

# Understanding the links between vestibular and limbic systems regulating emotions

Archana Rajagopalan,  
K. V. Jinu<sup>1</sup>,  
Kumar Sai Sailesh<sup>1</sup>,  
Soumya Mishra<sup>2</sup>,  
Udaya Kumar Reddy<sup>3</sup>,  
Joseph Kurien  
Mukkadan<sup>4</sup>

*Department of Physiology, Saveetha Medical College, Saveetha University, Chennai, Tamil Nadu, <sup>1</sup>Department of Physiology, Little Flower Institute of Medical Sciences and Research, <sup>4</sup>Department of Physiology, Little Flower Medical Research Centre, Angamaly, Kerala, <sup>2</sup>Department of Physiology, Jawaharlal Institute of Postgraduate Medical Education and Research, Puducherry, <sup>3</sup>International Stress Management Association-India, Hyderabad, Telangana, India*

**Address for correspondence:**

*Dr. Joseph Kurien Mukkadan, Department of Physiology, Little Flower Medical Research Centre, Angamaly, Kerala, India. E-mail: drmukkadan@gmail.com*

## Abstract

Vestibular system, which consists of structures in the inner ear and brainstem, plays a vital role in body balance and patient well-being. In recent years, modulating this system by vestibular stimulation techniques are reported to be effective in stress relief and possibly patient's emotional well-being. Emotions refer to an aroused state involving intense feeling, autonomic activation, and related change in behavior, which accompany many of our conscious experiences. The limbic system is primarily involved in the regulation of emotions. Considering the extensive networks between vestibular and limbic system, it is likely that vestibular stimulation techniques may be useful in influencing emotions. Hence, we review here, the possible mechanisms through which vestibular system can influence emotions and highlight the necessary knowledge gaps, which warrants further research to develop vestibular stimulation techniques as a means to treat health conditions associated with emotional disturbances.

**Key words:** Central nervous system and autonomic nervous system, emotions, mental health, vestibular system

## INTRODUCTION

Vestibular apparatus located in the inner ear coordinates the body balance and movement, which requires extensive neuronal networking. Vestibular system via the vestibular nuclei has a wide spread of network within the higher centers of the brain, which is evident from the observations of diverse activation patterns following vestibular stimulation.<sup>[1]</sup> Emotions are aroused state of mind involving intense feeling, autonomic activation, and related change in behavior, which often accompany many of our conscious experiences, including mental and physical components.<sup>[2]</sup> Vestibular stimulation can modulate

mood and hence influence emotions depending on the region of vestibular stimulation.<sup>[3]</sup> Indeed the concepts of vestibular system influencing emotions has been used therapeutically. For instance, spinning chair was used to treat mania or elevated arousal in nineteenth century.<sup>[4]</sup> While vestibular dysfunction is well known to affect mood and is associated with anxiety disorders and depression.<sup>[5,6]</sup> Conversely, changes in mood/emotions can also influence body balance, which may probably be mediated through vestibulo-ocular reflex pathways.<sup>[7]</sup>

The influence of vestibular stimulation on emotions is mediated through its projections to limbic system, insula,

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DOI:

10.4103/0976-9668.198350

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**How to cite this article:** Rajagopalan A, Jinu KV, Sailesh KS, Mishra S, Reddy UK, Mukkadan JK. Understanding the links between vestibular and limbic systems regulating emotions. *J Nat Sc Biol Med* 2017;8:11-5.

the cingulate gyre, the hippocampus, and the parabrachial nucleus, via cerebellar, brainstem, diencephalic centers, and amygdala cells.<sup>[8-13]</sup> Moreover, vestibular system is well-networked with dorsal raphe and the locus coeruleus, which are important structures involved in the regulation of the emotional state.<sup>[14,15]</sup> Most of the children and even adults such as movements associated with vestibular stimulation and often show positive emotions following movements leading to vestibular stimulation.<sup>[4]</sup> Recent research supports using vestibular stimulation as a simple, common therapy for stress-related disorders, which are often difficult to understand and treat with drugs and other conventional therapies.<sup>[16,17]</sup> One of the possible mechanisms involved in the benefits from vestibular stimulation may be, reintegration of impaired cortical areas through activating thalamocortical centers.<sup>[18]</sup> A thorough understand of the mechanisms involved in the benefits from vestibular stimulation are necessary to optimize the therapeutic benefits from these techniques; hence, we review here, the possible mechanisms through which vestibular system can influence emotions.

## MATERIALS AND METHODS

A detailed review of published literature from Google, PubMed, and MEDLINE was performed and analyzed. The following key words were used in our literature search: vestibular stimulation, mood, and/or emotions.

### Vestibular stimulation influences emotions through modulating cerebral cortex

The vestibular nucleus acts as a relay station between the peripheral and central nervous system. Experience and behavior are two major factors, which can influence emotions, and the cerebral cortex plays a critical role in mediating emotions.<sup>[19]</sup> Both superior and lateral vestibular nuclei have axons networking the ventral posterior nuclear complex of the thalamus, which projects to two cortical areas relevant to the vestibular sensation.<sup>[20]</sup> Vestibular stimulation was found to modulate brain functions,<sup>[21]</sup> probably by activating somatosensory areas, (particularly the thalamocortical), and deactivating the visual areas.<sup>[22]</sup> These studies strongly support the role of the cerebral cortex and the pathways networking the vestibular nuclei in regulating emotions. It is likely that these networks may exist in several forms include the chemical forms (dopamine, serotonin, acetylcholine, and norepinephrine) which are part of the diffused modulatory systems.

### Role of limbic system in vestibular stimulation influencing emotions

The limbic system is a major cluster of higher centers, which influences emotions. The limbic system consists

of cingulate gyrus and parahippocampal gyrus in the cerebral cortex, several nuclei in the cerebrum, amygdala, hypothalamus (mammillary body), and hippocampus. The anatomical organization of the limbic system varies across different species and is highly developed in species exhibiting strong emotional behaviors. The role of the limbic system in emotion was first explained by James Papez in 1937 in his paper titled “A proposed mechanism of emotion.” The model proposed by him was popularly known as Papez circuit,<sup>[23]</sup> which highlighted the presence of neuronal pathways between vestibular system and limbic system.<sup>[24]</sup> Vestibular stimulation activated the limbic system and neocortex; hence, providing a neuroanatomical and probably a neurochemical link between vestibular stimulation and the limbic dopaminergic system.<sup>[25,26]</sup> However, our current understanding of these complex neuronal networks is very limited, which warrants further research to decipher the mechanisms by which vestibular stimulation triggers these networks to influence emotions.

The hypothalamus is a vital part of the limbic system; hence, vestibular stimulation by influencing hypothalamus can impact emotions either independently or as part of the general limbic system networks. Indeed, the influence of hypothalamus on emotional behavior is previously reported,<sup>[27]</sup> which is not surprising considering the role of this center in thermoregulation and several vital endocrine functions. Lesions of hypothalamus are usually associated with extreme passivity, loss of drive/motivation, excessive eating and drinking, and rage and violent behavior.<sup>[2]</sup> Several of these behaviors are often of extreme social concern both from the patients and societal views. Hence, research to understand the role and utility of simple interventions such as vestibular stimulations to cure such disorders associated with hypothalamus malfunction may be of immense medical benefit. Such research may specifically look at further understanding the role of HPA axis modulation by vestibular stimulation through vestibulo-paraventricular polysynaptic pathways.<sup>[28]</sup> Interestingly, vestibular system is also connected with lateral and posterior hypothalamus,<sup>[13]</sup> which has a very diverse endocrine role and necessitates further research to understand the utility of vestibular stimulation in influencing this vital physiology.

Like hypothalamus, amygdala, and hippocampus are also part of the limbic system and hence are involved in the regulation of emotions and probably memory. Specifically, amygdala and prefrontal activity integration are reported to play a key role in the regulation of emotions.<sup>[29]</sup> Retrograde viral transneuronal tracing has strongly supported the existence of vestibular projections to central amygdala cells,<sup>[13]</sup> which indicates the possible utility of vestibular stimulation in influencing the physiology of amygdala. Amygdala is also a neural substrate which is involved in

the development of and habituation to motion sickness;<sup>[30]</sup> hence, it is likely that vestibular stimulation may have a role in treating motion sickness disorders and aid in promoting patients quality of life. The interaction of amygdale and hippocampus plays an important role in emotions. It was reported that amygdale can modulate both the encoding and the storage of hippocampal-dependent memories,<sup>[31]</sup> indicating a potential role for vestibular stimulation techniques in improving memory-related health issues. Further supporting the role for vestibular stimulations in influencing emotions is a presence of anatomical, functional and chemical connections between vestibular nuclei and hippocampus, which can be triggered to activate hippocampus.<sup>[32-34]</sup>

### **Vestibular stimulation regulates autonomic nervous system to influence emotions**

The activity of autonomic nervous system (ANS) is considered as a major component of peripheral nervous system, which can influence emotional response.<sup>[35]</sup> Within this, the balancing regulation of sympathetic and parasympathetic systems in influencing several systemic physiology is well known. Vestibular system influences autonomic regulation through vestibule-autonomic networks.<sup>[36,37]</sup> Interestingly, autonomic malfunctioning is reported as a probable cause for vertigo<sup>[38]</sup> and several other cardiovascular, renovascular, and cerebrovascular disorders. Probably, ANS may be one of the major targets that are positively influenced by vestibular stimulation techniques; hence, the systemic benefits observed with such interventions. Vestibular system balances autonomic activity by stimulating vagal system and inhibiting sympathetic system;<sup>[39-42]</sup> hence, driving the physiology toward a much calmer state.

### **Vestibular stimulation influences emotions through regulating several higher centers in the central nervous system**

The insula represents emotional experience because it receives interoceptive inputs from the whole body, and its connections with the prefrontal regions of the cortex can provide contextual information. Activation of the insula was reported to influence subjective feelings,<sup>[43]</sup> which may involve the inputs from the limbic system networks as highlighted above. Anterior cingulate cortex (ACC) and the medial prefrontal cortex have also long been thought to play a critical role in emotional processing,<sup>[23,44]</sup> either independently or possibly via the limbic networks. Hence, by modulating these higher centers in the central nervous system, vestibular stimulation may positively influence emotions. This is further supported by the core regions of the multimodal vestibular cortex, which is defined as the PIVC.<sup>[45-49]</sup> Anatomical, physiological, and chemical-based vestibular projections exist to anterior insula, adjacent inferior frontal gyrus, and ACC, which has a regulatory

role on interoceptive inputs necessary for physiology of emotions.<sup>[50-54]</sup>

The parabrachial nucleus produces somatic, emotional sense in integration with amygdale, and insula.<sup>[55]</sup> To and fro projections from vestibular nucleus to parabrachial complex were traced in several animal models,<sup>[39,56-58]</sup> which further supports the role for vestibular stimulation in regulating physiology of emotions. Indeed parabrachial nuclear complex containing neurons responsive to vestibular stimulation has been demonstrated.<sup>[59]</sup>

Dorsal raphe nucleus (DRN) is a major source of serotonin and modulation of serotonin levels, has a major role in value-based decision-making process.<sup>[60]</sup> Interestingly, serotonin is also a major player in diffuse modulatory systems, which help vestibular nuclei connect with the limbic system and hence regulate emotions. The malfunction of serotonin or its receptors (5-HT system) is associated with several emotional/neuronal disorders such as depression, schizophrenia, drug abuse, autism, and Parkinson's disease.<sup>[60]</sup> Indeed several direct and indirect connections exist between vestibular nucleus and DRN,<sup>[61-65]</sup> further supporting the role for vestibular stimulation in activating DRN<sup>[65]</sup> and regulation of emotions.

## **CONCLUSION**

The vestibular system is extensively networked with the limbic system, and hence vestibular stimulation can influence emotional behavior by regulating several higher centers in the central nervous system and autonomic nervous system. A detailed understanding of the anatomy, physiology, and biochemistry of these networks is necessary to refine the therapeutic utility of vestibular stimulation for various medical conditions influencing patient emotions.

### **Financial support and sponsorship**

Nil.

### **Conflicts of interest**

There are no conflicts of interest.

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