self reported an improvement in both mental and physical health (observation - O2, O3) which suggests that the changes noticed in the physiological signals can be attributed to the effect of Yoga on health. There is also an increase in correlation between the pulse harmonic features and the HRV features after practice of Yoga, while this is not the case for the control group (observation - O4, O5) . Also, we observe that the correlation pattern across the HRV features and the harmonics is clearly separable for Day 12 from Day 1 for the Yoga group and more importantly the Day 12 pattern is very similar to that of the healthy subjects (observation - O6). This means that we have a method based on PPG features which can clearly identify the health improvements effected by 10 days of Yoga practice.

VI. Conclusions and Future Scope

We propose a novel insight to analyze the effects rendered by Yoga for short duration. The features described owing to the fundamental frequency, its 12 harmonics and correlation to HRV features serve to be a better discriminator for short term Yogic effects monitoring. This method implemented in the form of a standard PPG based wearable can provide near time feedback to the Yoga practitioner and thereby motivate them to continue the practice of Yoga. We also believe that this correlation can be further researched to identify markers of general health and wellness.

VII. Acknowledgements

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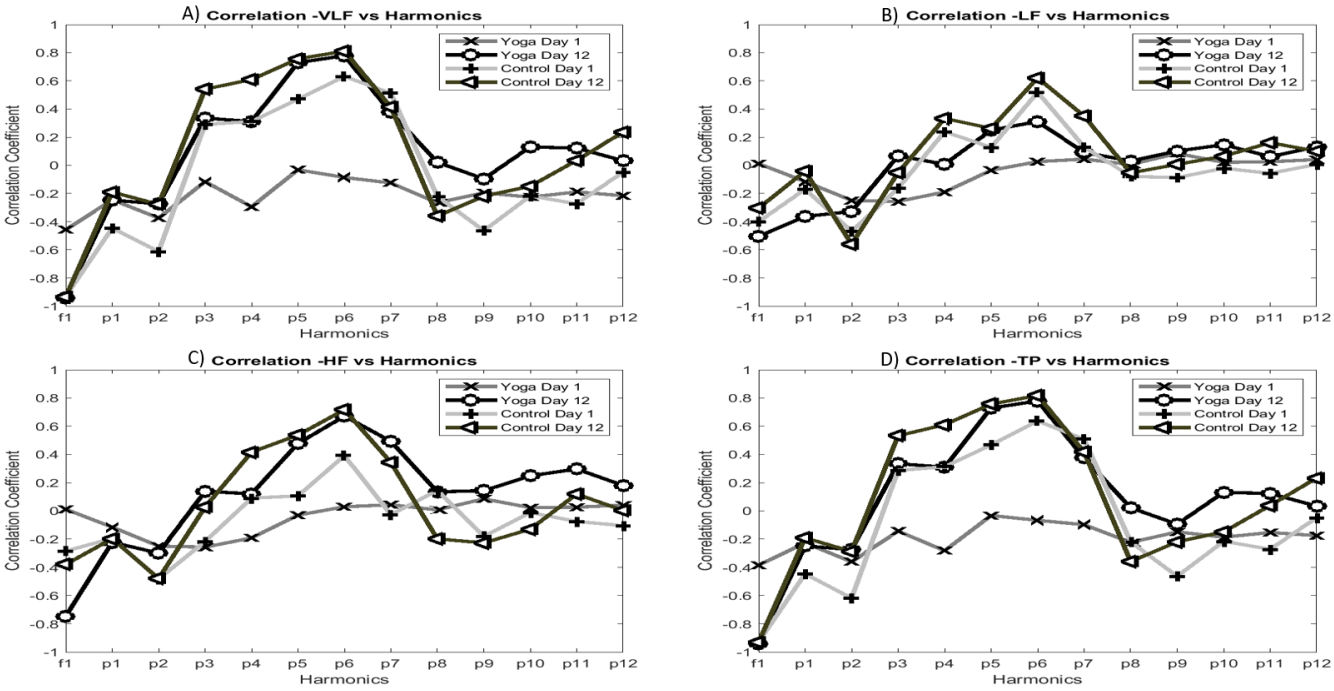

Fig. 3. Correlation among power of harmonics and HRV features VLF, LF, HF, Total Power for Yoga and control groups

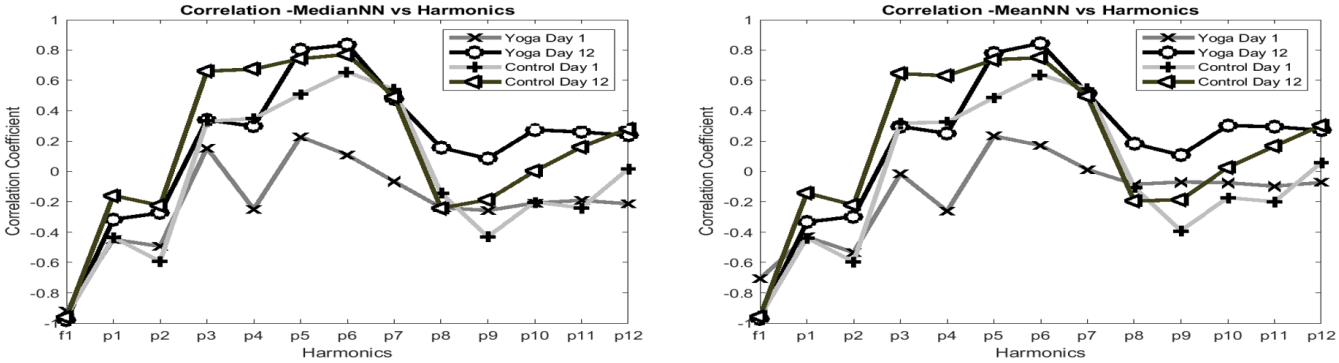

Fig. 4. Correlation among power of harmonics and HRV features meanNN, medianNN for Yoga and control groups

REFERENCES

[1] O Parshad, "Role of yoga in stress management.," *The West Indian Medical Journal*, vol. 53, no. 3, pp. 191–194, 2004.

[2] C.C. Streeter et. al., "Effects of yoga on the autonomic nervous system, gamma aminobutyric acid, and allostasis in epilepsy, depression, and post traumatic stress disorder," *Medical Hypotheses*, vol. 78–5, pp. 571–579, 2012.

[3] Cohen M Tyagi A, "Yoga and heart rate variability: A comprehensive review of the literature," *International journal of yoga*, vol. 9–2, pp. 97–113, 2016.

[4] U Panjwani, W Selvamurthy, SH Singh, HL Gupta, L Thakur, and UC Rai, "Effect of sahaja yoga practice on seizure control & eeg changes in patients of epilepsy.," *The Indian journal of medical research*, vol. 103, pp. 165–172, 1996.

[5] Shirley Telles, R Nagarathna, HR Nagendra, and T Desiraju, "Physiological changes in sports teachers following 3 months of training in yoga," 1993.

[6] ES Thanuja and L Suganthi, "Effect of integrated yoga on cardiovascular parameters during pregnancy," in *Intelligent Computing and Control Systems (ICICCS), 2017 International Conference on*. IEEE, 2017, pp. 804–809.

[7] Lena M Nilsson, "Respiration signals from photoplethysmography," *Anesthesia & Analgesia*, vol. 117, no. 4, pp. 859–865, 2013.

[8] Wan-An Lu, Yung-Sheng Chen, and Cheng-Deng Kuo, "Increased first and second pulse harmonics in tai chi chuan practitioners," *BMC complementary and alternative medicine*, vol. 16, no. 1, pp. 87, 2016.

[9] Fred Shaffer and J P Ginsberg, "An overview of heart rate variability metrics and norms," *Frontiers in public health*, vol. 5, pp. 258, 2017.

[10] James S Walker, *Fast fourier transforms*, CRC press, 2017.

[11] Sri Sri Ravi Shankar, *Patanjali Yoga Sutras*, Arktos, 2014.

[12] CMS50D-Plus, "https://www.cpap-supply.com/cms50d-plus-pulse-oximeter-p/cms50dplus.htm.," 2018.

[13] Marek Malik, "Heart rate variability: Standards of measurement, physiological interpretation, and clinical use: Task force of the european society of cardiology and the north american society for pacing and electrophysiology," *Annals of Noninvasive Electrocardiology*, vol. 1, no. 2, pp. 151–181, 1996.