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Increased core body temperature is accompanied by altered metabolic state during brief session of guided Kriya Yoga meditation: A Thermographic Study

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Abstract

Long-term meditation has been found to alter various physiological parameters of the body but the effects of brief meditation are relatively unknown. This paper mainly focuses on the effects of brief session of guided Kriya Yoga meditation on body temperature and metabolic variables. The core body temperature is found to increase after meditation. This increase can be due to the increase in the metabolic rate of the person. Fourier transform infrared (FTIR) spectra of saliva are obtained. 10 spectral peaks corresponding to the carbohydrate, protein and lipid region are significantly altered in post meditation phase [$P<0.001$; at 95% confidence interval].

1. Introduction

Meditation has been a well-known technique for stress regulation, relaxation enhancement and also for curing various psychological and physiological problems. Effects of different techniques of meditations like Mindfulness Meditation, Indic Meditation (Sahaja Yoga) etc have been studied by researchers. The studies suggest positive effects of meditation on moods, memory functioning, alertness, attention-concentration as well as on cognitive behaviour. Significant research is being conducted on exploring the effects of meditation on body and mind. Scientific studies suggest that meditation regulates body metabolism thus improving the immune system, energy level and overall health condition. However, the effects of brief meditation intervention on metabolic variables and body temperatures are relatively unknown. This paper aims to experimentally study effects of brief session of guided Kriya Yoga meditation on body temperature and metabolic variables.

Kriya Yoga is described by its practitioners as the ancient Yoga system which is revived in modern times by Mahavatar Babaji through his disciple Lahiri Mahasaya, in 1861. To Westerners, it is brought into popular awareness through Paramahansa Yogananda's book *Autobiography of a Yogi* and through Yogananda's introductions of the practice in the west since 1920 and India since 1917. The system consists of a number of levels of Pranayama based on techniques that are intended to rapidly accelerate spiritual development and engender a profound state of tranquility and God-communion [1].This work mainly focuses on the study of body temperature variations both core as well as peripheral temperature. The variations caused can be thought to be related with the variations caused in the metabolic rates of the person. The metabolic studies are also performed from the collected saliva samples. The subjects are guided to do 12-15 minutes Kriya Yoga meditation of which 10 minutes are dedicated for certain guided breathing exercise or pranayam.

The work is divided into the following sections. Section 1 being the introduction, section 2 shows complete flowchart of the work done, sections 3 and 4 shows the experimental setup and the methodology and section 5 forms the result and discussions.

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2. Workflow:

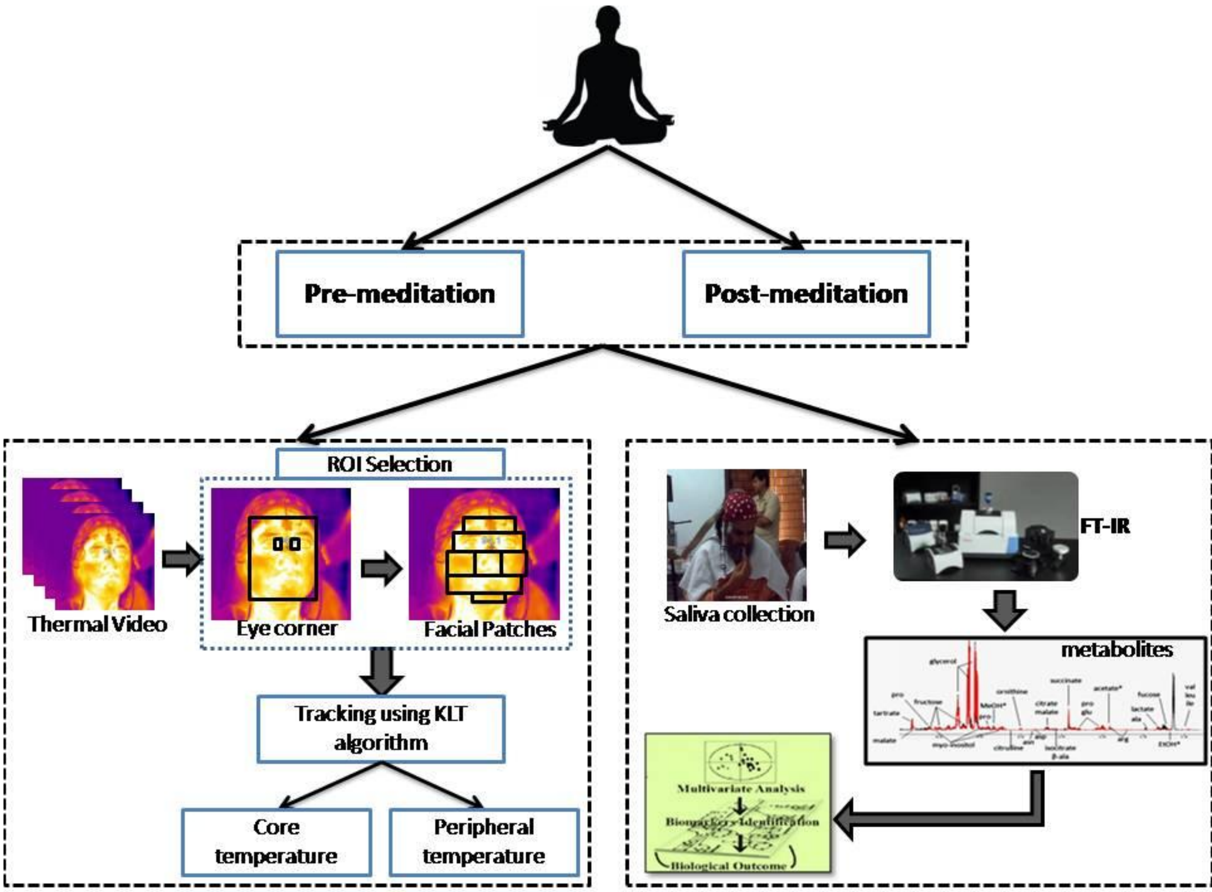

Fig. 1. *Schematic diagram of the workflow*

3. Experimental Setup:

An experiment is conducted in a monastery in Kendrapadai, India to study the effect of short term KriyaYoga meditation on body temperature and metabolic activity. Twenty one experienced Kriya Yoga meditators (11 males, 10 females), with a meditation experience of 11.11±1.75 years [Mean ± SEM] have participated in one session comprising of a 12 minute guided Kriya Yoga meditation. Subjects are given visual instructions prior to the experiment and asked to sit comfortably according to their meditation posture. This study is approved by the Institutional ethics committee and a written informed consent is taken from all participating subjects. Thermal videos as well as still images are captured using Fluke Ti400 with 320*240 pixel resolution and 9Hz frame rate.

4. Methodology:

This work comprises of two parts one being the thermographic assessment of the core as well as the peripheral temperature and the other being the saliva test which is conducted for finding the metabolic rate change in the body before and after the meditation and pranayam. The thermographic assessment consists of thermal videos capture, specific ROI selection for temperature estimation, tracking of the ROI throughout the total length of the video and finally estimating the change in the peripheral temperature. The core temperature assessment is done by monitoring the inner canthus of the eye. The assessment of core temperature assessment has been done using the SmartView software while that of peripheral temperature has been done using the Matlab 2013a software as well as the SmartView.

4.1 ROI Selection:

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Different Region of Interests (ROIs) are chosen for core or peripheral temperature estimation. It is already reported in literature that the inner canthi area of the eyes is a preferred site to represent the core body temperature [2] [3] however the other parts of the face can be screened for peripheral temperature estimation. Thus the ROIs are chosen according to the requirement. The inner canthus region is chosen as the best region for estimating the core body temperature while different facial patches are extracted and chosen as the tracking region to estimate the change in peripheral skin temperature. The Kanade -Lucas -Tomasi algorithm is used for tracking the frames of the video and the Minimum eigen value corner detection are chosen for finding the thermal signature variations over the ROIs. The thermographic assessment of the body temperature thus can be divided into two sections one being the core body temperature estimation and the other being the peripheral temperature estimation before and after Kriya Yoga.

4.2 Peripheral Temperature Assessment:

The facial skin is supplied with a number of superficial arteries supplying blood and lying immediately under the facial skin. Thus the heat produced due to the blood flow is finally through convection reaches up to the skin and is finally radiated to the environment. This radiation can be captured and thus the peripheral temperature change can be taken as a representation of the change in the blood circulation. As already mentioned facial patches are extracted and chosen as the ROIs for monitoring the change in thermal signature. The Minimum eigenvalue features from the ROIs are chosen as the tracking features which are tracked through all the frames in the video.

4.2.1 Feature Detection:

Minimum Eigenvalue features are chosen as the tracking features in this work. These features are basically corner features extracted based on the Shi-Tomasi algorithm. Corner features are such which have large intensity variations in an image. Thus in case of thermal images where the pixels are representations of the temperatures corner features detection may denote temperature variations. Shi-Tomasi algorithm is based upon the Harris-Stephens method which defines the corner detector operator as:

$$S(u,v)=\sum_x \sum_y w(x,y)[I(x+u,y+v)-I(x,y)]^2 \qquad (1)$$

where the image is scanned with a window by shifting it in different directions by small amount and finally computing the average changes in image intensity. *I(x,y)* gives the image intensity of the original window and *I(x+u,y+v)* gives the intensity of the shifted window where u and v are the window displacements in x and y directions repectively, *w(x,y)* is the weighting function of the window and *S(u,v)* is the sum of squared differences between original and moved window.
Simplifying equation (1) using Taylor series approximation we get,

$$S(u,v)=\sum_x \sum_y w(x,y)[I(x,y)+uI_x+vI_y-I(x,y)]^2 \qquad (2)$$

Now the above equation can be written in the matrix form as,

$$S(u,v)=[u \quad v]M\begin{bmatrix}u\\v\end{bmatrix}^T \qquad (3)$$

where, $M=\sum_x \sum_y w(x,y)\begin{bmatrix}I_x^2 & I_xI_y\\ I_xI_y & I_y^2\end{bmatrix}$

Now, a and b are considered as the eigen values of the square matrix M on the basis of which the parameter R is defined such that,

$$R=\det(M)-k(trace(M))^2 \qquad (4)$$

where $\det(M)=ab$, $trace(M)=a+b$ and R is taken to be a corner region when it has large positive value.
For finding the minimum eigen value features according to the Shi-Tomasi methodology R is taken such that,

$$R=\min(a,b) \qquad (5)$$

According to equation (5) R is taken as a coener region when its value is greater than a particular threshold.

4.2.2 Tracking:

The tracking of the selected features in each ROI through all frames of the video is done by Kanade-Lucas -Tomasi registration algorithm. In this algorithm the dissimilarity measurement between the chosen ROI of one frame and the next consecutive frame is minimized. The difference between a particular ROI of two consecutive frames can be computed using the L_2 norm which is mathematically represented as:

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$$E = \sum_{x \in \Re} [P(\mathbf{x}+\mathbf{h}) - Q(\mathbf{x})]^2 \tag{6}$$

where, P(**x**) and Q(**x**) are considered as two functions which are giving respective pixel values at each location in two consecutive images **h** is the disparity between the two functions. Both **h** and **x** are row vectors.

Taking a linear approximation such that, $P(\mathbf{x}+\mathbf{h}) \approx P(\mathbf{x}) + \mathbf{h}\frac{\partial P(\mathbf{x})}{\partial \mathbf{x}}$ and minimizing the error by equating its derivative with respect to zero i.e $\frac{\partial E}{\partial \mathbf{h}} = 0$ we can find an estimate of h.

$$\mathbf{h} \approx [\sum_{\mathbf{x}} \left(\frac{\partial P}{\partial \mathbf{x}}\right)^T [Q(\mathbf{x}) - P(\mathbf{x})]][\sum_{\mathbf{x}} \left(\frac{\partial P}{\partial \mathbf{x}}\right)^T (\frac{\partial P}{\partial \mathbf{x}})]^{-1} \tag{7}$$

Newton-Rapson iteration is finally used for finding the best estimate of **h.**
Considering $\mathbf{h_0}$=0,

$$\mathbf{h}_{k+1} = \mathbf{h_k} + [\sum_{\mathbf{x}} w(\mathbf{x}) \left(\frac{\partial P}{\partial \mathbf{x}}\right)^T [Q(\mathbf{x}) - P(\mathbf{x})]][\sum_{\mathbf{x}} w(\mathbf{x}) \left(\frac{\partial P}{\partial \mathbf{x}}\right)^T (\frac{\partial P}{\partial \mathbf{x}})]^{-1} \tag{8}$$

where $w(\mathbf{x})$ which is the weighting function can be defined as $P'(\mathbf{x})^2$ or $(\frac{\partial P}{\partial \mathbf{x}})^2$. Thus by choosing a proper estimate of **h** we can minimize the error such that the consecutive frames are properly registered and tracked so that the proper thermal signature is obtained. The thermal signature obtained gives an estimate of the change in skin temperature of the subjects undergoing meditation.

4.3 Core Temperature Assessment:

The core temperature assessment is done from the inner canthi of the eye using the SmartView software as already mentioned earlier. The thermal images or videos of the face are obtained using the FLUKE Thermographic Camera model Ti400. The camera emissivity is set to 0.98 and the range, level and span are properly calibrated. The IR camera is positioned and focused to ensure the clarity of the captured images and the temperature values. The chosen region of interest is positioned around the right and the left inner canthi of the eye by manually drawing rectangular patches. A series of images are captured before and after the meditation. The camera is positioned to capture the frontal facial images of the subjects. The maximum temperature of each ROI is chosen as the desirable data for analysis. The temperatures are recorded both before and after the pranayam and the result thus obtained is shown in the results and discussion section.

4.4 Saliva Test:

Salivary samples are collected pre and post meditation intervention. Saliva is collected into sterile polypropylene tubes of standard saliva collection kits and immediately frozen in a dry ice bath and stored at −80°C until further use.

Fourier transform infrared (FTIR) spectra of saliva are obtained in the wave number range of 600–4000 cm−1 at 4 cm−1 resolution. 10 spectral peaks corresponding to the carbohydrate, protein and lipid region are significantly altered in post meditation phase [P<0.001; at 95% confidence interval]. FTIR spectroscopy, a vibrational spectroscopic technique allows rapid, high-throughput non-destructive analysis of a wide range of sample types [4]. FTIR peaks are correlated directly to the vibration of a particular chemical bond/a single functional group within the molecule providing direct information about the biochemical composition. The utility of FTIR spectroscopy to acquire metabolic profile is gaining significance as it analyze different metabolites like carbohydrates, amino acids, fatty acids, lipids, proteins and polysaccharides simultaneously.

5. Results and discussion:

The results section can be divided into three parts: i) peripheral skin temperature estimation, ii) core body temperature estimation and finally iii) metabolic study through saliva test. The subsequent subsections describe each of the above in details.

5.1 Peripheral skin temperature estimation:

The subjects considered for the experiment are asked to rest and relax in the experimental room for sometime so that their temperature gets acclimatized with that of the surrounding. Then IR videos of the subjects' frontal faces are taken before as well as post meditation. The face videos thus captured are segmented into various patches as shown in figure 2. The facial patches are extracted based on ratio based segmentation of face:

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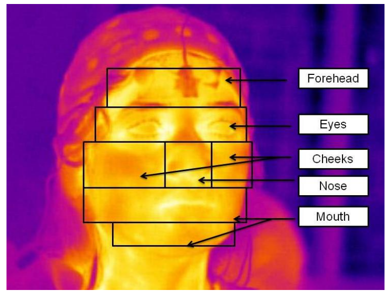


Fig.2. *Facial patch extraction*

The corner features from those patches are extracted using the Shi-Tomasi technique as mentioned earlier. The features thus extracted are tracked through all the frames of the video to get the thermal signature of the skin. The thermal signature from the videos obtained pre and post meditation are filtered. Videos of one minute length are taken both pre and post meditation. The peripheral temperature before and after meditation are also analysed from the SmartView software. A linear plot along the forehead region is taken and the maximum and the average is monitored across that line. The subjects and the corresponding line plot along the forehead region is shown in the figure below (figure 3).

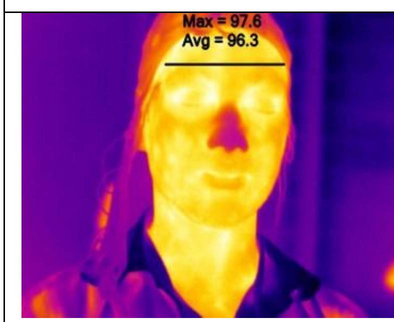
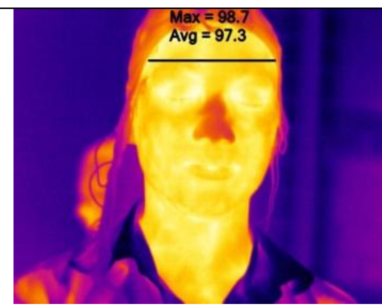
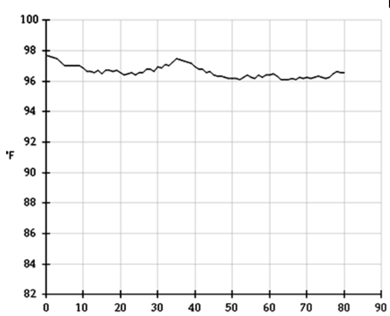
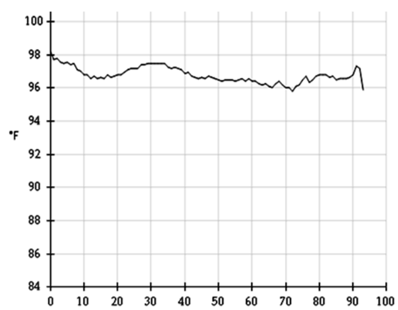
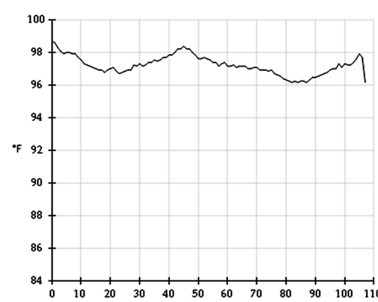
Before Meditation	**During Meditation**	**Post Meditation**
		
Max: 97.6 Avg: 96.3 	Max: 98.3 Avg: 96.8 	Max: 98.7 Avg: 97.3 

Fig.3. *Plot of peripheral temperature along forehead region before, during and after meditation*

The plot of the peripheral thermal signature before and after the meditation obtained with the help of corner detection and tracking algorithm is shown in figure 4.

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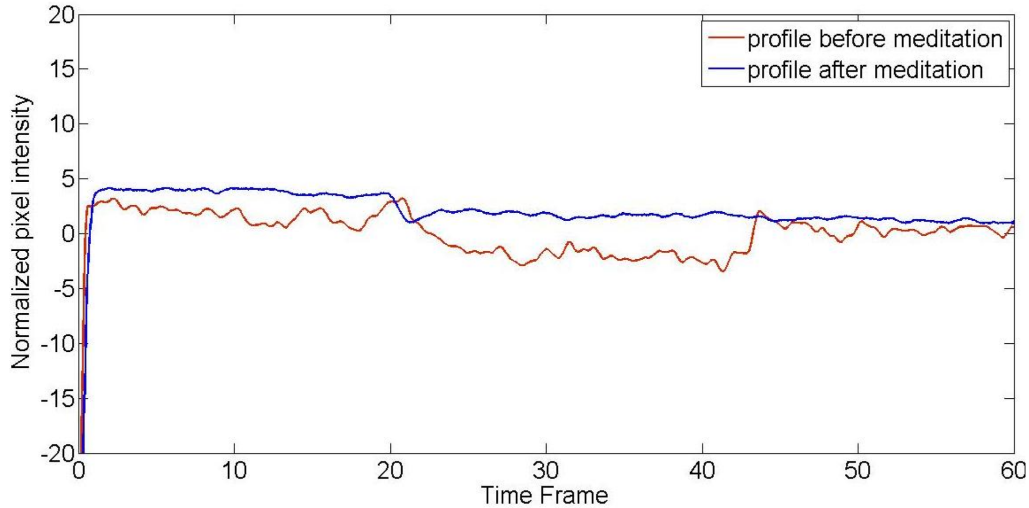

Fig.4. *Plot of peripheral temperature along forehead region before and after meditation using Matlab 2013a*

Thus from both the analysis i.e. from the SmartView analysis as well as from Matlab analysis it can be seen that the peripheral temperature is gradually increased during post meditation than that during pre meditation.

5.2 Core body temperature estimation:

The core body temperature estimation is done from the SmartView software which is provided with the thermal camera. Core temperature can be best estimated from the inner canthi of the eye. The images of the subjects before the start of Kriya Yoga meditation, during the meditation and also post meditation are captured which are stored in .IS2 extension. The images can also be stored in .jpg format but for analysis using the software it is required to be stored using .IS2 format. The images are captured with background temperature 80°F, emissivity 0.98 and the ironbow color palette. A rectangular region of interest is chosen around the right inner canthi of each person and the maximum temperature of the Region of Interest is chosen for analysis. Figure 5 shows the core body estimation of a female and a male subject in all three cases i.e. before, during and post meditation. It is observed from the results obtained by analysing all the data that the core temperature increases to some extent after the meditation. The increase of temperature may be due to the breathing exercise which comprises of 10 minutes out of 12 minutes of the meditation technique or due to attainment of some 'deep meditative state'.

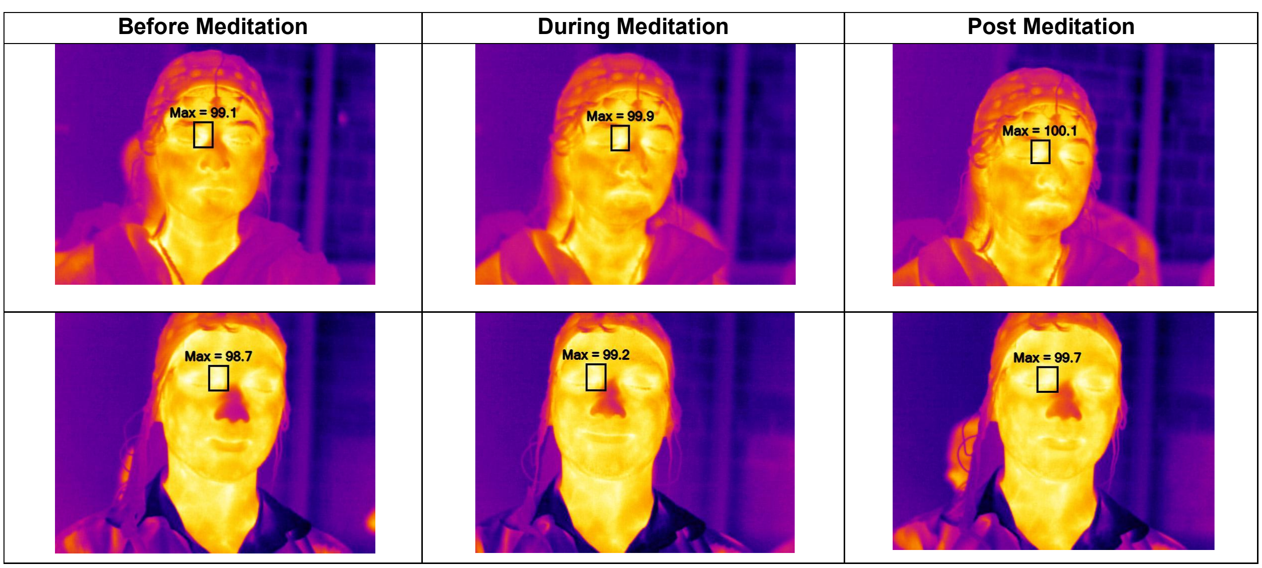

Fig.5. *Core temperature before, during and after meditation*

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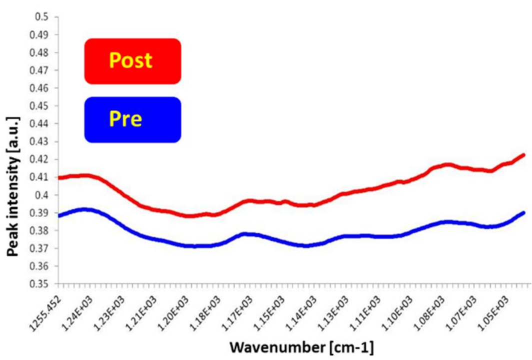
Table 1 gives the tabulated details of the core temperature before as well as after meditation.

Table 1. *Body temperatures pre and post meditation of both male and female subjects*

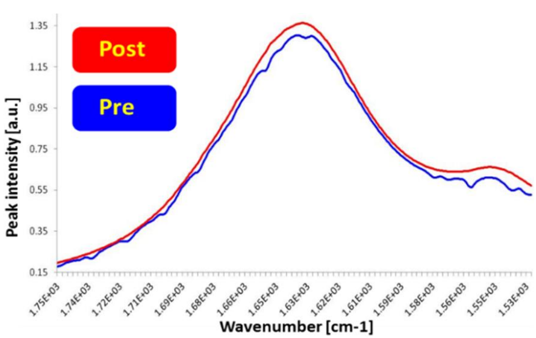
Subjects (Male)	Temperature Before Meditation(°F)	Temperature After Meditation(°F)	Subjects (Female)	Temperature Before Meditation(°F)	Temperature After Meditation(°F)
Subject 1	99.5	100.6	**Subject 1**	97.9	98.6
Subject 2	98.4	100.2	**Subject 2**	98.9	99.4
Subject 3	97.8	98.5	**Subject 3**	98.4	99.0
Subject 4	97.4	97.8	**Subject 4**	98.0	98.8
Subject 5	97.4	97.5	**Subject 5**	99.1	100.1
Subject 6	98.9	100.2	**Subject 6**	98.7	100.0
Subject 7	97.5	97.8	**Subject 7**	98.3	99.2
Subject 8	98.9	100.0	**Subject 8**	99.5	99.9
Subject 9	98.7	99.7	**Subject 9**	97.6	97.9
Subject 10	98.4	99.0	**Subject 10**	99.0	99.1
Subject 11	98.0	98.9			

5.3 Metabolic study through saliva test:



Peak [cm-1]	Proposed primary source [Proposed vibrational mode]
1078	Carbohydrates [C-O bending mode of carbohydrates bands]
1122	
1169	
1244	

Fig.6a. *FTIR spectra of pre and post conditions in the region of 1050-1260 cm^{-1} wavenumber*



Peak [cm-1]	Proposed primary source [Proposed vibrational mode]
1544	Proteins [Amide-II;C-N stretching & C-N-H bending vibrations]
1643	Proteins [Amide-I;C=O hydrogen bonded stretching vibrations]

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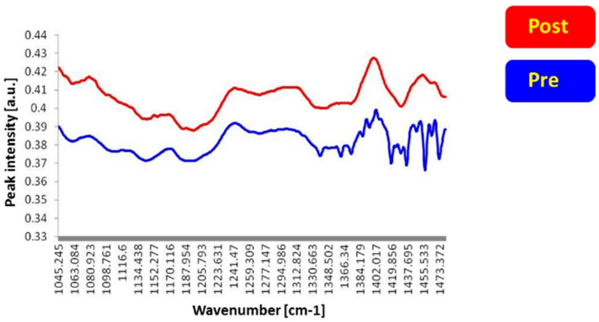
***Fig.6b**. FTIR spectra of pre and post conditions in the region of 1500-1750 cm^{-1} wavenumber*



Peak [cm-1]	Proposed primary source [Proposed vibrational mode]
1088	Lipids [symmetric stretching of phosphate groups from phospolipids]
1171	Lipids [ester C-O-C asymmetric +symmetric stretching vibrations of phospholipids, triglycerides and cholesterol esters]
1242	Lipids [PO2- asymmetric stretching vibration of phospolipid groups]

***Fig.6c**. FTIR spectra of pre and post conditions in the region of 1000-1480 cm^{-1} wavenumber*

FTIR spectroscopy is found to generate absorbance spectra in the frequency region 600–4000 cm^{-1}. It is well established that the mid-IR part of the spectrum (4000–600 cm^{-1}) contains several sharp peaks which are useful for the identification of metabolic activity pattern in biofluids [5]. The region 950–1800 cm^{-1} is selected to establish potential metabolic differences in saliva sample pre/post meditation phases, since the changes in the carbohydrate, proteins (amino acid) and lipids are best reflected in this region [6]. From figure. 6 a-c it can be observed that 10 FTIR spectral peaks corresponding to the carbohydrate, protein and lipid region are significantly altered in post meditation phase. Corresponding wave numbers are 1078, 1088, 1473, 1122, 1169, 1171, 1242, 1244, 1270, 1544, 1643, cm^{-1}[$P<0.001$; at 95% confidence interval]. It is also found that the metabolic activity in the carbohydrate, protein and lipid region is significantly increased in post-meditation phase as compared to pre-meditation phase.

6. Conclusion:

The peripheral body temperature is found to increase which may be due to increase in blood circulation caused due to performance of the breathing exercise or pranayam. The core body temperature which is considered to remain constant unlike the peripheral temperature is found to increase due to the performance of breathing exercises associated with Kriya Yoga Meditation. Moreover there is an increase in the metabolic activity as observed from the FTIR spectroscopic metabolic profiles. It may be suggested that the temperature increases during Kriya yoga may be not only due to meditation but also means to facilitate the achievement of “deep meditative states”. Future larger studies with experts in Kriya Yoga may offer promising research insights and approaches to investigating mechanisms of temperature and metabolic regulation. Future studies on a wide range of possible medical and behavior interpretations such as adaptation and functioning in hostile environments, resistance to infections, cognitive skills are warranted.

REFERENCES

[1] Paramahansa Yogananda, “Autobiography of a Yogi,” in *The Science of Kriya Yoga*, Self-Realization Fellowship, 1997.

[2] E. F. J. Ring, A. Jung, J. Zuber, P. Rutowski, B. Kalicki, and U. Bajwa, “Detecting Fever in Polish Children by Infrared Thermography,” no. figure 1, pp. 35–38, 2008.

[3] C. Childs, M. M. Zu, A. P. Wai, Y. T. Tsai, S. Wu, and W. Li, “Infra-red Thermal Imaging of the Inner Canthus: Correlates with the Temperature of the Injured Human Brain,” *Engineering*, vol. 04, no. 10, pp. 53–56, 2012.

[4] D. I. Ellis and R. Goodacre, “Metabolic fingerprinting in disease diagnosis: biomedical applications of infrared and Raman spectroscopy.,” *Analyst*, vol. 131, no. 8, pp. 875–85, Aug. 2006.

[5] P. D. Lewis, K. E. Lewis, R. Ghosal, S. Bayliss, A. J. Lloyd, J. Wills, R. Godfrey, P. Kloer, and L. a J. Mur, "Evaluation of FTIR spectroscopy as a diagnostic tool for lung cancer using sputum.," *BMC Cancer*, vol. 10, no. 1, p. 640, Jan. 2010.

[6] Z. Movasaghi, S. Rehman, and D. I. ur Rehman, "Fourier Transform Infrared (FTIR) Spectroscopy of Biological Tissues," *Appl. Spectrosc. Rev.*, vol. 43, no. 2, pp. 134–179, Feb. 2008.

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