Review Article

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Vestibular Stimulation in Neuropsychiatry

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Abstract

Neuropsychiatric disorders involve brain areas of self-awareness, affect voluntary attention to stimuli, and show cognitive processes' dysfunctions. Functional images demonstrated that the stimulation of the inner ear's vestibular receptors enhances the activity of the insular cortex, prefrontal cortex, hypothalamus and hippocampus, improving self-perception, attention, reasoning, and memory. Vestibular stimulation techniques (e.g., caloric, galvanic, and rotary) modulates those neuronal centers at the right or the left hemisphere depending on the kind of the stimuli and the side of stimulation, being a potentially useful therapeutic tool for mental disorders. Neuropsychiatric conditions are currently the leading cause of global disability. The present article reviews vestibular stimulation techniques in neuropsychiatry and discusses future directions.

Keywords: Vestibular stimulation, Brain asymmetry, Mental disorder, Insular cortex, Vestibular cortex, Hippocampus

Introduction

Every moment in our life, we have a feeling about who we are. Self-awareness is relatively stable along the time, however, in mental disorders, the healthy own-perception "turns off" leading to distortions in self-perception like occurs in depression, bipolar disorder or schizophrenia [1].

Despite the inner ear's vestibular system has an important role on the control of movements and the maintenance of the body balance, current evidence is showing now the relevance of vestibular system on self body/mind awareness and cognition. Vestibular receptors register and inform permanently, in a subliminal way, about movements and different positions of our body along the time, helping us to realize that we are alive as individual entities, different from others and separate from the environment [2]. The vestibular input integrates the whole body perceptions as a coherent unity, "I feel my body moving," "it is me." In this way, vestibular afferents

feed the human's self-consciousness that is created in the brain. They conform a functional neural network that is mutually dependent on each other [3].

Even though the brain areas involved in self-awareness have been challenging to define, direct and indirect studies reveals that the insular cortex would have an important role not only in self-perception of internal states of mind and body, but also in the regulation of attention, cognition, and memory [4-7]. Indeed, critical neural networks involved in human reasoning and behavior, like Default Mode Network (DMN), Salience Network (SN) and Central Executive Networks (CEN), depends on the insular cortex [8,9]. Insular dysfunctions found in depression [10-13], bipolar disorder [14], schizophrenia [15] and autism [16] also suggests the involvement of this brain area in self-awareness and mental states.

Several studies in healthy subjects showed that the stimulation of the vestibular system produced an enhancement of the activity of the insular cortex,

thalamus, prefrontal cortex, hypothalamus and hippocampus [17-19]. In fact, these crucial areas for high brain functions and self-perception receive modulatory inputs from the vestibular system [20-23].

The physiological overlapping between the vestibular and self-awareness centers allow considering the vestibular stimulation as an exciting possibility for the treatment of mental disorders. Neuropsychiatric disorders emerged as the great epidemic of the 21st century, now are the primary cause of disability worldwide [24]. The development of effective treatments has become the main challenge in our days. This article reviews the vestibular stimulation techniques and their effects on neuropsychiatric disorders.

The vestibular system

Ciliary cells in the macular epitheliums of semicircular canals respond to angular acceleration of the head, while utricular and saccular ciliary macular cells are sensitive to horizontal and vertical linear acceleration. In order to acquire reliable information about movements and body position, the right and left vestibular receptors must be equally sensitive. Vestibular nerves and vestibular nuclei also must function symmetrically. If this is not the case, vertigo and dizziness appear.

Three semicircular canals containing endolymph register movements in three different directions. The sensitive hair cells of the ampulla are stimulated with ampulipetal and inhibited by an ampulifugal inclination of cilia [25] (Figure1).

Figure 1: Angular acceleration of the head toward the kinocilium (ampulipetal) in the right ear (+), and contrary (ampulifugal) in the left ear (-) produce stimulation and inhibition correspondingly.

Physiological stimuli for the vestibular system include rotations in the corresponding three-dimensional orientation of each semicircular canal, although there are other artificial methods for stimulating the vestibular receptors. These include unilateral caloric stimulation of the ear, which can induce stimulation of receptors with warmth or inhibition with cold irrigation of the ear, and galvanic stimulation in which the cathode stimulates vestibular receptors and the anode inhibits them (See Figure 2).

Figure 2: Each different modality of vestibular stimulation; caloric (CVS), galvanic (GVS) and angular acceleration (rotatory), can stimulate (+) or inhibit (-) the vestibular receptors of the vestibular system at the right or left ear separately.

In the brain stem, the four vestibular nuclei-superior, medial, lateral and inferior- receive sensorial information from semicircular canals, utricle, and saccule, inducing antigravity muscular activity, eyes movements (vestibular-ocular reflex) and widespread brain activation. In humans, the primary vestibular cortex, which described in macaque monkeys, corresponds to the parieto-insular vestibular cortex (PIVC), which is responsible for the perception of dizziness. The prefrontal, hypothalamic, thalamic, and hippocampal areas also are activated by changes of head position sensed by the vestibular system [26] (Figure 3).

In physiological conditions, natural body movements stimulate the right or left vestibular system randomly. It is both brain hemispheres have an equal probability of being activated. However, the different vestibular stimulation techniques: caloric, galvanic or Rotary vestibular stimulation, allow the stimulation/inhibition of the right or the left ear independently. Brain images allow demonstrating that the stimulation of the right ear's vestibular system produces brain activation mainly at the right hemisphere [27]. The stimulation of the left

ear enhances the activity of the left side of the brain. (See Figure 4).

Figure 3: The insular cortex, hippocampus and hypothalamus receive vestibular modulation.

Figure 4: Inhibitory/excitatory ipsilateral brain afferents coming from the vestibular system allow modulating separately right or left hemispheres.

Caloric vestibular stimulation

After reviewing the literature we found only three studies with caloric stimulation in neuropsychiatric diseases. All of them used cold water in the left ear.

The first one dates back to 2004 when Dodson reported a significant decrease in the Young Mania Rating Scale (YMRS), from 32 to 10 of a woman with bipolar disease who was in the manic phase of the illness. The improvement lasted 24 hours after irrigating the left ear with cold water 4°C for 3 to 4 minutes [28].

The second was published by Levine in 2012 who used the same technique of cold water at 4°C applied in one ear first, and after four days applied in the other ear, in three bipolar patients in a manic phase. The stimulation in the left ear increased the electroencephalogram activity, especially on the right side, also showing improvement in the symptoms for approximately 20 minutes [29].

The third study corresponds to a randomized clinical trial published by Gerretzen, where caloric stimulation with water at 4°C was applied sequentially in the right ear and left ear of patients within the spectrum of schizophrenia. This study showed improvement in symptoms and of the insight that lasted approximately 30 minutes after application of the cold water in the left ear [30].

We also found a case of conversion disorder in a 26-year-old woman who had involuntary movements of the extremities. With caloric stimulation, water at 20°C in the left ear in three sessions (day 1, day 14, day 21), the abnormal movements disappeared [31].

The vestibular caloric stimulation also has been shown short term beneficial effects in a variety of neurological conditions, especially in lateralized brain lesions [32,33].

Galvanic vestibular stimulation

Only one published study used galvanic vestibular stimulation, although it was not in psychiatric patients, we included it in this review. It consisted in the applied GVS in three conditions: sham, 38 minute session of GVS and 76 minute session of GVS in a group of 32 students. They observed a significant decrease in anxiety after a 38 minute session. The polarity of the galvanic stimulus changed 4 to 8 times depending on the duration of the stimulus [34].

Motion vestibular stimulation

We found some investigations applying vestibular stimuli, such as movements and physical exercise. Five in children with Attention Deficit Disorder (ADHD), one in Autism Spectrum Disorder (ASD) and one study for anxiety and stress in young subjects [35]. These studies do not quantify the stimulus, nor are they lateralized. All of them report beneficial effects. Studies in ADHD show improvements in attention, motor skills, inhibition of motor response and in motor planning, after 2 to 3 sessions of vestibular exercises per week.

In the only study conducted in autistic children, the six children who received vestibular and tactile stimulation improved their behavior, while the six children who did not receive it, did not change [36].

Conclusions

There is ample evidence of the modulatory capacity of the vestibular system on self-perception and cognitive abilities such as attention, decision making, executive functions, and memory; however, the investigation of vestibular stimulation in neuropsychiatric diseases is scarce.

We found studies of CVS in mania, schizophrenia, and conversion disorder. GVS was used for anxiety, while studies of vestibular stimulation with random movements, exercises, and rocking chairs, were used for ADHD and autism, and to evaluate the anxiolytic effect in university students. We did not find studies of vestibular rotatory stimulation in neuropsychiatric conditions.

The reports about CVS allow us to conclude that for mental disorders like manic states, schizophrenia and conversion disorder, the stimulation must be unilateral with specific lateralization: cold water in the left ear. Cold water would eventually inhibit the left ear and consequently inhibit the left brain vestibular cortex, producing the beneficial effects in self-perception and behavior, rebalancing the bilateral brain activity. From these reports, we can conclude that the optimal healthy right-left balance of activity can be restored by the stimulation of the right side or by the inhibition of the left side. We wonder if in these cases, the stimulation of the right ear with hot water or the GVS with the cathode in the right ear would produce similar sound effects.

We find one study protocol, no published results yet, using unilateral vestibular stimulation in bipolar disorder's

depressive phase [37]. Given that there is evidence of decreased activity of right insula in depression [38,39], and also of diminished vestibular activity at the right side [40], it would be interesting to develop lateralized vestibular stimulation protocols to stimulate the right side hemisphere in this pathology.

GVS of alternating polarity within both ears was useful for anxiety. Vestibular stimulation performed with movements and exercises decreased the symptoms of autism and ADHD. In either cases, both sides were stimulated equally in an alternating fashion. The vestibular information reaches right hemisphere mostly; the beneficial effects are likely due to increased activity in right-sided neuronal centers of the self-perception influencing the DMN, the SN and the CEN. It would be interesting to quantify if there is an improvement of the neural activity at the insular cortex and PIVC at the right side brain hemisphere.

A balanced activity between both brain hemispheres is an essential issue for mental health and probably also for proper brain functioning. Changing the optimal bilateral relationship would lead to the impairment of superior brain abilities and mental disorders. Several studies have shown abnormal anatomical and functional asymmetries in neuropsychiatric conditions [41]; however, the neuronal structures and the side involved in the different mental illness, are still uncertain matters. The experience with brain stimulation techniques like transcranial magnetic stimulation (TMS), Direct Current Stimulation (DCS), or Electroconvulsive Therapy (ECT), show that the unilateral stimulation, is more efficient than bilateral [42,43], suggesting the importance of considering abnormal brain asymmetries in mental disorders.

Vestibular stimulation techniques can be useful for restoring the balance between brain hemispheres. The challenge is finding the adequate side to stimulate and a technique that produces long-lasting beneficial effects.

Declarations

Ethics approval and consent to participate

N/A

Consent for publication

AMS consent the publication of this article.

Availability of data and material

N/A

Competing interests

AMS has competing interests in vestibular stimulation techniques.

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Authors' contributions

AMS conceived and wrote the paper.

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