Study

PHOTOPLETHYSMOGRAPHY: *A NONINVASIVE TOOL FOR POSSIBLE SUBTLE ENERGY MONITORING DURING YOGIC PRACTICES*

M. Mukunda Rao & R. Ramana Ram

ABSTRACT

The process of breathing occurs as a physiological cycle in which one nasal cavity is functionally active while the other is resting, i.e., breathing alternates between the nostrils according to a regular pattern referred to as the "nasal cycle" and this cycle has been found to have a profound effect on a number of brain functions. It is suspected that some cross coupling exists between the dominant nostril and the active cerebral hemisphere. It is believed that breathing has a profound effect on man's physical/psychological functioning and is the link between the body and the mind. Pranayama is a well-proven technique for controlled rhythmic breathing with beneficial effects reported both for the body and the mind. In this study the arterial blood volumetric changes from 10 normal breathing subjects and 30 subjects practicing pranayama are monitored non-invasively at the earlobes using optical sensors. This method is known as Photoplethysmography (PPG). Spectral analysis and Heart Rate Variability (HRV) studies are performed on the collected PPG data. The results show fundamental changes in the spectral components of the PPG signal in relation to the breathing brought about by pranayama. In addition, a bi-nasal respiratory airflow monitor is designed and developed for this study utilizing miniature thermistors that can be introduced into the two nostrils of the subject without causing discomfort to the subject. Another study is also reported in which changes in microcirculation in chakra points were studies as a result of concentration on these points. Results indicate the low frequency component around 0.18 Hz changes dramatically during these procedures. Concentration on heart increases the amplitude of the low frequency by about 4.5 times. Concentration on the eyebrow chakra increases the value of this component by about 3 times, but the curve is much broader showing more "power" in that band of frequencies. Since prana or chi is related to amount of blood flow, it is likely the increase in microcirculation is related to increase in prana, as suggested in ancient texts. Further work is contemplated to peruse this line of thinking through standard clinical methods.

KEYWORDS: Pranayama, photoplethysmography, breathing sensors, heart rate variability, biomedical signal processing

INTRODUCTION

Breathing is a grossly underestimated source of life giving healing and purifying energy. Studies have revealed that olfactory information is not only responsible for smell but also travels to the limbic system—primitive brain structures that govern emotions, behavior, and memory storage—and the brain's cortex, or outer layer, where conscious thought occurs. In addition, it combines with taste information in the brain to create the sensation of flavor. Thus odors affect our thoughts, emotions and behavior and breathing is believed to have a deep neurological impact on the human body.

A normal human being inhales between 18,000 and 20,000 breaths per day, totally an average of 5000 gallons of air. In weight alone, this is 35 times as much as we take in from food or drink. We can go for weeks without food, days without water, hours without heat (in extreme cold), but only minutes without air. This is because each breath nourishes and feeds our circulatory system, which distributes oxygen throughout the entire body.

The importance of breathing cannot even be expressed by these simple facts. Aside from maintaining basic life functions, the breath is one of our most powerful tools for transforming ourselves; for burning up toxins, releasing stored emotions, changing body structure and modulating consciousness. Without breath we could not speak, for air is the force behind our voice; we could not metabolize our food, because the process needs oxygen and for that matter, our brain could not even think.

BREATHING

The breathing cycle consists of three parts: Inhalation, exhalation and suspension of breath. Inhalation is an active expansion of the chest by which the lungs are filled with fresh air. Exhalation is a normal and passive recoil of the elastic chest wall by means of which stale air from the lungs is emptied. Suspension is a pause at the end of each inhalation and exhalation. If one observes one's own breath carefully, the manner in which air flows in and out of the nostrils, it can be seen that at any given time the respiratory activity is predominant through one of the two nostrils and this prominence will change over a period of few hours (normally two to three hours depending on the person). This is referred to as a nasal cycle in scientific literature. Physiologically it implies that it must have an impact on the nervous system, producing certain type of stimulus. Therefore, it must have a specific influence on the brain, which requires very systematic study.

Breathing Asymmetry

It is believed that the content of consciousness changes according to the dominance of one nostril over the other. Only on very rare occasions electrical activity is equally distributed in both halves of the brain. Under normal conditions, electrical activity—as manifested in the form of brain waves—is concentrated more in one hemisphere than the other. Observations by brain researchers show that each hemisphere has unique characteristics of behavior, and that this behavior is normally present when electrical activity centers in that hemisphere.

The shift of electrical activity from one hemisphere to the other occurs simultaneously with the change of breath from one nostril to the other. When the right nostril dominates, left hemisphere dominates; when left nostril dominates, so does the right hemisphere. When both nostrils operate, both hemispheres exhibit same intensity of activity.[1,2] Refer to Figure 1 for a schematic representation of this laterality.

Controlled Breathing (Pranayama)

Pranayama can be described in simplistic terms as controlled intake and outflow of air, in a firmly established posture/procedure.[3] Contrary to normal breathing, in pranayama breathing through both the nostrils is regulated as per well laid down and accepted procedure in yogic literature. The basic and normally accepted procedure for pranayama is as follows:

1. Breathe in through left nostril
2. Hold the breath
3. Breathe out through the right nostril

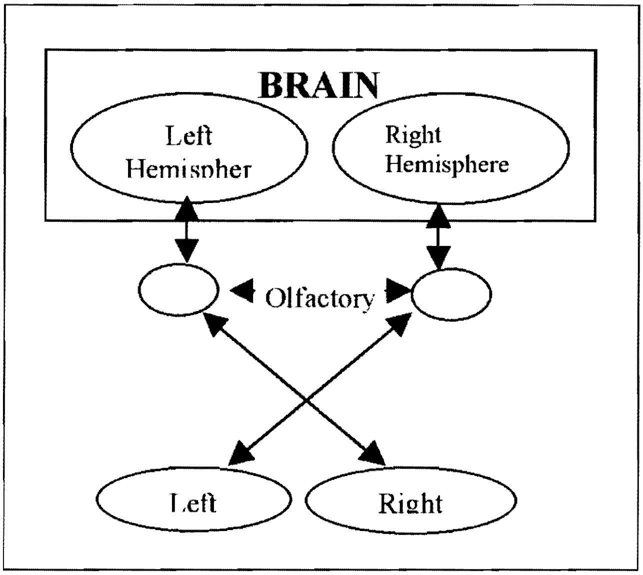

Figure 1. Schematic of nostril dominance and brain function.

4. Hold the breath
5. Breathe in through right nostril
6. Hold the breath
7. Breathe out through left nostril
8. Hold the breath.

This procedure is repeated cyclically from step 1. Theory of Pranayama says that by training the lungs, breathing is made more efficient; changing the rate and depth of breathing improves overall metabolic activity and contributes to longevity. It is also believed that it can affect the nervous system. Under normal circumstances, an average adult takes in about 500 cubic centimeters of air and thus only a small part of the lung capacity is utilized. However, by proper training, the intake of air is enhanced as much as five or six times, to about 2500 or 3000 cubic centimeters of air. The purpose of pranayama amongst other things is to make the respiratory system function at its best. This improves the circulatory system, which in turn improves the processes of digestion and elimination of toxins from the body. Improved blood circulation also improves the efficiency of the brain. In this age of alternative medicine, it is important to validate or debunk the claims of pranayama by rational thinking and scientific research. For this purpose well thought out experimental procedures based on suitable scientific tools with which data is gathered, documented and analyzed are essential.

PHOTOPLETHYSMOGRAPHY (PPG)

PhotoPlethysmoGraphy (PPG) is a non-invasive technique by which blood volume changes can be measured from peripheral circulation/skin perfusion. The measurement of blood volumetric changes in the skin perfusion by means of PPG depends on the fact that blood absorbs infrared light many times more strongly than the surrounding tissues. PPG uses low-level infrared light to detect small changes in blood volume/content in these regions. It gives a voltage signal that is proportional to the amount of blood present in the blood vessels. This method gives only a relative measurement of the blood volumetric changes and it cannot quantify the amount of blood. However, it can reflect the dynamics of the blood volumetric changes exceedingly well. The PPG signal consists mainly these components:

1. Arterial blood volumetric changes that reflects cardiac activity.
2. Venous blood volume changes that is a slow signal having a modulatory effect on the PPG signal.
3. A DC component due to the optical property of the biological tissue.
4. Possible subtle energy changes in an individual as he/she concentrates on energy centers of the body.

In the study reported here our main interest lies in monitoring the arterial blood volume changes and suitable preprocessing was carried out to monitor it. PhotoPlethysmoGraphy (PPG) uses two types of sensors for non-invasive diagnostics. One is the reflecting type sensor (R-PPG), where the emitter and detector are on the same side of the sensor head. The other is the transmission type sensor (T-PPG) where the emitter and detector are on opposite sides of the sensor head. The detailed principle, design and operation of these sensors and electronic circuitry can be found in references.[4,5] In the present study T-PPG sensors are used for recording the PPG signal.

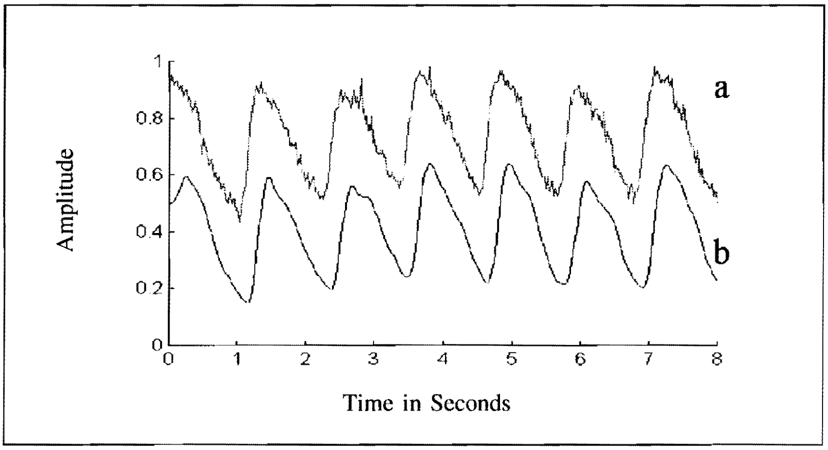

Figure 2. (a) Raw PPG signal and (b) filtered PPG signal.

DATA COLLECTION

The study comprised of 40 (10 normal; 30 practicing pranayama) subjects. The mean age of both the normal and pranayama subjects was 36. For all the 40 subjects the recording was made in normal erect position for 30 minutes. In pranayama subjects, an initial 2-minute warm-up was given for the subject to get started with the technique. In case of controls, the subjects were asked to keep a calm attitude. The PPG signal was recorded from both the ear lobes. The outputs of the two PPG sensors were digitally sampled at 40 Hz and stored for further analysis.

PREPROCESSING

Figure 2a shows the raw PPG signal. In order to eliminate noise, data was filtered using a Butterworth low pass filter of order 8 (cutoff at 7 Hz) to remove high frequency components present in the signal. Figure 2b shows the same signal filtered to remove artifacts.

Very low frequency components contained in the signal are artifacts caused either by the instruments used to acquire the signal or the movement of the subject, which shifts the PPG signal up or down. The PPG sensor is very sensitive to these shifts. These low frequency components smear the power spectrum of the PPG signal and influence the results. Furthermore, the PPG signal consists of a quasi DC signal that corresponds to changes in the venous pressure. While it is the arterial blood volume changes that have a direct bearing on cardiovascular dysfunction this quasi DC signal needs to be removed and the signal was detrended before being subjected to analysis. A linear detrending was applied to the PPG data. All the preprocessing and analysis was done using MATLAB.

ANALYSIS

SPECTRAL ANALYSIS

Fast Fourier Transform (FFT) based spectral analysis was performed on the data. This is a standard mathematical procedure to determine the frequency spectrum of the signal. The spectrum was found to have many spurious peaks. Figure 3 shows the FFT spectra for a normal subject. The normal subjects typically had a peak around 0.1 Hz and 1-1.5 Hz. Since the FFT technique gave many spurious peaks, only the gross features about the signal could be obtained. For instance the peaks at 2-2.5 Hz cannot be discarded as noise and gives trouble in analyzing the data. Hence spectral analysis was performed by estimating the power spectral density (PSD) for the normal subjects as well as for Pranayama subjects. PSD estimate yielded a smoother curve than the conventional FFT frequency domain analysis.

A typical PSD estimate for a normal subject is shown in Figure 4. We observe three distinct frequency components. The component marked (1) is the low frequency component existing at 0.08-0.1 Hz. The component marked (2) is the component with a frequency of 0.2-0.25 Hz, while the component marked (3) is the cardiac component with a frequency of about 0.9 Hz. A harmonic of the cardiac component is also observed at 1.8 Hz.

Human body can be thought of comprising two oscillators—the heart, which beats at 60-70 bpm (beats per minute) and the breathing at 14-16 bpm whose amplitude and frequency can be controlled. However there is no

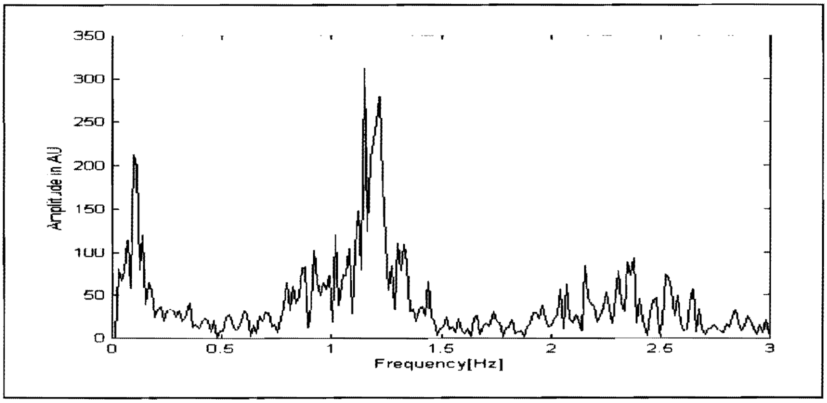

Figure 3. *FFT spectra of a normal subject.*

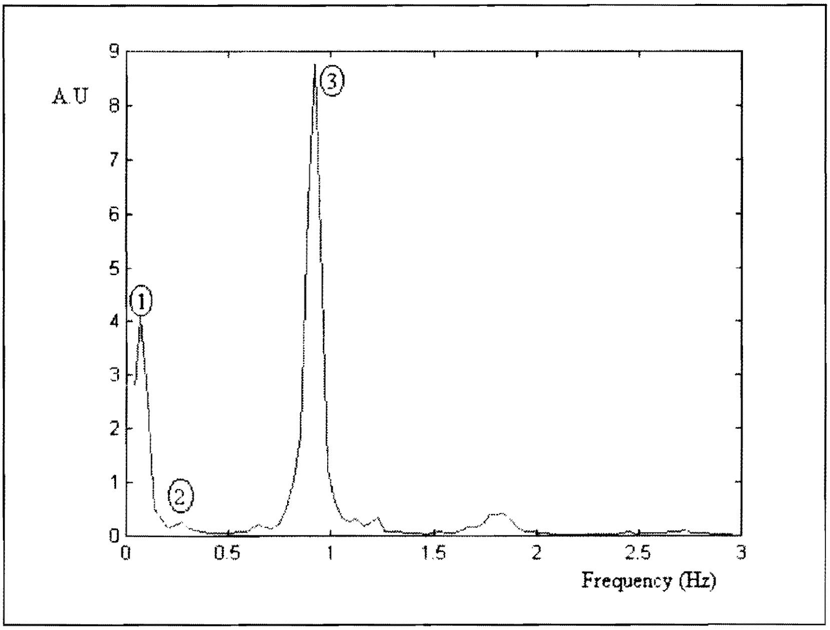

Figure 4. Power spectral density estimate of a normal subject.

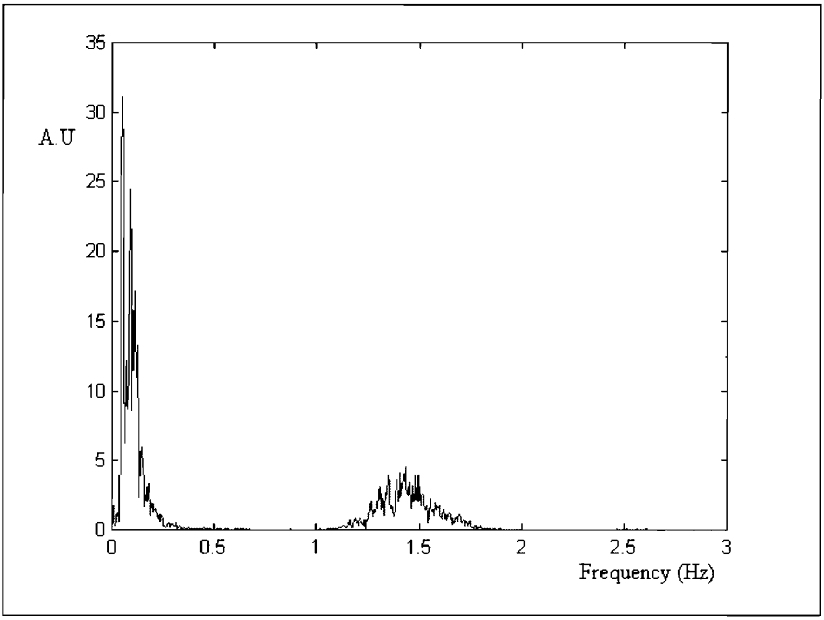

Figure 5. *Power spectral density estimate of a subject performing pranayama.*

oscillator corresponding to the "Ziege" rhythm of 0.08-0.1 Hz. We believe that this component is the result of the non-linear interaction between the two oscillators. The energy contained in the "Ziege" rhythm could be taken from any one of the oscillators or from both. The origin and significance of this low frequency rhythm has been the subject of intense study in the past few years.[6]

In the case of pranayama subjects, it is interesting to note that during pranayama there is an increase in the heart rate up to 90 bpm (1.5 Hz) coupled with a broadening of the peak. There is also an occurrence of a strong component in the low frequency range centered at 0.1 Hz as seen in Figure 5. The increased amplitude of the low frequency component indicates that controlled breathing (Pranayama) enhances positive feedback in the mechanisms responsible for the Ziege rhythm. The ratio of the peaks of the low frequency component to that of the heart component is 6:1 compared to 1:2 for a normal subject.

Heart Rate Variability (HRV)

It is widely known that the HRV spectrum comprises of two peaks, one corresponding to the sympathetic component of the heart rate and the other corresponding to the parasympathetic component.[7,8] From the EKG signal, the HRV spectrum is calculated by measuring the time intervals between instantaneous R-R peaks and performing spectral analysis of the obtained time series. However, R peak detection by itself is computationally intensive and needs a signal averaged EKG, which would suppress transients and variability in the R-R intervals. In this paper, we perform analysis on the PPG signals similar to HRV to study the influence of Pranayama on the sympathetic and parasympathetic components. Thus we calculate the time differences between two PPG peaks and obtain the HRV spectrum from the PPG signal for all subjects.

To obtain a smooth curve of the HRV spectrum, parametric estimation using Burg method with an order 8 was used. The linear trends in the time difference were removed by using a 100-point moving average detrending algorithm.

Figure 6 show the HRV spectrum of the normal subject derived from the PPG signal. Here two prominent peaks—one centered at 0.1 Hz and the other centered at 0.3 Hz are observed. These respectively correspond to the sympathetic component and the parasympathetic component of the heart rate. Here they hold relatively same magnitudes i.e. the ratio is 1:1. However for the subject who is doing pranayama the HRV spectrum as shown in Figure 7 has a very high sympathetic component (0.1 Hz) when compared to parasympathetic component (0.3 Hz) is seen. The ratio of the peaks of the sympathetic to the parasympathetic component is nearly 7:1.

POSSIBLE SUBTLE ENERGY MONITORING

PPG has also been used in experiments where the changes in PPG output may be related to alterations in the subtle energy of prana. Though the ideas in this section may be somewhat premature, yet it is worth discussing since there is still a dire need for detection of subtle energy in many investigations. Experiments carried out have indicated that increase in microcirculation may be related to increase in chi or prana in the region. In an experiment conducted

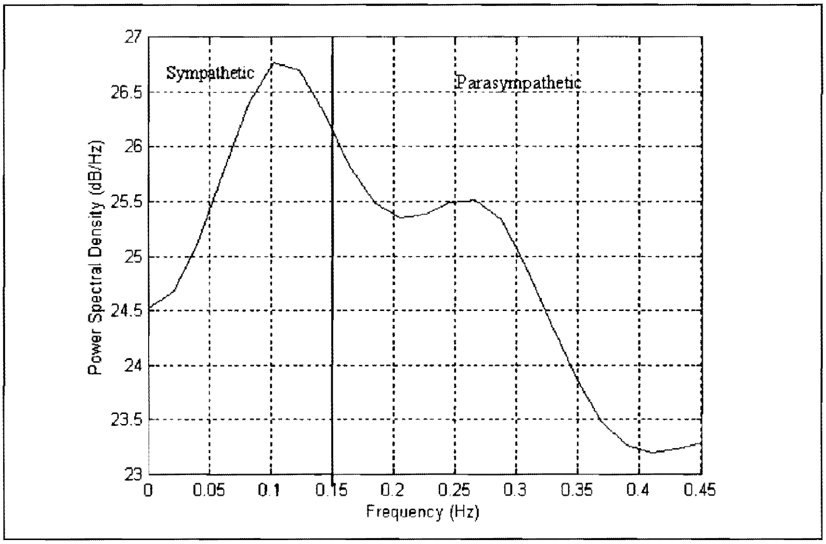

Figure 6. *HRV spectrum of normal subject.*

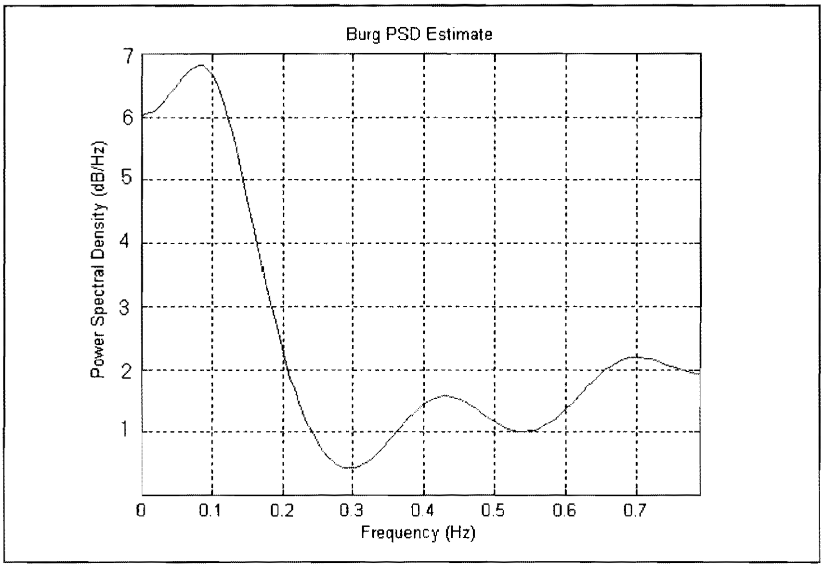

Figure 7. *HRV spectrum of pranayama subject.*

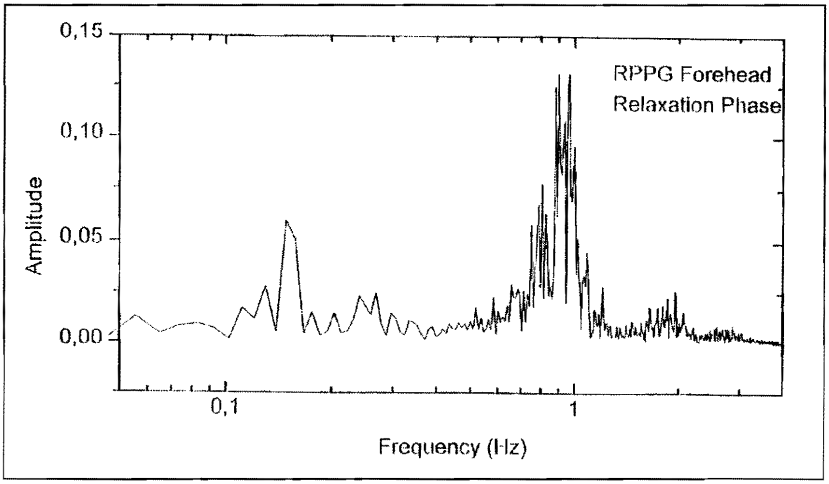

Figure 8. RPPG spectrum from the forehead of a subject while relaxing.

using PPG, an advanced student of meditation was monitored as she was focusing alternatively on eyebrow chakra and heart chakra.[9] Two PPG monitors were placed, one on the chest and the other on the eyebrow chakra location. The data collected was subjected to FFT (described earlier) and plots generated for comparison. Figures 8, 9 and 10 show representative plots of the frequency spectra of the PPG signals from the forehead region only. In Figure 8, the person was relaxing; in Figure 9 she was concentrating on heart chakra and in Figure 10, she was concentrating on the eyebrow chakra. The low frequency component around 0.18 Hz changes dramatically in these plots. Concentration on heart increases the amplitude of the low frequency by about 4.5 times. Concentration on the eyebrow chakra increases the value of this component by about 3 times, but the curve is much broader showing more "power" in that band of frequencies.

It has been mentioned in the acupuncture literature that chi (its equivalent known as prana in Sanskrit) is related to blood flow or in real terms, microcirculation. One author claims, "For example, Western medicine believes that blood flow controls organ function. However, in Oriental philosophy, chi controls blood flow."[10] In any way, there seems to be a close link between microcirculation and availability of prana in that region. Without prana, the

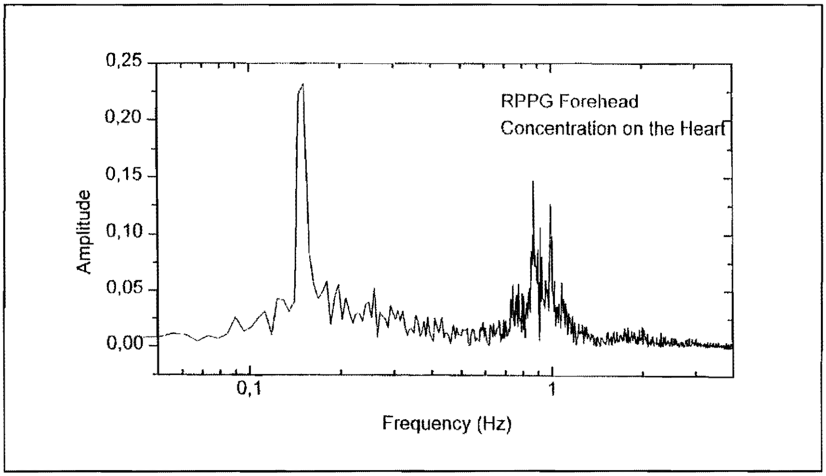

Figure 9. RPPG spectrum from the forehead of subject while concentrating on heart chakra.

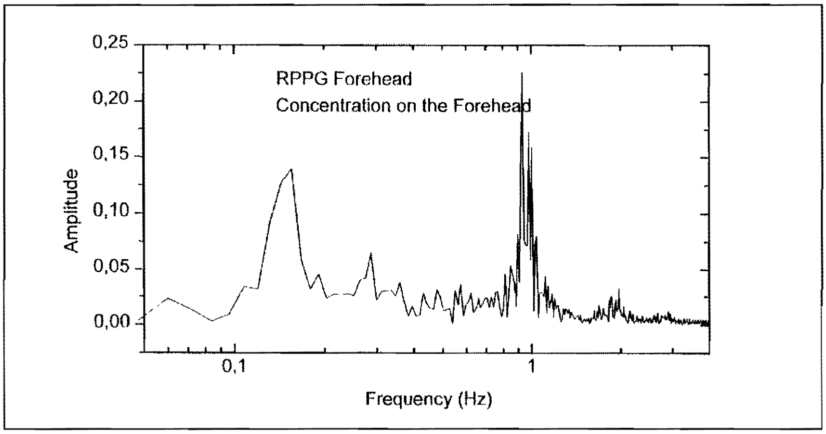

Figure 10. RPPG spectrum from forehead of subject while concentrating on eye brow chakra.

cells are said to loose life force and die. As the person is concentrating on different chakra points, it is likely the flow of prana increases in those parts and hence there is an increased in microcirculation as seen by PPG. As mentioned earlier, this could be a speculation at this time; only more work with PPG could tell if this is indeed the case.

CONCLUSION

Photoplethysmography (PPG) has been widely used in many biomedical applications such as Pulse oximetry, detection of varicose veins, muscle pump test etc. In this report we present, the evidence for a "Ziege" rhythm that occurs due to pranayama. Similar rhythms (0.1-0.15 HZ and 0.2-0.3 Hz) have been experimentally observed[11-15] and models have been constructed to explain the underlying process.[16-24] In all the cases the rhythms have been observed in the HRV spectrum and in blood pressure signal. However in this report we demonstrate the occurrence of a 0.1 Hz low frequency component in the PPG spectra. Though controlled breathing has been the only external input in our experiment, the possible origin of this rhythm could be due to various factors like:

1. Local microcirculation control.
2. Self sustained vasomotor oscillations
3. Endogenous control mechanism due to baroreceptor feedback loop.[21]

Presently two different viewpoints exist in explaining the low frequency (LF) components seen in the HRV spectra. One explains the LF as a result of external perturbation like controlled breathing,[12,18,19] while the other attributes the LF to the feedback mechanism of the baroreflex control of the heart rate.[17,20,21] Presently we are not certain if our observation can be explained with any of the existing models. Also the shift in the PSD amplitudes from 1 Hz component to the 0.08-0.1 Hz low frequency components in subjects during pranayama needs an explanation, which the present models do not provide. The HRV spectrum of pranayama subject indicates dominance of sympathetic activity during pranayama. This can be attributed to the fact that, during pranayama the subjects tend to focus on the breathing. Hence the subject initiates a concentrated mental effort thereby enhancing the sympathetic activity. As a result of sympathetic pacing there is marginal increase in the heart rate from 1 Hz to about 1.4 Hz as seen in Figure 5. This is absent in the case of normal subjects. What remains unclear is the exact time instance of the onset of this sympathetic activity in pranayama subjects.

An interesting application of this technique is to understand and study changes in microcirculation as related to the flow of prana. There is no method available currently for observing pranic flow alone. A study undertaken in this connection has indicated a possible link between prana and microcirculation. Since popular opinion seems to favor this link, it is worthwhile to study that such a link exists. The frequency content of PPG signal indicates a profound increase in microcirculation in chakra areas as a person meditates on the centers. It is possible that an increased parasympathetic arousal might increase microcirculation. Different meditation techniques to activate different chakras and track the PPG changes might give an indication in this regard. Work in this area has been undertaken and hopefully more details available in the near future.

The present result limits our conclusions, as the following questions are unanswered. What is the effect on the PPG signal when a subject is made to do forced nostril/deep breathing without rhythmic closing and opening of the nostrils? What is the exact physiological significance of this 0.08-0.1 Hz "Ziege" rhythm and its result of increasing the heart rate? Is the rhythm a manifestation of the already reported rhythms or is due to the microcirculation? Future work aims to study these and the effects of Pranayama on the sympathetic and the parasympathetic nervous systems using PPG in normal and pranayama subjects.

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