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Original Article

Evaluation of Mental Rotation Ability in Patients with Unilateral Benign Paroxysmal Positional Vertigo

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BACKGROUND: Our study aims to determine whether there are differences in mental rotation abilities between unilateral benign paroxysmal positional vertigo patients and healthy controls using object-based mental rotation tasks.

METHODS: Our study included 17 unilateral posterior canal benign paroxysmal positional vertigo patients and 20 healthy adults. Spontaneous nystagmus test, saccade test, and dynamic positional tests with videonystagmography and object-based mental rotation test with 2-dimensional images of cubes rotated at certain angles in 3-dimensional space were performed on the participants. The mental rotation test response time and the number of correct answers were compared between patients and controls. We also evaluated whether there was a relationship between saccade test parameters and mental rotation test parameters in our study.

RESULTS: No significant relationship was found between benign paroxysmal positional vertigo patients and controls on any of the dependent measures ($P > .05$). When we evaluated the relationship between saccadic latency and accuracy and mental rotation test response time and number of correct answers in benign paroxysmal positional vertigo patients, no significant relationship was found ($P > .05$).

CONCLUSION: Our findings show that unilateral, posterior canal benign paroxysmal positional vertigo does not affect object-based mental rotation performance. In our study, no correlation was found between saccadic function and mental rotation ability in unilateral benign paroxysmal positional vertigo patients.

KEYWORDS: Vestibular, cognition, mental rotation, benign paroxysmal positional vertigo, visuospatial ability

INTRODUCTION

Spatial ability enables the organism to navigate familiar or unfamiliar environments, locate objects, interact with them, and store their locations in memory.[1] This ability is a critical cognitive function for the survival of the organism. Like many species, humans have to learn the environmental map to return home or navigate between familiar places.[2] Space is perceived according to the position of the object in the space, the relations between objects, the relations between the body's own parts, and the relations of the body with the objects.[3]

The abilities such as spatial memory, mental imagery, mental rotation, depth and distance and perception, spatial navigation, and visuospatial structure are sub-components of visuospatial ability. Visuospatial ability is used to describe how the mind organizes and understands 2- and 3-dimensional space.[4] Mental rotation is the ability to change the direction of the object in the mind from various angles.[5]

Gravity information from vertical semicircular canals (SCCs) and otolith organs is impaired in vestibular disorders.[6] Recent studies show that incomplete information about the direction of gravity and dysfunctional vestibular inflow can affect the mental rotation ability that requires this information in patients with vestibular disorders.[7,8] Vestibular input about the direction of gravity from

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the otoliths was impaired during exposure to microgravity in benign paroxysmal positional vertigo (BPPV) patients.[7] In the literature, few studies evaluate the mental rotation ability in patients with BPPV, and different findings were obtained in terms of response time and the number of correct answers in mental rotation tasks.[7,9] The aim of our study is to find out whether there are differences in mental rotation abilities between unilateral BPPV patients and healthy controls using object-based mental rotation tasks.

MATERIAL AND METHODS

Participants

Seventeen patients who were diagnosed with unilateral, posterior canal BPPV by an otolaryngologist as a result of positional tests in videonystagmography (VNG) performed by the investigator and 20 healthy adults were included in the study. Spontaneous nystagmus test and dynamic positional tests (Dix–Hallpike test and Head Roll test) were applied to the participants and the eye movements were recorded. Participants who met the inclusion criteria according to VNG test findings were included in the study. Mini-mental state examination was administered to the participants by the investigator with reference to the "Standardized Practice Guide."[10] Participants' mini-mental state examination scores, age, gender, educational status, and dominant hand information were recorded.

Inclusion criteria for both groups were not using drugs that may affect vestibular function (such as streptomycin, gentamicin), not having spontaneous nystagmus with VNG, having a mini-mental state examination score of 24 and above. Participants with blindness and/or spine instability, any psychiatric or neurological disease, and a history of head trauma were excluded from the study. Healthy controls with a history of vestibular disease and/or having a finding suggestive of BPPV or vestibular pathology in positional tests in VNG and BPPV patients with a history of vestibular disease accompanying BPPV were not included in the study. Patients diagnosed with bilateral BPPV and lateral canal BPPV were excluded from the study.

Research Procedures

This study was approved by the Başkent University Institutional Review Board (Project no: KA20/165). All procedures were performed by the ethical standards of the Institutional Review Board and Helsinki Declaration. Written and verbal informed consent was obtained from all participants. The study was conducted at the Audiology Unit in the Department of Otorhinolaryngology from September 2020 until March 2022. Saccade test with VNG were performed on the patients. Object-based mental rotation test (MRT) was performed on the participants. The patients were tested before the treatment of BPPV.

MAIN POINTS

- An incomplete information about the direction of gravity and dysfunctional vestibular inflow can affect the mental rotation ability in patients with vestibular disorders.
- Information about the direction of gravity is required in spatial cognitive tasks.
- Information about the direction of gravity from the otoliths is impaired during exposure to microgravity in patients with Benign Paroxysmal Positional Vertigo.

The MRT response time and the number of correct answers were compared between patients and controls. We also evaluated whether there was a relationship between saccade test parameters and the MRT parameters in our study.

Saccade Test with Videonystagmography

Videonystagmography testing was performed using a Micromedical VisualEyes 4 Channel (Micromedical Technologies, Ill, USA) VNG device. Saccade test were applied to the patients who met the inclusion criteria according to the findings spontaneous nystagmus test, dynamic positional tests (Dix–Hallpike test and Head Roll test).

The light bar 1 m away from the patients' eye level was used in the saccade test. The test was performed while the patients were sitting on the stretcher. The patients were asked to follow the target with their eyes, which makes random jumps to the right and left in the horizontal plane at an angle of 15°-20° with respect to the center of the light bar and at 2-3 second intervals, while their head is fixed. The eye movements were recorded. Accuracy and latency were evaluated in the saccade test.

Mental Rotation Test

In the computer-based MRT, image files belonging to the "Mental Rotation Stimulus Library"[11] constituted by Peters and Battista (2008) were used with the permission of the authors. These images, which are valid and reliable,[11] were constituted by adding 10 cubes end-to-end. The pictures consist of 2-dimensional images of cubes rotated at certain angles in a 3-dimensional space.

The MRT used in this study consists of 8 questions and a "trial x" question for the *x*-axis, 8 questions and a "trial z" question for the z axis, a total of 18 questions. Each question contains 4 images selected from the library. One of the pictures is the reference picture. Only 1 of the 3 pictures below the reference picture is the same as a reference picture. The only difference between this picture and the reference picture is that this picture is rotated at a certain angle in 3-dimensional space. The angle of rotation for both axis groups was chosen between 0° and 180° and was determined as 30°. Figure 1 shows an example of a question for the *x*-axis. The questions were ordered as "trial x" question, questions created by rotating the reference picture around the *x*-axis, "trial z" question, and questions created by rotating the reference picture around the *z*-axis. Later, these images were arranged by adding "response time," "correct/incorrect answer," and "incorrect operation" functions.

The MRT was performed in a quiet room while the participants were sitting. The participants were asked to find the picture that was the same as the "reference picture" among the 3 pictures as soon as possible. Each participant's response time in seconds for each question and correct/incorrect answers were recorded by the computer. Trial questions were not included in the scoring, and the maximum number of correct answers was 16.

Statistical Analysis

Statistical analyses were made using IBM Statistical Package for Social Sciences version 25.0 (IBM SPSS Corp.; Armonk, NY, USA) package program. Descriptive statistics are presented as mean ($\pm$) SD, frequency distribution, and percentage. Testing of normality for continuous variables was evaluated using the Shapiro–Wilk test.

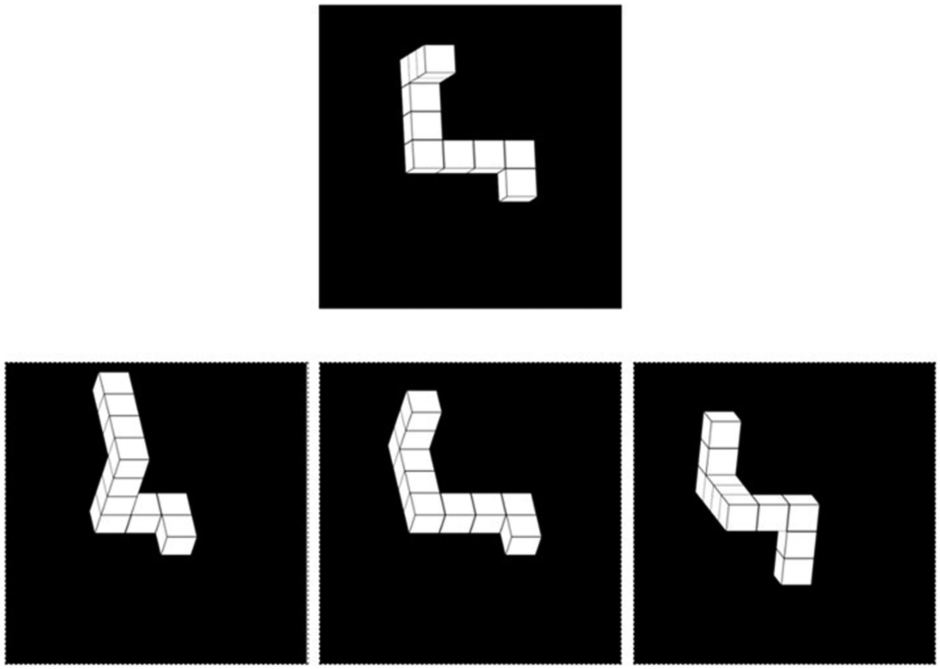

Figure 1. An example of a question (*x*-axis) prepared with pictures selected from the "Mental Rotation Stimulus Library."

The homogeneity of variances was evaluated by the Levene test. Independent samples *t*-test was used when comparing normally distributed variables, and Mann–Whitney *U*-test was used when comparing non-normally distributed variables between 2 independent groups. The correlation between mental rotation ability and saccadic function was evaluated with Pearson's correlation analysis or Spearman's correlation analysis. The *P*-value of $\leq$.05 was considered statistically significant.

RESULTS

The ages of the BPPV patients were between 49 and 75, the mean age was 62.59 $\pm$ 8.26, the ages of the controls were between 47 and 73 and the mean age was 60.60 $\pm$ 6.97. There was no statistically significant difference in age between the groups ($P = .432$). There was no statistically significant difference in gender ($P = .137$) and educational status ($P = .333$) between the groups. All participants are right-handed. Thirteen patients were diagnosed with right posterior canal BPPV, and 4 patients were diagnosed with left posterior canal BPPV.

Mental Rotation Test Findings

Table 1 shows the MRT results of unilateral BPPV patients and controls. There was no statistically significant difference between the groups in regard to MRT response time and the number of correct answers ($P > .05$).

When evaluating, the relationship between saccadic latency and accuracy and MRT response time and number of correct answers in BPPV patients, there was no significant correlation between saccadic test parameters and the MRT parameters ($P > .05$) (Table 2).

DISCUSSION

Our study aimed to determine whether there are differences in mental rotation abilities between unilateral BPPV patients and controls using object-based mental rotation tasks.

Vestibular system is important to provide a reliable gravicentric information and to perceive the location of one's own body in space. Information about the direction of gravity is dependent on the input from the vertical SCCs and otolith organs.[6] This knowledge is required in spatial cognitive tasks. Studies show that the processing of vestibular information is involved in mental rotation tasks.[7,8] The relationship between the gravicentric information and mental rotation tasks has been discussed in the studies on astronauts under different gravity conditions.[12,13] Astronauts have to recognize visual landmarks in microgravity (without otolith input) that allow them to orient themselves relative to surrounding objects to know where to look, where to hold, or where to move in the cabin. Spatial orientation in microgravity, rotation, and recognition of 3-dimensional objects depends on the ability to accurately mentally visualize the appearance of an array of objects

Table 1. Mental Rotation Test Results of Benign Paroxysmal Positional Vertigo and Control Groups

	BPPV Group	Control Group	*P*
	Mean $\pm$ SD (Minimum–Maximum)	Mean $\pm$ SD (Minimum-maximum)	
MRT response time (s)	160.35 $\pm$ 64.98 (84-356)	134.60 $\pm$ 42.67 (66-230)	.259[a]
MRT number of correct answers (n)	11.35 $\pm$ 2.60 (7-15)	12.80 $\pm$ 2.26 (9-16)	.079[b]

MRT, mental rotation test; n, frequency; s, seconds; SD, standard deviation.
[a]Mann–Whitney *U*-test; [b]Independent samples *t*-test.

Table 2. The Relationship Between Saccadic Latency and Accuracy, and the MRT Response Time and Number of Correct Answers in Benign Paroxysmal Positional Vertigo Patients

	Mean ± SD	MRT Response Time (s)		MRT Number of Correct Answers (n)	
		r	*P*	*r*	*P*
Saccadic latency (ms)	241.40± 36.72	0.298	.246[a]	0.007	.979[a]
Saccadic accuracy (%)	97.69 ± 4.88	0.142	.586[a]	−0.322	.207[b]

MRT, mental rotation test; n, frequency; ms, milliseconds; SD, standard deviation.
[a]Spearman correlation; [b]Pearson correlation.

after an imaginary change in position or viewing orientation (mental rotation).[12]

The studies evaluating the mental rotation ability in vestibular disorders indicated that the mental rotation performance of the patients with vestibular loss is lower than the healthy controls, especially in egocentric mental rotation tasks.[7,8] The studies using object-based mental rotation tasks in patients with unilateral and bilateral vestibular losses are limited, and the findings of the studies differ.[7,8,14] Damage to the vestibular end organ or the vestibular nerve creates a tonic imbalance. This imbalance occurs at different levels of vestibular system activity (such as vestibular nerve in vestibular neuritis and macula for BPPV). Candidi et al[7] (2013) stated that one of the reasons for the different findings in the studies may be the altered central vestibular processing caused by different pathologies. The current studies investigate the shared neural overlap between mental rotation and vestibular processing. It has been reported that altered vestibular processing as a result of vestibular dysfunction may affect spatial cognitive tasks such as mental rotation.[14-17]

One of the reasons for no statistically significant difference in MRT parameters between BPPV patients and controls in our study may be unilateral canal involvement of BPPV patients in our study. This can be interpreted as partially protecting cognitive functions with the bilateral projection of the intact labyrinth in patients with unilateral canal involvement.

Only a few studies have evaluated mental rotation ability in different vestibular pathologies[8,14] and in patients with BPPV.[7,9] BPPV is a common vestibular disorder in which calcium carbonate crystals in the utricle enter one of the SCCs and cause inertial changes in the SCC and vertigo and abnormal nystagmus attacks when the head position changes.[9] There is an imbalance of bilateral vestibular input in BPPV pathophysiology. During exposure to microgravity, there is no vestibular input about the direction of gravity from the otoliths in BPPV patients.[6] We suggest that incomplete information on the direction of gravity and dysfunctional vestibular inflow in BPPV patients, as in astronauts, can affect tasks involving this information, such as mental rotation.

The findings of studies evaluating mental rotation ability in BPPV patients differ.[7,9] Candidi et al[7] compared the mental rotation ability of healthy controls with unilateral acute vestibular neuritis patients and unilateral BPPV. They found that the number of correct answers decreased and reaction times were prolonged in those with both vestibular neuritis and BPPV. Nair et al[9] also compared the mental rotation ability of unilateral BPPV patients and controls. Likewise in our study, Nair et al[9] stated that BPPV patients and controls did not differ in terms of MRT general performance. In the study of Nair et al,[9] as in our study, the MRT was applied to BPPV patients before the patients were treated. In the study of Candidi et al,[7] patients were also evaluated in the early period. The misperception of the external world and of their own bodies in patients with vestibular disorders may interfere with tasks related to mental imagery. Abnormal spatial perceptions are more common in the acute phase of vestibular disorders and this abnormality is improved over time by vestibular compensation.[14] Studies show that patients with unilateral vestibular disorders tested in the late stage had a decrease in error rates in mental rotation tasks,[14] and mental rotation performance is similar to controls.[8]

Different stimuli can be used in mental rotation tasks. One of the reasons for the differences in the findings in the studies may be the types of stimuli used. Three-dimensional abstract shapes made from blocks tend to rotate much more slowly than alphanumeric characters such as letters, numbers, or line drawings of common objects.[18] In our study, similar to the study of Nair et al,[9] 2-dimensional images of cubes rotated at certain angles in 3-dimensional space were used as stimuli. During this task, participants mentally rotate the object directly to solve the task. Unlike our study, Candidi et al[7] used human figures as stimuli in mental rotation tasks. Lopez[19] stated that when human figures are used in mental rotation tasks, the person integrates her/his body into the observed figure and automatically rotates his/her body to solve the task.[19] Mental rotation is similar to the actual rotation of concrete objects. Mental rotation tasks activate cortical regions that are activated during the performance of acti ons.[20,21,22,23,24] Imagining one's own body rotations, similar to real body rotation induces eye movements.[25] Mental rotation response times are prolonged during vestibular stimulation when human figures are used rather than objects or non-human figures in mental rotation tasks.[26] Peruch et al[14] found that the patients with unilateral vestibular dysfunction had higher errors in object-based MRT than controls. Grabherr et al[8] (2011) reported that object-based mental rotation tasks should not be considered as mere visuospatial tasks, they also contribute to vestibular processing. Different types of stimuli as well as the changes in angular differences between stimuli can also affect mental rotation performance. Shepard and Metzler[27] stated that the response time increases as angular differences between the reference picture and target increase proportionally. Response time peaks at 180° (degrees) and tends to be symmetrical around 180°. Considering this, images between 0° and 180° were selected from the Mental Rotation Stimulus Library in our study, and the angle of rotation between the reference image and the target image was determined as 30°. In our study, we did not examine whether angular differences change the MRT response time and the number of correct answers. Nair et al[9] applied mental rotation tasks at 0°, 20°, 40°, 80°, or 120° to BPPV patients. They found that BPPV subjects performed the test more slowly at higher angular orientations compared to the 0° orientation condition.

In our study, we evaluated the relevance between saccadic accuracy, latency, and MRT response time and the number of correct answers. In the literature, it has been stated that eye movements play an important role in mental rotation experiments.[25,28] During mental rotation tasks, participants visually perceive 3-dimensional objects and mentally rotate the objects until they are identified. It is generally accepted that the mental rotation process includes 5 cognitive stages:[29] (1) processing visual information and forming mental images of presented objects (imagining and evaluating presented objects from different angles); (2) mentally rotating objects or images; (3) comparison of the presented objects; (4) determining whether the objects presented are the same; and (5) to decide whether the presented objects are the same or different.[27,30] Visual fixation is responsible for the acquisition of visual information in mental rotation tasks.[31] The subjects examine the objects which is presented to them as reference picture and the other pictures created by rotating the reference picture at certain angles in three-dimensional space with visual fixation;[32] Saccades are rapid eye movements between fixations.[33] Saccades are rapid shifts of fovea to a new target to integrate visual information from fixations. The integration enables the brain to compare the visual information obtained from the fixation with the remembered image of the object.[34] In our study, no significant correlation was found between the accuracy, latency of saccadic eye movements, and the MRT response time, and the number of correct answers.

In our study, the MRT and saccade tests were applied while the participants were sitting. During mental rotation tasks, patients did not have to move their heads to perform the task. At the same time, the saccade test is applied with the head fixed. Peruch et al[14] stated that spontaneous nystagmus, inadequate gaze stabilization, and imbalance reported after vestibular loss decrease the attentional resources allocated to the cognitive task. This causes a decrease in performance in the cognitive task. They stated that it is possible to explain the performance decrease in mental imagery tasks such as mental rotation in vestibular disorders with this mechanism.[14] In our study, BPPV patients did not have spontaneous nystagmus. At the same time, symptoms such as nystagmus/inadequate gaze stabilization and vertigo occur during provocative positions with head movements in BPPV patients. In our study, we suggest that the absence of spontaneous nystagmus in patients and the stability of the head during MRT and saccade test reduced the effect of inadequate gaze stabilization.

Limitations of the Study

The limitations of our study are as follows: the angular difference between the target image and the reference image was kept constant, and this angular difference was determined as 30°. The participants were not presented with images from different angles, and it was not determined whether there was a difference between the images presented at different angles in regard to MRT response time and the number of correct answers. In future studies, by using objects (such as recognizing geometric shapes and alphabetic characters presented at different angles), human bodies, and body parts with different stimulus types, the MRT is constituted and the angular differences between the presented images are presented to the participants as well as mirror images. It is recommended to evaluate whether different stimulus types affect the results of the MRT in BPPV patients and healthy controls. Since unilateral posterior canal involvement was observed in all BPPV patients in our study, it could not be determined whether bilateral canal involvement in BPPV would affect the object-based MRT results. In future studies, it is recommended to increase the sample size and include bilateral BPPV patients in the study and to determine whether there is a difference in object-based and egocentric mental rotation ability between healthy controls, unilateral BPPV patients, and bilateral BPPV patients.

The results of our study show that using object-based mental rotation tasks with 2-dimensional images of cubes rotated at certain angles in 3-dimensional space, unilateral posterior canal BPPV does not affect mental rotation ability. More studies are needed due to the limited number of studies in the literature and the differences between the findings.

Ethics Committee Approval: This study was approved by Ethics Committee of Başkent University (Approval No: KA20/165).

Informed Consent: Written informed consent was obtained from the patients who agreed to take part in the study.

Peer-review: Externally peer-reviewed.

Author Contributions: Concept – A.P.P., Design– A.P.P., S.D., Ö.K., B.D.K., H.S.E.; Supervision – H.S.E.; Resources –A.P.P., H.S.E.; Materials – A.P.P., S.D., Ö.K., B.D.K., H.S.E.; Data Collection and/or Processing – A.P.P., S.D., Ö.K., B.D.K., H.S.E.; Analysis and/or Interpretation – A.P.P., H.S.E.; Literature Search – A.P.P., S.D., Ö.K., B.D.K., H.S.E.; Writing – A.P.P., S.D., Ö.K., B.D.K., H.S.E.; Critical Review – A.P.P., H.S.E.

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