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Research Article

Immediate Effect of Kapalabhati Kriya on Diastolic Augmentation: A Pilot Study

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Abstract

Kapalabhati (*KB*) is one of the six main yogic cleansing processes. *KB* is a yogic breathing technique in which the practitioner resorts to bellow breathing through an active exhalation and passive inhalation, wherein the lower part of the abdomen gets pulled in with every active exhalation. The aim of this fundamental study was to find out an immediate effect of *KB* on Diastolic Augmentation in a group of young and healthy volunteers. The pulse waves of all the subjects were recorded by Photo Plethysmography (PPG). Each subject was made to practice *KB* for 3 sets, each of 50 strokes while a continuous recording of the pulse wave was made using PPG. The analysis of the recorded data of pulse wave forms showed a significant increase in the Diastolic peak amplitude during *KB* practice, showing an increase in Augmentation Index (AI) when compared with the readings recorded immediately before *KB* practice. Student's t-test was done on the data obtained and statistically significant changes were seen in AI between data recorded before and while performing Kapalabhati. We can conclude that practicing *KB* may, convincingly, lead to Diastolic Augmentation that clearly reduces the workload on heart. An increase in the values of AI also indicates that *KB* improves coronary perfusion and also helps in collateral formation of capillaries.

Keywords: *Kapalabhati*; Diastolic augmentation; Augmentation index; Compliance; Pulse plethysmography

Introduction

The word *Kapalabhati* (KB) is made up of two words: *kapala* meaning “forehead” and *bhati* meaning “shining” [1,2]. The term Forehead Shining is indicative of blissful meditation like feeling. The technique of *KB* involves gentle, active exhalation just as a blacksmith’s bellow, while inhalation is allowed to happen with a passive automation. *KB* steps are rather straightforward. However, it is important to ensure that one performs it properly as per traditional directions or may end up hurting himself or herself. A detailed step by step instruction on the technique is presented here according to classical/traditional yogic texts, followed at Kaivalyadhama Yoga Institute Lonavla, India (Figure 1):

1. Sit straight with spine erect in a comfortable cross-legged seated yogic posture such as *Sukhasana* and *Padmasana*.

2. Exhale with a gentle, active bellow-like force, making a puffing sound of the blacksmith’s bellow. While exhaling, allow the abdominal muscles below the umbilicus to draw inward in such a way that exhalation and a concavity in the abdomen happen simultaneously. The abdomen relaxes during inhalation and gets pulled in during exhalation.

3. Continue for 50 strokes of KB and then take a brief break. Perform two more such consecutive sets, each of 50 strokes.

Blood vessels expand and contract passively with changes in pressure. The ability of a blood vessel to distend and increase volume with increasing transmural pressure can be quantified as vessel Compliance (C) which is the change in volume (ΔV) per change in pressure (ΔP) and $C=\Delta V/\Delta P$. The aorta up to the iliac bifurcation and its main branches namely the carotid and the innominate arteries are compliant vessels, which work as reservoirs and conduits. The radial and femoral arteries are more muscular than the compliant arteries. The iliac, subclavian and auxiliary vessels are intermediate in structure. The extensible fibres of the vessel wall govern its behaviour when that artery is under pressure. The volume accommodated for a smaller rise in pressure is greater for a more elastic vessel [3,4].

Pulse wave of the artery is a contour developed by the blood pumped by heart when the left ventricle contracts. This wave travels along the walls of the arteries in the tree-like structure of arteries. This wave has two main components-a forward wave which is formed when the ventricles expel blood during systole and a reflected wave which returns in the diastolic phase, after the closure of the aortic valve. The wave travelling down the aorta reflects back from the bifurcation where the aorta gets divided into two iliac arteries. The wave returning

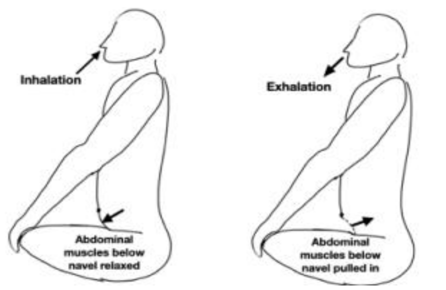

Figure 1: Steps followed while performing *Kapalabhati.*

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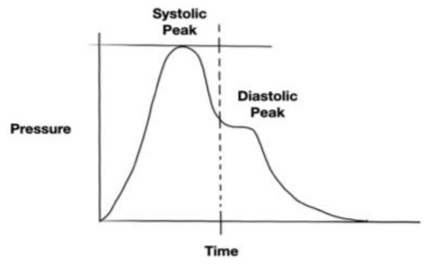

Figure 2: Pulse Wave.

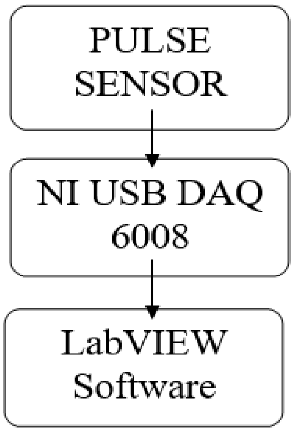

Figure 3: Block diagram of experimental setup.

to the heart helps in supplying blood to the myocardium by filling the coronary arteries during diastole. That is why the velocity of the returning wave is very important. If the arteries are stiffer, the blood returns faster. If the returning wave is faster, then it may enter into the forward wave of the same cardiac cycle and increases the blood pressure reading and inadequately fills the coronary arteries [5]. It clearly shows schematic form of a typical PPG waveform (Figure 2).

The diastolic wave can be augmented using devices like Intra-Aortic Balloon Pump (IABP) or Enhanced External Counter-Pulsation Technique (EECP). IABP consists of a balloon which is synchronised with the ECG and inflates in the aorta during the diastole [6,7,8,9]. The EECP machine consists of three cuffs, which are placed over the calf, thighs and buttocks. These cuffs are also synchronised with the ECG and create a squeezing action starting from the calf towards the abdomen [10,11,12,13].

To monitor the blood volume changes in microvascular bed of tissue, we can use Photo Plethysmography (PPG) which is a simple and low-cost technique [14,15,16,17,18,19,20]. It is a non-invasive technique used to measure heart rate from skin surface. Blood is pumped by the heart to periphery during each cardiac cycle. The pressure drops by the time blood comes to the skin, but it is sufficient to change the diameter of the arteries and arterioles in the subcutaneous tissue. The change in volume because of the pressure wave can be detected with gentle placement of a light emitting diode over the skin, which illuminates the skin and then measures the amount of light, which gets transmitted or reflected back to a photodiode. In this work, we are exploring the therapeutic use of *KB* like IABP and EECP, without any expenses.

In this experimental work, we are presenting the data from two different experiments. In one experiment, BIOPAC MP 45 module was used to detect the pulse waves on one subject. In second experiment, we used a device called PulseSensor to acquire the PPG signal. The intra-abdominal pressure is raised transiently while practicing *KB*. In the above-mentioned traditional technique, the whole of abdominal musculature is not contracting forcefully. In this technique, only the abdominal musculature below the umbilicus is getting pulled in during the exhalations. This movement can generate a pressure wave in the aorta to the returning wave and help in coronary filling. These experiments were designed to examine this aspect of *KB* so that it can be recommended to patients with cardiovascular diseases as a therapeutic measure.

Materials and Methods

In the first experiment, the BSL (Biopac Student Learning) system was used. It includes data acquisition hardware MP 45 which has built-in universal amplifiers to record and condition various bio-signals. This data acquisition system receives the signals from PPG sensor placed on the finger of the individual. The signal was acquired through Acqcheck 4.0 software. In the second experiment, PulseSensor [21] hardware was used to record the PPG signals. The signal which comes from this device is analog voltage signal with a predictable wave shape. This sensor was connected to the computer via NI DAQ USB-6008, which is a data acquisition device that can perform many functions. The data acquired through this device was visualised on the computer using NI LabView software. Informed consent was taken from all subjects prior to the experiments.

The first study was performed on seven male subjects. However, it was observed that there were much motion artefacts in most of the data and the data from only one subject could be processed. The issue of motion artefact was solved in the subsequent experiment by designing a hand stabiliser, which prevented the body movements from reaching the sensor placed on the fingertip. A group of 15 healthy subjects within the age group of 20-21 participated in the second study. All subjects had a normal blood pressure and had no history of any cardiovascular disease. They were asked to practice KB as per instructions stated above. The sensor was placed on the right index finger of each subject. None of the subjects had any previous experience of *KB* practice.

The pulse sensor consists of three terminals, one for Ground, second for +5V VCC and third one for Output Analog pin. The Sensor was given a power supply of +5V and grounded. The Analog output pin was connected as input to the NI DAQ 6008, which was integrated inside the LabVIEW software. Sampling rate was set as 100Hz for the signal acquisition and stored as *.xlsx* file. The pulse signal was visualized in the graph indicator of the LabVIEW software. "*While*" loop was used for the data acquisition block to have a continuous monitoring of the pulse signal obtained from the sensor. For removing noise form the signal, smoothing filter was used. Smoothing filter is a moving average filter, which averages the values of the signal and gives a clear waveform without the noise. Smoothing filter block is available in the LabVIEW software and it was placed just after the signal acquisition block for the DAQ. Smoothing filter was useful for the first derivative signal, which had noise with ripples (Figure 3).

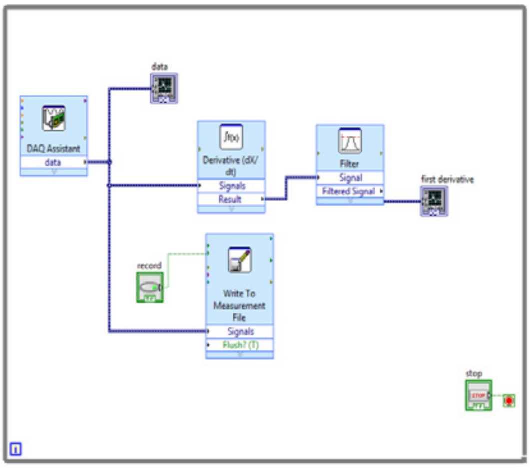

Figure 4: Block Setup in LabVIEW.

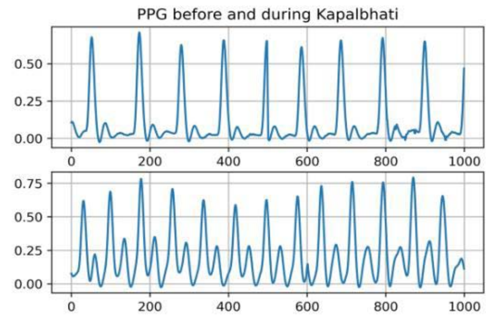

Figure 5: Plots of PPG waves before and while practicing *Kapalabhati* with Voltage in mV on X-axis and time in milliseconds on Y-axis.

Python programming language was used to visualize and analyse the PPG signals of the subjects. Python packages 'pandas' and 'bioread' were used to load the data files. 'BaselineRemoval' package was used to remove the baseline drifting of the PPG signal. 'Matplotlib' package was used to plot and visualize the PPG signals. The segments of normal pulse waves and those with increased diastolic peaks were plotted to compare the changes in diastolic peaks. The package 'numpy' was used to apply first derivative to the PPG signals.

The upper panel in (Figure 5) shows the waveform of PPG before practicing *KB* and the lower panel shows the waveform of PPG while practicing *KB* in one of the subjects. It is clearly visible that the diastolic peaks in the plot while practicing *KB* show higher diastolic peaks.

To detect the systolic and diastolic peaks, the first derivative of the acquired signal was taken. The points in the first derivative signal, with zero value, coincide with the peaks in the original signal. The systolic and diastolic peaks were obtained by superimposing the original signal with the first derivative plot of the same signal. The amplitude was noted at all such time points in the original denoised signal to get the values of the systolic peak (X) and diastolic peak (Y) amplitudes. The AI was calculated by using the formula-

AI = Y/X

Where X is Systolic peak amplitude and Y is Diastolic peak

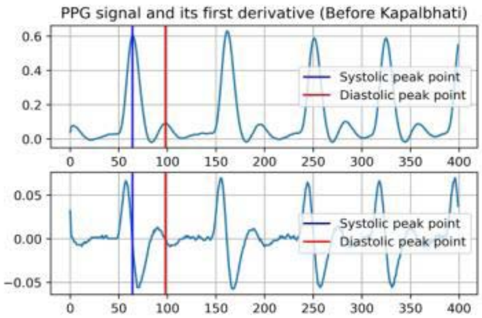

Figure 6: Superimposition of first derivative of the original signal over the original signal in a signal acquired before performing *KB*.

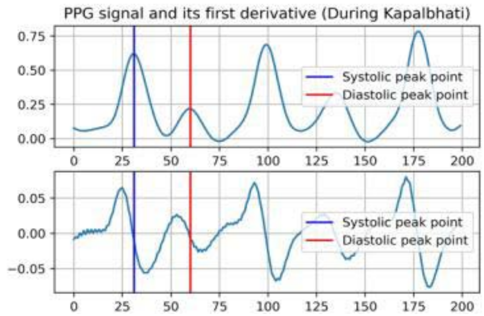

Figure 7: Superimposition of first derivative of the original signal over the original signal in a signal acquired while performing *KB*.

amplitude.

Figure 6 shows the PPG signal taken before practicing *KB*, being superimposed on the first derivative plot of the same signal. (Figure 7) shows the PPG signal taken while performing *KB*, which is superimposed on the first derivative plot of the same signal.

Results

In the first experiment, there were least motion artefacts in one subject. The data collected was analysed using Python programming language. The SciPy package was used to check for normality of the data using the normal function. The *p*-value was 0.000635, which is way less than the alpha value of 0.05. Thus, we assumed for all our data that the data is normally distributed and used Student's t test to test the significance of difference between values of AI before and while performing *KB*. The averages of the values of AI were plotted along with their standard deviations as shown in (Figure 8).

t-value

From the table, the t Stat value was obtained as -13.255 (Table 1). The t Critical values for both the one-tail and two-tail test were greater than the t Stat value. This indicates that the there was a significant difference in the AI values of the subject before and while performing *KB*.

p-value

The *p*-values from both the one-tail and two-tail tests are 1.64E-07 and 3.29E-07 respectively. These values are far lesser than the significant level alpha, which is generally taken as 0.05. If the *p*-value is greater than significance level of 0.05, it means that there is 95%

Table 1: Student's t test Results in First Experiment.

t-Test: Paired Two Sample for Means		
	Variable 1	***Variable 2***
Mean	0.213081	0.515796
Variance	0.000677	0.005068
Observations	10	10
Pearson Correlation	0.142897	
Hypothesized Mean Difference	0	
df	9	
t Stat	-13.255	
P(T<=t) one-tail	1.64E-07	
t Critical one-tail	1.833113	
P(T<=t) two-tail	3.29E-07	
t Critical two-tail	2.262157	

Table 2: Student's t test Results in Second Experiment.

t-Test: Paired Two Sample for Means		
	Variable 1	***Variable 2***
Mean	0.180911	0.442849
Variance	0.001214	0.011704
Observations	15	15
Pearson Correlation	-0.28659	
Hypothesized Mean Difference	0	
df	14	
t Stat	-8.26147	
P(T<=t) one-tail	4.70E-07	
t Critical one-tail	1.76131	
P(T<=t) two-tail	9.40E-07	
t Critical two-tail	2.144787	

chance that there is no significant difference between the two groups on which the t-test was performed. The *p*-values obtained were lesser than 0.05, which shows that there was significant difference between the values before and during *KB*.

In the second study, a wrist stabiliser was used to prevent the body vibrations from reaching the index finger where the sensor was placed. The AI values for all the 15 subjects, before and during *KB*, were calculated. To examine if there is a significant change in the AI values before and while performing *KB*, Student's t-test was used. The results of t-test, for paired two sample for Means, were obtained as below using Microsoft Excel.

t-value

From the table, the t Stat value was obtained as -8.261465381 (Table 2). The t Critical values for both the one-tail and two-tail test were greater than the t Stat value. This indicates that the there was a significant difference in the AI values of the subjects before and while performing *KB*.

p-value

The p-values from both the one-tail and two-tail test are 4.69971E-07 and 9.39941E-07 respectively. These values are far lesser than the

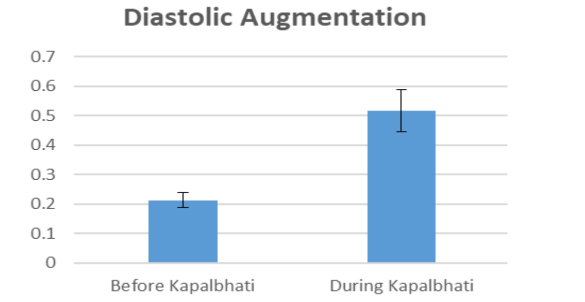

Figure 8: Average of AI values of 1 subject before and while performing *KB* in the first experiment.

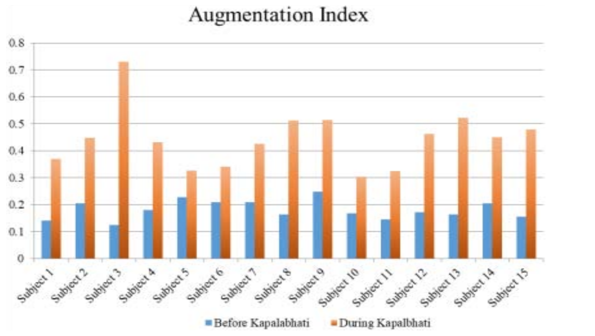

Figure 9: Plots of all 15 subjects before and while performing *KB*.

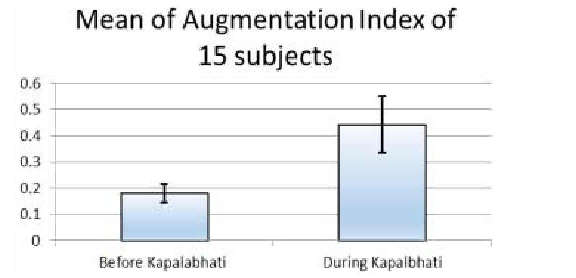

Figure 10: Average of all 15 subjects before and while performing *KB*.

significant level α, which is generally taken as 0.05. The *p*-values obtained were lesser than 0.05, which shows that there was significant difference between the values before and during *KB*.

The AI values of all the 15 subjects were separately plotted as shown in (Figure 9). The values for all 15 subjects were then averaged and plotted collectively, as shown in (Figure 10). With these results, it is observed that practice of *KB* causes diastolic augmentation in the capillaries of the finger.

Discussion

Various traditions of Yoga instruct the practice of *KB* in different ways. In one tradition, the procedure says the practitioner should sit with erect neck and back, inhale through both nostrils and exhale rapidly by flapping the abdomen during each exhalation at a pace of 60-120 breaths/min [30]. In the technique, which was followed in our experiments, only the lower abdominal muscles are used during exhalation and that too with a gentle force. The results from our two pilot experiments show that there is significant diastolic augmentation while practicing traditional KB used in this study. Diastolic augmentation, seen in PPG signal, represents the transient increase in pressure in the arteries during diastole. Diastole is the time when the heart relaxes and prepares for the next systole. The blood which remains in the arterial tree at the end of the diastole creates load on the heart. The heart has to pump the blood from the left ventricles into the aorta. When the aortic valve opens up in the ejection phase of the cardiac cycle, the blood which is already in the arterial tree opposes the blood which is being newly pumped by the ventricle [3]. During diastole, if the volume of blood in the arterial tree is pushed forward in the tributaries by pressure created by the reflected wave, then the left ventricle gets lesser resistance in upcoming systole.

Thus, the load on the heart gets reduced. We have found in our study that while performing *KB* the diastolic pressure wave gets enhanced i.e., augmented. This augmented pressure wave during diastole distributes blood to all organs of the body, thus improving the overall perfusion of all organs. Also, the coronary arteries get a better volumetric filling if the diastolic augmentation takes place [6-13]. Heart receives its own adequate blood supply during the diastole only, as during systole the contracted myocardium squeezes the coronaries and empties them. Hence, during diastole, the reflected wave pushes blood into the coronaries through the ostia. Thus, the study shows that *KB* provides all the benefits of diastolic augmentation and can be used as a therapeutic process. Various studies on *KB* have shown that there is sympathetic stimulation of the heart with practice of *KB*. With our results, it can be seen that there is diastolic augmentation of the arterial system using PPG. Along with the diastolic augmentation of the arterial system, the gentle strokes on lower abdomen also exert force on the inferior vena cava, thereby improving the venous return to the heart. The increased venous return to the right atrium must be responsible for the increase in the LF/HF ratio which is a parameter showing increase in sympathetic activity in the sympathovagal tone of the heart [27,28,29]. It is evident from our study that the most probable cause of increase in LF/HF ratio is the Frank-Starling mechanism [3] and not the increase in sympathovagal tone. It may be possible that the increased venous return to the right atrium causes the increase in the heart rate and increases the LF/HF ratio of the HRV. Increased venous return may increase heart rate by 10 to 15 % above the existing baseline rate, before practicing *KB*. Thus, it may rise from normal 72-84 to 84-96 beats per min. In well controlled hypertensive patients with anti-hypertensive drugs, baseline pulse rate is normal up to 80/min and so *KB* should not have any adverse effect.

As *KB* causes diastolic augmentation, it is also evident that it will give all the good effects of other techniques like EECP. The diastolic augmentation improves the perfusion of brain, heart as well as kidneys. Due to reduction in afterload on the heart, the stroke volume of the heart also improves. This improves the left ventricular ejection fraction as well. The increased perfusion of various organs stimulates the endothelial cells. They produce nitric oxide and Vascular Endothelial Growth Factor (VEGF) [12,22,-25] which are known to help in angiogenesis. This helps in development of collateral blood vessels in the arterial tree. Thus, all vital organs benefit from the practice of KB. As observed in studies on EECP [10-13], KB must also be reducing the endothelin and Brain Natriuretic Polypeptide (BNP) which are released in ventricular stress. All these benefits of EECP should further be investigated for *KB*.

Conclusion

When *KB* is practiced with the instructions used in our experiments, it shows significant increase in the AI values while performing *KB*. The statistical analysis of our data collected from 15 healthy individuals shows that *KB* produces significant diastolic augmentation. These results indicate that *KB* improves coronary filling, as well as, perfusion to all vital organs in the body as it causes diastolic augmentation. Thus, *KB* can be used as an alternative to expensive treatment modalities like EECP and give good results. A more extensive study is needed to further explore the effects of *KB*. Thus, we can conclude that *KB* can be a good economic alternative to EECP, which is used in treating angina.

At present, hypertensive and Ischaemic Heart Disease patients are not advised to perform *KB* with an apprehension that *KB* might increase load on heart. In one study it was observed that *KB* does not cause Hyperventilation Syndrome [26]. It is clear that *KB* only marginally increases the heart rate. But, by not allowing patients to practice *KB* one deprives them of the benefits of improved health of heart musculature which is obtainable due to improved coronary perfusion as a result of diastolic augmentation. This also reduces the heart load due to redistribution of blood to all organs and in the process improves their functions, which in turn, will improve the overall health in general. Besides being deprived of cardiovascular system benefits, one is also deprived of the most important effects and benefits of KB on respiratory system [30], if patients are not allowed to practice *KB*. To name a few benefits; 1. Improving the overall lung capacity by opening up alveoli in passive regions of the lungs, 2. Providing adequate oxygenation to all organs so as to make them work efficiently, 3. Forceful exhalation improving the blood supply of the respiratory tract mucosa. This enhances phagocytic action against pathogens, thus improving immunity [31].

We would like to conclude that if one practises classical *KB*, as described above, in relation to method and also quantity, one may immensely be benefitted. However, controlled studies on a larger scale would alone fully authenticate the results of this study and lend credence to our plausible claim that the classical mode of *KB* can be practiced by all with advantage. It is conjectured, through this study, that the gentle nature of the traditional *KB* practice may show more enhanced meditative feelings, thus facilitating meditation a far better way.

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