Spatial Navigation after Surgical Resection of an Acoustic Neuroma: Pilot Study

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Abstract

Objective: To characterize navigation errors made by patients with the absence of vestibular function on one side owing to surgical resection of an acoustic neuroma.

Methods: Seventeen young (18–38 years) and 9 older healthy individuals (67–83 years), as well as 5 patients 2 to 20 months following surgery (37–61 years), were studied. They sidestepped laterally with eyes closed toward memorized targets located 1.25 m to their right or left. They stopped when they judged that they were in front of the target. The position of head and body markers was recorded in three dimensions with a six-camera Vicon 512 system (Oxford Metrics Ltd., Oxford, UK). Navigation errors were (1) distance error, the distance between the end target and a perpendicular line drawn from the sternum to the plane of targets, and (2) deviation, the angle formed between the line joining the initial and end targets and the line joining the subject's shoulders.

Results: Mean distance error was 20.9 ± 22.0 cm in patients, 29.6 ± 30.3 cm in young healthy subjects, and −1.7 ± 18.4 cm in older subjects ($p < .01$ compared with young subjects). Mean deviation was symmetric and 8° and −3° in healthy young and older subjects, respectively. In contrast, patients had a significantly larger deviation when navigating toward the side of their lesion than the intact side (13° ± 9° versus 3° ± 9°; $p < .01$).

Conclusions: Our results suggest that patients with vestibular deficits have impaired ability to control body rotations when walking sideways without vision toward the side of their vestibular lesion.

Sommaire

Objectif: Caractériser les erreurs de navigation des patients dont la fonction vestibulaire est absente d'un côté à la suite de la résection d'un neurinome acoustique.

Méthode: Nous avons étudié 17 jeunes (18–38 ans) et 9 plus vieux (67–83 ans) individus en bonne santé ainsi que 5 patients 2 à 20 mois suivant la chirurgie (37–61 ans). Nous leur demandions de se déplacer latéralement en direction d'une cible qu'ils avaient mémorisée et qui était située à 1.25 mètres à leur gauche ou leur droite. Ils s'arrêtaient quand ils se croyaient devant la cible. La position de la tête et du corps était enregistrée grâce à un système tridimensionnel de six caméras Vicon 512 (Oxford Metrics). L'erreur de navigation se mesure par (1) la distance entre la cible et une droite perpendiculaire tracée en partant du sternum et (2) la déviation, soit l'angle entre une ligne joignant la position initiale et la cible finale et la ligne joignant les épaules du patient.

Résultats: L'erreur en distance est en moyenne de 20.9 ± 22.0 cm chez les patients, de 29.6 ± 30.3 cm chez les jeunes en santé, et de −1.7 ± 18.4 cm chez les individus plus agés ($p < .01$ comparé aux jeunes en santé). L'erreur en déviation était symétrique et de 8 et −3 chez les sujets jeunes et plus âgés respectivement. Par contre les patients avaient une déviation significativement plus grande entre le côté opéré et le côté sain (13 ± 9 versus 3 ± 9; $p < .01$).

Conclusions: Nos résultats suggèrent que les patients avec un déficit vestibulaire ont une habileté diminuée à contrôler la rotation de leur corps quand ils marchent de côté sans vision en direction de leur lésion vestibulaire.

Key words: acoustic neuroma, deviation, distance error, kinematics, spatial navigation

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The ability to navigate in a memorized environment can be tested by asking an individual to walk with eyes closed toward a previously seen target. Such navigation through a memorized mental image of the surrounding space requires the integration of sensory, motor, and cognitive functions.[1] It has been proposed that spatial navigation can be guided by vestibular inputs, a neural process called path integration.[2] With this process, linear displacement information could be obtained from double integration of otolith inputs.[3] However, this possible path integration is likely imperfect because healthy subjects are generally unable to stop exactly at the target's spot when they walk *forward* without vision.[4–9]

The path integration hypothesis has been challenged by the results of Glasauer and colleagues, who found that patients with bilateral vestibular deficits did not make larger distance errors than healthy subjects during blind walking in the *forward* direction.[10] Similar results have been reported in patients with unilateral vestibular deficits.[11] This is in contrast to the inability of bilateral vestibular deficit patients to estimate their *lateral* displacement during passive transport.[12]

At present, very little is known regarding navigational abilities in directions other than forward. To further investigate spatial navigation, we have studied the ability to navigate during lateral walking (sidestepping). We hypothesize that blind walking in the lateral direction will better reveal unilateral vestibular deficits than forward walking. The specific aim of this study was to compare distance (linear) errors and deviation (angular errors) made by healthy subjects and patients with complete unilateral vestibular deficit during lateral walking without vision.

Methods

Five subjects with complete absence of vestibular function on one side owing to surgical resection of an acoustic neuroma participated. Individual patients' characteristics are listed in Table 1. In addition, 17 young (18–38 years old) and 9 older healthy subjects (67–83 years old) with no history of neurologic or neuromuscular disorders were studied. All subjects signed an informed consent form approved by a local ethics committee.

Table 1 Characteristics of Subjects Who Had Undergone Surgical Resection of an Acoustic Neuroma

Patient	*Age (yr)*	*Gender*	*Side of Surgery*	*Time Post Surgery (mo)*
1	61	M	Left	20
2	54	F	Right	4
3	46	F	Left	2
4	55	F	Left	4
5	37	F	Left	2

Subjects stood in a lighted room 1.15 m in front of a starting target (T1) located at eye level, as illustrated in Figure 1. They were instructed to look at another eye-level target (T2) located 1.25 m to the right side of T1 and then to close their eyes and walk rightward laterally (sidestep) in a straight line parallel to the T1–T2 line until they believed they were in front of T2. After a brief pause at this location, they walked back toward the starting target without opening their eyes. This was to prevent them from getting feedback on their performance and correcting the following trials accordingly. They were permitted to open their eyes only to turn around and reposition themselves in front of T3 to be ready for the next trial. The same task was repeated as the subject walked leftward toward T4. Subjects walked using non-natural short steps to discourage the use of step counting and kinesthetic information to estimate the distance and direction of displacement. Forty trials were performed, that is, 20 alternate rightward-leftward trials.

The three-dimensional head and body position data were acquired with the Vicon512 system (Oxford Metrics), except in four healthy subjects and two patients for whom the ELITEplus system was used. The position of reflective body markers was recorded during 10 seconds at a frequency of 120 Hz. Markers were affixed to the chin, top, front, back, and two sides of the head, shoulder acromions, sternum, and tip of the shoes, bilaterally.

Two dependent variables have been measured: distance error and deviation. Both of them were measured at the end of each walk. The distance error was the distance between the end target and a perpendicular line draw from the sternum to the plane of targets. The deviation was the angle between the line formed by the

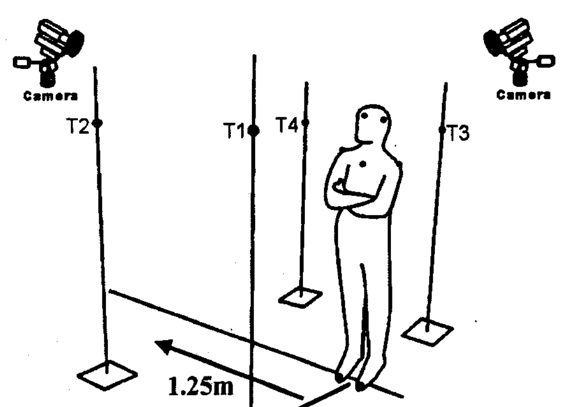

Figure 1 Diagram of the experimental set-up showing the location of subject and targets and the position of markers on the subject. For rightward trials, subjects walk laterally from their position in front of target 1 (T1) toward target 2 (T2). For leftward trials, subjects face target 3 (T3) and walk laterally toward target 4 (T4).

start and end targets and the line formed by the two acromions. A positive angle indicates deviation toward the end target, whereas a negative angle is a deviation away. For example, at the end of a rightward navigation trial, if the right shoulder is closer to the plane of targets than the left shoulder, this is positive deviation.

Distance error and deviation obtained during right and left trials in healthy subjects were compared using nonpaired *t*-tests. The effects owing to group (young healthy vs. older healthy vs. vestibular subjects) and direction of navigation (leftward vs. rightward) were identified with a two-way analysis of variance (ANOVA) for repeated measures.

To test the within-subject reproducibility, five young healthy subjects repeated the testing procedures a second time. Retesting was done 7 days after the first test. Intraclass correlation coefficients (ICCs) have been calculated to quantify the strength of the test–retest reproducibility relationship.

Results

Distance Error

All subjects made errors of navigation, that is, they were unable to stop exactly in front of the end targets when walking toward their right or left side. A majority of subjects walked too far and overshot the end targets. The two-way ANOVA revealed a significant effect of subject groups ($p < .01$) but no significant effect of navigation direction or interaction between the two factors for distance error. Figure 2 illustrates that vestibular subjects made similar distance errors (20.9 ± 22.0 cm) than young healthy subjects (29.5 ± 27.5 cm). Older healthy subjects had mean distance errors significantly smaller (–1.7 ± 18.4 cm) than young healthy subjects ($p < .01$). However, the smaller mean is attributable to half of the older subjects (n = 5) overshooting and the others (n = 4) undershooting the end targets. Mean absolute values of distance errors in older subjects are 12.8 cm toward the right and 10.1 cm toward the left. In young and vestibular subjects, absolute distance errors are larger, that is, 30.3 cm toward the right and 30.7 cm toward the left in young subjects and 24.4 cm toward the right and 26.5 cm toward the left in vestibular subjects.

The test–retest showed that, on average, the five subjects overshot end targets by 24 ± 26 cm on the test and 32 ± 39 cm on the retest. The ICC was .78, indicating very good reproducibility of distance errors.

Deviation

All subjects deviated from an ideal straight trajectory. A significant effect of subject groups ($p < .01$) was found on the two-way ANOVA. Navigation direction had no significant effect on deviation. Figure 3 shows that, on average, young healthy subjects deviated 8° ± 8° and 8° ± 9° and older subjects deviated 2° ± 10° and –3° ± 12°

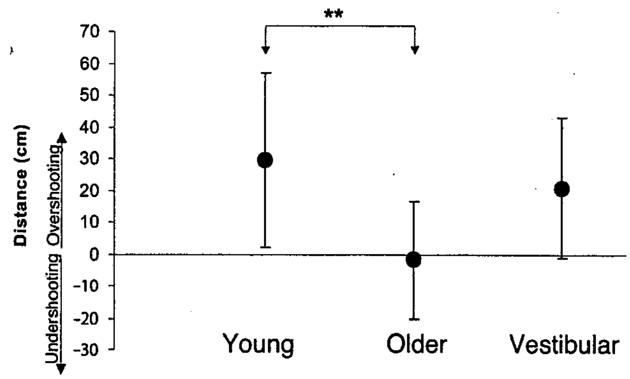

Figure 2 Mean ± 1 SD distance errors. Rightward and leftward trials have been averaged. $^{**}p > .01$.

when navigating rightward and leftward, respectively. In the test–retest, mean deviation was similar, that is, 9° ± 10° at test and 9° ± 8° at retest. Good reproducibility of deviation was shown by the ICC = .60.

In contrast to healthy subjects who had symmetric deviation when navigating rightward and leftward, vestibular subjects deviated significantly more when navigating toward the side of their vestibular lesion (13° ± 9°) than toward their intact side (3° ± 9°; $p < .01$). There was no relationship between the time following surgery and the extent of deviation as the two vestibular subjects with the largest deviation were 4 and 20 months following surgery.

Discussion

We have found that all subjects made errors of navigation when walking laterally toward a memorized target located 1.25 m to their right and left sides. On average, young healthy subjects overshot the end targets by 24% of the distance to be covered. This is much larger than the distance error obtained in studies on forward

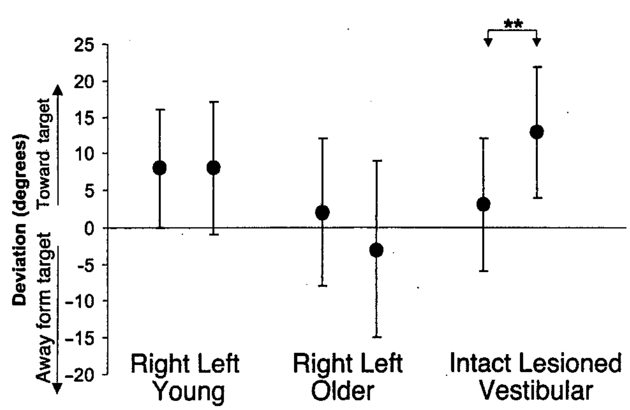

Figure 3 Mean ± 1 SD for rightward and leftward trials obtained in young and older healthy subjects. In vestibular subjects, deviation is represented for navigation toward the intact side and the lesioned side. $^{**}p > .01$.

walking with eyes closed toward targets located 2 m (overshooting error of 13%[7]) or 4 m away (overshooting errors of 6%[5] and 4%[10]). The large overshooting we have found is likely an accurate representation of navigation abilities because distance error was not significantly different in our test–retest executed a week apart and the ICC of distance error was .78, indicating very good reproducibility.

Overshooting of the end target during lateral walking could be attributable to an overestimation of the end target's distance and/or an underestimation of the subject's own displacement. Regarding this last option, it has been proposed that double integration of acceleration signals from otolith organs to produce displacement information may be an imperfect vestibular process, even in healthy individuals.[3,13] This could explain the difficulty subjects had in perceiving their own linear displacement.

Our subjects may also have overestimated the end target's distance. One important point is that our experimental paradigm may involve a different visual perception of the end target than in the forward walking paradigm. For instance, our subjects did not walk toward the location of the end target but toward a position located behind the end target. Thus, our arrangement pertains to triangulation rather than straight blind walking toward a target. Triangulation is an experimental paradigm in which the line of visualization of the end target is the hypotenuse of a right angle triangle and the walking path is its long side. With this paradigm, Fukusima and colleagues demonstrated that healthy subjects perceive the target's location accurately when they are located up to 15 m away.[14] Although more experimental results are necessary to confirm this finding, it seems that significant overestimation of the end target's distance may not be the main reason for target overshooting in our experiment. Among other unlike factors, our large distance errors are probably not caused by the use of short steps because the size of steps has been found not to influence distance errors.[15] However, in the same experiment, short steps have been associated with twice the variability in distance errors, which may help to explain the large variability in distance error we have found.

Our results indicate that older healthy subjects had smaller distance errors than young subjects. This is owing in part to the averaging of negative (undershooting, n = 4 older subjects) and positive (overshooting, n = 5) distance errors. In reality, older subjects had a mean distance error of 12.8 cm (absolute value). However, this is still 16.8 cm less than the mean distance error found in young subjects. It is possible that, by chance, more older subjects with good navigation abilities have been recruited than in the group of young subjects.

Patients with absence of vestibular function on one side because of surgical resection of an acoustic neuroma had similar distance errors than healthy subjects. This feature of patients with unilateral vestibular deficits has also been obtained in a study on forward walking with eyes closed.[11] It suggests that the absence of one otolith organ has no impact on the ability to estimate one's distance, at least in patients 2 months or more following surgery and within the parameters of our testing protocol.

Deviation was small (means less than 10°) and symmetric in young and older healthy subjects. We have found good reproducibility of deviation within 7 days with our test–retest. Small deviations were also found with the forward walking paradigm, that is, less than 2°.[5,10] This indicates that healthy subjects are able to perceive and control their body rotation during sidestepping toward the right and left and forward walking, even in the absence of vision.

We have found that subjects with complete absence of vestibular function on one side had asymmetric deviation, in contrast to healthy subjects who had similar deviation when navigating toward the right or left. Vestibular subjects had significantly larger deviation when walking toward the side of their lesion (13° ± 9°) compared with toward their intact side (3° ± 9°). Our result is consistent with the larger deficit in roll-tilt perception during the application of centrifugal forces toward the side of the lesion in patients with unilateral vestibular deficits.[16] However, such influence of the side of vestibular lesion on deviation has not been found by Péruch and colleagues, in a study in which patients following resection of an acoustic neuroma performed normally in turning to face a target and walk forward toward it with eyes closed.[11] It is possible that difficulty in detecting navigation impairments in these patients was attributable to the testing method involving walking in the sagittal plane rather than the frontal plane.

Our new testing method of spatial navigation seems to differentiate subjects with unilateral vestibular lesions from healthy subjects. Furthermore, it can identify the side of the vestibular lesion. These promising preliminary results support the planning of subsequent navigation studies in this patient population, as well as the development of a new clinical tool to assess navigation abilities.

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