INDIAN JOURNAL OF SCIENCE AND TECHNOLOGY

REVIEW ARTICLE

A Framework of Measurable Features of *Bhramari Pranayama* Leading to Meditation

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OPEN ACCESS

Received: 04-04-2022
Accepted: 06-06-2022
Published: 27-01-2023

Citation: Ushamohan BP, Belur YK, Rajasekaran AK, Ilavarasu J, Srinivasan TM (2023) A Framework of Measurable Features of *Bhramari Pranayama* Leading to Meditation. Indian Journal of Science and Technology 16(4): 259-265. https://doi.org/10.17485/IJST/v16i4.752

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Funding: None

Competing Interests: None

Published By Indian Society for Education and Environment (iSee)

ISSN
Print: 0974-6846
Electronic: 0974-5645

Abstract

Background: *Bhramari pranayama*, a yogic technique comprises a self-vocalized humming sound emulating a female bumblebee. Attention to this sound leads to a meditative state. The component of its stimuli, the sustained self-evoked humming sound with breath control, is overt unlike the stimuli of most of the meditations**.** These observable and measurable components of *Bhramari pranayama* offer a rare opportunity to study the causal component of meditation in research. **Objectives:** Considering the growing interest in this area, Bhramari's potential as a unique research tool, and a framework of the mechanism of it leading to meditation is attempted. **Methods**: We review relevant current scientific literature and classical yoga texts to understand the framework of how the overt features of *Bhramari pranayama* cause the meditative state. We present our argument in three sections, where we present the *Bhramari pranayama* practice into its sub-components, namely i) pranayama, ii) Bhramari sound-producing phase, and iii) Shanmukhi practice. **Findings:** This has facilitated the identification of the measurable attributes of Bhramari like fundamental frequency, resonant vibrations, articulation, etc. Concepts related to its processing like efference copy, corollary discharge, and sense of agency, are also observable in electrophysiological investigations. This information would be useful to harness the therapeutic benefits of *Bhramari pranayama* due to its ability to produce self-evoked resonant vibrations, sensory entrainment, and gamma waves, that have specific clinical significance. **Novelty:** This framework elucidates the mechanism of how the overt, observable, and measurable features of *Bhramari Pranayama* cause meditation. It presents the relation between breath and self-vocalized acoustics, that produce synchrony among multisensory systems to facilitate meditation.

Keywords: Bhramari Pranayama; Meditation; Self-evoked sound; Resonance; Sensory entrainment

1 Introduction

Many contemporary researchers define meditation as a set of cognitive techniques involving attention and observational tasks under the umbrella term meditation. Different traditions and cultures practice various techniques of meditation. On deeper analysis, these meditation practices of distinct traditions intend to achieve a final subjective inner state of equanimity and eventually attain Buddhahood, or the state of Samadhi or in simple terms a natural meditative state. Ancient Indian scriptures distinguish several tools to aid the meditative process. The potentiality of each of these tools varies. Among various tools adopted to effectively practice meditation, *Bhramari Pranayama* (BhPr) is one of the techniques mentioned in the classical yoga texts. In this work, we propose to elucidate how BhPr can aid in meditation, particularly we would emphasize how self-evoked overt stimuli can be an efficient aid to meditation. Moreover, the process of the practice of BhPr can pave the way to Dharana, dhyana, and samadhi, which are the antharanga yoga as per Patanjali.

There are two types of stimuli that can be taken as an aid to meditative practices, overt and covert. A covert stimulus is one where the process of invoking and using that stimulus is not perceptible to outside people, like the mental chanting of a mantra. On the other hand, the overt stimulus can be easily perceived by others, as the loud chanting of a mantra. Often in traditional practices, the mantras given by a competent guru are kept secret and are often chanted covertly. It is often argued that in meditative practices, stimuli are covert and therefore subjective. They are mere first-person accounts of the phenomenological descriptions without objective third-person measurements. This may lead to varied results and interpretations.

Therefore, meditation research has challenges while studying the effect and mechanism of different types of meditation. Despite such challenges, and amidst many axioms that are hard to test, meditation researchers are curious to understand the mechanism of meditation. At an empirical level, the study of the stimulus, its components, its processing mechanism, and relevant neuronal pathways that are activated, all lead to a better understanding of the process of meditation and its benefits. *Bhramari Pranayama* is one such rare stimulus with a few overt features that is observable and measurable by the investigator at the empirical level. It seems to provide a rare opportunity to relate to the cause of meditation at least to some extent, which may lead to a better understanding of the process of meditation.

2 Methodology

We attempt to review BhPr as an aid in mediation along with its added features like the sustained self-evoked humming sound, and breath, which make BhPr an overt and explicit process. In this review article, to elucidate the above point, we present our argument in three sections, where we present the BhPr practice into its sub-components, namely i) pranayama, ii) Bhramari sound-producing phase, and iii) shanmukhi practice. Under each of the sections, we review relevant current scientific literature to bring parallels to the traditional yogic science of BhPr practice. Also, we provide how these stimuli are integrated and avoid distractions, in the information processing section. Hence, in this article, we attempt to propose a framework of how BhPr causes the meditative state, based on existing scientific literature.

3 Results

3.1 *Bhramari Pranayama* - An Overview

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योगीन्द्राणामेवमभ्यासयोगाच्चित्ते जाता काचिदानन्दलीला ॥

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yogīndrāṇāmevamabhyasayogaccitte jata kacidanandalila|| 2.68

According to the ancient yoga texts, Hata Yoga Pradeepika, and Gheranda Samhitha, BhPr is a breathing technique, where a humming sound is produced with breath control in a sustained low pitch, emulating the buzz of a female bumblebee. This breathing technique with acoustics is also the object of meditation. The practitioner who meditates on this acoustics vibration along with controlled breathing can eliminate external experiences and become fully absorbed in the inner sound. In this process, as per the classical yoga texts, the practitioner starts to hear spontaneous distinct internal sounds or Dashavida Nada (ten different sounds like bells, flute, conch, etc.) culminating in the highest stage of 'OM'. Classical texts like Upanishads, Shaivagama texts, and Yoga Taravali of Adi Shankaracharya hail this meditation technique known as Nada Yoga an ancient and exalted form of meditation, and considered it an exceptional means to attain higher meditative states [1]. Therefore, the practice of BhPr is said to eventually enable the practitioner in attaining a higher state of meditation.

In a couple of EEG studies conducted on practicing *Bhramari Pranayama*, it was also reported that it induced paroxysmal gamma waves (PGW) consisting of biphasic hypersynchronous activity in high gamma range similar to a Buddhist meditation study [2]. An increase in theta range activity which is similar to results obtained with other meditation techniques was also observed [3,4].

3.2 Components of *Bhramari Pranayama*

Bhramari Pranayama has three components: a) pranayama, b) Bhramari sound-producing phase, and c) shanmukhi practice.

3.2.1 Pranayama

It is a set of breathing techniques that aims at direct and volitional modulation of the parameters of respiration, like inhalation/exhalation ratio, depth, and frequency. In the case of BhPr, it is short optimal inhalation and longer exhalation. During exhalation, a humming sound is produced. Along with this, conscious and deliberate engagement in the practice is necessary.

3.2.2 Automatic Breathing Versus Conscious and Voluntary Breathing

In general, in individuals, the primary function of breathing is to facilitate gas exchange at a cellular level which involves the intake of oxygen and the removal of carbon dioxide from the lungs. Generally, breathing is an automatic (unconscious) process. Its automatic, continuous breathing patterns are involuntarily generated by the Pre-Bötzinger complex in the brain stem in response to feedback from the self-regulatory processes, regarding the levels of carbon dioxide in the blood. Though the continuous breathing patterns are generated for the exchange of gases, it also adapts rapidly to multiple complex feedback systems of physiological, emotional, and real-time stress, to maintain homeostasis as required to survive the external challenges. Respiratory rhythm also influences cognitive functions. This self-regulation is not static and unvarying, but a dynamic self-adjusting process.

Breathing which is normally an automatic and involuntary activity can also be influenced by conscious intention. Pranayama is not only voluntary but also conscious regulation of breathing. Nasal stimulation during slow breathing is considered fundamental for reaching meditative states [5]. Slow respiratory frequency i.e., slow nasal inhalation at an optimal level and slower exhalation is said to aid meditation [6].

3.2.3 Bhramari Pranayama

Bhramari Pranayama is a humming sound depicting the buzz of a female bumblebee, primarily during exhalation. Literature related to speech deals extensively with humming. Humming is said to be one of the easiest ways to initiate vibration and promote resonance. To produce the resonant humming sound depicting the buzzing sound of a bumblebee, recent yoga text recommends using low pitch sustained phonation (humming) of nasal consonants [m], [n], or [η].

The air passing through the vocal folds causes it to vibrate (thereby voice is produced). The sound thus produced (with air) is streamed through the nasal cavity to produce nasal sounds. The nasal cavity and the cranial sinuses would add (some) resonant characteristics to the sound. As the sound passes through the nasal cavity and sinuses, vibrations of the related cranial structure are bound to happen. The sound energy here transduces to mechanical (vibratory) energy and if the imposed vibration and the natural vibratory frequency of the cranial structures are the same then it is at resonance (maximum vibration). An interesting fact here is the relation between the production of nasal sounds (humming) and BhPr. Recent studies have noted the relation between BhPr and the release of nitric oxide from the maxillary sinuses [7]. The release of blocked nitric oxide is possible by the resonant vibration, which again may be due to the BhPr-induced vibration. The release of nitric oxide is associated with a feeling of blissfulness, and due to this BhPr practice, gives rise to calming effects in the practitioners.

The frequency of vibration of the vocal cords determines the pitch of the voice. Humming sound can be produced in a wide range of frequencies, the fundamental frequency being the lowest. The usual humming is an individualistic tonal pattern and is often imitating any familiar melody. However, the humming sound in BhPr is only one specific stimulus for all. The practice of BhPr requires humming, at a low and sustained pitch depicting a female bumblebee [8]. Acoustic studies of the flight of female bees of different species including bumblebees show that they produce resonant buzzing sounds at a constant frequency of 120-260 Hz [9]. The fundamental frequency of the human voice also ranges from 100-300 Hz, across genders and ages [10]. This is perhaps why BhPr is suggested to be emulated like a female bumblebee's buzzing frequency.

3.3 Modes of Propagation of the Resonant Vibration

The resonant vibrations are propagated to the brain through various pathways. The air stream passing through the vocal folds and modulated during phonation in the throat and back of the mouth is intense enough to vibrate the cheekbones, mandible, and structures of the head, primarily creating mechanical vibrations in the bones of the skull. The acoustic energy of the humming produced by the vibration of the vocal folds then passes through the three resonators i.e., pharynx, oral and nasal cavities, achieving resonant vibration that ranges from 200-300 Hz [11]. These resonant vibrations may match with the natural frequency of the maxillary bony structures and anterior alveolar ridge (the hard palate, upper teeth, and cheekbones), which causes sympathetic resonance. Direct resonance that occurs is passed from the nasal bone to the other facial and cranial bones in the skull. Direct resonance occurs when a vibrating object is placed in direct physical contact with another object, whereas sympathetic resonance occurs when the sound waves from a vibrating object setup vibration in an object some distance away. These mechanical vibrations in turn could set piezoelectric effects in the cranial system, to produce an electromagnetic signal inside the cranium. These resonance-induced piezoelectric signals could propagate to the brain, and nervous systems [12]. If this resonant vibration propagates well, it will also reach the spinal vertebrae and ribs, which can support meditation processes. Generally, propagation and perception of the acoustic resonant vibrations are further enhanced through the proprioceptive feedback provided through the kinaesthetic sensations on the alveolar ridge and the facial bones [13]. We propose that the overall feeling of vibrations experienced by the BhPr practitioner around the facial and cranial regions would help in inner grounding, as these sensory perceptions are vivid. This can enhance the overall experience of meditation.

3.3.1 Shanmukhi Mudra

Shanmukhi mudra is a yogic gesture, which symbolizes sensory abstinence from all the five sensory sources. This mudra is adopted by using all the fingers. Thumbs are used to occlude the ear canal. Fore fingers are placed on the closed upper eyelids, the middle fingers on the nasal bridge to perceive the facial vibration and to partially block and channel the passage of the breath. The ring and the little fingers are placed on the upper and lower lips respectively. Adoption of *shanmukhi mudra* while practicing BhPr may make the propagation of the vibrations more effective. It channelizes the mind towards the internal sensations created in BhPr and also aids in the effective propagation of the vibration produced. According to ancient texts, in the process of meditation, *pratyahara*, the act of withdrawing the mind from the external sense objects, internalizing the mind towards the object of meditation is essential. *Shanmukhi mudra* acts as an effective means of *pratyahara*. BhPr practice along with *shanmukhi mudra* offers a multi-sensory withdrawal which makes the mind effortlessly focused on the object of meditation. Hence, BhPr has an inherent mechanism to reduce external distractions. In some of the versions of BhPr practices, *shanmukhi mudra* may not be used, though ears are always closed. But we observe the above-mentioned advantages of using *shanmukhi mudra*. Now we shall review the mechanism of important sensory feedback that happens during BhPr.

3.3.2 Auditory Feedback

Of all the modes of feedback, the acoustic resonant vibration is predominant in BhPr. During the self-evoked speech, the acoustic vibrations are known to propagate via air conduction and bone conduction and are similarly processed in the cochlea. But due to the adoption of *shanmukhi mudra*, the external air canal of the ears is occluded, obstructing the air pathway. The occlusion has the advantage of the acoustic vibrations being heard more dynamically as the ear canal serves as a sound amplifier, enhancing the perceived loudness by as high as 29 dB. This enhanced perceptibility reaches its maximum at 200 Hz of self-created sound and gradually decreases with an increase in frequency (0 dB for frequencies above 2000 Hz) [14]. The acoustic component is propagated to the cochlea through the bone conduction pathway. The bone-conducted signal primarily contains the fundamental frequency of the speaker's voice [15], and hence it is essential to make the humming sound in the fundamental frequency, for effective propagation of sound while practicing BhPr. Bone conduction of the skull is more effective than air conduction. The speed of sound in the skull bones is seven times faster, and in tissue, blood, and brain matter it is about four times greater than in the air [16]. Therefore, in BhPr, along with *shanmukhi mudra*, enhanced auditory processing is experienced, due to bone conduction and humming at the fundamental frequency.

3.3.3 Olfactory feedback

BhPr involves breathing with slow inhalation and slow exhalation while humming. The mechanical stimulation of the olfactory bulb by intranasal breathing is a pathway crucial in the regulation of the link between respiratory rhythms and the brain. Respiration modulates neural activity and influences a wide network of cortical and subcortical structures [17,18]. Nasal breathing has a great influence on cortical oscillations due to respiration-locked modulation of sensory inputs. Fluctuations in blood oxygen levels affect cortical rhythms, but it appears to be minor in comparison to the effects of sensory inputs. This rhythmic activity of breath directly modulates cognitive functions by synchronizing neural activity. Focusing attention during conscious

breathing enhances coherence between the neural oscillators. As a consequence, voluntary modulation of breathing i.e., pranayama can be a powerful tool for manipulation of cognitive functions[19]. It is also suggested that nasal stimulation during slow breathing is fundamental for reaching meditative states and there exists a dynamic interaction between respiratory frequency, mechanical stimulation of the nasal epithelium, and focused attention. Thus, BhPr can lead to an effective meditative state through harmonizing various neural activities, and it can also enhance cognitive processing.

3.3.4 Tactile Feedback

While adopting *shanmukhi mudra* the fingers are placed on the areas of the facial regions, where the important trigeminal nerves exist. The trigeminal nerve is also responsible for the proprioception and transmission of the vibrations to the thalamus. Placing fingers over the underlying trigeminal pathway, there is an enhanced tactile perception of sensory vibrations caused by BhPr around the fingertips. The Pacinian corpuscles, the primary mechanoreceptors at the fingertips have their functional significance in tactile perception in response to any vibratory stimuli. The vibration perception threshold of a human finger could be most sensitive around 200-250 Hz, which again coincides with the resonant frequencies[20]. The proprioceptive feedback caused by the kinaesthetic sensation on the facial bones felt by the fingers placed on the nasal ridge, lips, and also on eyes, will be propagated to the brain as tactile/somatosensory feedback. It should be noted that all sensory information except olfaction enters the brain through the thalamus and is further relayed to specific sensory centers in the cerebral cortex. BhPr practice is enhanced through such a tactile feedback process.

3.4 Information Processing

Auditory stimulations resulting from self-initiated sounds (like humming in BhPr) are processed differently than stimulation received from external sources. The external stimuli are often processed spontaneously in a reflexive mode, just to be aware of the stimuli, whereas internal self-created stimuli like BhPr, are processed to fine-tune and invoke a higher degree of awareness of the stimuli.

The self-initiated sounds being a motor control system involve neural mechanisms of both productions (speech) and feedback for error correction[21]. This feedback occurs through corollary discharges[22]. In simple terms, brain structures that perform motor planning for vocalization also send parallel information (corollary discharges/efference copy) to the structures that perform auditory processing. This information (code A) anticipates the sound to be produced. As and when the sensory feedback (code B) arrives, a comparison of codes is performed. The resultant is the sensory filtering mechanism for error correction and fine-tuning. This comparison is vital for the identification of self-produced sounds. A desynchrony of the production-feedback mechanism may distort the self-identification (perception) of one's speech (internal) and thus result in perceiving as an outside stimulus. This could be the case in auditory hallucination[23]. Recognizing auditory input as self-vocalization involves Self of Agency (SoA). SOA is the experience of oneself as the agent of one's actions (agency). Further, it is postulated that fundamental frequency (voice) is a critical factor in the experience (identification) of self. Hence, the production-feedback mechanism can be thought to reflect a form of self-awareness[24]. In BhPr, humming is produced at a fundamental frequency which could mean promoting corrections and fine-tuning during meditation.

In this context, BhPr humming is to be treated as a mode to attain the meditative state. While in the usual humming, not enough attention needs to be paid to the hum, in BhPr however, complete attention is paid to the humming sound stimulus and its processing is consciously maintained. It is known that humming at a constant fundamental frequency can transform aerodynamic energy into resonant mechanical energy which is propagated through bone conduction and multisensory pathways. Here again, maintaining the same fundamental frequency seems to promote the SoA experience. BhPr can lead to a resonant vibratory stimulus, consciously attending to this stimulus seem to aid in better fine-tuning of its processing and thereby progressively leading to a higher level of meditation.

3.5 Sensory Entrainment

Processing of the resonant vibration, its propagating through bone conduction, and multisensory pathways to the brain may be the source of modulation of the neural activity of the brain to the meditative state as seen in an EEG study performed on BhPr practitioners. It has been reported to have generated theta band activity and high-frequency gamma waves of unusual strong amplitude[2,3]. It may amount to sensory entrainment, which is well known to modulate the ongoing oscillations in the human brain. Sensory entrainment is the process, where neurons in the sensory cortex adjust their frequency of synchronization in response to external stimuli. Rhythmic auditory stimulation is also known to generate maximal responses at specific resonance frequencies. It has been widely accepted by the scientific community that auditory stimulation may constitute a distinctive gateway to modulating oscillations in the human brain. BhPr may also facilitate sensory entrainment resulting in the coherent

processing of information.

4 Discussion

In this work, we have attempted to elucidate how BhPr can aid in the process of meditation. In meditation, the self-evoked humming has to be at a certain frequency, articulated in a certain way, and also has to be propagated effectively. If the stimulus is coherent, it may be propagated to relevant brain centers effectively, else it may be inhibited from further propagation [(25)]. The whole process of generation of resonant vibration, its propagation, and its processing is the actual object of meditation here.

According to Patanjali, the components of antharanga yoga, Dharana, dhyana, and samadhi progressively take the practitioner to higher meditative states. In Dharana, attention acts as a powerful filtering system to select only the relevant stimuli, discarding other irrelevant stimuli. This invariably is accompanied by inhibiting mind-wandering that is associated with self-related negative emotional thoughts. Strong emotional stimuli can disturb the self-regulating homeostasis mechanisms of autonomic systems, which can impede the progression of mediation. Focused attention-styled meditations clear the path of meditation from these disturbances which will harmonize autonomic imbalances [(26)]. Generally, regulation of autonomic processes happens without conscious awareness, through various regulatory feedback systems. Conscious awareness, as in BhPr, enables the effective removal of distracting thoughts. When attention towards the object of meditation is consistent, it is said to have moved to the phase of Dhyana. In this phase, effort and self-awareness are still retained to produce the humming stimuli, or in other words, Self of Agency (SoA) is actively present. The object of meditation in this context, the resonant vibration produced by BhPr, the shift from automatic processing of breathing and humming to conscious processing leads to profound enhancement in the quality of perception. One of the functions of consciousness is said to transform autonomic processes to conscious processing and thereby modulate information processing and perception.

Perception in the process results from the interplay between the bottom-up sourced sensory afferent signals and top-down efferent signals modulated by attention and expectation through feedback and feed-forward loops. The process happens spanning multiple stages at multiple cortical levels. The bottom-up sensory evidence and top-down predictive signals are matched and what remains after this matching process is the gap, that is yet to be perceived or called a predictive error. The predictive error propagates up the hierarchy allowing a similar process to be repeated in sequence in higher cortical regions which may be inferred as a higher level of consciousness. According to models like predictive coding, the outcome of this hierarchical prediction error reduction process is perception. Each successive stage of the information processing sequence involves a certain transformation of input from the previous stage. This process is repeated in progressive hierarchy resulting in finer perception as the process aids in activating or manifesting latent properties of the object of meditation. It is affected by progressively higher levels of consciousness. These hierarchical processes transform and restructure information, and often information processing also structure itself. Transformation of the information structures could mean the biostructures involved in the processing like the sensory afferent pathways and top-down efferent pathways, may heal the structures wherever necessary and also activate the inherent dormant capabilities of the structures. The constant and repeated production of the stimuli for a long duration in meditation is essential for effective fine-tuning and processing. Therefore, long-term regular practice of meditation is required to produce long-term benefits.

The same effect seems to happen with BhPr too. Due to the regular practice of BhPr, the auditory system becomes competent to spontaneously hear the inherent sound called Nada, which is imperceptible to ordinary ears. This stage is similar to the ”ajapajapa” in Mantra Yoga, where the recitation of Mantra happens spontaneously without effort. Once Nada begins to be heard, the need to practice BhPr will cease, as the Nada itself will be the object of meditation. Nada is said to be inarticulate, yet melodious, enthralling, captivating, resonant vibration. This state seems to be an indication of having reached the state of Samadhi. Meditation attending to Nada and its processing has to continue to ascend the remaining nine consecutive stages of higher consciousness over a period of time, culminating in the highest state of ”OM” (Refer to table 1 in Ushamohan et al. [(1)]). To the best of our knowledge, no other meditation technique offers the practitioner so clear and explicit self-assessment of the stages of Samadhi. This provides another unique means to study the stages of Samadhi.

5 Conclusion

The overt features of BhPr used to aid meditation provides an opportunity to observe and measure many of its components and sub-components like fundamental frequency, resonance, etc. The components, efference copy, Self of Agency, etc., indicated in the processing, are also observed in electrophysiological and imaging studies like ERP and fMRI. It can help in understanding the neural correlates of the meditative states. This framework has provided a unique opportunity to understand the role of stimulus, the importance of application of attention, and awareness in the information processing of the stimulus used for meditation. It facilitates enhanced clarity in understanding the properties and processing of the stimulus that lead to meditation.

BhPr seems to be capable of producing sensory entrainment by self-evoked or self-vocalized sources and not sourced by external inputs.

This work can also be used to design future meditation studies using fMRI, and ERP techniques. Studies involving inhalation phonation with humming, and the effect of other nasal consonants like [n], or [η] on resonance need to be carried out in the future. This framework also helps to investigate the utility of BhPr in inducing meditative states and also as a therapeutic tool. Employing relevant tests and study designs would further reinforce the utility of this framework. This could also serve as a benchmark at least to some extent in understanding other types of meditation where the study of the stimuli is not feasible.

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