Influence of Vestibular Disorders on Tilt Perception and Short Term Memory

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Abstract

Introduction: Spatial orientation refers to the fact that the brain integratively recognizes its own position, posture and motion in space through several sensory systems. Vestibular, visual and somatosensory inputs with various motion are constantly integrated in central nervous system to determine the spatial orientation. Among the various parameters of spatial orientation, there has been no study about tilt perception and the memory of tilt perception. Methods: The following subjects participated in these experiments; normal volunteers under 65 years of age (Control group) and bilateral no response to the Caloric test (Bilateral group). Procedure was measurement of the short term memory of tilt perception that were reproduction of 0°and reproduction of right by 5°and left by 5°with improved electric goniometer. Results: Control group: There were no significant differences in the time course, or right and left direction of tilt for any of the age groups. Bilateral group: There were no significant differences in any of the tasks in the procedures between the control group and the bilateral group. Conclusion: Although tilt perception is formed from the vestibular and somatosensory input, it became clear that the vestibular are less important than the somatosensory input, because the bilateral group could also successfully remember tilt positions. It also is clear that such information is remembered for at least a short period of time.

1 INTRODUCTION

Spatial orientation refers to the fact that the brain integratively recognizes its own position, posture and motion in space through several sensory systems. Vestibular, visual and somatosensory inputs with various motion are constantly integrated in central nervous system to determine the spatial orientation.[1]

Among the various parameters of spatial orientation, the measurement of tilt perception for gravity was first done by Grahe in 1922, when he measured the vertical position with a measuring apparatus.[2] He first tilted it manually and returned the subject to the vertical position gradually. He made volunteers with their eyes closed make a sign at the moment they accurately perceived the vertical position. The results were from 2° to 3°, thus indicating that they perceived it very accurately.

Later, Israel et al had volunteers sit inside an opaque fiberglass sphere.[3,4] The sphere was mounted within two motor-driven rings. The subjects were secured onto the chair with three belts, and their head was fixed with a helmet to keep them in the same position. The chair position was adjusted so that the head was at the centre of rotation. Two push-buttons were fixed on the right side of the chair, with which the subjects could control the position of the sphere. The subjects were first required to position their body at an angle of 90°, 180° or 360°, right or left, with the push-buttons, and then to rotate back to the initial position after 3-6 s. The results were as follows; the mean rotation from 0°- 90^{deg} was 93.2^{deg}, for 0^{deg}- 180^{deg} was 169^{deg}, 0^{deg}- 360^{deg} was 313^{deg}, 90^{deg}- 0^{deg} was 92.6^{deg}, 180^{deg}- 0^{deg} was $157^{deg}$and 360^{deg}- $0^{deg}$was 293^{deg}. These results confirmed that subjects accurately perceived their vertical position.

However, both of these previous studies were presented by analogue displays.

Berthoz et al studied the memory of body linear displacement.[5] Volunteers were seated on a robot, their head was fixed in place, and their eyes were covered. After undergoing a displacement of 2, 4, 6, 8, or 10 m, they reproduced, as accurately as possible, the distance that was imposed. Even when the stimulus acceleration (range 0.06 to 1 m/s^2) was changed or the stimulus duration was kept constant (16 s) over the different distances, they could reproduce the distance very accurately.

Although these studies indicate the remarkable ability of the body for special awareness, there has been no study about tilt perception and the memory of tilt perception. We hypothesized that patients who have vestibular dysfunction, especially bilateral vestibular dysfunction with the Jumbling phenomenon, would have disorders in tilt perception and memory.

Therefore, we developed an electric goniometer that enabled digital display of the tilt angle for easy analysis of the results and we studied the influence of vestibular disorders on the tilt perception and short term memory of tilt perception in normal volunteers and patients with no bilateral response to the caloric test.

2 SUBJECTS AND METHODS

2.1 Subjects

The following subjects participated in these experiments.

Normal volunteers under 65 years of age (control group)

N= 50, age: 21- 42 years, average age: 29 years, standard deviation (SD): 5 years, and age distribution: second decade: 20, third decade: 22, fourth decade: 8. The definition of normal volunteers was that they had no vertigo or past history of neurological disease.

Bilateral no response to the Caloric test (bilateral group)

N= 20, age: 18- 75 years, average age: 51 years, SD: 17 years, and age distribution: first decade: 3, third decade: 4, fourth decade: 3, fifth decade: 4, sixth decade: 3, seventh decade: 3. The details of the underlying diseases in the 20 patients are as follows: idiopathic: 8, meningitis: 5, neurofibromatosis type 2 (NF2): 4, auditory nerve disease[6]: 2 and syphilitic labyrinthitis: 1. The Caloric test used irrigated cold water (4, 2 ml) for 20 seconds.

2.2 Methods

For this study, we improved the electric goniometer (NAGASHIMA MEDICAL INSTRUMENTS co., Ltd.) so that we did not monitor any other position (for example, up-and-down of the center of gravity) except for tilt stimulation, and that the movement could be stopped with a joy-stick immediately when volunteers perceived a level of tilt. We were also able to measure the tilt angle from the standard level with a digital display of the tilt angle.

There is a direct-current motor behind the tilt bedplate. This motor connects a right and left changeover switch of the tilt direction, and has a potentiometer that displays the angle and enables measurement to 0.1^{deg}.

It is possible to tilt the subject to a maximum of 20^{deg}on both sides, and to change the angular velocity. This enabled us to maintain the experimental conditions better than the past manual studies and allowed for easy and objective measurement, in contrast to the past studies because of the digital display of the tilt angle.[2-4]

We studied the tilt perception and very short term memory of the tilt in normal volunteers in standing and sitting positions as a pilot study. We found that the sitting position to be more difficult than the standing position. Therefore, we decided to study the patients in a sitting position, and set up the chair on the tilt bedplate of the electric goniometer (Figure 1). We made volunteers sit in the chair without leaning against the backrest. We covered their eyes with goggles to remove the visual input and used an instrument fixed to the trunk, and fixed their head in place with ear pads attached to the chair. Patients were also required to take off their shoes and float both of their legs (Figure 2). We regulated the angular velocity of the tilt at 1^{deg}/sec.

2.3 Experiment

Procedure: Measurement of the short term memory of tilt perception (Figure 2)

Reproduction of 0^{deg}

First, we ordered subjects to memorize their perception of 0^{deg} for 1 minute. We then tilted the subjects to the right by 5^{deg} (R 5^{deg}) and asked them to evaluate this position for 1 minute. Finally, we had them reproduce the initial perception of 0^{deg} immediately, or 1, 3, 5 and 10 minutes later. We recorded tilt angle of their reported position. We also studied the left condition (L 5^{deg}) in the same manner.

Reproduction of R and L 5^{deg}

First we tilted the subjects to R 5^{deg} and asked them to memorise the position of R 5^{deg} for 1 minute. We then returned the subjects to 0^{deg} and asked them to accustom themselves to this position for 1 minute. Finally, we asked the subjects to reproduce the initial R 5^{deg} immediately, or 1, 3, 5 and 10 minutes later. We recorded tilt angle of their reported position. We also studied the left condition (L 5^{deg}) in the same manner.

2.4 Statistical analysis

With regard to the statistical analysis of the results, we performed an analysis of variation (ANOVA) between each of the groups, for the time course between each group, for the right and left directions of tilt between the same group and for differences in age between each of the groups. When a significant difference was observed, we added a t- test.

3 RESULTS

The results are shown in Table 1 and Figure 3, 4.

1. Control group

There were no significant differences in the time course, or right and left direction of tilt for any of the age groups.

2. Bilateral group

There were no significant differences in any of the tasks in the procedures between the control group and the bilateral group. There were also no significant differences in the time course, right and left

direction of tilt or ages between the groups.

Furthermore, there were also no differences between the patients with (5 patients) and without (15 patients) Jumbling phenomenon.

4 DISCUSSION

The spatial orientation is formed from the vestibular, visual and somatosensory inputs as mentioned above.[1] In this study, we covered the patients' eyes with goggles to remove the visual input. Therefore, all of the patients had to rely on their vestibular and somatosensory inputs when they tried to reproduce 0^{deg}, and right and left 5^{deg}in this study.

There were no significant differences in any of the tasks during the procedure between the bilateral group and the control group. There were also no differences in the right and left direction of tilt within each of the groups. The bilateral group do not receive vestibular input. But there were no differences. Therefore, the somatosensory input is sufficient to provide information about the spatial orientation. Fitzpatrick et al and Horak et al reported that the contribution from visual and somatosensory inputs are the most important, and that the vestibular input is primarily used for balance control of normal humans.[7,8] Bronstein et al.

reported that patients with bilateral vestibular disorders are "visually dependent" soon after the vestibular insult, but that they gradually learn to ignore conflicting visual stimuli as compensation develops.[1]Nashner et al, Bles et al, and Peterka et al reported that somatosensory input increases for balance control in patients with bilateral vestibular disorders.[9-12] Nandapalan et al used the Sway Weigh balance platform to determine the efficacy of a walking stick in 25 patients with peripheral vestibular balance disorders.[13] In their study, the patients were tested with their eyes open and closed while they were standing on a flat surface and on an air-filled bed (to alter limb proprioception) on the Sway Weigh balance platform. All the tests were carried out with and without a walking stick. They found that body sway decreased when the subjects used a walking stick when they were standing on an air-filled bed with their eyes either opened or closed, although there were no differences with or, without the walking stick when they were standing on a flat surface.

We suppose that humans form spatial orientation by effectively using remaining information and control their balance according to this information. Judging from these reports, and the tilt perception in this study, it appears that while the contribution of vestibular input is important, somatosensory input is more important (the source of somatosensory input was the hip, because we studied subjects under the condition that they had to sit in their chair without leaning against a backrest).

Although the Jumbling phenomenon is able to occur when bilateral vestibular function is disordered, there were no significant differences between patients with and without it. There were also no differences when we covered subjects' eyes with goggles to remove the visual input. Therefore, we concluded that the somatosensory input is more important than the other types of input.

Furthermore, we also tested a patient with multiple sclerosis (MS) who had disequilibrium and dysbasia due to anesthesia of the hip and bilateral lower legs and a lesion with contrastable effect in the spinal cord under Th4 magnetic resonance imaging (MRI). The result was that the patient was unable to correctly perceive a tilt over the mean tilt angle +- 2 SD of control group in most of the task in the procedure (Table 1, Figure 3, 4). The importance of somatosensory input was further supported by this result.

Although we studied tilt perception immediately, and 1, 3, 5 and 10 minutes after changing positions in order to study the memory of tilt perception, there were no significant differences in the both groups.

There have been reports showing that the hippocampus is involved in memory and recognition of space by experiments on the rat hippocampus.[14, 15] Furthermore, it has been known that there are neurons involved in movement and memory of space in the monkey hippocampus.[16, 17] In addition, there is a neuron group which fires to synchronize a rat's movement that was demonstrating by simultaneously recording freely moving rats' hippocampus, including nearly a hundred neurons. These neuron groups react to differences in position, and they are distributed like a belt in the hippocampus.[18] Based on these reports, it appears that the information processing in the hippocampus facilitates memorization of space and position, via groupable and cooperative neurons, and dynamic change of many neuron circuits are likely involved in the memory of space and position with action.

With regard to the spatial orientation and posture control, groupable and cooperative information processing of many neural circuits including the hippocampus, vestibules, visual system, somatosensory system, cerebellum, limbic system and so on are done unconsciously. It is suspected that many cooperatively and functionally connected neuron circuits dynamically change in response to input of information for that purpose.

There were no abnormalities in tilt perception in the control and bilateral groups in the present study, because the vestibular and somatosensory input that are necessary to integrate spatial orientation function adequately.

Therefore, it is suspected that groupable and cooperative information processing of the above-mentioned neuron circuits, as well as the hippocampus-related memory of tilt perception, can be maintained for at least 10 minutes.

5 CONCLUSION

Although tilt perception is formed from the vestibular and somatosensory input, it became clear that the vestibules are less important than the somatosensory input, because the bilateral group could also successfully remember tilt positions. It also is clear that such information is remembered for at least a short period of time, thus allowing for a return to a normal position.

6 ETHICAL CONSIDERATIONS

This study was carried out in concordance with international ethical standards and the World Health Organisation Helsinki Declaration. It was approved by the institutional review board. Informed consent was obtained from all of the subjects.

Key points

Tilt perception is formed from the vestibular and somatosensory input.

We improved an electric goniometer that enabled digital display of the tilt angle for easy analysis of the results to study the tilt perception and short term memory of tilt perception.

It became clear that the vestibules are less important than the somatosensory input.

The bilateral group could also successfully remember tilt positions.

It is clear that such information is remembered for at least a short period of time.

CONFLICTS OF INTEREST AND SOURCE OF FUNDING

There was no financial and material support for this study.

The authors disclose no conflicts of interest.

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FIGURE LEGENDS

Figure 1 Our improving electric goniometer.

We set up chair on the tilt bedplate of electric goniometer.

Figure 2 Tilt perception and memory.

We made subjects sit in the chair without leaning against the backrest, covered their eyes with goggles, fixed their trunk and head, and made them take off their

shoes and let both of their legs hang freely from the chair.

Figure 3 Tilt perception and short term memory (R5°- 0deg, L5deg- 0deg)

There were no significant differences in any of the tasks in the procedures between the control group and the bilateral group.

vertical axis: tilt angle (deg), white bar: Control group, black bar: Bilateral group, gray bar: MS

Figure 4 Tilt perception and short term memory (0deg- R5deg, 0deg- L5deg)

There were no significant differences in any of the tasks in the procedures between the control group and the bilateral group.

vertical axis: tilt angle (deg), white bar: Control group, black bar: Bilateral group, gray bar: MS

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