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Diagnosis of Acute Unilateral Vestibular Deficit by Virtual Reality

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Abstract: The aim of our study was to establish a new diagnostic approach, through the use of virtual reality, to the study of the subjective vertical bar in unilateral peripheral vestibular dysfunction. We subjected 174 patients with unilateral peripheral vestibular dysfunction (ages 18–82 years) to vestibular diagnosis with the virtual reality system. We changed the classic configuration of the subjective visual vertical into a subjective visual horizontal bar. This technique revealed values of the subjective visual horizontal outside the normal range in 91% of patients.

Key Words: acute unilateral vestibular deficit; vertigo; virtual reality

Unilateral acute peripheral vestibulopathy is manifested as severe, sudden vertigo that often occurs during the night, may gradually increase over several hours, and can persist for more than 24 hours [1]. Spontaneous nystagmus is manifested on the plane of the damaged semicircular canal, with a slow phase directed toward the pathological side. The plane of horizontal nystagmus is horizontal or horizontal-rotatory [2,3]. Otolithic involvement may, instead, be revealed by the presence of a skew deviation (or vertical strabismus) with cyclotorsion of the eyes and inclination of the head to one side (ocular tilt reaction).

This pathology may stem from trauma (temporal bone fracture); infection (suppurative labyrinthitis; specific viral neuritis, such as herpes zoster); or autoimmune, toxic, and vascular causes (ischemia, spasm, Wallenberg's syndrome). In many cases, however, the cause is unknown [4]. In addition to careful anamnesis and otoneurological examination, diagnostic maneuvers (head-shaking test), such instrumental tests as the galvanic and caloric tests, and examination of the subjective visual vertical are necessary for a correct diagnosis. The aim of our study was to establish a new diagnostic approach through virtual reality (VR) to the study of the subjective vertical in unilateral peripheral vestibular dysfunction.

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SUBJECTS AND METHODS

To test the application of VR on our patients, we used a VR helmet sold commercially and connected to an ordinary personal computer. This head-mounted display uses two visors with liquid crystals mounted on a band support, very similar to that used on Clarke's photophore. The head tracker is positioned at the nape of the subject's neck. This system permits binocular vision on two screens and is comfortable even if a patient wears glasses. To improve immersion in VR, the structure was covered with opaque plastic material, and tests were carried out in a room without visual or acoustic stimuli.

For our purposes in setting up the system, 800 normal subjects underwent testing. We thus obtained a range of normality between +1.3 and −1.3. Subsequently, 174 patients with unilateral peripheral vestibular dysfunction (81 female, 93 male; ages, 18–82 years) underwent vestibular diagnosis with the VR system. No limits were set in seeking patients to treat.

Our protocol involves thorough anamnesis, an objective otoneurological examination, instrumental tests (galvanic and caloric), and examination of the subjective visual vertical. At the start of the VR test, a patient sits on a rigid support and initially looks straight ahead.

The helmet then is fitted, which enables the patient to see a horizontal white line in the center of a black field of vision. The center of the field of vision consists of the plane of "absolute horizon," around which the line of reference shifts in accordance with the patient's head movements.

After 20 seconds, the computerized system shows the width of the angle (expressed in degrees) between the final position of the line and the horizontal line passing through zero. The patient always sits facing away from the computer, which enables the position sensor on the helmet to use the same initial spatial coordinates for each patient. This allows for assigning a positive score to the final angle as a result of the final leftward inclination of the patient's head and a negative score to the final angle as a result of the final rightward inclination of the patient's head. All subjects considered for our study were studied 24 hours after executing the caloric test.

RESULTS

This VR technique revealed values of the subjective visual horizontal outside the normal range in 91% of patients. In the 76 patients with left unilateral peripheral vestibular dysfunction, the final score corresponding to the inclination corner appeared on average to consolidate on values of −3.26 (arithmetical average) and so were out of the normal range of values (66 patients); 10 patients were found not to exhibit this tendency on taking the VR test to the left. In the other group consisting of 98 subjects with right unilateral peripheral vestibular dysfunction, 92 patients appeared on average to consolidate on values of +3.47 (arithmetical average) and therefore also were out of the normal range; 6 patients were found not to exhibit this tendency on taking the VR test to the right.

Even in patients in whom the VR test result turned out to be negative, as evidenced by the use of the caloric test, a considerable decrease was seen in the number of provoked nystagmic movements. The number of these nystagmic movements for right and left hyporeflexia consolidate on average on values of 46 and 38 horizontal rhythmical movements, respectively, with a rapid movement toward the side opposite the hyporeflexive side.

DISCUSSION

Our objective was to test the possibility of applying VR technology to new diagnostic fields. To this end, we decided to use the sight sensory channel in patients experiencing dizziness [5,6]. Our attention focused on experimentation with a new method for studying the subjective horizontal in patients with acute unilateral peripheral vestibular dysfunction. When the otolithic signal to the vestibular nuclei is asymmetrical, the internal representation of parameters of verticality is distorted, thus altering the vertical sensation [7,8]. Traditional methods (line of Maddox, direct ophthalmoscopy) have revealed that normal subjects can clearly distinguish the true vertical [4]. By contrast, patients with unilateral peripheral vestibular dysfunction show vertical visual deviation, which is more marked when the lesion has been present for a shorter time. In fact, with the passage of time, the central compensation is corrective of the vestibular dysfunction by adaptive mechanisms. When some information is missing, especially visual information, or when various senses give conflicting information, illusions and space disorientation can arise. In patients with unilateral peripheral vestibular dysfunction, three important semiotic elements have been identified—inclination of the head to one side, vertical strabismus, and conjugate cyclotorsion of the eyeballs—all of which are directly related to an acquired alteration of vertical perception [9–12].

The head is inclined toward the same side as the inclination of the vertical line; this deviation is caused by a process of postural adaptation to the abnormal sensation of vertical position felt by an affected patient [13]. Regarding vertical strabismus, the lower eye is situated on the side toward which the vertical line is inclined. This positional anomaly brings the plane of gaze nearer (i.e., the plane toward which the optical axes pass, which is perceived as a new horizontal plane) [14].

The cyclotorsion of eyeballs tends to bring the vertical axes of the eyeballs in line with the abnormal vertical axis perceived [12,15]. Assessment of the three aforementioned parameters can yield important information on otolithic function (i.e., on peripheral vestibular function). The ideal condition in which to study the time course of the phenomenon is that of vestibular neurectomy: In this case, the head in orthostatism on the abnormal side deviates by an average of ±12.5 degrees to the side opposite the side of vestibular neurectomy. This alteration tends progressively to diminish, returning to normal over a period that varies from subject to subject [16,17].

In the presence of a central lesion, particularly one due to unilateral vascular pathology of the brainstem, analysis of the vertical line is a sensitive method, revealing significantly abnormal findings in 94% of patients; the mean deviation is approximately 8 degrees but may be as much as 53 degrees. In caudal brainstem lesions, the tilt of the subjective vertical line is ipsilateral to the lesion, whereas in rostral lesions the deviation is contralateral to the abnormal side. Normalization without therapy generally takes 4–6 weeks.

Our data show an association between the inclination of the head (output values of normal range) toward a precise direction and corresponding vestibular hyporeflexia and vertical line data. This indicates a relationship between the deviation on the horizontal axis (and the pertinent reference angle) and alteration of vestibular function. In studying the ocular kinetic reflex, action of the neck-eye reflex on modulation of the vestibuloocular function is very important: Subjects who had completely lost vestibular function on only one side were seen to have compensated for this deficit not only through the visual and proprioceptive peripheral channel but through hyperresponsivity of the neck-eye reflex.

In normal conditions, eye movements can be compensated, on slow rotation of the head, by the neck-eye reflex, which in this case plays a fundamental role as a neuromediator. In complex movements involving rapid rotation of the head, the vestibuloocular reflex becomes the fundamental stabilizing element of the visual field image, whereas the neck-eye reflex becomes negligible in the stabilization of vision [18,19]. This means that the cervical ocular reflex acts only on low-frequency rotatory head movements. Lateral inclination of the head unaccompanied by rotation would create optokinetic reflexes apparently similar on both sides.

The complex relationship between the vestibular apparatus and the proprioceptive stimuli of the neck can be explained further by the fact that, when a normal subject receives a punctiform light stimulus having a variable frequency between 0.005–1 Hz and 0.4 Hz, in the absence of other external visual or auditory stimuli, a response is obtained, such that the subject is able to identify the target partly through the vestibular and proprioceptive system of the neck. If the frequency is higher, only the vestibulo-ocular system is involved [18–20]. This result would further confirm former neurological studies in terms of which elements of the perceptive system would be used as a basis for judging the direction of the glance and the spatial orientation. In addition, the tradeoff in response time when head and glance are aligned would suggest an incapacity of the perceptive system to keep the position of the head relative to the direction of the glance. With regard to this issue, we should bear in mind the importance of the data provided by the computer on the amplitude of head tilting in relation to the subjective vertical in the different spatial planes [21].

As regards the important role of the central nervous system in the mechanisms that regulate the oculomotor system and body movement, one must remember that in complete darkness, even the normal subject has difficulty in maintaining a correct body position before and after following a target. This means that the central nervous system is playing a complex neuromodulatory role [21]. Unlike traditional vestibuloocular evaluation methods, in which the normal range extends from −2 degrees to +2 degrees, in our method it extends from −1.3 degrees to +1.3 degrees and is therefore more specific [7,8]. The 16 patients in whom alterations to the VR test were not evident or in whom the test was less conclusive have received a proprioceptive "reward" in that the complex neuromodulatory function of the central nervous system has afforded such subjects greater plasticity in postural correction.

Data obtained from the subjective horizontal line refer to the final tilt of the head. This information is more complete and specific in that it is based on data found in the literature [22].

CONCLUSION

Our study reveals a clear relationship between the data obtained from traditional vestibular tests (caloric test, subjective vertical line) and those yielded by VR testing. This finding is especially interesting in that VR offers numerous advantages: It is a noninvasive method, patient compliance is improved [5], and execution is remarkably easy.

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