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Head Movements in Patients with Vestibular Lesion: A Novel Approach to Functional Assessment in Daily Life Setting

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Objectives: (1) To determine if head movements in patients with vestibular deficiency differ from those in normal subjects during daily life activities. (2) To assess if these differences can be correlated with patients' perception of dizziness-induced handicap.
Study Design: Prospective matched-pairs study
Setting: Tertiary referral center
Patients: Thirty-one vestibular schwannoma patients with documented postoperative unilateral vestibular loss and their age-, gender-, and physical activity level–matched controls with symmetric vestibulo-ocular reflexes.
Interventions: Head movements during 10 tasks from daily life were recorded using body-worn movement sensors.
Main Outcome Measures: The time to complete the task, the average head velocity and acceleration during each task, and the number of head turns performed were compared between cases and controls. These measures were then correlated with the self-reported Dizziness Handicap Inventory (DHI) scores of the patients.
Results: Patients with a unilateral vestibular deficit took significantly longer to perform most daily life activities compared to controls. Their head movements, however, were not always slower. They adopted a different movement strategy, in certain instances less efficient and more disorganized. Dimensions of movement are not all affected equally after a unilateral vestibular loss with evidence of clear clustering of the differences within dimensions across tasks. There was no correlation between the DHI and patients' performance in those tasks.
Conclusion: Vestibular loss, even when compensated, affects patients' movements, which can be measured in an ambulatory setting of daily life activities. The differences in movements associated with vestibular loss do not correlate with the degree of self-reported handicap. **Key Words:** Activities of daily living—Dizziness-Handicap Inventory—Head movements—Vestibular rehabilitation—Vestibular schwannoma.
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After injury to the peripheral vestibular system, standard diagnostic tests, such as calorics, vestibulo-ocular reflex testing (VOR), and posturography, are used to assess vestibular function. They inform us about the physiologic state of the vestibular system and the presence of dysfunction, and document the status of the compensation process of the central nervous system. These tests, however, are imperfect indicators of recovery because their results do not correlate well with the severity of dizziness-related symptoms the patent is experiencing (1). Several studies have documented large discrepancies between subjective and objective measurements of vestibular function (2–10). Overall, most of these vestibular tests do not provide an accurate picture of either the extent of dizziness-induced functional limitation (disability) or the impact of the vestibular disorder on the patient's life (handicap). Because objective measures of impairment or improvement are of little significance unless the patient perceives a benefit, there is a need for an objective measure of functional status that correlates with the presence of vestibular dysfunction and with patients' subjective perception of handicap. With the vestibular impairment having an impact on patients' movements, we believe that an assessment of movements in daily life is the closest approach that can be used to objectify the resulting disability and handicap.

From short tests performed in artificial settings, it is known that after unilateral vestibular loss, patients tend to walk and move their arms slower (11,12), have more sway of their center of gravity (13–15), and take longer to perform ambulatory test such as the ''Timed Up and Go''

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and the ''Five times sit to stand'' test (16). Overall, these studies suggest that patients with vestibular loss move slower. It is, however, not known how these tests translate to daily life realities and how movements are affected in an unrestricted setting. Are patients also slower during tasks of daily life? Are all their movements slower or are they simply using different movement strategies? Are all planes of movement equally affected?

Routine daily activities are complex but well-learned motor tasks, practiced thousands of times over the course of a lifetime. It has been suggested that vestibular disorders may introduce some inefficiency in performance with these tasks requiring more energy than they did before (17). This idea is supported by the fact that many patients complain of fatigue, difficulty concentrating, and decreased attention span after a vestibular injury (17). Identifying the nature of these inefficiencies and adaptation strategies through careful movement analysis has implications in retraining motor skills during rehabilitation by directly targeting these problems.

In this context, the present study describes the use of innovative technology as an attempt to reveal differences in behavior in people with vestibular dysfunction compared to normal subjects in daily life activities. Using a very lightweight and precise body-worn sensor that allows for movement recordings in unrestricted and natural conditions, we are aiming for a better understanding of movement differences in patients and their relationship to the perceived handicap in a daily life setting.

MATERIALS AND METHODS

Subjects

The study group consisted of patients with a diagnosis of vestibular schwannoma (VS) who had undergone a primary surgical resection of their tumor via suboccipital craniotomy and retrosigmoid approach with sectioning of the vestibular nerve at least 6 months before their participation in the study. Subjects were excluded if their final pathology was not VS and if they were not able to mobilize without assistance. Control patients were recruited from the Head and Neck, Rhinology and General otolaryngology clinics at a tertiary care university center. One age-, gender-, and physical activity level–matched control was recruited for every case. Physical activity level was assessed using the Brief Stanford Physical Activity Screener (18) and matching was performed based on a final activity level. Control patients were excluded if they had any history of VS, were evaluated for hearing or balance complaints, or reported any dizziness symptoms. Approval for the study was obtained from the Hospital Research Ethics Committee.

This study involved a one-time participation in four parts: (1) a subjective assessment of symptoms using the Dizziness Handicap Inventory (DHI) questionnaire, (2) VOR testing, (3) maximal self-generated head movement measurements, and (4) daily tasks performance using a movement sensor.

Dizziness Handicap Inventory

The DHI is a 25-item validated clinical tool used to document symptomatic complaints and perceived functional disability of individuals with vestibular disorder, with higher scores indicating greater handicap (19). Scores on the DHI range from 0 (no perceived handicap) to 100 (the maximum perceived handicap).

VOR Assessment

Passive VOR assessment was performed via horizontal head impulse testing using a head-mounted monocular vestibulo-oculography device, the EyeSeeCam (EyeSeeCam, Munich, Germany). After calibration of the light eye-tracker on the left pupil, a single examiner generated horizontal head impulses in both directions while the subjects were instructed to fixate in light a standardized point in front of them. The passive VOR gains for rotations ipsilateral and contralateral to the lesion were determined by plotting the eye and head velocities in Matlab (MathWorks, Natick, MA, USA). A dynamic regression model was used to quantify the VOR gain and phase.

Maximal Head Movements Assessment

Maximal self-generated head movement measurements while sitting were performed to assess the maximal movement capabilities in both cases and controls when there was no risk of imbalance or falls. The head-mounted EyeSeeCam device was used to record angular head velocities while the subjects were instructed to perform 10 full cycles of head rotations in the yaw (left-right) and pitch (up-down) planes in light without instruction for fixation. The peak head velocity of each turn and each direction were tabulated, and an average was generated for each subject.

Tasks of Daily Living

Movement performance in daily life was assessed through a standardized protocol of 10 tasks set up within the clinic and aimed at safely challenging the known areas of difficulty in patients with vestibular dysfunction (20). The details of each task are described in Table 1. Head movements were recorded using a micro-electromechanical systems (MEMS) module (iNemo platform, STEVAL-MKI062V2; STMicroelectronics, Geneva, Switzerland). This MEMS module combines three linear accelerometers (recording linear accelerations along the fore-aft, inter-aural, and vertical axes) and three gyroscopes (recording angular velocity about pitch, roll, and yaw) (Fig. 1). The data from the six sensors were sampled at 100 Hz and recorded wirelessly on a microSD card. The MEMS module, the battery, and the microSD card were regrouped in an extremely light (64 g) and small (35 × 35 × 15 mm) enclosure. Two such enclosures were integrated in an elastic headband specially designed to prevent enclosure movement. The plane spanned by the fore-aft and inter-aural axes of the MEMS module was set parallel to the subject's Frankfurt line. The recording was manually stopped after each task ensuring independent recordings with no inclusion of the transition between tasks.

Data Analysis

For each subject, the time taken to complete each task was measured. The dish-sorting task (no. 7), while being the longest, is also the task involving the most head movements. It was therefore selected for an analysis of head turns in the yaw and pitch plane, to determine the maximal velocity generated and the number of head turns needed to complete the task. Dish sorting was noted to be an asymmetrical task with the target bag containing the dishes being preferentially placed on the left side across all cases and controls. The count of head turns was therefore reported as the number of head turns ipsilateral or contralateral to the tumor and the number of left- or right-sided turns.

For all 10 tasks, a systematic analysis of all head movements was performed using a custom-written script in Matlab that

TABLE 1. *Detailed description of the tasks of daily living performed by the subjects*

Task number and name	Instruction	Materials	Challenge
1—Bed	The subject is lying supine on the bed, and is instructed to sit up with the legs extended on the bed without using the arms if possible, then turn around while swinging the legs off the bed, and then stand up. Barefoot, the subject flexes-extends the legs three times with each flexion bringing the thighs to 45 degrees from the vertical.	Flat examining room chair	– Whole body movements – Dynamic balance
2—Pants	Standing up, the subject puts a pair of loose extra large scrubs one leg at a time without leaning on the bed nor touching the walls. The scrubs have a drawstring at the waist, which the subject did not tie.	Extra large scrubs	– Reduction of supporting foot area – Shifting of center of gravity
3—Shoes	Without sitting or kneeling, the subject puts his/her shoes on. Subject's own shoes were used and they were instructed to bring their most comfortable pair of flat shoes with ties.	Subjects' own shoes (despite instructions, subjects had a very large variety of shoes)	– Head motion – Reduction of supporting foot area
4—Sink	The subject walks 2 m in a straight line toward the sink, bends down to wash his/her face with eyes closed three times without leaning on the sink.	Sink	Absence of vision
5—Walk	Going out of the examining room, the subject walks in the corridor for 15 m at his or her most comfortable pace wearing his/her shoes.		Simplest ambulatory task without challenge (added for possible comparisons with other more challenging tasks)
6—Foam	The subject walks over a foam mattress wearing shoes, turns around on the mattress, and walks back over it.	191 cm long, 1 m wide, 10-cm-high firm polyester fiber foam	Modification of feet proprioception
7—Dishes	The subject sorts 30 dishes from a bag on the ground into the shelving unit according to color and shape as fast as possible while standing in the middle of the shelving unit. 15 different dishes are already positioned on the shelves to guide the sorting.	− IKEA 4 × 4 Expedit shelving unit (149 cm × 149 cm × 50 cm) − Three plastic cups, bowl and plates of five different colors (total 45) (Ikea Kalas plastic kit: cups 237 mL—0.2 kg, bowls 12 cm—0.2 kg, plate 19 cm—0.3 kg)	Rapid alternating head movements
8—Stairs	The subject goes down a series of seven stairs and back up without holding to the banister.	Seven consecutive stairs width: 135 cm × height: 16 cm	Shifting of center of gravity
9—Weight	The subject carries in one hand a 2.27-kg bag over 5 m.	A cloth bag with 2.27 kg of books	Shifting of center of gravity
10—Uphill/ Downhill	Subject walks 2 m over a 15-degree elevation with eyes open, then with eyes closed. Subject turns around and then walks downhill with eyes closed and then with eyes opened without holding onto the wall.	Ground elevation (two sets of 15 degrees elevation over 2 m)	− Modification of feet proprioception − Absence of vision

Descriptive details of each task including the instructions provided, materials needed, and specific component that makes it challenging for a patient with decreased vestibular function.

provided an average acceleration and velocity generated in all six planes of movement performed by the subjects.

Matched-pairs *T* test statistics were used for comparisons of VOR gains, task duration, and the generated accelerations/velocities between cases and controls, with a significance level of 0.05. Because DHI scores are not normally distributed, to assess for any relationship between the DHI score among cases and parameters of movement, Spearman's rho correlations were performed. The JMP 10 statistical software (SAS Institute Inc., Cary, NC, USA) was used for the analyses.

RESULTS

A total of 31 cases and 31 controls were included in the study. There were 15 females and 16 males in each group. Among cases, 11 patients had the VS on the left and 20 had a right-sided tumor. The median age was 56 years old with a normal distribution. Tables 2 and 3 describe the physical activity level and DHI scores among cases, respectively.

VOR Testing

The head impulse stimulus for VOR testing was delivered by a single examiner with an average peak velocity of 176.7 ± 3.8 degrees per second and a duration of 0.33 ± 0.009 seconds. In controls, VORs were symmetrical with a mean gain of 0.97, whereas in cases, the mean VOR gain ipsilateral to the tumor was 0.64 compared to 0.88 on the contralateral side with a mean matched-pair difference of 0.26 ($p < 0.0001$) as depicted in Figure 2. These results document that controls had symmetrical

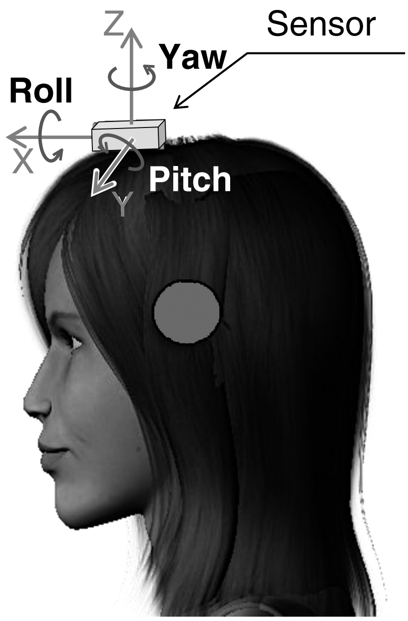

FIG. 1. Planes of head movements recorded by the sensor. The accelerometer within the micro-electromechanical system (MEMS) records linear head accelerations in the X, Y, and Z planes in meters per second squared, with the directions of movements being fore-aft for the X plane, left-right for the Y plane, and up-down for the Z plane. The gyroscope within the MEMS records the velocity of head rotations in the yaw, pitch, and roll planes in degrees per second, with the directions of head turns being ipsilateral-contralateral to the tumor for the yaw and roll planes and up-down for the pitch plane.

passive VOR gains whereas cases had significant weakness ipsilateral to the tumor, compared to their healthy contralateral side.

Quantification of Head Movements During Maximal Active Head-on-Body Rotations

Maximal self-generated head velocities during 10 head turns in the pitch and yaw plane while sitting were performed to assess the maximal movement capabilities in both cases and controls when there was no risk of imbalance or falls. The results, shown in Table 4, demonstrate no difference between cases and controls. All matched pairs of subjects have similar maximal movement capabilities while sitting (p value = 0.54 in yaw and 0.92 in pitch), suggesting that the surgery did not affect the neck musculature of the patients, and that they were able to generate the same maximal head velocities.

TABLE 2. *Physical activity levels among cases*

Stanford overall physical activity level	No. cases
Inactive	4
Light activity	13
Moderate activity	12
Hard activity	2

TABLE 3. *Dizziness Handicap Inventory (DHI) scores among cases*

DHI score	No. cases
0–10	6
11–20	5
21–30	7
31–40	5
41–50	5
51–60	3

Quantification of Time Required for Completion of Tasks

Duration for task completion was the first outcome of interest in the performance of tasks of daily living. Patients with a unilateral vestibular deficit took significantly longer than their peers to perform most daily life activities. The range of durations for task completion by the cases and controls is visually represented in a box-and-whiskers plot in Figure 3.

Quantification of Movement Features During Everyday Tasks

The dish-sorting exercise (Task 7) is the task with the most rotational head movements. When looking at the mean of the top 10 peak velocities in each direction of the yaw and pitch plane generated by the subjects while performing this task, no difference between cases and controls is noted (Table 5A and Fig. 4). The cases took, however, significantly longer to perform the same task. To explain the difference, the number of head turns needed for task completion was compared. The cases turned their head in the direction contralateral to the lesion significantly more times than controls (three turns more on average—Table 5B) (p = 0.025) which corresponds, in terms of left-/right-sided head turns, to a significantly higher number of head turns toward the left, where the target container with the dishes to be sorted was located (p = 0.02). This could correspond to a potential inefficiency in task performance with more visual confirmation needed to grasp dishes. The box-and-whiskers plots in Figure 4 visually translate the range of the Task 7 performance data.

Figure 5 depicts the results of the systematic analysis of all movements of the head in all six dimensions (X, Y, Z, yaw, pitch, and roll) for all 10 tasks in cases and controls. For the vast majority of tasks, there were no differences in movements in the different dimensions. Condition for which differences were noted in the average head velocities recorded for rotational motion, or the average head accelerations recorded for translational motion, are colored on the grid. For translational motions, during some of the tasks, cases are generating higher accelerations than controls. Similarly, for head rotation around the yaw axis, cases were turning their head faster than

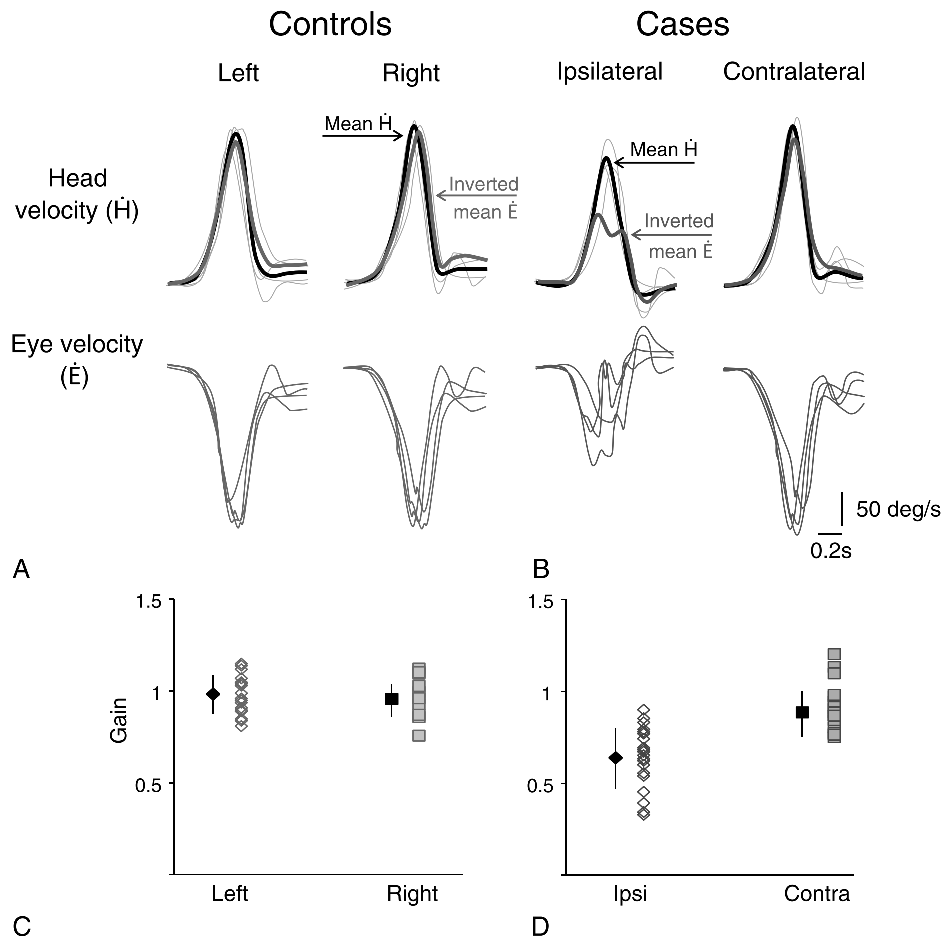

FIG. 2. Horizontal vestibulo-ocular reflex (VOR) gains in cases and controls. Sample head and eye movements during horizontal head impulse testing in controls (*A*) and cases (*B*), demonstrating a decreased gain with turns ipsilateral to the tumor. The distribution of the horizontal VOR gains obtained for each direction of head turn in controls (*C*) demonstrated symmetry with gains clustered around 1 for both direction of movement, whereas the cases (*D*) showed significant asymmetry.

controls during Tasks 1 to 4, tasks that on description do not seem to require any specific head turns. However, for up and down rotations of the head (i.e., pitch plane), controls had faster head movements than cases for the majority of tasks (Task 2, 4, 6, 8, 9, 10). Similar results were observed for head movements in the roll plane during Task 6 and 10.

Overall, there appears to be clustering of the differences within dimensions across all tasks. In the translational motions and yaw head turns, cases are often generating higher accelerations and velocities than controls. Conversely, for pitch and roll head turns, controls are reaching higher velocities. Dimensions of movement are not all affected equally after a unilateral vestibular loss, which might hint at adaptational movement strategies developed by the patients after the injury.

Comparison of Subjective and Objective Measures

Finally, in the patients with a unilateral vestibular deficit, the relationship between the DHI score and the different parameters of movement measured was assessed to determine if patients' perceived symptoms are related to their performance. Overall, we found that the DHI score did not correlate with any parameters of movements measured in this study. It did not correlate with the time taken to complete the task, the maximal self-generated head velocities while sitting, the velocities of maximal rotational head movements during dish sorting, the number of head turns during dish sorting, nor the average accelerations and velocities for all tasks in all six

TABLE 4. *Mean of the maximal self-generated head velocity performed by the subjects while sitting*

Plane		Cases		Controls		
		Mean velocity in deg/sec	S dev	Mean velocity in deg/sec	S dev	*p*
Yaw	Ipsilateral	389	126	362	118	>0.05
	Contralateral	377	123	374	127	>0.05
Pitch	Up	223	97	216	85	>0.05
	Down	221	94	224	91	>0.05

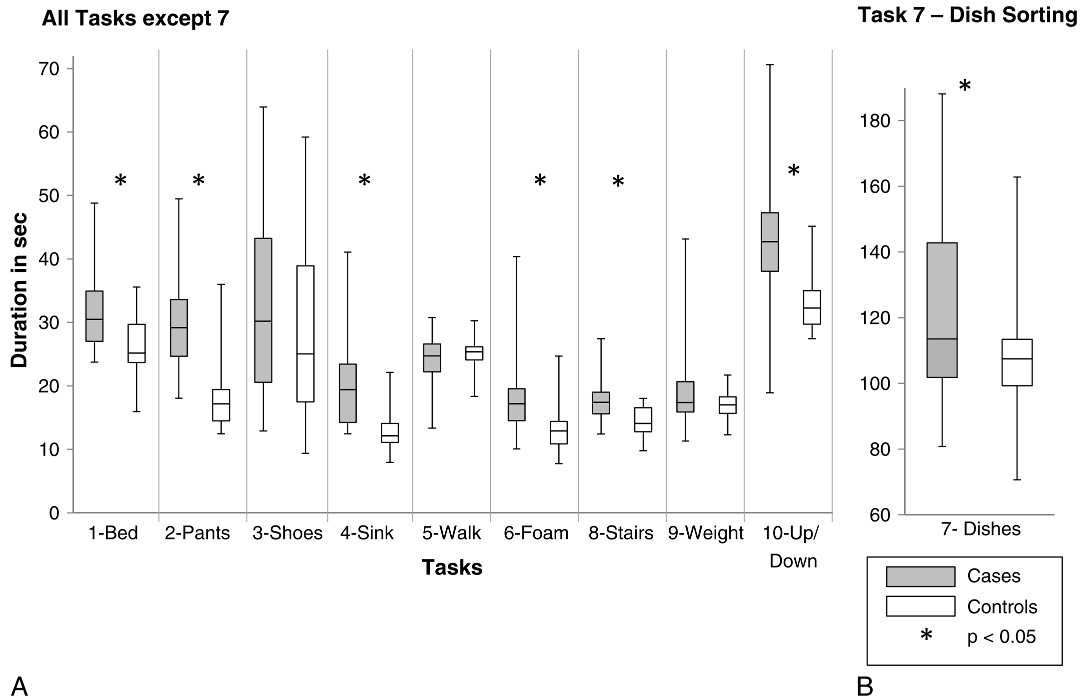

FIG. 3. Task duration in cases and controls. The box-and-whiskers plot of the time needed by the subjects to complete each task describes the distribution of the timed performance in cases versus controls. As per convention, the partitions in the box-and-whiskers plot represent the minimum, first quartile, median, third quartile, and maximal values recorded. The *asterisk* is used to highlight that the cases took significantly longer than their matched controls to perform the task. Note that the figure is split in *A* and *B* because a different scale is used for the Y axis (duration in seconds) because Task 7 (*B*) is significantly longer than any other tasks.

planes with the *p* values of the Spearman's correlation exceeding the adjusted significance level in all instances.

DISCUSSION

Patients with a unilateral vestibular deficit move differently than healthy controls during activities of daily life, but these differences do not correlate with the patients' perceived handicap.

More specifically, we first show that there is no difference in the maximal movement capabilities between cases and controls when there is no risk of imbalance or falls, confirming that the surgery undergone by patients with VS did not affect their neck musculature, and in a safe setting, they are still able to generate the same head velocities as controls. Any difference in head movement velocities in a task setting would therefore be the result of a functional adaptation to the task.

Duration for Task Performance

In a functional setting of daily life activities, individuals with a unilateral vestibular deficit take significantly longer to complete most tasks. This is consistent with patients' reports of performing many routine daily-life tasks more slowly and more carefully than they did before the onset of their symptoms (17). Among activities of daily living, the tasks reported most often to be impaired after VS surgery were ladder climbing and night driving (21). Self-care activities, such as lower extremity dressing (22) and bathing (23), had also been reported to be problematic in patients with vestibular disorders which is reflected in our performance data where significantly

TABLE 5. *Head rotations during dish sorting (Task 7) in cases and controls*

A. Mean and standard deviation of the maximal self-generated head velocities while performing Task 7

Plane		Cases: Mean max velocity in deg/sec	Cases: S dev	Controls: Mean max velocity in deg/sec	Controls: S dev	*p*
Yaw	Ipsilateral	220	53	205	50	>0.05
	Contralateral	205	42	192	48	>0.05
Pitch	Up	240	37	216	48	>0.05
	Down	192	46	189	48	>0.05

B. Mean and standard deviation of the number of head turns performed during Task 7

Plane		Cases: Mean no. of head turns	Cases: S dev	Controls: Mean no. of head turns	Controls: S dev	*p*
Yaw	Ipsilateral	29	4.6	27	4.6	>0.05
	Contralateral	28	4.4	25	5.5	0.025*
Yaw	Left	29	4.4	24	5.4	0.020*
	Right	29	4.6	28	4.4	>0.05
Pitch	Up	33	4.8	31	5.4	>0.05
	Down	32	5.6	31	4.7	>0.05

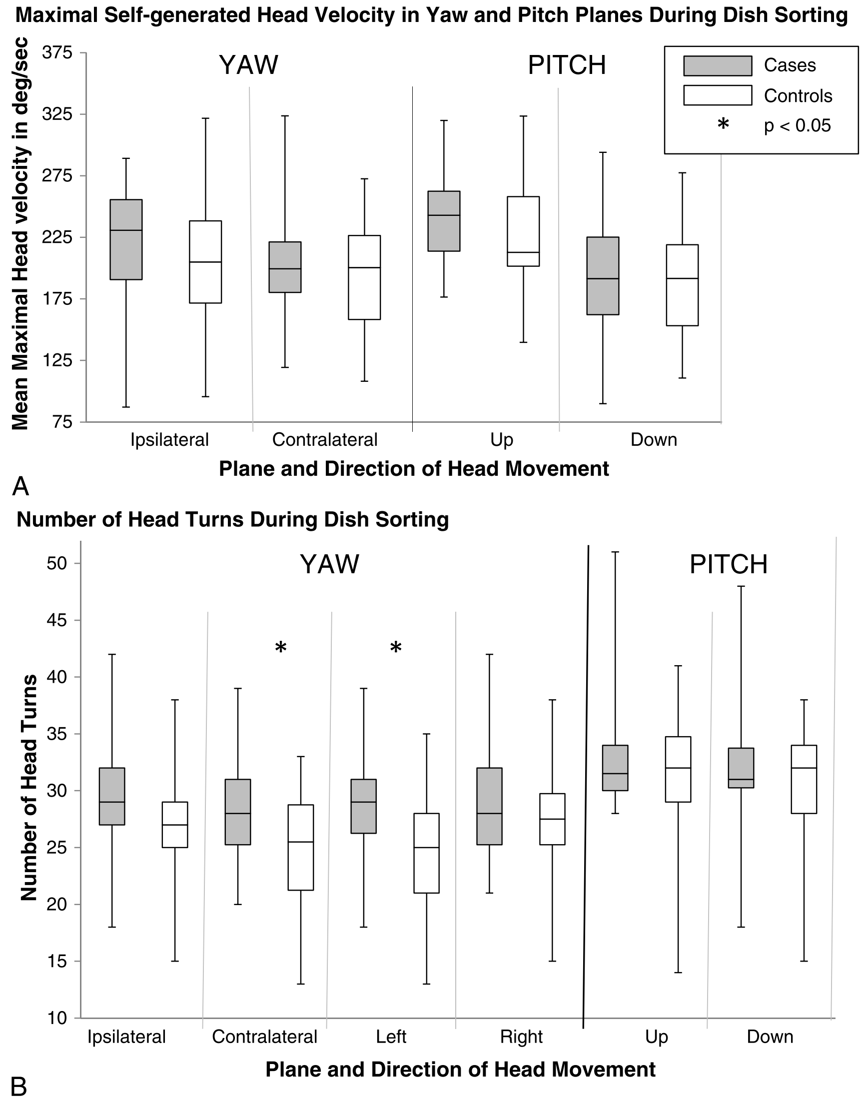

FIG. 4. Head rotations during dish sorting (Task 7) in cases and controls. The *asterisk* is used to highlight when significant difference between cases and controls is found. The box-and-whiskers plot describes the distribution of the mean maximal self-generated head velocity in yaw and pitch planes during the dish-sorting task. The matched-pairs comparison of the mean maximal self-generated head velocity showed no difference between cases and controls. The box-and-whiskers plot describes the distribution of the number of head turns in the yaw and pitch plane that were needed to sort the 30 dishes. The directions of head turns in the yaw plane is divided in both ipsilateral-contralateral to the vestibular deficit and left-right, to account for the asymmetry of the task with the bag of dishes being located on the left side of the subjects. The matched-pairs comparison of the mean number of head turns performed demonstrated significantly more turns contralateral to the tumor and to the left in cases.

longer times for putting on pants (Task 2) and face washing (Task 4) have been recorded.

Several authors have documented the impact of vestibular dysfunction on motor tasks. Patients with a vestibular disorder take significantly longer to move bags of beans while sitting (24), they take more time to perform the ''five times sit to stand'' test (16), their gait speed is significantly slower in different artificial settings (11), and they take longer to reach for a target with their dominant hand than healthy controls (12). The present study is, however, the first to our knowledge in which performance during several functional tasks in a daily-life setting was assessed for comparisons between patients with unilateral vestibular deficit and matched controls using body-worn movement sensors. Our results confirm that the lower performance on these short tests, as reported by other studies, translates to that obtained during most tasks of daily living.

Dish-Sorting Task

The detailed analysis of each head turn during the dish-sorting exercise shows that when faced with a practical task, patients with a unilateral vestibular deficit are not rotating their head any slower than the controls. As pointed out previously, cases do, however, take significantly longer

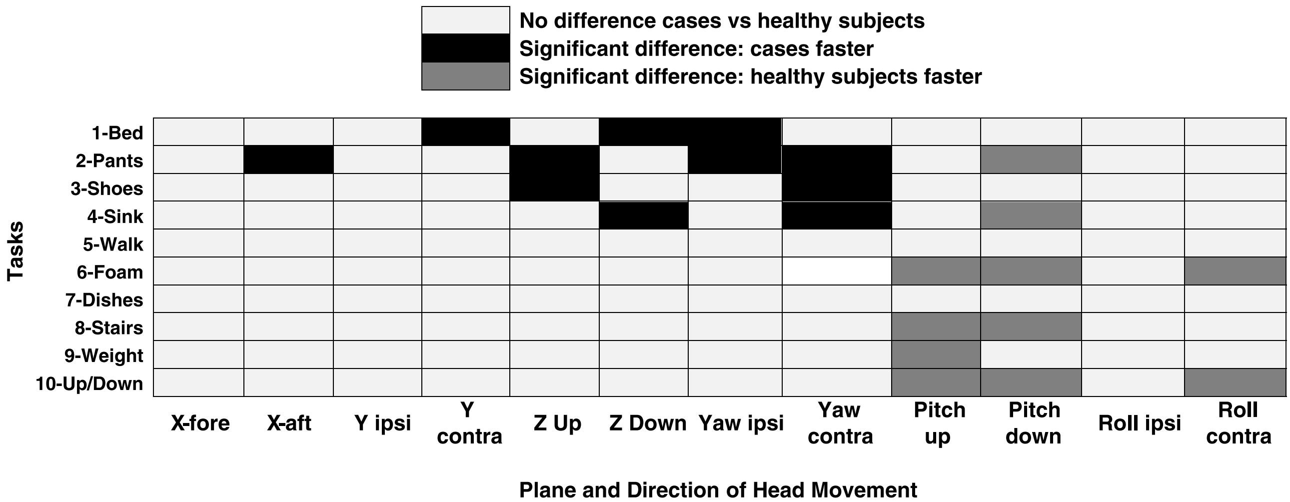

FIG. 5. Differences in head movements in cases versus controls for all tasks in all six dimensions. The grid layout highlights the differences (or lack of differences) in the accelerations and velocities generated by the cases versus the controls in all the dimensions of movement recorded by the sensor (see *Figure 1* for orientation) while performing the 10 tasks of daily living. The X axis lists all the planes and directions of movements whereas the Y axis lists the 10 tasks. As per the legend, the color shading at the intersection of the two axes indicates the relative performance of cases versus controls at that particular task in a specific dimension (i.e., *white*—there is no difference between cases and controls, *black*—cases are significantly faster than controls, and *gray*—controls are significantly faster than cases). For instance, in translational motion in the x dimension (i.e., fore-aft), there were no differences noted except in the "putting on pants" tasks (Task 2), where cases had higher accelerations going backward. For translational motion along the Y axis (i.e., ipsilateral/contralateral translation), there was no difference in the average acceleration between cases and controls for all tasks except for getting out of bed (Task 1), where cases had higher accelerations moving away from their lesion. For the up and down translation movements (Z axis), cases were again generating higher accelerations during Tasks 1 to 4, etc. Overall, there is a clear visual demonstration of clustering of differences across the dimensions of movements.

to complete the task. One explanation for taking longer to sort the dishes could be the significantly higher number of head turns toward the left performed by the cases than the controls. Indeed, on average, cases performed 28 turns towards the left, where the target bag containing the dishes was located, whereas controls performed 24 turns to sort out the same 30 dishes. It seems that cases might require more frequent visual confirmation of the target before grasping, whereas controls were able to store in their memory the location of the target and grasp the dish without requiring visual confirmation each time. The presence of a vestibular deficit as an additional challenge that needs to be taken into account by the central nervous system might have an impact on overall neural processing, attention, and task performance strategies beyond the simple effect of vestibular dysfunction on balance and visual stability.

Movements Across Tasks

In the systematic analysis of all head movements across tasks, some differences are noted between cases and controls. Rather than focusing on the magnitude of those differences, the nature of those differences and their clustering is more informative. It appears that not all planes or directions of movement are affected equally by a vestibular deficit; in some planes, cases were faster than controls whereas in others controls were faster. This difference remains consistent in that plane across different tasks of daily living. This could have significant implications in vestibular rehabilitation, where knowledge of the difference between impaired patients and normal subjects allows for more adequate therapy targeting.

As mentioned, one noticeable trend is the tendency of cases to generate lower angular velocities in the pitch plane during complex ambulatory tasks such as walking on foam (Task 6), walking with a weight (Task 9), walking uphill/downhill (Task 10), and taking the stairs (Task 8). No such difference was noted during simple walking (Task 5). Pitch rotations are the type of head movements that naturally occurs during gait, and adequate vertical VOR is required to maintain the picture of the surrounding environment stable on the retina. In a study measuring gaze stability in individuals with vestibular dysfunction, poor gaze stability in the pitch plane had the strongest association with measures of gait performance (''Timed Up and Go'' and Dynamic Gait Index) (25). The trend noted in the present study could be part of an adaptational strategy where subjects with a vestibular deficit would preferentially reduce the up and down wobbling of the head while ambulating in a complex setting to avoid eliciting oscillopsia and maintain there visual stability despite their poor VOR, with minimal effect on their other planes of movement.

Gait speed was not affected during simple walking nor walking with a weight because cases did not take any longer than controls to walk the same distance. Although the average of all fore-aft linear accelerations were not any different between cases and controls in any of the other ambulatory tasks, cases took significantly longer to walk on foam, take the stairs, and walk up/downhill. It is possible that their path was not as straight because it has been shown that during active locomotion task subjects with vestibular impairment veer significantly more than normal (26). Their gait was also described as more disorganized. Indeed, in a study of gait in normal and hypovestibular subjects, body acceleration, although not significantly different in amplitude, was more chaotic in patients with less regularity and recurrence patterns noted (27).

Task Performance and DHI

The degree of patients' perceived dizziness and self-reported handicap does not appear to correlate with the parameters of performance in tasks of daily living. Movement assessment is another objective measure that does not correlate with the patients' perceived symptoms.

In a study by Whitney et al. (16), the DHI score of patients with dizziness of all etiologies was compared with known measures of functional performance, namely the Dynamic Gait Index (DGI), the ''five times sit to stand'' test (FTSST), the ''Timed Up and Go'' (TUG), and Gait Speed. They concluded that the patients with the greatest perception of handicap were the most functionally impaired, which is not supported by our results. A closer look at that study's data demonstrates that only patients with a vestibular disorder who report scores greater than 60 on the DHI are functionally impaired based on their DGI and FTSST scores. No correlation between DHI score and TUG and Gait Speed was noted, and none of these performance measures showed correlation with DHIs bellow 60. In our study of patients post-VS surgery, the median DHI was 30 (mild), and we did not have any patients with a DHI score above 60 (the highest DHI score reported was 56). Our lack of patients with severe symptoms could explain the lack of correlation between performance in tasks of daily living and perceived symptomatology because the impact on performance is only noticeable in the extreme level of perceived handicap. One might hypothesize that only patients with the most dizziness would be slowing their movements to avoid eliciting symptoms. Our lack of subjects in this symptoms range is a limit of our study. Performing such a study would be challenging because rates of DHI scores above 60 are low, with 6.74% of operated VS patients falling in that range (28).

Similar to our results, single leg stance time (29), functional reach distance (29), and the TUG performance (30) did not correlate with the DHI scores of patients with peripheral vestibular deficit. Clinical balance tests such as balance while standing on one leg and walking in a figure of eight did not correlate with the total DHI score in a population of patients with vestibular dysfunction (31). A more systematic assessment of balance through computed posturography yielded inconsistent results with some studies showing correlation between DHI and sensory organization measures of balance (30,32–34) whereas others reported that there was essentially no relationship between disability and computerized posturography testing (35).

In the present study, each subject's perceived level of functional disability was quantified with the DHI. This questionnaire has been both (1) adequately validated for the bilingual (French-English) population in this study and (2) extensively used in the clinical literature thus allowing direct comparison with previous studies. Nevertheless, it is important to emphasize that although the DHI is generally considered to provide a good assessment of vestibular handicap and disability (36), it remains an imperfect tool. Notably, the use of a three-point scale limited by the fact that many patients note the definition of the middle level (level 2) is ''sometimes'' variable (23). Also, because the DHI attributes equal weight to all situations, it can underestimate the overall impact of the disability on the patient's quality of life (36). For example, a patient may have severe symptoms in one specific situation that are extremely distressing. Therefore, it is possible that the lack of correlation found in this study between subjective measures of disability and the objective measures of performance might be accounted by the limitation of the DHI as the tool to quantify subjective impairment. We cannot exclude the possibility that testing with a more detailed scale, such as the 10-point Vestibular Disorders Activities of Daily Living scale (23), might provide different results. This possibility should be considered in future studies.

Overall, our study joins the vast body of literature that states that it is not possible to accurately predict the degree of disability or handicap that is produced by the disease simply by considering the results of objective testing, even if these are looking directly at the movements in daily life that are linked with the handicap. Dizziness-induced handicap is by definition a complex phenomenon which takes into account not only the specific impairment but also the individual's lifestyle, environment, and expectations. Disability is not simply a result of the presence of dizziness but is the result of a complex interplay between performance and perception that is depending on patients' motivation and tolerance of postoperative vestibular symptoms that are all influenced by social, professional, psychological, affective, and cognitive factors. A combination of both subjective and objective measures of dizziness and disequilibrium during the assessment of patients with vestibular dysfunction would therefore be required.

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