Balance, mobility and gaze stability deficits remain following surgical removal of vestibular schwannoma (acoustic neuroma): An observational study

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Question Are there residual deficits in balance, mobility, and gaze stability after surgical removal of vestibular schwannoma? ***Design*** Observational study. ***Participants*** Twelve people with a mean age of 52 years who had undergone surgical removal of vestibular schwannoma at least three months previously and had not undergone vestibular rehabilitation. Twelve age- and gender-matched healthy people who acted as controls. ***Outcome measures*** Handicap due to dizziness, balance, mobility, and gaze stability was measured. ***Results*** Handicap due to dizziness was moderate for the clinical group. They swayed significantly more than the controls in comfortable stance: firm surface eyes open and visual conflict ($p < 0.05$); foam surface eyes closed ($p < 0.05$) and visual conflict ($p < 0.05$); and feet together: firm surface, eyes closed ($p < 0.05$), foam surface, eyes open ($p < 0.05$) and eyes closed ($p < 0.01$). They displayed a higher rate of failure for timed stance and gaze stability ($p < 0.05$) than the controls. Step Test ($p < 0.01$), Tandem Walk Test ($p < 0.05$) and Dynamic Gait Index ($p < 0.01$) scores were also significantly reduced compared with controls. There was a significant correlation between handicap due to dizziness and the inability to maintain balance in single limb and tandem stance ($r = 0.68$, $p = 0.02$) and the ability to maintain gaze stability during passive head movement ($r = 0.78$; $p = 0.02$). ***Conclusion*** A prospective study is required to evaluate vestibular rehabilitation to ameliorate dizziness and to improve balance, mobility, and gaze stability for this clinical group. **[Low Choy N, Johnson N, Treleavan J, Jull G, Panizza B and Brown-Rothwell D (2006) Balance, mobility and gaze stability following surgical removal of vestibular schwannoma (acoustic neuroma): An observational study. *Australian Journal of Physiotherapy* 211–216]**

Key words: Vestibular Schwannoma/Acoustic Neuroma, Balance, Dizziness, Gaze Instability

Introduction

Vestibular schwannoma (acoustic neuroma) is a benign tumor that arises from the Schwann cells surrounding the vestibular nerve, usually within the internal auditory canal (Wiegand et al 1996). It is the third most common intracranial tumour (10% of all intracranial tumours) (Herdman 2000), and occurs in 1 per 100 000 people each year (Wiegand et al 1996). Hearing loss is the most common initial symptom although tinnitus, dizziness, unsteadiness, vertigo, and sensation of fullness in the ear can occur. With larger tumors symptoms may include headache, diplopia, difficulty with co-ordination, facial weakness, hoarseness, and difficulty swallowing (Weigand et al 1996). Surgical excision is the most common treatment (Kartush and Brackmann 1996).

Surgical excision of vestibular schwannoma usually involves the complete resection of the vestibular nerve resulting in permanent, unilateral vestibular loss even if total loss had not already occurred prior to surgery. As the vestibular system has an important role in ocular and postural control, deficits in balance, mobility, and gaze stability may present prior to and after surgery (Allum and Pfaltz 1985, Horak et al 1990). Few studies have measured balance, mobility, or gaze stability deficits post-surgery, although self-reports of residual symptoms are prevalent. Disequilibrium has been documented (Hussan et al 1998, Lynn et al 1999) with up to 45% of patients reporting long-term balance deficits (Andersson et al 1998, Rigby et al 1997). Self-assessment of health suggests it is less than normal (de Cruz et al 2000) and 54% of patients report a negative impact on the quality of life (Nikolopoulos et al 1998). Thus it is relevant to identify the range and extent of balance, mobility, and gaze stability deficits that persist post-surgery to determine if intervention is warranted.

Some evidence is available to support the use of vestibular rehabilitation immediately after surgery (Herdman et al, 1995; Enticott et al, 2005). Redfern et al (2003) studied well-compensated people following surgical resection of the vestibular nerve or surgery for Meniere's disease. The only balance and mobility deficits present were slower reaction time and reduced dual task performance. Physiotherapists are often involved in acute postoperative rehabilitation to ensure safe mobility prior to discharge home, but few patients at that time or after discharge receive a targeted vestibular rehabilitation program. Only those with severe balance and mobility deficits are considered for rehabilitation at the post-surgical review. This study investigated people at least three months post-surgery who had not participated in a vestibular rehabilitation program after discharge from hospital and compared them with healthy age-and gender-matched controls, in order to quantify balance, mobility, and gaze stability deficits. Knowledge of the range and extent of these deficits after surgery is required in order to establish whether intervention is required.

Method

Design An observational study was carried out using a range of clinical measures of balance, mobility, and gaze stability, and laboratory measures of balance using tests with reliability and validity for clinical populations. Three unblinded investigators conducted all tests. A design attempting to blind the investigator was considered flawed given the hearing and likely balance impairments of the clinical participants, making them quite distinct from the control group. Two experienced clinicians performed the clinical measurements (inter-rater reliability 0.93) whilst a third investigator performed the laboratory measurements. The measurements were conducted in a random order with regular rest periods to reduce the effects of fatigue. Participants were asked not to consume drugs or alcohol for at least 12 hours prior to the assessment as these substances could influence alertness, balance, and eye movements (Ferrari 1999). Ethical clearance for this study was obtained from the institutional and tertiary hospital medical ethics committees and all participants provided informed consent.

Participants Participants were recruited from the surgical registry of a large tertiary hospital. They were included if they had had surgical removal of a vestibular schwannoma at least three months previously. They were excluded if they had other neurological or musculoskeletal disorders known to disturb balance (Carr and Shepherd 1998, Herdman 2000, Leipzieg et al 1999, Tinetti et al 1988), or severe complications following surgery, or had received post-discharge physiotherapy. Thirteen participants accepted the invitation to participate from a pool of 25 who were aged between 20 and 60 years. One was excluded on the basis of being much younger than the other participants (33 years). The clinical group included six males and six females with a mean age of 52 years (range 43–57) who had had surgery 14 months (range 3–48) previously. Twelve healthy participants with no history of dizziness, matched for age (mean 52 years, range 43–57) and gender acted as controls.

Measurement of handicap due to dizziness The impact of dizziness on daily life was measured using the Short-Form Dizziness Handicap Inventory (SF-DHI) (Tesio et al 1999). The inventory yields a score from 0 to 13 where 13 indicates no handicap and 0 indicates maximum handicap.

Measurement of balance Postural sway under altered visual and support conditions in both the medial-lateral (ML) and anterior-posterior (AP) directions was measured using computerised posturography. Recordings of sway were made standing on a computerised force platform (40 cm × 60 cm) under the six conditions for the Clinical Test for Sensory Integration of Balance (Shumway-Cook and Horak 1986): firm surface eyes open, firm surface eyes closed, firm surface visual conflict, foam surface (foam density 3.75 lb/ft^3, Alhanti et al 1997) eyes open, foam surface eyes closed, foam surface visual conflict. Postural sway under four conditions was recorded for both comfortable stance and narrow stance (feet together): firm surface eyes open and closed; foam surface eyes open and closed. The test was also recorded as a failed test if the participant was unable to balance for 30 seconds.

Single limb stance was recorded for both lower limbs (eyes open and closed) and tandem stance (dominant limb behind) with eyes open and closed for 30 seconds (Bohannon et al 1984). Performance was considered normal when the participant maintained balance for 30 s.

Response to backward external perturbation was measured using the Pastor-Marsden Test (Pastor et al 1993). Four perturbations were applied by the examiner and the responses graded 1–4, with scores greater than 2 indicating a delayed or an abnormal response.

Measurement of mobility The Fukuda Step Test (Fukuda 1959, Bonnani and Newton 1998) required the participant to march on the spot for 50 steps with eyes closed and arms outstretched at shoulder height. The distance travelled (m) and rotation from the starting point (degrees) were recorded. Performance was considered normal when the participant travelled less than 1 m forward and rotated less than 45°.

The Step Test (Hill et al 1996) was recorded for both lower limbs. The test required the participant to step one foot on and off a block as many times as possible in 15 seconds. The number of steps completed in 15 s was recorded.

The 10 m Walk Test (Wade et al 1987) was recorded at preferred speed, with the participant turning the head from side-to-side (Herdman 2000), and at fast (‘fast as you safely can walk’) speed (Bohannon 1997). The time taken to walk 10 m was recorded.

The Tandem Walk Test (Herdman 2000) was recorded as the time to walk heel-toe along a line. The time taken for 10 steps forwards and then 10 steps backwards was recorded.

The Dynamic Gait Index (Shumway-Cook et al 1997, Shumway-Cook and Woollacott 2001) was recorded as a measure of community ambulation. Eight walking tasks were performed over a walkway 6 m long and 0.25 m wide. The tasks included walking on a firm surface at preferred speed, walking with changing speed, walking with horizontal head movement, walking with vertical head movement, stepping over and around obstacles, walking with a pivot turn, and walking up and down stairs. Each task was scored on an ordinal scale (0–3) yielding a maximum score of 24. A normal score for healthy elderly people is 21 (SD 3).

Measurement of gaze stability The ability to follow a moving target (ie, visual pursuit) through full range was recorded. The presence of corrective saccades at rest and/or with movement across the mid-line was used as the criterion for an inadequate vestibular-ocular reflex (Herdman 2000).

Ocular responses to passive head movements about the mid-line were recorded. The participant fixated on a stationary object during 10–12 small oscillations applied at a rate of 2 Hz. The ability to maintain gaze stability was rated as 1 (able to maintain) or 2 (unable to maintain) (Herdman 2000).

Ocular responses to a single rapid head movement to the mid-line from 30° of cervical rotation were recorded using the Halmagyi Impulse Test (Baloh and Halmagyi 1996). A positive response was recorded if the participant’s eyes deflected and a single catch-up saccade was observed towards the side of the lesion.

Ocular responses to active head movements were recorded following 25 headshakes. The ability to maintain gaze stability was rated as: 1 (immediate ability to fixate; no observable nystagmus); or 2 (delayed suppression of nystagmus) (Baloh and Halmagyi 1996).

Dynamic visual acuity was recorded using the protocol of Herdman (2000). The participant stood 3 m from a Snellen Chart mounted on a wall and read from the top of the chart, using corrective lenses if required, to the smallest correct print line to determine a baseline score. The examiner then stood behind the participant and held the head tilted forward to 30° and applied small oscillations about the mid-line at a frequency of 2 Hz. The participant read from the chart during the head movements until an error in reading

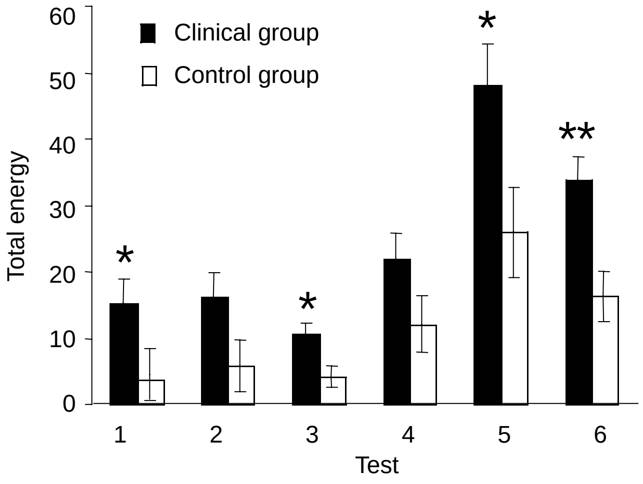

Figure 1. Mean (SD) of total energy of postural sway for clinical (solid bars) and control (open bars) group in comfortable stance. 1 = firm surface / eyes open, 2 = firm surface / eyes closed, 3 = firm surface / visual conflict, 4 = foam surface / eyes open, 5 = foam surface / eyes closed, 6 = foam surface / visual conflict. One asterisk indicates significant between-group differences (*p* < 0.05), two asterisks indicate *p* < 0.01.

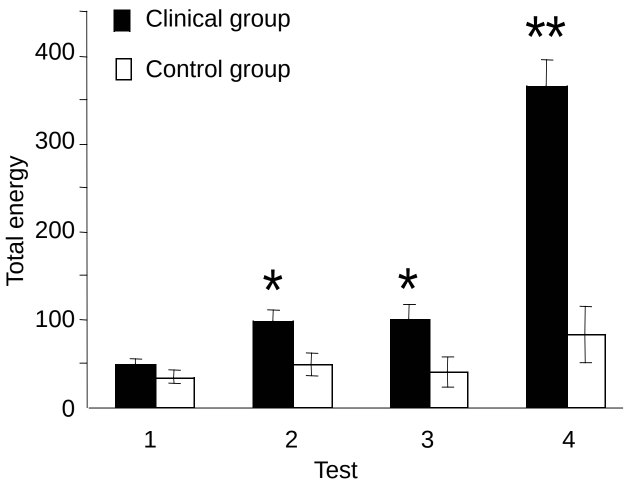

Figure 2. Mean (SD) of total energy of postural sway for clinical (solid bars) and control (open bars) group in narrow stance. 1 = firm surface / eyes open, 2 = firm surface / eyes closed, 3 = foam surface / eyes open, 4 = foam surface / eyes closed. One asterisk indicates significant between-group differences (*p* < 0.05), two asterisks indicate *p* < 0.01.

occurred or the examiner could feel the participant tensing the cervical muscles to reduce the head movement in an attempt to continue reading accurately from the chart. The smallest correct print line was thus determined and the difference between head stationary and head moving was calculated. A score of 3 or more lines was rated as abnormal (Herdman 2000).

Data analysis All data were checked for normality. For the postural sway data generated from the computerised posturography, a wavelet analysis was carried out since it has been found to be a more precise measure of change in sway over time (Thurner 2000, Treleaven et al 2004). The wavelet analysis was performed for both antero-posterior and medio-lateral traces for each test condition. The total energy combined from antero-posterior and medio-lateral traces at the first four frequencies was used to summarise the information contained in the trace. Participants who could not balance for 30 s were given an arbitrary maximum value for sway based on the maximum score over the cohort for participants who completed the test (Nashner and Peters 1998). A multivariate analysis of total postural sway was conducted, adjusted for multiple comparisons between the test conditions using a Bonferroni test.

ANCOVA, adjusted for age and gender, was used to compare balance and mobility between the control and clinical groups for: the number of steps taken in 15 s during the Step Test, the distance travelled (m) and rotation (degrees) during the Fukuda Step Test, the time taken (s) to walk 10 m with and without head turning and at both preferred and fast speeds, the time taken (s) to tandem walk 10 steps forwards and backwards, and the Dynamic Gait Index score (0 to 24). Examination of the percentage of participants with abnormal responses was used to compare balance between the control and clinical groups for single limb stance, tandem stance, and response to backward external perturbation in the Pastor-Marsden Test. Chi-square test was used to compare gaze stability between the control and clinical groups for visual pursuit, passive head movement, and dynamic visual acuity.

Spearman's r was used to determine the relation between handicap due to dizziness (SF-DHI score) and balance, mobility, and gaze stability in the clinical group. The level of confidence for all statistical analyses was *p* < 0.05.

Results

Handicap due to dizziness The SF-DHI score for the clinical group was 8.4 (range 2–13) out of 13. Only two participants in the clinical group reported no impact of dizziness on daily life.

Balance There was a significant difference in postural sway between the clinical group and the control group for 3 of the 6 conditions tested in comfortable stance and 3 of the 4 conditions tested in narrow stance. In comfortable stance on a firm surface, sway of the clinical group was significantly greater with eyes open and during visual conflict, but not with eyes closed (Figure 1). In comfortable stance on a foam surface, sway of the clinical group was significantly greater with eyes closed and during visual conflict but not with eyes open (Figure 1). In narrow stance on a firm surface, sway of the clinical group was significantly greater with eyes closed and during visual conflict but not with eyes open (Figure 2). In narrow stance on a foam surface, sway of the clinical group was significantly greater with eyes open and closed (Figure 2).

In single limb stance with eyes open, 25% of the clinical group could not balance for 30 s compared with 0% of the control group. In single limb stance with eyes closed, 100% of the clinical group could not balance for 30 s compared with 33% of the control group. In tandem stance with eyes open, 50% of the clinical group could not balance for 30 s

Table 1. Mean (SE) score and mean (95% CI) difference between groups of balance and mobility for the clinical and control groups.

Test	Score		Difference between groups
	Clinical group	Control group	Clinical minus control
Step Test (# steps/15 s)			
Left – Affected side	14.8 (0.5)	21.2 (0.8)	–6.4 (–8.9 to –3.9)***
Left – Unaffected side	16.1 (0.6)		–5.1 (–7.5 to –2.7)**
Right – Affected side	14.8 (0.5)	21.3 (0.9)	–6.6 (–9.3 to –3.9)***
Right – Unaffected side	16.1 (0.6)		–5.3 (–7.5 to –3.0)***
10m Walk Test (s/10 m)			
Preferred speed – no head turning	9.4 (0.5)	7.8 (0.3)	1.6 (0.5 to 2.7)*
Preferred speed – head turning	10.4 (0.5)	7.9 (0.5)	2.5 (0.6 to 4.3)*
Fast speed	7.1 (0.5)	5.4 (0.2)	1.7 (0.4 to 3.0)*
Tandem Walk Test (s/10 steps)			
Forward	10.9 (0.8)	6.7 (0.5)	4.3 (2.3 to 6.2)**
Backward	13.5 (1.2)	6.8 (0.4)	6.7 (3.9 to 9.4)***
Dynamic Gait Index (0–24)	19.7 (0.8)	23.3 (0.2)	–3.7 (–5.5 to –1.8)**

* = $p < 0.05$, ** = $p < 0.01$, *** = $p < 0.001$

Table 2. Number (%) of participants and odds ratio (95% CI) of gaze stability for the clinical and control groups.

Test	Abnormal finding	Clinical Group	Control Group	Odds Ratio
Visual pursuit	Presence of saccades	11 (92)	5 (42)	15.4 (1.5 to 161.0)*
Passive head movement	Inability to maintain gaze	3 (25)	0 (0)	∞ (1.4 to ∞)†*
Single rapid head movement	Presence of catch-up saccade	5 (42)	0 (0)	∞ (3.5 to ∞)†*
Active head movement	Delayed suppression of nystagmus	12 (100)	1 (8)	∞ (24.1 to ∞)*
Dynamic visual acuity	≥ 3 lines	8 (67)	4 (33)	4.0 (0.7 to 21.8)

† = one-sided likelihood-based confidence interval; * = $p < 0.05$

compared with 0% of the control group. In tandem stance with eyes closed, 100% of the clinical group could not balance for 30 s compared with 17% of the control group.

A small proportion of the clinical group (25%) displayed delayed or abnormal responses when a backward external perturbation was applied using the Pastor-Marsden Test compared with 0% of the control group.

Mobility During the Fukuda Step Test, 42% of the clinical group rotated 41° (34 SD) towards the side of the lesion compared with 8° (14 SD) of rotation by the control group. The clinical group travelled 0.52 m (0.19 SD) which was not significantly different than the 0.56 m (0.26 SD) travelled by the control group. The clinical group always took fewer steps in 15 s, always took longer to walk 10 m, took longer to tandem walk 10 steps forward and backward, and scored lower on the Dynamic Gait Index than the control group (Table 1). The clinical group took 1 s (95% CI –2 to 0) longer to walk 10 m with the head stationary compared to with the head turning, which was not statistically different from the control group who took 0.1 s (95% CI –0.6 to 0.4) longer.

Gaze stability Control of the vestibular ocular reflex was significantly more impaired in the clinical group (Table 2). Deficits in ocular responses were identified for visual pursuit and passive, single rapid, and active head movement.

Relation between handicap due to dizziness and balance, mobility and gaze deficits There was a significant correlation between handicap due to dizziness and the inability to maintain balance for 30 seconds in single limb and tandem stance (r = 0.68, $p = 0.02$) and in the ability to maintain gaze stability during passive head movement (r = 0.78, $p = 0.02$).

Discussion

The results of this observational study revealed that, compared to healthy controls, people who had had surgical removal of a vestibular schwannoma and who had not participated in a vestibular rehabilitation program had significant deficits in balance, mobility, and gaze stability. Our findings support earlier self-reports of deficits in balance long after the period when spontaneous recovery or vestibular compensation should have occurred (Andersson et al 1998, Hussan et al 1998, Lynn et al 1999, Rigby et al 1997). Certainly the range and extent of the deficits in balance and mobility appears to be greater than in patients who had received vestibular rehabilitation following resection of the vestibular nerve (Redfern et al 2003).

Some measures demonstrated the deficits more clearly than others. In standing, removal of vision or visual conflict, particularly on a soft surface, demonstrated the deficits in balance of the clinical group compared to the controls. This is not surprising given that the vestibular system provides an internal reference system to resolve conflict when the visual or somatosensory system is challenged (Horak et al 1990, Horak and Shupert 2000). More surprising was the difference between the groups during standing with feet in a comfortable stance on a firm surface with eyes open.

Deficits in balance were also evident during standing with a narrowed base of support (ie, feet together, tandem stance and single leg stance), particularly with removal of vision. The clinical group either swayed significantly more, or was unable to maintain the position for 30 seconds. These findings were expected as the vestibular system has a major role in maintaining stability under more challenging conditions (Horak et al 1990, Horak and Shupert 2000). The controls were able to stand with feet together (eyes open and closed) and tandem stand and single limb stand with eyes open. Consistent with other studies of healthy participants, a small proportion of participants in the control group failed the latter tasks with the eyes closed (Bohannon et al 1984). However, in the clinical group, up to half failed tandem and single limb stance with eyes open and all failed the tasks with eyes closed.

There were also deficits in mobility. During the Step Test, the clinical group demonstrated a reduced ability to step quickly. This is not surprising since good medial-lateral control is required during this repeated rapid task. The controls performed at the upper end of the normal range established for women in their 40s and 50s (Isles et al 2004) while the clinical group performed at a rate similar to the norms established for women in their 60s (Isles et al 2004) or those aged 65–86 years (Brauer et al 2000).

While the clinical group walked at a speed that was slower than the control group for each of the 10 m walk tasks, the between-task differences for each group were not significant when head movement was introduced or when the participants were asked to walk faster. Although walking at a comfortable pace is less likely to yield differences between the groups as it is a task regularly undertaken throughout the day, it was surprising that the requirement to walk fast, and particularly the addition of head-turning, did not discriminate between the groups. The small sample size in this preliminary study may have accounted for this finding. Future studies could assess changes in gait pattern with and without head rotation, as recommended by Herdman et al (1995).

There was reduced mobility for tandem walking (forwards and backwards) with significantly slower scores for the clinical group. As the vestibular system helps to control balance when the base of support is narrow, this finding is not surprising when ipsilateral vestibular loss presents and there has been no targeted rehabilitation. The Dynamic Gait Index (Shumway-Cook et al 1997) also demonstrated a difference between the groups. The control group scored 23/24 on this test which is above the normal healthy elderly score of 21/24. The clinical group scored slightly lower at 20/24 but well above the score of 11/24 for those with a history of falls (Shumway-Cook et al 1997). This is in contrast to the score of 23/24 in patients who had received vestibular rehabilitation following resection of the vestibular nerve (Redfern et al 2003). It is possible that the amount and type of training in which the latter group participated following surgery could account for this finding.

Investigations of gaze stability revealed that corrective saccades were used more frequently in the clinical than the control group in response to visual pursuit, and passive, active, and rapid active head movements. Corrective saccades are used to regain visual fixation on a target when the vestibular ocular reflex is inadequate. Our results indicate that deficits persist in the vestibular ocular reflex with difficulty maintaining visual fixation evident during head movements and confirmed by the Dynamic Visual Acuity Test. It remains to be determined whether improved outcomes can be gained with gaze stability training for this group as suggested by the outcomes of other studies (Herdman et al 1995, Enticott et al 2005, Redfern et al 2003).

The majority of the clinical group reported symptoms of dizziness with only 30% rating their handicap due to dizziness as minimal at the time of the study. It was therefore surprising that there were few correlations between the participants' rating of their handicap due to dizziness and the measures of balance and mobility. There were, however, moderately high correlations between handicap due to dizziness and the inability to maintain balance for 30 seconds in single limb and tandem stance and the ability to maintain gaze stability during passive head movement.

A major limitation of this study was that the clinical group was not assessed preoperatively which meant that comparisons could not be made with postoperative deficits. In other pathologies, vestibular rehabilitation has increased dynamic visual acuity (Herdman et al 2003), improved balance and reduced the risk of falls (Asai et al 1997, Black and Pesznecker 2003, Cohen and Kimball 2003, Cohen and Kimball 2004, Horak et al 1992). Given the overall performance of those in our study, the impact of advancing age could impose an added risk of falls in this clinical group unless steps are taken to address the identified deficits. Thus investigation of the effectiveness of the introduction of a vestibular rehabilitation program for clients following surgical removal of vestibular schwannoma is warranted. Post-surgery, targeted interventions could be delivered to ensure safe mobility for discharge home as well as a progressive vestibular rehabilitation program within community settings to address added challenges relevant to home, work and recreation environs. A prospective study evaluating outcomes for this clinical group across the continuum of care is required.

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