The Laryngoscope

TRIOLOGICAL SOCIETY CANDIDATE THESIS

An Adaptive Vestibular Rehabilitation Technique

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Objectives/Hypothesis: There is a large variation in vestibular rehabilitation (VR) results depending on type of therapy, adherence, and the appropriateness for the patient's level of function. A novel adaptive vestibular rehabilitation (AVR) program was developed and evaluated.

Study Design: Technology and procedure development, and prospective multicenter trial.

Methods: Those with complete unilateral vestibular hypofunction and symptomatic at least 3 months with a Dizziness Handicap Inventory (DHI) >30 were eligible. Patients were given a device to use with their own computer. They were instructed to use the program daily, with each session lasting about 10 minutes. The task consisted of reporting orientation of the letter C, which appeared when their angular head velocity exceeded a threshold. The letter size and head velocity required were adjusted based on prior performance. Performance on the task was remotely collected by the investigator as well as a weekly DHI score.

Results: Four patients aged 31 to 74 years (mean = 51 years) were enrolled in this feasibility study to demonstrate efficacy. Two had treated vestibular schwannomas and two had vestibular neuritis. Starting DHI was 32 to 56 (mean = 42), which was reduced to 0 to 16 (mean = 11.5) after a month of therapy, a clinically and statistically significant ($P < .05$) improvement. The three who continued therapy an additional month improved to a DHI of 4.

Conclusions: This AVR method has advantages over traditional VR in terms of cost and customization for patient ability and obtained a major improvement in symptoms. This study demonstrated a clinically and statistically significant decrease in symptoms after 4 weeks of therapy.

Key Words: Vertigo, human, rehabilitation, vestibular, dizziness.

Level of Evidence: 2b

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INTRODUCTION

Unilateral vestibular hypofunction (UVH) is a common cause of dizziness and disequilibrium associated with head motion. The most common etiology is vestibular neuritis,[1] which accounts for 7% of visits to vertigo clinics.[2] Other etiologies include blast trauma,[3] neoplasms,[4] cholesteatoma, and iatrogenic causes.

Current treatment of UVH is limited and inadequate. Vestibular suppressants, such as meclizine, are commonly used but are no better than a placebo[5] and do not improve balance.[6] Steroids may accelerate recovery of vestibular neuritis,[7,8] but offer no long-term benefit.[9] Antiviral medications have been shown to have no effect.[8] The possibility for vestibular implants to replace lost peripheral vestibular function is being investigated,[10,11] but use as a human therapy will likely be limited to patients with complete bilateral vestibular loss.

The mainstay of treatment for UVH is vestibular rehabilitation (VR). A recent review has found VR to be effective for improving dizziness, quality of life, and balance based on multiple randomized controlled trials.[12] Recently, clinical practice guidelines have been established for VR.[13] VR exercises have been shown to significantly improve dynamic visual acuity (DVA)[14] and Dizziness Handicap Inventory (DHI)[15] score.[16–18] Despite the benefits, there are significant limitations to the current VR techniques. When patients do VR independently at home, compliance (adherence) with therapy is unreported in most studies[12] but probably poor.

Another limitation is that patients probably do not do the technique properly. A typical adaptive VR technique based on gaze stabilization is to have the patient view a visible target while rotating their head side to side. However, head velocity should be at least 100°/s to ensure effective therapy.[19] Although face-to-face therapy with a trained therapist is effective, it is impractical, because in many areas such therapists are not available, patients have limited time for these visits, and cost may be prohibitive for some patients. Evidence suggests five visits are needed to demonstrate a clinically significant improvement.[20] However, outside of clinical studies, it is likely that few patients attend more than two visits.

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Multiple studies have shown patients with acute UVH who attended in-person VR therapy at least twice per week have a 57% to 66% DHI improvement.[16,18,21] However, simply instructing patients to do exercises at home is much less effective, with a DHI improvement of 10% to 27%.[17,22,23] Although these small decreases are statistically significant, DHI must decrease by 18 points or 42% to be clinically significant.[24]

The current study describes the development and testing of a web-based adaptive vestibular rehabilitation (AVR) technique that patients do at home. The technique was designed to be able to individually monitor and adjust the therapy based on individual abilities as well as monitor compliance similar to in-person VR, but have low cost and the convenience of home exercises. We demonstrate both the feasibility and efficacy of this approach.

MATERIALS AND METHODS

Technology

Subjects were given a headset (Fig. 1) that included a small universal serial bus (USB)–based device (Phidgets, Calgary, Alberta, Canada) containing three orthogonal gyros that measure rotational head velocity over the range of ±2,000°/s at a resolution of 0.1°/s in pitch, yaw, and roll, as well as linear accelerometers that cover the range of ±8*g* at a resolution of <1 cm/s^2. The device had a standard USB port that allowed it to be connected to a standard personal computer (Windows [Microsoft, Redmond, WA] or OS X [Apple, Cupertino, CA]) with a provided cable. Each headset had a unique, machine-readable serial number, which allows the data collected to be associated with an individual without direct identification.

Participants used a Web page to participate with their headset plugged into an USB port on their computer (Fig. 2A). The first time they entered their screen size and viewing distance (Fig. 2B), allowing stimulus sizes to be calibrated. Next, they were brought to a menu that directed them to which tasks should be completed during that session (Fig 2C). The "therapy" task was highlighted at each visit, whereas others, such as "survey," were shown only when they were required (i.e., the DHI survey will be completed once per week). The therapy button brought subjects to an area where they were guided through a static visual acuity task followed by the adaptive dynamic task (Fig. 2D). Subjects were given appropriate directions for each task through the Web page. For the AVR task, the head shown on the screen rotated at an appropriate frequency (0.8 Hz) and velocity, and the optotype was only shown when a head velocity threshold was reached. The velocity threshold was set based on previous performance of between 80°/s and 200°/s. Effective therapy requires a minimum velocity of 100°/s.[19] The starting velocity threshold was set at 80°/s to allow subjects to gain experience and confidence with the technique without becoming frustrated and abandoning therapy early. It was our experience that most subjects made head movements with a peak velocity above 100°/s when the minimum is set at 80°/s. Thus, the adaptive algorithm moved the threshold to above 100°/s in the initial session. The size of the optotype was adjusted based on the speed and accuracy of prior responses.

Inclusion Criteria

Subjects were eligible for the study if they were adults with a complete loss of unilateral vestibular function by caloric testing. In all four of the patients, there was no caloric function on one side (including ice water calorics). Patients also needed to have had the lesion for at least 3 months and to have been symptomatic during this period, such that the DHI was >30 at the time of enrollment. The 3-month waiting period was used so that patients who were likely to experience a spontaneous recovery were not included. Patients also had to have an appropriate computer and internet access at home to participate.

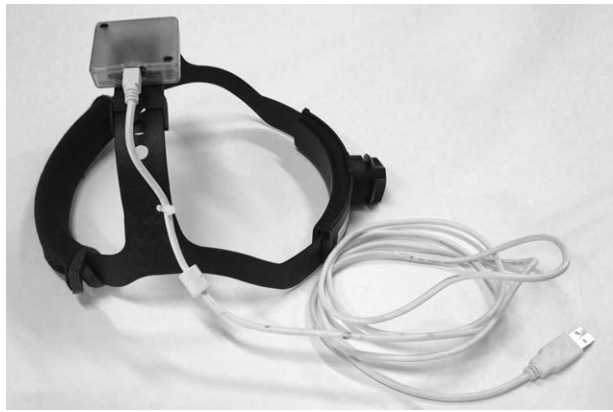

Fig. 1. The headset given to participants to complete the adaptive vestibular rehabilitation program. The headset is adjustable to a range of head sizes using a ratchet and has a 6-foot universal serial bus cable to allow the subject to sit an appropriate distance from their computer screen. The headset has a sticker, which tells the subject the website they should visit and a number to call if they need technical support. The system gave the user some feedback to provide motivation such as showing the size of the optotype and revealing the fraction of correct responses at the end of a trial block. For each response entered, the data collected on the server included the time required, the orientation and size of the optotype, the accuracy of the response, the recent history of head movements, and information regarding the performance of the subject's computer.

Patients were excluded if they had Meniere's disease by the American Academy of Otolaryngology criteria[25] with vertigo attacks in the past 3 months that had not been definitively treated with either a labyrinthectomy or gentamicin. They were also excluded if they had symptoms that were exacerbated by computer use (common with vestibular migraine), and if they were currently engaged in any other vestibular therapy programs, although prior participation did not disqualify. They were also excluded if they had a physical condition that would make them unable to participate (e.g., blindness, neck immobility, poor muscle control).

All patients completed signed informed consent prior to participation. The protocol and consent forms were approved by the research science review board at the author's institution.

Human Subjects

Four patients (three female), aged 31 to 74 years (mean = 51 years), were enrolled between December 2011 and May 2013. Two had treated vestibular schwannomas, one had vestibular neuritis, and one had labyrinthitis. By chance, all four had right-sided lesions. All four had a positive head thrust test[26] with rapid rotation toward the right. In one subject, the head thrust test was documented with quantitative eye movement recordings. Three who had cervical vestibular evoked myopotential testing had absent responses on the right. Subject 1 was a 31-year-old male who had a sudden onset of vestibular neuritis with no hearing loss 3 months prior to enrollment. Subject 2 was a 59-year-old woman who had a 2.1-cm right-sided vestibular schwannoma

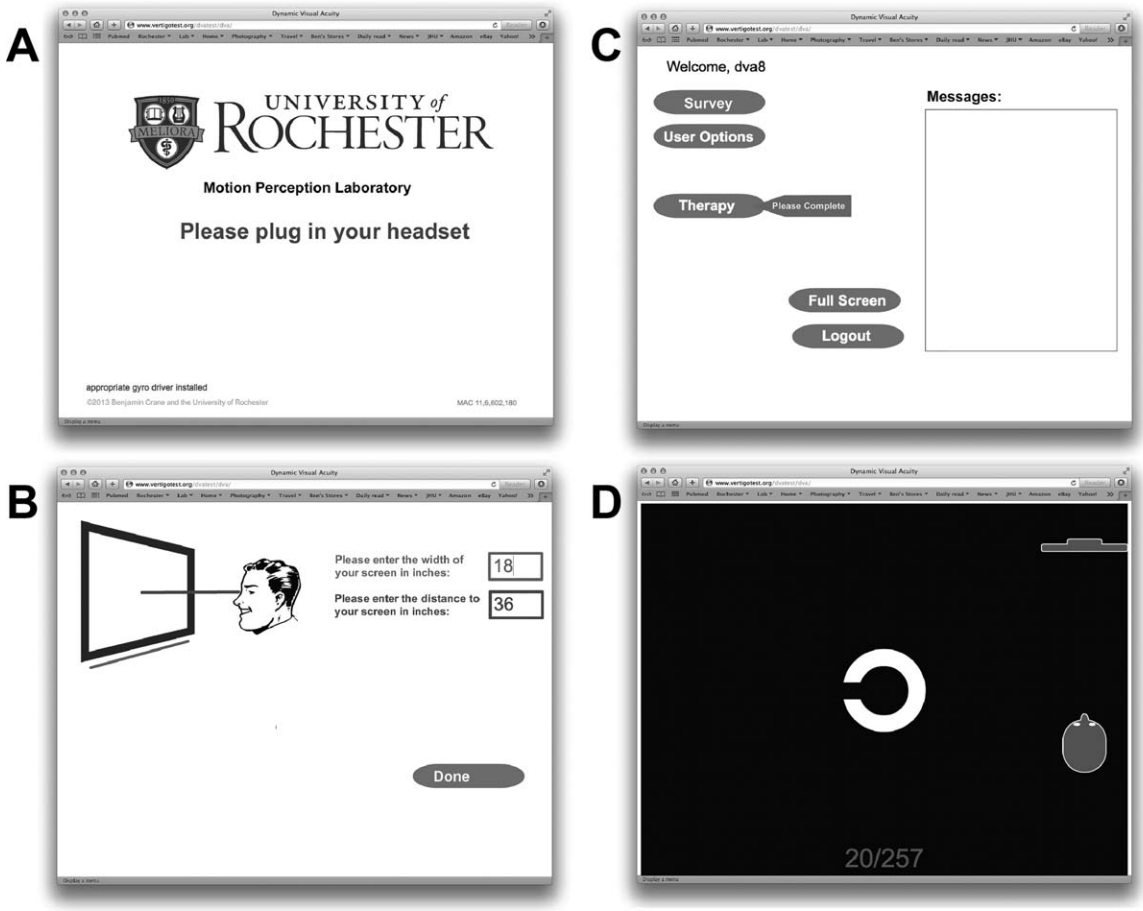

Fig. 2. Sample screen images from the computer-based task. (A) The introductory screen that the participant sees when first visiting the website. (B) Subjects are prompted to enter some setup information at the first visit, which includes the size of their computer screen and the distance they are sitting. This can be updated as needed. (C) A menu directs subjects to potential tasks, marking the ones expected to be completed during that visit. (D) The "therapy" button brings up either the adaptive vestibular rehabilitation task or a placebo. Although the image shows the rehabilitation task, the placebo looks similar.

resected via a retrosigmoid approach 7 months prior to enrollment. Subject 3 was a 39-year-old woman with a history of right labyrinthitis (idiopathic sudden unilateral loss of vestibular function and hearing) that occurred 17 months prior to enrollment. Subject 4 was a 74-year-old woman who underwent gamma knife for a 1-cm right vestibular schwannoma 9 months prior to enrolling, and subsequently developed dizziness and imbalance 3 months prior to enrollment.

Three additional subjects met the enrollment criteria and agreed to participate but failed to complete more than one session. One subject dropped out due to technical issues with their computer. Two other subjects did not feel they had time for to participate. In two of the subjects, no further clinical follow-up was available. The third re-presented in the clinic a year later with similar symptom severity, she was offered the study again, agreed to participate, and again did not participate. Results from these subjects are not reported or considered further.

Protocol

Subjects were asked to complete the AVR task daily. This included logging into the system and completing three blocks of exercises. The first block was a static visual acuity task, in which the subjects were instructed to keep their head still and report the orientation of the Landolt C. This task was used as a control condition and was useful in measuring baseline visual acuity as well as the degree of performance improvement that could be attributed to repeating the task without any improvement in vestibular compensation. In the second and third block, subjects oscillated their head from side to side, and the optotype appeared only when a velocity threshold was reached in the rightward (block 2) or leftward (block 3) direction. In practice, the direction specificity was likely unnecessary, as subjects generally made symmetric head oscillations. Prior to starting and on a weekly basis, subjects completed the Jacobsen Dizziness Handicap Inventory (DHI),[15] which was the primary outcome measure. Secondary outcome measures included fraction of correct responses, time required to make responses, peak head velocity, and optotype size.

RESULTS

All four subjects were able to complete 4 weeks of therapy. Of these initial subjects, three wished to continue for a total of 51 to 104 days. The mean DHI at the time of enrollment was 42 (range, 32–56). After 4 weeks of therapy, the DHI significantly (t test, $P = .004$) decreased to 11.5 (range, 0–16). In the three subjects who completed additional therapy, the DHI decreased significantly (t test, $P = .002$) to 4 (range, 2–6) relative to the pre-enrollment value at the end of therapy but

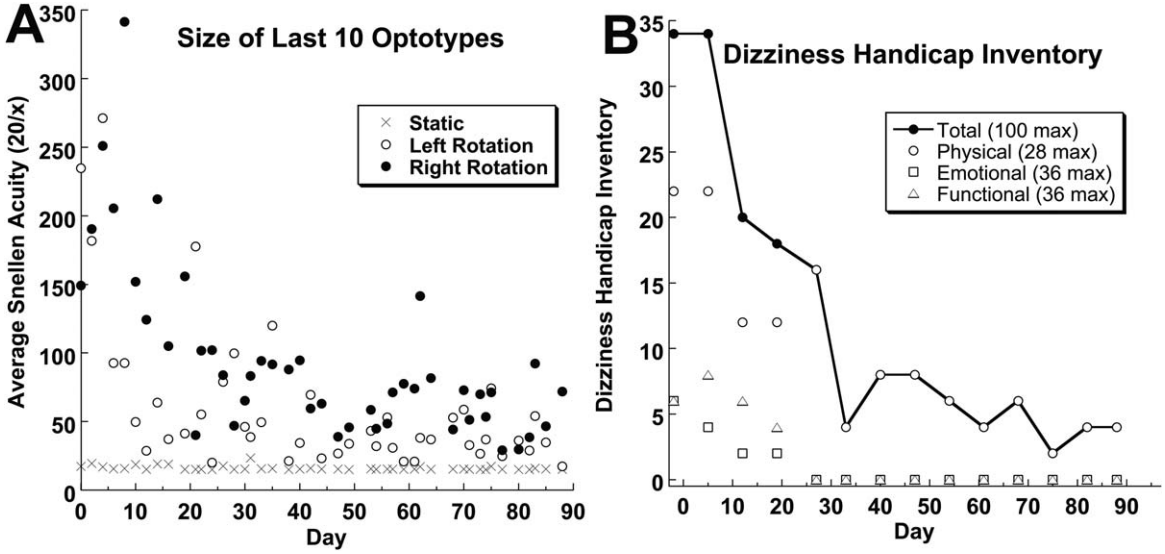

Fig. 3. Sample data from subject 2 (59-year-old woman with a history of chronic right-sided unilateral vestibular hypofunction). This subject participated in the AVR program for 3 months. Each session consisted of static visual acuity, followed by a left and then right DVA task. The acuity is given as the denominator on a Snellen scale based on a 20-foot viewing distance, although the viewing distance was less than 20 feet. The performance on the DVA task (A) was correlated with the DHI (B). AVR = adaptive vestibular rehabilitation; DHI = Dizziness Handicap Inventory; DVA = dynamic visual acuity.

was not significantly improved ($P = .3$) from the DHI at 4 weeks. This represents an average improvement of 30.5 points or 73% decrease at 4 weeks and 33.3 points or 90% decrease at 8 weeks. The performance on the AVR and DHI is shown for a typical subject (Fig. 3).

The performance of the static visual acuity task did not improve over the course of the study. As shown in Figure 3, the best performance remains stable at the equivalent of 20/16, which was also typical of other participants. However, the DVA measures did improve over the course of the study, similar to the DHI. This is consistent with most of the improvement in the DVA being due to recovery of gaze stability,[27] and not due to increased practice with the task itself. When the DVA task with ipsilesional rotation was compared with that of contralesional rotation, the acuity with contralesional rotation was on average twice as good as for ipsilesional rotation. However, the difference was largest during the first 20 days when it was 2.6 times better and smaller after 30 days. Thus, the AVR task seems to preferentially improve vestibular function during ipsilesional rotation.

Despite the patients having a uniform improvement with the AVR task, the compliance with the task was variable. Although all subjects were instructed to do the task every day, only one subject (subject 4) had 100% compliance. Two subjects (subjects 1 and 2) completed the task about every other day, with compliance rates of 58% and 52% during the first month. The remaining subject (subject 3) did the task only about weekly, or 17% of the days during the first month. This suggests daily sessions may not be needed.

DISCUSSION

The current study demonstrates a clinically and statistically significant improvement in the DHI for patients with UVH. This study enrolled only chronic UVH subjects to minimize potential effects of spontaneous improvement. Other studies of rehabilitation of chronic peripheral vestibular lesions using home-based VR therapy[17,23,28] form a benchmark for evaluation of the current technique. Although these studies have demonstrated a statistically significant improvement with VR, the improvement was below the 18 point or 42% decrease proposed for clinical significance.[24] Although comparable improvement was described with acute lesions,[16,29] there is also a high rate of spontaneous recovery in acute lesions. The current results using the AVR technique are superior than those seen for home-based therapy of chronic vestibular lesions and similar to those seen for in-person therapist-directed VR (Fig. 4), though with a small cohort. The reason for this is likely because the AVR technique adjusts the therapy to patient ability so that the exercises remain feasible to complete while challenging enough to be therapeutic.

A second major advantage of the current technique was that adherence to therapy was directly monitored. Compliance or adherence with therapy is rarely reported in studies of VR that patients complete independently.[12] In a previous study of VR for Meniere's, compliance was found to be low at 50% in the control group and 38% in the treatment group.[23] This measure was based on self-reporting, which is considered a low quality measure of compliance. Thus, the compliance with VR was actually below the 43% to 78% range cited for compliance with medications in clinical trials.[30] However, VR patients with good adherence to therapy had a significantly better outcome than those with poor adherence.[23] The primary reason for poor compliance in that study was that the therapy aggravated symptoms.[23] In previous medication compliance reports, it has been shown that compliance rates in studies are better than in practice because

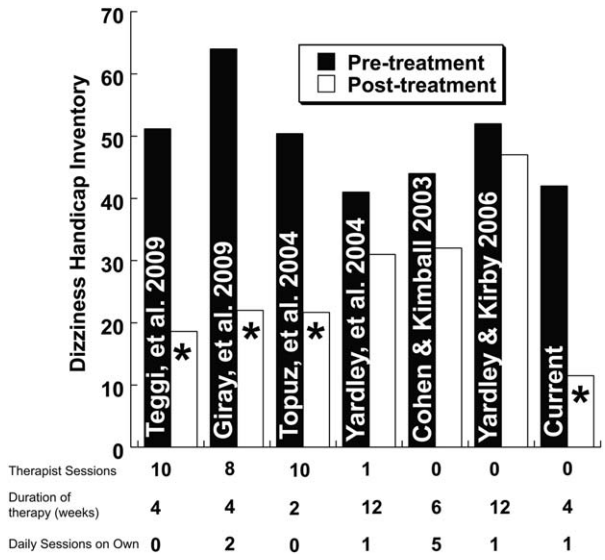

Fig. 4. Historical data and current results for pre- and post-treatment DHI using various VR protocols. The method of VR varied, with some relying on patients doing the therapy independently and others focused on in-person sessions with a therapist. Datasets that met the criteria for a minimal clinically important response (either 18 points or a 42% decrease in DHI) are marked with an asterisk.[24] In the prior studies, only in-person VR sessions were able to meet this threshold. All of the studies shown, except Teggi et al.,[16] included only patients with symptoms present for 2 months or longer. The current data (furthest right column) demonstrate that the AVR method has a similarly large decrease in DHI in home-based therapy. AVR = adaptive vestibular rehabilitation; DHI = Dizziness Handicap Inventory; VR = vestibular rehabilitation.

of the additional attention paid to the patients.[30] Thus, compliance with unmonitored vestibular rehabilitation techniques in clinical practice is likely to be very poor, and compliance may explain the wide variation in outcomes between patients in some VR studies.[12,22,23,31]

The compliance was extremely variable with one subject doing the AVR daily as directed, two doing it about every other day, and the remaining subject doing it only about weekly. In addition, two subjects whose data were not presented in the study did the task only one time and did not continue beyond the first week. Thus, the overall compliance is probably near the 38% previously reported for patients with Meniere's.[23] In the Yardley and Kirby study, which reported compliance, it was recommended that the exercises be completed daily; however, other studies have recommended more frequent therapy at 3 to 5 times daily.[14,18,22,32] Given that in the current study only one participant actually did the exercises daily as directed, expecting patients to do the exercises three to five times daily may be unrealistic, and given our preliminary yet strong results with once daily therapy, likely unnecessary.

The current AVR technique offered significant advantages. Although the efficacy appears similar to protocols that include eight to 10 sessions with a therapist (Fig. 4), it allowed patients the convenience of therapy at home. The cost of hosting the Web-based software is minimal, so the AVR technology would be significantly cheaper than multiple visits with a therapist. It also has the advantage that adherence can be remotely monitored.

The current study had limitations. Subjects were not randomized, so some degree of spontaneous improvement was possible, although only patients with chronic lesions were included to decrease this potential effect. The technique may have also had a placebo effect associated with it. There were also only a small number of patients enrolled in the current study, which was largely due to the stringent entry criteria. However, even with these small numbers the effect seen was highly statistically significant.

CONCLUSION

A novel home, computer-based AVR technique was tested in individuals with chronic complete UVD causing significant dizziness symptoms. In these patients, 4 weeks of daily therapy significantly decreased the dizziness handicap by a mean of 71%. The majority of the benefit was seen in the first month of therapy.

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