Review

Progress in Research on Vestibular Rehabilitation Therapy

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Abstract

The deterioration of vestibular function is a side effect of numerous diseases of the inner ear. Vertigo is the most common symptom of vestibular dysfunction. Vestibule-suppressing drugs can control symptoms but impede the rehabilitation of vestibular function. Surgical treatment can effectively resolve vestibular dysfunction associated with some progressive diseases, including tumors. However, unilateral vestibular function remains permanently damaged after surgery, causing problems like vertigo and imbalance. To enhance the understanding of Vestibular rehabilitation therapy, this paper presents a summary of the progress in research on Vestibular rehabilitation therapy for patients with vestibular dysfunction.

The deterioration of vestibular function is a side effect of numerous diseases of the inner ear. These diseases include blood disorders, such as hypertension, hyperviscosity syndrome, and atherosclerosis, as well as various infections, such as vestibular neuritis, labyrinthitis, and Meniere's disease. Vertigo is the most common symptom of vestibular dysfunction. If a patient with vestibular dysfunction does not receive timely treatment, psychological problems, such as depression and anxiety, will occur and greatly affect the patient's quality of life^[1]. Vestibule-suppressing drugs can control symptoms but impede the rehabilitation of vestibular function. Surgical treatment can effectively resolve vestibular dysfunction associated with some progressive diseases, including tumors. However, unilateral vestibular function remains permanently damaged after surgery, causing problems like vertigo and imbalance. Vestibular rehabilitation therapy (VRT), which is based on compensatory mechanisms, has gradually become the main treatment method for vestibular dysfunction given its effectiveness and reliability^[2,3].

Concept and development history of VRT

By as early as the 1940s, Cawthorne and Cooksey had

proposed the possibility of improving vestibular functions through systematic rehabilitation training. Their proposed treatment method is called Cawthorne–Cooksey Exercises. In 1972, based on the theories of Cawthorne and Cooksey, McCabe suggested that rehabilitation training could alleviate symptoms of vertigo. In 1974, Heeker *et al.* reported that 89 patients who were trained for 2 months in accordance with the above method experienced a significant therapeutic effect: vertigo disappeared in 17% of the patients, symptoms improved in 67% of the patients, and symptoms were aggravated in 4% of the patients^[4]. Vestibular rehabilitation therapy (VRT) is a training-based therapy method for patients with vestibular dysfunction. This method is implemented with the aim of improving the patient's sense for vestibular position, vision, and proprioception in coordinated control over the balance and transfer of the compensatory function of the central nervous system. VRT is not strictly defined and can be understood as a series of professionally prepared sports training. VRT is repeatedly conducted for the head, neck, and body to: 1) strengthen balance; 2) increase postural stability; 3) improve vertigo symptoms; and 4) improve daily life. VRT can boost the balancing functions of patients and increase the ability to resist dizziness. As its effectiveness and reliability have been

demonstrated by increasing numbers of clinical studies, VRT has gradually become another important treatment method for vestibular dysfunction in addition to medicine and surgery^[5,6].

Mechanism of action

VRT is realized through the plasticity and functional compensation of the central nervous and vestibular systems. Vestibular compensation is a central process with an extremely complicated mechanism of occurrence. All structures related to the vestibular system might participate in this process^[7]. VRT possibly induces vestibular compensation via the following mechanisms.

Vestibular adaptation

Through the adaptability of the central nervous system to vestibular damages, the vestibular system adapts to the long-term input of asymmetric information from the peripheral vestibule. The vestibular system exerts adaptive control over the vestibular reflex by changing the gain, time phase, and direction of the vestibular reflex^[8]. The main vestibular reflexes are: 1) Vestibulo-spinal reflex (VSR), which mainly maintains balance through the dominance of the lateral vestibulospinal tract over the trunk and limbs after combined input from peripheral senses like vision, proprioceptive sense, and vestibular sense. Romberg's test is the first to evaluate VSR. In recent years, VSR has been commonly evaluated using posturography (PG) technology. 2) Vestibulo-ocular reflex (VOR), in which the signal is transferred to the center through the nuclei of cranial nerves III, IV, and VI on the adjacent and opposite sides of the cerebrum. The vestibular sense can immediately create reflexive ocular movement and allow the eyeball to turn to the opposite side when the head rotates to one side, thus maintaining stable vision^[9]. In patients with reduced unilateral vestibular functions, the gain in their VOR decreases and the visual image appears to repeatedly slide in the retina. This sliding signal repeatedly irritates the vestibular nervous system and enables the vestibular center to increase the gain in VOR, causing vestibular adaptation.

Vestibular habituation

The reactivity of the vestibular system gradually decreases after suffering from a series of repeated irritations. The mechanism of vestibular habituation includes two

components: the neural storage section, which is used to store spatial sensory information; and the comparative unit, which enables the comparison of previously stored sensory information with currently intercepted information^[10]. Its specific mechanism remains unknown. Vestibular habituation is directional and metastatic. Once formed, it can be maintained for a certain period and can be sustained for even longer durations if continuously irritated. The exercise methods for habituation are similar to those for astronauts to overcome space sickness and include swinging and turning in a rotating chair.

Vestibular compensation

Symptoms like vertigo, nausea, and physical imbalance occur when the peripheral vestibule is damaged on one side. After some time, however, these symptoms retreat or disappear. Possible mechanisms for vestibular compensation include changes in the contralateral vestibular nucleus, particularly in the expression of nitric oxide synthase and in the secretion of neurotransmitters, such as choline acetyltransferase; these changes adjust the excitability of the vestibular center^[11].

Substitution

To sustain body balance, the lost functions of the vestibule are replaced by vision and proprioception or neck-eye reflexes.

Substitution of vision and proprioception

Although vision and proprioception can aid the recovery of postural stability when unilateral or bilateral vestibular functions are lost, they do not always work in any situation, e.g. they fail in a dark environment. Therefore, this substitution method has some limitations.

Neck-eye reflex

Neck-eye reflexes are slow-phase eye movements that result from sensory input after the irritation of cervical tendons, muscles, and articular surface. These responses can compensate for the insufficiency of VOR in slow and instantaneous head movement. The different mechanisms for VRT are crucial for the design of a specific rehabilitation scheme. Not all patients with vestibular dysfunction can benefit from rehabilitation training. Vestibular compensation can achieve optimal effects only if some physiological mechanisms in the body remain intact^[12]. Given the

different degrees of damage to vestibular function and the compensation ability of different patients, the vestibular functions of patients should be first checked and evaluated prior to the preparation of suitable rehabilitation training programs^[13].

Training method for VRT

General training

Cawthorne–Cooksey Training is the most common VRT training method. The principle of this training method is that patients should desensitize themselves by performing activities with gradually increased speed and scope. Patients complete the following actions under the direction of a physician: 1) In a recumbent position, the patient first moves their eyeballs quickly and then slowly; moves their head slowly and then quickly; and finally closes their eyes. 2) In a sitting position, in addition to eye and head movement, the patient shrugs, turns their shoulder, and bends forward to pick an object from the ground. 3) In an erect position, in addition to completing the related actions done in the sitting position with their eyes open or closed. The patient then changes from the sitting position to the erect position. With both hands below the eye plane, the patient throws a small ball back and forth. The patient repeats the same action with both hands below the knee plane. The patient then moves from the sitting position to erect position and turns around simultaneously. The patient then walks around one person and throws or passes a large ball to or from the person in the center of the circle, walks around with their eyes first open and then closed, walks uphill and downhill with eyes first open and then closed, climbs upstairs and downstairs with eyes first open and then closed. Cawthorne–Cooksey Training is mainly suitable for patients with poor functions of the vestibule. Early and regular training provides good clinical effects. The main advantages of this method are economy and convenience. Moreover, this method will be more effective if built on the basis of accurate diagnosis.

Individualized physical therapy

The VRT method advocated by Horak *et al.* in the 1980s complements the pertinent training program based on the functional defects and diagnosis of patients, as well as on the timely adjustment of the rehabilitation plan based on the patient's conditions during treatment. Its main training measures include: fixation stability, vision reliability

training, proprioception reliability training, and posture reliability training^[15]. Fixation stability training improves the gain of the vestibule-eye reflex and improves symptoms like clouded vision and dizziness during head movement and walking. This training method is suitable for patients whose unilateral vestibular functions are poor or lost and whose bilateral vestibular functions have been completely lost. By closing their eyes during vision reliability training, the patient decreases visual irritations and visual reliance, and can better use the input of proprioception or vestibular sense. This training method should be combined with exercises that increase postural stability.

In proprioception reliability training, patients stand or work on a cushion, a surface mimicking a sandy beach, a plastic foam mat, or a cross bar. Standing or working on these surfaces intervenes with the proprioception of the patient, thus decreasing reliance on proprioception and extending vestibule and vision input. This training is suitable for patients with low or lost unilateral vestibular functions, but should be combined with exercises that increase fixation and postural stability.

In posture reliability training, patients stand on foam plates of different densities. Patients then stand on their tiptoes and spread or close their legs with their eyes open or closed. These exercises aim to improve postural stability by training proprioception. Individualized physical therapy is more expensive than general training but provides significant therapeutic effects.

New VRT methods

With the rapid development of science and technology, some training devices have been gradually integrated into VRT; virtual reality training is an example. VRT integrated with technology^[16]. In this training method, a computer is utilized to generate a vivid three-dimensional audiovisual stereoscopic projection, allowing the patient to interact with the virtual world and realize the effect of VRT by irritating retina sliding and through vestibular habituation in specific environments^[17]. The virtual reality training method is promising and provides challenging environments under safe and easily controlled conditions to strengthen training effects. Virre *et al.*^[16] suggested that this method increases vestibule–eye reflex gain and reduces the degree of dizziness. Thus, this method is suitable for vertigo patients with low gain in vestibule–eye reflex or psychological disorders like acrophobia and agoraphobia. Nevertheless, the virtual reality

training method remains at the testing stage without large-size clinical trials.

Application of VRT in various patients with dizziness

Benign paroxysmal positional vertigo

Benign paroxysmal positional vertigo (BPPV) is a paroxysmal transient vertigo induced by the changes in specific head position or a common lesion of the peripheral vestibular organ. BPPV is mainly treated with manual reduction, including the Epley and Barbeque roll maneuvers. Wu Ziming *et al.*^[18] found that BPPV can appear in patients with inner ear lesions and manifests as sudden deafness, vestibular neuritis, and Meniere's disease. The effects of manual reduction on secondary and primary BPPV are similar. Liu Xingjian, *et al.*^[19] used the Epley Maneuver to treat 402 BPPV patients with ear disease symptoms. Of these patients, 376 patients were cured after repositioning once, 17 patients were cured after repositioning twice, and 9 patients did not show any improvement. Kong Weijia *et al.*^[20] used the Epley maneuver to treat 55 patients with posterior semicircular canal BPPV. They also used the Barbeque roll maneuver to treat eight patients with lateral semicircular canal BPPV. They reported that symptoms were completely alleviated after one or multiple treatments. Banfield, *et al.*^[21], however, argued that although Epley maneuver and VRT present the same long-term therapy effect, the long-term therapy effect of VRT is superior to that of Epley maneuver; the researchers also emphasized the application value of VRT in the treatment of BPPV. In addition, manual reduction is unsuitable for some elderly patients and BPPV patients with cervical spondylosis. VRT should be selected to relieve the symptoms of these patients.

Unilateral vestibular hypofunction

Patients with poor spontaneous compensation induced by non-progressive vestibule lesions^[22], such as unilateral vestibular hypofunction (UVH) caused by post-labyrinthectomy, post-acoustic neuroma surgery, and vestibular neuritis, can use VRT as the preferred therapy method. The results of previous studies suggested that VRT is unsuitable for patients with Meniere's disease given the large fluctuation in the state of illness. Whitney *et al.*^[23], however, found that VRT during the symptomatic remission of patients improves the ability of patients to conduct their daily

activities. Bittar *et al.*^[24] stated that VRT can promote the effect of the vestibule–spinal cord reflex and compensation of patients who underwent unilateral vestibular surgery or post-acoustic neuroma surgery, thus significantly improving the symptoms of vertigo. This conclusion and the findings of Tokumasu *et al.* are identical.

Bilateral vestibular hypofunction

Symptoms of bilateral vestibular hypofunction (BVH) generally include oscillopsia, dizziness, and tinnitus with less true vertigo. The main origin of BVH is drug-induced ototoxicity. Ward *et al.*^[26] recently conducted a large-scale study in the United States. Their report showed that among 100,000 adult Americans, 28% have BVH. The symptoms of 44% of these patients are linked to their driving habit and those of 56% are due to a decrease in their social activities. VRT is used to substitute vision function and proprioception for missing or attenuated vestibular signals, thus improving balance. However, most of the patients had difficulty recovering to their normal functional level because of habituation.

Abnormality of vestibular function in the elderly

Although symptoms like dizziness usually appear in the elderly due to their age and organ function failure, no abnormalities of vestibular function are generally found upon examination with electronystagmography. At this point, VRT will help maintain posture balance among the elderly^[27].

Central vestibular dysfunction

Central vestibular dysfunction (CVD) mainly results from traumas and tumors. Given its primary focus, VRT does not have a significant effect on CVD but greatly influences postural stability^[28]. The balance and dizziness of patients with vertigo from the relapsing–remitting form of MS significantly improve after undergoing rehabilitation training.

Conclusion

The deterioration of vestibular function caused by various diseases has drawn increasing attention from clinicians given that it causes extreme discomfort and greatly influences the quality of life of patients. Regardless of the origin, duration, and intensity of the disease and the ages of the patients, VRT is suitable for patients with stable vestibular lesions and

whose vestibular function is decompensated. Although there have been numerous pieces of evidence for the validity of VRT, its safety remains problematic and there are currently no reliable means for evaluating its effect. VRT is another important means to treat the deterioration of vestibular function in addition to surgery and drugs. Patients who have been treated with this method experience no adverse reactions. Given its simplicity, economy, and easy acceptance, VRT is worth popularizing.

Declarations

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No.

Competing interests

The authors declare that they have no competing interest.

Authors' contributions

Y Wang made the literature analysis and wrote, discussed and revised the manuscript of this review. Q Guo critically analyzed and corrected the manuscript. All authors read and approved the final manuscript.

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