Published in final edited form as:

J Neurol Phys Ther. 2010 June ; 34(2): 76–81. doi:10.1097/NPT.0b013e3181dde582.

Perceptual and Motor Inhibition in Individuals With Vestibular Disorders

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Abstract

Background and Purpose—Vestibular dysfunction has been shown to be associated with altered cognitive function. The purpose of this study was to examine changes in cognitive function in participants with vestibular disease during the course of vestibular physical therapy.

Methods—Twenty-two participants (mean age = 52, standard deviation = 11) with previously diagnosed vestibular disorders were tested at the beginning and end of rehabilitation. The Motor and Perceptual Inhibition Test (MAPIT) was used to assess manual reaction times when responding to various stimuli presented on a computer screen. Additional physical performance measures and questionnaires related to dizziness, fear of falling, and activities of daily living were used to quantify change during the 6-week intervention period. The repeatable battery for the assessment of neuropsychological status (a measure of memory and executive function) was used to ensure that participants did not have memory or executive function deficits.

Results—Overall, there were no significant differences in MAPIT score before versus after physical therapy intervention, however there were some participants who demonstrated improvements in motor inhibition (MI) and perceptual inhibition (PI) scores. Interstingly, 8 of the 9 participants with abnormal caloric test findings had improvements on 2 of the PI scores. Overall 50% to 64% of the participants demonstrated improvement in the 4 different MAPIT scores. There were improvements in physical performance and self-report measures at the end of the 6-week physical therapy intervention program.

Discussion/Conclusion—Individuals with vestibular disorders may show improvement in MI and PI after a 6-week physical therapy intervention program; those with abnormalities on caloric and rotational chair tests appear especially likely to experience improvement in PI. Additional study is needed to determine whether individuals with vestibular disorders have remediable deficits in MI and PI.

Keywords

vestibular; reaction time; cognition

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Participants with vestibular disorders have a variety of symptoms directly related to functions of the vestibular system (eg, nystagmus, dizziness, vertigo, increased sway while standing still).1,2 Recent evidence has shown that vestibular dysfunction also affects cognitive function including attention,3,4 spatial memory,5 and may result in increased cognitive load.[6] Persons with bilateral vestibular disorders have deficits in hippocampal function 5 and hippocampal atrophy, as noted by magnetic resonance imaging volumetry.7 Spatial memory deficits are noted even while not moving because individuals with chronic bilateral vestibular loss have difficulty navigating around objects and drawing a map.[5],7 Initially, studies of the cognitive impact of vestibular lesions focused on the hippocampus because of its role in spatial information processing.7 However, a recent study suggests that the cognitive impairments are not limited to spatial processing.8

Redfern et al [8] showed that participants with unilateral vestibular loss have increased reaction times (RTs) when performing an auditory reaction task while standing on a platform and while seated. These findings suggest that, in addition to the traditional understanding of the influence of a vestibular lesion, vestibular disorders may also change the way in which spatial and nonspatial cognitive centers process information. These changes in auditory processing speed appear to persist even in well-compensated participants.8 Yardley et al [6] also demonstrated differences, among both persons with vestibular disorders and control subjects, in RTs while seating and standing during information processing tasks that required spatial and nonspatial information.

Perceptual inhibition (PI) and motor inhibition (MI) are 2 types of inhibitory cognitive processes that have been assessed by determining how quickly people respond to a task in the presence of distracting stimuli.9 PI is used to reduce attention to conflicting stimuli; it facilitates attention to the task-relevant stimulus while suppressing attention to the irrelevant stimulus.[10],11 PI is required to focus attention when interfering stimuli are present. MI suppresses the incorrect response that may be triggered by the presented stimulus. For example, one must inhibit the natural tendency to push a button in the direction of an arrow when instructed to push the opposite button to perform the task as requested.12 PI is important during early processing of interfering stimuli (where there is a stimulus that the subject must attend to and simultaneously another stimulus that distracts the subject from performing the task), whereas MI comes at a later stage to inhibit undesired responses.

The Stroop effect is the most common test of inhibition processes.[13] The test requires naming the ink color of words that are printed in an incongruent ink color (eg, saying “green” when the word “blue” is printed in green ink). The test, however, does not provide a method of separating these inhibitory processes. Nassauer and Halperin 9 presented a novel method of quantitatively measuring PI and MI separately in healthy subjects. Jennings et al [10] proposed a modified version of the test proposed by Nassauer and Halperin,9 the Motor and Perceptual Inhibition Test (MAPIT).10,11 The MAPIT records subjects’ RTs to different tasks that measure MI and PI.

The recent evidence discussed above demonstrates that individuals with vestibular disorders exhibit a wide variety of cognitive disorders. It has been the authors’ clinical experience that this patient population shows improvement in cognitive function after a program of vestibular physical therapy. However, to date, there have been no studies examining whether individuals with vestibular disorders show improvement in cognitive function after vestibular physical therapy.

The purpose of this study was to examine whether cognitive function changes during the course of rehabilitation in persons with vestibular disorders. Our hypothesis was that participants with vestibular disorders would demonstrate improvements in PI and MI after vestibular physical therapy.

METHODS

Participants

Twenty-two participants (mean age 52 years, standard deviation = 11 years, range: 27–70, 6 male) with vestibular dysfunction were recruited for a vestibular physical therapy study. Participants were included in the research study if they were diagnosed by a neuro-otologist as having a vestibular disorder. Diagnostic vestibular testing included caloric, rotational chair, static positional, ocular motor, and vestibular-evoked myogenic potential testing. Participants were contacted about the intervention study at the time of their vestibular diagnosis. All participants signed the written consent form, and all study procedures were approved by the University of Pittsburgh Biomedical Institutional Review Board. Exclusion criteria included (1) a medical history of a neurologic condition such as stroke, Parkinson's disease, and epilepsy, (2) a medical history of a psychological condition such as phobias or panic attacks, (3) a musculoskeletal problem that limited their mobility or prevented prolonged standing, (4) visual acuity (with corrective eye wear) worse than 20/40, and (5) peripheral sensory loss to tactile stimuli >10 g as identified with Semmes-Weinstein monofilament testing.

Participant diagnoses included 14 participants with peripheral vestibular disorders (4 left, 7 right, 1 bilateral peripheral hypofunction, and 2 participants with a nonlocalized peripheral vestibular lesion), 3 participants with central vestibular disorders, and 5 participants with mixed central and peripheral vestibular disorders. Eight of the participants were treated for benign paroxysmal positional vertigo in addition to other vestibular pathology. All participants had vestibular function tests performed but not all completed the full test battery.

Participant characteristics and individual vestibular test results are shown in Table 1. Alternate binaural bithermal caloric irrigation was performed on 20 participants; 9 participants showed an abnormal response. Caloric testing is a test of the vesticular-ocular reflex. Hot or cold air or water are applied to the external auditory canal. Responses are recorded from eye movement. Ten participants had abnormal rotational chair findings and 2 had abnormal ocular motor test results. Eight had abnormal positional nystagmus. The vestibular-evoked myogenic potential test was performed on 20 participants: 6 participants had a reduced response (2 unilaterally and 4 bilaterally) and 1 participant had an absent response bilaterally.

Procedure

The participants were tested using the MAPIT and the Repeatable Battery for the Assessment of Neuropsychological Status (RBANS) test. The MAPIT is a standardized test with a formalized, written manual that was used for all testing. It was administered on a personal computer using E-Prime software (version 1.1, Psychology Software Tools, Pittsburgh, PA) connected to an electronic button interface box supplied with the software. The test was administered using an 18-inch monitor with a resolution of 1024 × 768 pixels. The MAPIT was performed by 1 blinded, trained examiner while participants were seated in front of a computer monitor placed 50 cm away; participants used their right and left index fingers to indicate their response by pressing buttons on a box placed on a table in front of the participants. The test measured the participants' median RTs in response to 5 different attention tasks. The tasks are illustrated in Figure 1A–D, with the motor congruent task (A) repeated twice during testing.

The first task was the motor congruent task (Fig. 1A). During this task, participants were asked to press a button compatible with the direction of a centered arrow. For the second task (not illustrated), a rectangle was displayed on either the right or left side of the computer screen. Participants were asked to press the button that corresponded to the location of the rectangle. The rectangle remained on the screen until the subject made a response. This task was not included in the analyses; it was used to entrain subjects to respond to the spatial location of the target stimulus.

The third task was designed to "inhibit" the entrained natural response of pushing the button on the same side as the target stimulus. The third task measured PI (Fig. 1B and C). A right- or left-pointing arrow appeared 8.5 cm to either side of the center of the screen. Rather than pressing the button that corresponded to the location (right versus left side of the screen) of the stimulus, the participants were asked to press the button that corresponded to the direction (left- versus right-pointing) of the arrow. For one-half of the trials, the side on which the arrow appeared (the spatial location) was the same as the direction the arrow pointed (congruous condition; eg, right pointing arrow on the right side of the screen, ie, Fig. 1B). For the other half of the trials, the side on which the arrow appeared did not match the direction the arrow pointed (incongruous condition, eg, right pointing arrow on the left side of the screen; Fig. 1C). The congruous and incongruous trials were randomly intermixed. To perform the task correctly, it was necessary for the participants to focus on the direction of the arrow and inhibit processing its location. After this task, a repeat of the motor congruent condition was performed (Fig. 1A). The goal was to reestablish the salient stimulus again (ie, the direction of a centered arrow). A median of RTs on all motor congruent trials was calculated. Motor incongruent testing was performed last, which is a test of MI. A centered arrow was displayed and the participants were asked to press the button in the opposite direction to where the arrow was pointing (Fig. 1D).

Each task began with a short practice to confirm that participants understood the required movement. There were 40 trials for each task (200 total RT data). During all trials, participants were encouraged to keep their vision fixed on the center of the computer screen; this was achieved by presenting a plus sign (+) at the central fixation point. The interval between the participant's response at any given trial and the subsequent trial was always 1.5

seconds. The arrows were 3.7 cm long and were presented until the participant provided a response. The median RT and number of errors were recorded for each task.

The MI score was calculated by subtracting the median RT of the motor congruous condition from the median RT of the motor incongruous condition. Similarly, the PI score was calculated by subtracting the median RT of the perceptual congruous condition from the median RT of the perceptual incongruous condition. Comparing RTs during the incongruous condition of the PI task and the motor congruent task provided information about the slowing of the response because of the discrepancy between the arrow location and direction, the comparison allowed calculation of the PI interference score (PII).10 Comparing RTs during the congruent conditions of the perceptual congruent task (Fig. 1B) and the motor congruent task (Fig. 1A), provided information about the facilitation of the responses because of the compatibility between arrow location and direction, which is expected to speed up the response.[10] This comparison resulted in the perceptual facilitation score (PFc). The reliability of these scores has been shown to be adequate using internal consistency measures, although the reliability of the PI score is marginal.10 Validity has not been firmly established, although a relationship with accepted interference measures has been shown, as have relationships with measures of balance.9,11

In summary, median RTs were used to calculate the 4 variables of interest according to the following equations:

MI = Motor Incongruous - Motor Congruous

PI = Perceptual Incongruous - Perceptual Congruous

PI_I = Perceptual Incongruous - Motor Congruous

PF_C = Perceptual Congruous - Motor Congruous

The RBANS measures attention, language, visuospatial/constructional abilities, and immediate and delayed memory.[14–16] The RBANS test was originally developed to detect dementia in the elderly.[16] It has the advantage of taking only approximately 30 minutes to administer. The RBANS was individually administered in a quiet room.[16] The RBANS is a test of executive function and has been used in physical therapy to determine mild cognitive decline.[17] Twelve different areas of memory are included in the RBANS: list learning, story memory, a figure copy test, line orientation, picture naming, semantic fluency, digit span, digit coding, list recall, list recognition, story memory, and figure recall. A total composite score is calculated, and there are 5 subset scores (not reported in this article). Scores between 90 and 109 are considered an average score, with some variability based on age.16 Higher scores indicate better performance. The test was used to determine whether any of the participants in the study had cognitive decline.

In addition to the MAPIT and RBANS test, all participants completed selected physical performance measures and questionnaires. The Dynamic Gait Index,[18] Functional Gait Assessment,19 the Sensory Organization Test (SOT) of the computerized dynamic posturography, gait speed, and the Timed Up and Go 20 test were performed before and after the vestibular physical therapy intervention. In addition to these physical function measures, participants were asked to complete the Activities-specific Balance Confidence Scale,[21] the Vestibular Activities of Daily Living Scale,[22,23] and the Dizziness Handicap Inventory.[24]

Participants were tested 1 week before the start of their vestibular physical therapy rehabilitation and were retested within a month after the end of a 6-week intervention program. The vestibular rehabilitation program included habituation to visual stimuli, gaze stabilization exercises, sensory organization exercise in upright standing, and dynamic gait exercises. Participants were treated once a week for 6 weeks and were given a custom-designed home exercise program to be performed daily.

Data Analysis

Raw data are reported for all participants in this case series. Means, standard deviations, and ranges are reported where indicated. Statistical analysis was performed using SPSS (SPSS Inc., Chicago, IL). A paired t-test was used to compare the physical performance and self-report measures before versus after physical therapy intervention. The sign test was used to assess effects for MAPIT. Pearson product moment correlations and t-tests were used to determine whether there were any relationships between changes in the PI and MI scores and changes in physical performance and self-report measures. The level of significance was set at $P \leq .05$.

RESULTS

There were no statistically significant differences between the participants' 4 inhibition scores before versus after therapy. Because the MAPIT was recently developed, minimal clinically significant differences have not been established for the 4 inhibition scores. In this study, we compared participants' scores posttherapy to their pretherapy scores (absolute differences). Although the changes were not statistically significant, in more than half of the participants, the absolute value of the responses on the 4 inhibition scores were faster posttherapy compared with pretherapy (Table 2). Of the 9 participants with caloric reductions, after therapy, 5 had scores indicating improvement on MI (not significant), 6 had scores indicating improvement on PI (not significant), 8 had scores indicating improvement on PII ($P = .039$), and 8 had scores indicating improvement on PFc ($P = .039$).

There were significant changes in participants' performance before and after intervention on the Dynamic Gait Index ($P = .007$), Functional Gait Assessment ($P = .003$), SOT ($P = .023$), Activities-specific Balance Confidence Scale ($P = .023$), and Dizziness Handicap Inventory ($P < .001$). The changes in gait speed and Vestibular Activities of Daily Living Scale approached significance ($P = .065$ and $P = .064$; respectively). There were no significant changes on the Timed Up and Go Score ($P = .638$).

The correlation among changes in the 4 inhibition scores (MI, PI, PII, and PFC) with changes in the physical and self-report measures were not significant. Because standing postural sway on a sway-referenced surface with eyes open (SOT IV) has been shown to be related to PII scores in adults older than 70 years,[14] we evaluated whether persons with improvement in SOT IV scores were different with regard to their MAPIT scores. We found that in the group of participants with a 10-point or greater improvement in SOT IV (sway-referenced surface (n = 12), eyes open condition), there was a significantly smaller average PII score (P = .016) compared with those participants without such an improvement in the SOT IV.

DISCUSSION

There were no significant differences detected in the 4 MAPIT scores for the overall study sample before versus after physical therapy. However, >50% of the participants showed faster times (ie, improvement) at the end of the 6-week intervention program. For participants with laboratory evidence of vestibular dysfunction, PI (PII and PFC) improved after rehabilitation.

Standing postural sway on a sway-referenced surface with eyes open (SOT IV) has been related to PII scores in adults older than 70 years; greater sway was correlated with greater PII scores.11 In our study, which did not include any subjects older than 70 years, there was no correlation between total SOT score and PII scores or between SOT IV score and PII scores. Participant age in the current sample ranged from 27 to 70 years, making it difficult to compare our data with those of Redfern et al 11 because of the age differences. Also, Redfern et al 11 reported on sway amplitude rather than the SOT score generated from computerized dynamic posturography, further complicating direct comparisons. Although there was no significant correlation between SOT scores and MAPIT scores, we found that participants whose sway on SOT IV improved after rehabilitation had better PII scores. Moreover, because 8 of the 9 participants with caloric reductions improved their PII and PFC scores, individuals with peripheral vestibular dysfunction may be especially able to achieve improvement in PI.

The MAPIT task may be too easy for some of the participants in this sample, especially because the testing was performed while seated. Both Yardley et al [25],26 and Redfern et al [8] have noted changes in RTs in persons with vestibular disorders in standing. Redfern et al [8] reported differences in auditory RTs in well-compensated individuals with vestibular disorders while seated, compared with a control group. The auditory RTs may have been impaired in the study by Redfern et al 8 because all participants were seen postsurgically candidates (13 after acoustic schwannoma and 12 after vestibular nerve section surgery). In contrast to the auditory RT task used by Redfern et al,8 the MAPIT is a visually driven RT test.

The RBANS scores obtained in this study suggest that this group of participants with vestibular disorders scored within the normal range. Participants for the study were selected based on meeting the inclusion criteria and their willingness to come to the tertiary care site on a weekly basis. Six of the participants had doctoral degrees, 1 had a high school education and the remainder of the sample had a university degree (n = 15; 9 had additional education beyond the bachelors degree). The education level of the participants suggests that they may have significant cognitive functional reserve based on their education.

CONCLUSION

Participants with vestibular disorders, especially those with peripheral vestibular deficits, may show improvement in PI after a 6-week physical therapy intervention program in this pilot project. Additional study is needed to determine whether individuals with vestibular disorders have remediable deficits in MI or PI. Greater diversity in the sample characteristics and a larger sample size may provide a more definitive answer to this question.

ACKNOWLEDGMENTS

The authors would like to acknowledge Anita Lieb and Khalid Alahmari for their contribution to data collection and processing.

Supported by grants NIHK23 DC005384 and P30 DC05205.

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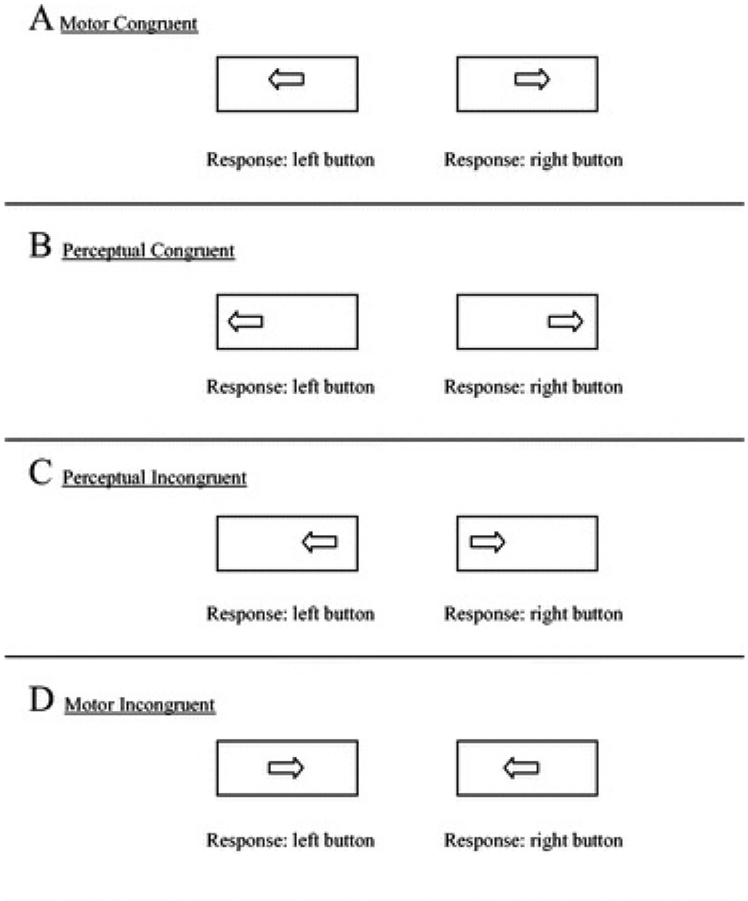
A Motor Congruent
Response: left button
Response: right button
B Perceptual Congruent
Response: left button
Response: right button
C Perceptual Incongruent
Response: left button
Response: right button
D Motor Incongruent
Response: left button
Response: right button

Figure 1.

TABLE 1

Patient Demographics (N = 22) of People Who Completed a 6-Week Vestibular Rehabilitation Program

Patient	Dx	LOS	Age	Sex	Caloric	Rotational Chair	Oculomotor	Positional	VEMP
1	3	4	51	F	N	N	N	N	Reduced
2	1	10	27	F	—	Ab	N	Ab	N
3	1	7	60	M	Ab	Ab	N	N	N
4	1	—	55	F	Ab	N	N	N	—
5	1	2	51	F	N	N	N	N	Reduced
6	2	4	60	F	N	Ab	N	N	N
7	3	6	50	M	N	N	N	N	N
8	1	28	59	F	—	Ab	N	N	Reduced
9	1	1	55	F	N	N	N	Ab	N
10	2	3	30	M	N	N	N	N	N
11	1	1	53	F	Ab	N	N	Ab	N
12	1	2	39	F	Ab	Ab	N	N	N
13	1	12	62	F	Ab	N	N	Ab	Absent
14	3	8	47	F	Ab	Ab	N	N	Reduced
15	2	8	66	F	N	N	N	Ab	N
16	3	12	43	F	N	N	N	N	Reduced
17	1	2	46	M	N	Ab	Ab	Ab	N
18	1	3	43	F	N	Ab	Ab	Ab	N
19	3	9	47	M	Ab	N	N	Ab	—
20	1	6	70	F	N	N	N	N	Reduced
21	1	3.5	58	M	Ab	Ab	N	N	N
22	1	1	61	F	Ab	Ab	N	N	N

Abbreviations: Dx, diagnosis: 1, peripheral; 2, central; .3, both peripheral and central; LOS, length of symptoms in months: VEMP, vestibular evoked myogenic potentials: n, normal test result: Ab, abnormal test result: —, missing data.

TABLE 2

Individual Change in Patient Scores for MI, PI, PI_I, and PF_c After 6 Weeks of Vestibular Rehabilitation

Patient	ΔMI	ΔPI	$ΔPI_I$	$ΔPF_c$
1	**−28.8**	51.5	**−21.3**	**−72.8**
2	**−48.8**	**−36.5**	**−25.8**	10.8
3	**−38.8**	**−26.0**	**−37.3**	**−11.3**
4	**−12.0**	7.5	**−22.0**	**−29.5**
5	28.5	0.5	18.0	17.5
6	12.0	6.5	**−23.0**	**−29.5**
7	9.3	**−47.0**	**−8.8**	38.3
8	60.0	2.5	54.0	51.5
9	**−65.3**	**−16.0**	4.3	20.3
10	15.5	6.0	10.0	4.0
11	**−36.3**	**−1.0**	**−27.3**	**−26.3**
12	**−48.8**	14.0	**−30.8**	**−44.8**
13	28.5	**−35.5**	45.5	81.0
14	**−97.0**	**−57.0**	**−70.0**	**−13.0**
15	75.3	**−31.5**	58.3	89.8
16	**−10.8**	**−6.0**	15.3	21.3
17	6.0	27.5	**−29.5**	**−57.0**
18	—	**−25.5**	9.8	35.3
19	6.8	**−57.5**	**−138.8**	**−81.3**
20	**−23.8**	**−79.0**	**−91.8**	**−12.8**
21	**−60.0**	**−6.0**	**−8.5**	**−2.5**
22	50.0	11.5	**−19.5**	**−31.0**
Total no. of participants who improved	11/21 (52)	13 (59)	14 (64)	12 (56)
Range	−65.3 to 75.3	−79.0 to 51.5	−138.8 to 58.3	−81.3 to 89.8
Mean change of participants who improved	−42.8	−32.7	−39.6	−34.3
Mean change of participants who got worse	29.2	14.2	26.9	37.0
Ratio of participants with abnormal caloric results who improved	6/9 (67)	6/9 (67)	8/9 (89)	8/9 (89)
Ratio of participants with abnormal rotational chair findings who improved	5/10 (50)	5/10 (50)	8/10 (80)	7/10 (70)

Negative numbers shown in bold for the inhibition measures indicate improvements after physical therapy intervention.

Abbreviations: —, missing data; MI, motor inhibition; PI, perceptual inhibition: PI_I, perceptual inhibition interference; PF_C, perceptual facilitation.