Disability and Rehabilitation

ISSN: 0963-8288 (Print) 1464-5165 (Online) Journal homepage: http://www.tandfonline.com/loi/idre20

Three-dimensional, virtual reality vestibular rehabilitation for chronic imbalance problem caused by Ménière's disease: a pilot study

Su-Yi Hsu, Te-Yung Fang, Shih-Ching Yeh, Mu-Chun Su, Pa-Chun Wang & Victoria Y. Wang

To cite this article: Su-Yi Hsu, Te-Yung Fang, Shih-Ching Yeh, Mu-Chun Su, Pa-Chun Wang & Victoria Y. Wang (2016): Three-dimensional, virtual reality vestibular rehabilitation for chronic imbalance problem caused by Ménière's disease: a pilot study, Disability and Rehabilitation, DOI: 10.1080/09638288.2016.1203027

To link to this article: http://dx.doi.org/10.1080/09638288.2016.1203027

Published online: 15 Jul 2016.

DISABILITY AND REHABILITATION, 2016
http://dx.doi.org/10.1080/09638288.2016.1203027

Taylor & Francis
Taylor & Francis Group

ORIGINAL ARTICLE

Three-dimensional, virtual reality vestibular rehabilitation for chronic imbalance problem caused by Ménière's disease: a pilot study*

Su-Yi Hsu[a,b], Te-Yung Fang[b,c], Shih-Ching Yeh[d], Mu-Chun Su[e], Pa-Chun Wang[b,c] and Victoria Y. Wang[f]

[a]Department of Otolaryngology, Sijhih Cathay General Hospital, New Taipei City, Taiwan; [b]School of Medicine, Fu Jen Catholic University, New Taipei City, Taiwan; [c]Department of Otolaryngology, Cathay General Hospital, Taipei, Taiwan; [d]School of Information Science and Technology, Fudan University, Shanghai, P. R. China; [e]Department of Computer Science & Information Engineering, National Central University, Taoyuan, Taiwan; [f]Department of Computer Science, Stanford University, Stanford, USA

ABSTRACT

Purposes: The purpose of this study was to evaluate a three-dimensional, virtual reality system for vestibular rehabilitation in patients with intractable Ménière's disease and chronic vestibular dysfunction.
Methods: We included 70 patients (36 for study, 34 as control) with a chronic imbalance problem caused by uncompensated Ménière's disease. The virtual reality vestibular rehabilitation comprised four training tasks (modified Cawthorne–Cooksey exercises: eye, head, extension, and coordination exercises) performed in six training sessions (in 4 weeks). Measurements of the task scores and balance parameters obtained at the baseline and after final training sessions were compared.
Results: A significant improvement was observed in extension and coordination scores. Patients in the early stages of Ménière's disease had a significantly greater improvement in the center of gravity sway and trajectory excursion in the mediolateral direction than did patients in the late stages of Ménière's disease. Mild functional disability attributable to Ménière's disease was a predictor of improvement in the statokinesigram and maximum trajectory excursion in the anteroposterior direction after rehabilitation. The control group showed no significant improvement in almost all parameters.
Conclusion: Virtual reality vestibular rehabilitation may be useful in patients with Ménière's disease, particular those in the early stages or having mild functional disability.

ARTICLE HISTORY
Received 16 July 2015
Revised 6 April 2016
Accepted 14 June 2016
Published online 12 July 2016

KEYWORDS
Chronic imbalance; Ménière's disease; vestibular rehabilitation; virtual reality

➤ IMPLICATION FOR REHABILITATION

- Chronic imbalance caused by uncompensated Ménière's disease is an indication for vestibular rehabilitation.
- The interactive virtual reality video game, when integrated into vestibular rehabilitation exercise protocol, may assist patients who have mild disability Ménière's disease and who cannot benefit from treatment with drugs or surgery.
- The initial data from this study support the applicability of three-dimensional virtual reality technology in vestibular rehabilitation programs. The technology gives professionals a new tool to guide patients for vestibular rehabilitation exercises through three-dimensional virtual reality video game playing.
- The virtual reality vestibular exercise game can provide patients a step-wise, interactive, dynamic, three-dimensional, and interesting rehabilitation environment.

Introduction

Vertigo and post-vertigo disequilibrium can impair the quality of life in patients with Ménière's disease. Rotational vertigo and vegetative symptoms can persist from minutes to several hours, and disequilibrium can persist for days or months in elderly patients. In patients with active fluctuating disease, relieving constant disequilibrium and unsteadiness between attacks is critical.

Vestibular rehabilitation is a safe, effective, and noninvasive treatment for unilateral peripheral, central, or mixed vestibular dysfunction.[1,2] Vestibular rehabilitation can integrate proprioceptive, visual, and residual vestibular function to improve overall balance function including gait, gaze and postural stability, physical mobility, and function with activities of daily living.[2,3] Vestibular rehabilitation entails adaptation exercises for visual-vestibular interaction to improve the vestibular-ocular reflex; habituation exercises for reducing the responsiveness of the symptoms caused by repetitive motion; and substitution exercises for increasing or replacing vestibular input by using visual or somato-sensory input.[1,4] In addition, vestibular rehabilitation can maximize central compensation. Cawthorne–Cooksey exercises are one of the vestibular rehabilitation protocols that can reduce the sense of imbalance and improve coordination through repeated eye movements, head motions, limb extensions, and balance training.[5–7] However, the exercises are time-consuming, repetitive, and monotonous; and compliance is generally poor when patients are asked to practice at home on daily basis.

CONTACT Pa-Chun Wang, M.D., M.Sc., MBA drtony@seed.net.tw Department of Otolaryngology, Cathay General Hospital, 280 Sec. 4 Jen-Ai Road, 106 Taipei, Taiwan
*Preliminary data of this study were presented at the 2012 Collegium Oto-Rhino-Laryngologicum Amicitiae Sacrum meeting, Rome, Italy

Virtual reality systems can be equipped with real time simulation, interactive functions, and game features to enable adaptation, habituation, and substitution exercises for vestibular rehabilitation.[8] These systems can provide visual, auditory, and haptic feedbacks that may motivate patients, establish a sense of physical presence in the virtual world, and enable the measurement of performance and customized training. Vestibular rehabilitation based on virtual reality systems is an effective treatment for mild traumatic brain injury and acute vestibular neuritis.[9,10] In addition, vestibular rehabilitation can improve dynamic balance and balance confidence in older adults and, desensitize patients to diverse disorienting visual stimuli.[3,11]

In patients with Ménière's disease, vestibular rehabilitation can be useful in treating unsteadiness that persists despite alleviation in episodic vertigo or after definitive destructive therapy.[12–14] We selected patients with Ménière's disease to investigate the training effectiveness of the three-dimensional virtual reality system because of the following advantages: (1) the diagnosis criteria for Ménière's disease are clear, (2) laterization can be easily accurately identified in patients with Ménière's disease, unlike that in patients with other chronic vestibular dysfunction conditions, (3) the stage and functional status of Ménière's disease stage and functional status are readily available for categorization analysis. The advantages reduce the heterogeneity of the study population to eliminating the confounding bias from other vestibular dysfunction conditions. The purpose of this study was to evaluate vestibular rehabilitation by using our three-dimensional virtual reality system in patients with chronic imbalance caused by Ménière's disease, we compared the effectiveness with that of traditional Cawthorne–Cooksey exercises.

Materials and methods

Subjects

We recruited 70 consecutive patients with definite Ménière's disease. We used a single-blind study design and randomly assigned the patients into study and control groups. We included 36 and 34 patients in the study and control groups, respectively. The groups had similar sex and age distributions ($p > 0.05$). The diagnostic criteria, Ménière's disease stages (early stages I and II and late stages III and IV), and functional level scales (effect on the overall daily function increased from level 1 to 6) were based on the 1995 guidelines of the American Academy of Otolaryngology.[15] The distributions of the affected side, stage, and functional level in the study and control groups were similar ($p > 0.05$) (Table 1).

Table 1. Patient demographics.

Characteristic	Control group ($N = 34$) Mean ± SD	Study group ($N = 36$) Mean ± SD	p values
Age (years)	66.5 ± 11.9	69.0 ± 12.6	0.41
Sex			0.14
Male	10 (29%)	16 (44%)	
Female	24 (71%)	20 (56%)	
Height (cm)	159.4 ± 8.7	162.7 ± 7.3	0.11
Weight (kg)	62.2 ± 7.6	63.0 ± 12.9	0.77
Stage			0.51
I	13 (38.2%)	9 (25%)	
II	5 (14.7%)	9 (25%)	
III	12 (35.3%)	15 (41.7%)	
IV	4 (11.8%)	3 (8.3%)	
Functional level			0.32
1	0	2 (5.6%)	
2	8 (23.5%)	13 (36.1%)	
3	24 (70.6%)	11 (30.6%)	
4	2 (5.9%)	7 (19.4%)	
5	0	3 (8.3%)	
6	0	0	

[a]Data reported as number or mean ± SD.
[b]Based on the 1995 guidelines of the American Academy of Otolaryngology.[15]

The inclusion criteria were: (1) a clinical diagnosis of unilateral or bilateral Ménière's disease; (2) an age >18 years; (3) fluctuating symptoms or chronic unsteadiness for >3 months; and (4) the ability to participate in balance rehabilitation tasks. The exclusion criteria were: (1) a diagnosis of vertigo not associated with Ménière's disease; (2) other acute medical conditions; (3) neurological deficit or cognitive dysfunction; (4) weakness or paralysis in the lower limbs; and (5) planned medical or surgical vestibular ablation during the rehabilitation program.

The study was approved by the institutional review board of Cathay General Hospital (CT-100008).

Rehabilitation system

The three-dimensional virtual reality interactive rehabilitation system consisted of two major components: training and assessment. The training component comprised four training tasks that were similar to games designed on the basis of the modified Cawthorne–Cooksey vestibular rehabilitation exercises: (1) head exercise, (2) eye exercise, (3) extension exercise, and (4) coordination exercise. The training component integrated an animated game, stereoscopic images, and interactive technology to provide stereoscopic vision and an interactive interface that felt natural to the user. The hierarchical training contents had various difficulty levels that enabled customizing of training programs according to patients' requirement. The system enabled assessing and recording the kinematic performance during training sessions. In the assessment component, the sensor technology recorded time-history and center of pressure data in different conditions. These data were used to monitor the progress of the patient's performance (Figure 1).

The system used specialized software (Microsoft Kinect, Microsoft Corp., Seattle, WA) that recorded the movements of the patients and enabled them to interact with a virtual basketball scenario. An ultrashort-focus projector displayed images on a large screen to cover the entire visual field of the patients, and three-dimensional glasses were worn to provide a sense of depth that enabled the patients to judge the location of the ball in the virtual environment. A tracking system with an optical marker accurately determined when the head of a patient rotated beyond the workspace.

Training tasks

Eye exercise: The goal of the patients was to move the eyes to the side as much as possible without rotating the head. Participants were asked to keep the head stationary while moving the eyes upward, downward, left, and right. The patients were also asked to read numbers aloud as soon as they saw random numbers appearing at the margin of the screen. In total, 25 numbers with 1 or 2 digits were randomly generated (1 number at a time); the numbers appeared at the margin of the screen in a clockwise or counterclockwise direction that was randomly predetermined. A single eye exercise game consisted of 25 trials; the appearance of 1 number was defined as 1 trial. When the head of a patient (shown as a ball in the virtual environment) did not stay in the red square, the patient heard a sound that denoted a failed trial.

Head exercise: The goal of the patients was to rotate the head while keeping the eyes fixed on an object. The patients were asked to rotate the head left, right, upward, and downward while

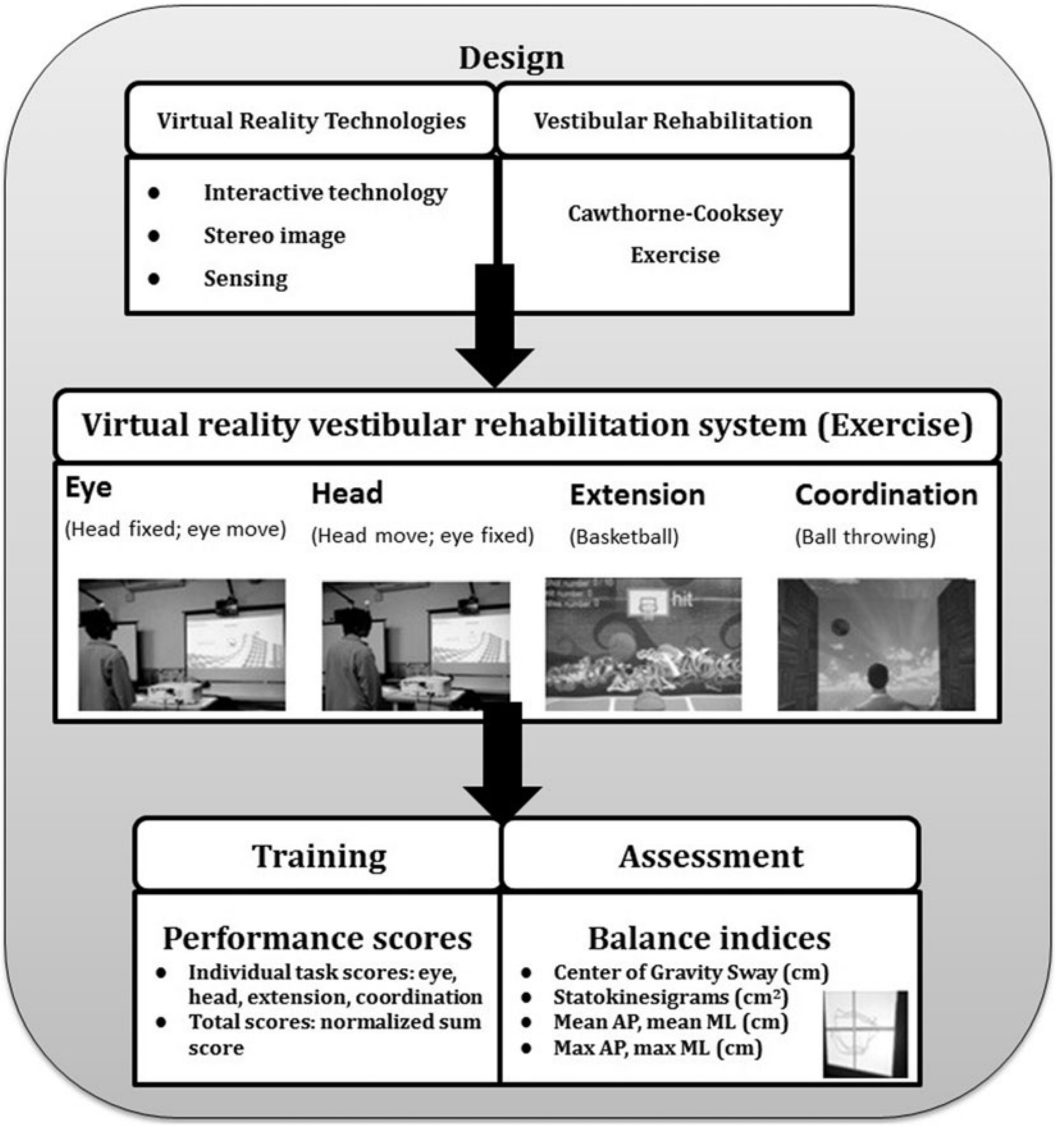

Figure 1. Virtual reality vestibular rehabilitation system: design, exercises, training, and assessment. maxAP: maximum trajectory excursion in the anteroposterior direction; maxML: maximum trajectory excursion in the mediolateral direction; meanAP: mean trajectory excursion in the anteroposterior direction; meanML: mean trajectory excursion in the mediolateral direction.

keeping the eyes fixed on a red square at the center of the screen. The patients were required to read numbers aloud as soon as they saw the random numbers appearing around the red square. The numbers appeared when a patient reached the maximum range of head rotation. A single head exercise game consisted of 20 trials; 1 trial was defined as 1 head rotation to the maximum range while reading a number. When a patient did not respond, the numbers disappeared after 2 s, and the next trial started when the patient was ready.

Extension exercise: The exercise was designed to simulate shooting a basketball. The goal of the exercise was for the patient to lift the arms above the shoulder level to a specified point. The position of the a patient's hand was indicated by hand holding a yellow ball in the virtual environment. After the game started, the patients were instructed to grab the virtual basketball and throw it onto the target position indicated by a red ball. The position of the red ball was predetermined and randomly appeared in the virtual environment. A single extension game consisted of 10 trials; 1 trial was defined as 1 throw.

Coordination exercise: The exercise was designed to simulate throwing and catching a ball. The goal of the exercise was to improve the coordination of both arms. After the game started, the patients were instructed to touch a ball that randomly appeared in the virtual environment on the side ipsilateral to the tested hand. As soon as a patient touched the ball with 1 hand, the ball was automatically thrown to the contralateral side for the contralateral hand to catch. In 1 trial, the ball moved from side to side until the patient missed the ball to end this trial. A coordination exercise game consisted of 10 trials.

At each training session, the patient typically completed the game program in 30 min. The study group patients underwent six training session during 4 weeks.

The patients in the control group were instructed to perform Cawthorne–Cooksey vestibular rehabilitation exercises at home for 4 weeks.

Outcome measures

The virtual reality system recorded the chronological data and center of pressure of the patients in different task conditions. Changes in upright balance were measured using a video game platform (Wii Fit, Nintendo Phuten Co., Ltd., Taipei, Taiwan) before and after the virtual reality training session. The patients were asked to quietly stand on the video game platform with the eyes open for 20 s without any assistance. The pressure sensors of the video game platform responded to changes in the patients' center of pressure and upright balance.

Chronological data about the center of pressure were recorded from the video game platform and were used to calculate five indices of upright balance, namely, the maximum trajectory excursion in the mediolateral (maxML) and anteroposterior (maxAP) directions, mean trajectory excursion in the mediolateral (meanML) and anteroposterior (meanAP) directions, and a statokinesigram;[16,17] the statokinesigram was the area of the trajectory of the center of pressure during the test, fitted using an envelope area. The envelope area for the trajectory of the center of pressure is an important index for assessing the rehabilitation improvement in patients who have vestibular dysfunction, and smaller areas indicate more effective rehabilitation.[18]

The scores for each training task and total scores were calculated by scaling up the success frequency (in a percentage) 100-fold, and scores ranged from 0 to 100 (0 lowest, 100 highest performance).

Evaluation

The patients participated in six rehabilitation training sessions (four interactive virtual reality task exercises per session) within 4 weeks. During training sessions, performance data, including the task completion rate, task completion time, and task success frequency were recorded using the virtual reality system. The upright balance was measured using the video game platform before and after each training session. The virtual reality training tasks and upright balance test were conducted by licensed physical or occupational therapists who were provided the technical manual of the interactive rehabilitation system. One control group and two study group patients experienced virtual reality – induced motion sickness. These patients were provided special attention, which involved slowly starting rehabilitation (or evaluation) when they were using three-dimensional goggle.

The first training session was used as a practice session, and data from the first training session were excluded. The assessment conducted immediately before the second training session was defined as the baseline assessment. The baseline and data after the final (sixth) training session were compared.

Data acquisition, processing, and statistical analysis

The optical tracking system and Microsoft Kinect (Redmond, WA) recorded kinematic information in each session. The pressure sensors of the video game platform captured the trajectory of the center of pressure and detected changes in upright balance. Recorded game parameters and balance indices from WiiFit were classified using the SVM (supported vector machine) classifier. Linear, quadratic, and Gaussian kernels were applied to identify the structure of the collected data.

Data were analyzed using the Statistical Package for Social Science (Version 16, SPSS Inc., Chicago, IL). The post-intervention outcomes were adjusted for the baseline and severity by using one-way analysis of covariance. Comparisons were performed using independent (between groups) and paired *t* tests (within group, baseline and after intervention – 6th training session). Multiple regression models analyses were performed to evaluate predictors (age, sex, height, weight, co-morbid conditions, training session, lateralization, stage, and baseline functional status) of improvement (center of gravity sway, statokinesigram, maxML, maxAP, meanML, meanAP, and performance score) after rehabilitation. Statistical significance was defined as $p \leq 0.05$.

Results

Most patients had stage I, II, or III Ménière's disease and functional level 1 to 4. Medical comorbidities including hypertension, diabetes, hyperlipidemia, and cervical spondylosis were equally distributed between the study and control groups. All patients in both groups completed the follow-up after intervention. In the study group, adherence to the treatment protocol was 100%. In the control group, 100% of the patients independently performed vestibular exercise at home at least four times in 4 weeks.

In the study group, a significant improvement was observed in all eye, head, extension, coordination, and total training task scores from the baseline to the final virtual reality training session (Table 2). Significant differences were observed in the changes of head rotation ($p = 0.002$) and total ($p = 0.015$) training task scores between the study and control groups (Table 2). Moreover, in the control group, significant improvements were observed in the eye and total training tasks scores (Table 2).

The balance indices exhibited a decreasing trend ($-1.2\,cm^2$) in the center of gravity sway from the baseline to the final training session (Table 3, Figure 2). The study group exhibited significantly greater improvement in the statokinesigram ($p = 0.002$), maxML ($p = 0.009$), and maxAP ($p = 0.036$) indices than did the control group. In addition, patients in the early stages of Ménière's disease (stage I or II) exhibited significantly greater improvement in the center of gravity sway and meanML than did patients in the late stages of Ménière's disease (stage III or IV) ($p < 0.05$).

Multiple regression model(s) showed that the functional level of the patients had a significant effect on the statokinesigram ($\beta = -0.4$, SE $= 0.9$, $p \leq 0.05$) and maxAP ($\beta = -0.5$, SE $= 0.2$, $p \leq 0.05$). Mild functional severity of Ménière's disease was a predictor of greater improvement in the statokinesigram and maxAP after virtual reality vestibular rehabilitation.

Table 2. Rehabilitation exercise scores[a] in patients following virtual reality training system (study group) or self-administered (control group) vestibular rehabilitation.

Balance index	Before session 2 (Baseline)[b]	After final session (Adjusted)[c]	Change	p values
Study group (virtual reality vestibular rehab.), $N = 36$				
Eye	66.0 (57.5–74.1)	78.0 (73.1–81.9)	12 (−5.8–8.2)	0.003
Head[d]	79.0 (74.7–83.5)	76.0 (70.5–80.7)	−3.5 (−5.8 to −1.2)	0.007
Extension	59.0 (47.9–69.9)	72.0 (62.8–80.1)	13 (−2.6–5.2)	0.000
Coordination	60.0 (53.6–67.2)	71.0 (68.4–73.2)	11 (−6.3–8.5)	0.011
Total[e]	65.0 (59.4–70.2)	72.0 (68.3–75.1)	6.9 (4.1–9.8)	0.000
Control (self-administered vestibular exercise), $N = 34$				
Eye	80.0 (72.0–87.4)	88.0 (86.6–89.4)	8.3 (0.5–16.1)	0.056
Head	85.0 (72.4–98.4)	86.0 (81.5–91.1)	0.9 (−13.4–15.3)	0.899
Extension	66.0 (55.6–75.4)	62.0 (48.9–74.3)	−4.0 (−8.6–0.8)	0.142
Coordination	51.0 (34.7–67.5)	61.0 (47.3–74.3)	10.0 (−14.5–33.8)	0.467
Total	59.0 (51.5–67.5)	67.0 (63.2–71.2)	8.0 (1.9–13.5)	0.021

[a]Data reported as mean (95% CI).
[b]Baseline measurements were made before the second training session; the first training session was a practice session.
[c]Control group after 4 weeks of self-administered vestibular exercise.
[d]Comparisons of balance index score (head) change between Study and Control groups, $p = 0.002$.
[e]Comparisons of balance index score (total) change between Study and Control groups, $p = 0.015$.

Table 3. Balance indices[a] in patients following virtual reality training system (study group) or self-administered (control group) vestibular rehabilitation vestibular rehabilitation.

Balance index	Before session 2 (Baseline)[b]	After final session (Adjusted)[c]	Change	p values
Study group (virtual reality vestibular rehab.), $N = 36$				
Center of gravity sway	12.0 (10.9–13.7)	11.0 (10.6–11.6)	−1.2 (−2.5–0.07)	0.077
Statokinesigram (cm²)[d]	4.0 (2.8–5.6)	4.0 (3.6–4.4)	−0.2 (−1.4–1.1)	0.796
maxML (cm)[e]	1.3 (1.1–1.5)	1.35 (1.3–1.4)	0.1 (−0.1–0.3)	0.366
maxAP (cm)[f]	2.2 (1.9–2.5)	2.3 (2.0–2.6)	0.1 (−0.2–0.4)	0.506
meanML (cm)	0.7 (0.6–0.8)	0.55 (0.5–0.6)	−0.05 (−0.1–0.02)	0.141
meanAP (cm)	0.9 (0.8–1.0)	0.85 (0.8–0.9)	−0.1 (−0.2–0.06)	0.239
Control (self-administered vestibular exercise), $N = 34$				
Center of gravity sway	10.6 (9.3–11.9)	10.8 (10.5–11.1)	0.2 (−0.9–1.3)	0.736
Statokinesigram (cm²)	1.9 (1.4–2.5)	2.5 (2.4–2.6)	0.5 (−0.01–1.08)	0.071
maxML (cm)	0.9 (0.7–1.2)	0.97 (0.9–1.0)	0.02 (−0.1–0.2)	0.765
maxAP (cm)	1.6 (1.4–1.8)	2.1 (2.0–2.2)	0.5 (0.3–0.7)	0.000
meanML (cm)	0.56 (0.5–0.6)	0.56 (0.5–0.6)	0.01 (−0.02–0.04)	0.653
meanAP (cm)	0.7 (0.6–0.8)	0.75 (0.7–0.8)	0.1 (−0.02–0.2)	0.157

[a]Data reported as mean (95% CI). maxAP, maximum trajectory excursion in the anteroposterior direction; maxML, maximum trajectory excursion in the mediolateral direction; meanAP, mean trajectory excursion in the anteroposterior direction; meanML, mean trajectory excursion in the mediolateral direction.
[b]Baseline measurements were performed before the second training session; the first training session was a practice session.
[c]Control group after 4 weeks of self-administered vestibular exercise.
[d]Comparison of Statokinesigram (cm^2) between Study and Control groups, $p = 0.002$.
[e]Comparison of maxML (cm) between Study and Control groups, $p = 0.009$.
[f]Comparison of maxAP (cm) between Study and Control groups, $p = 0.036$.

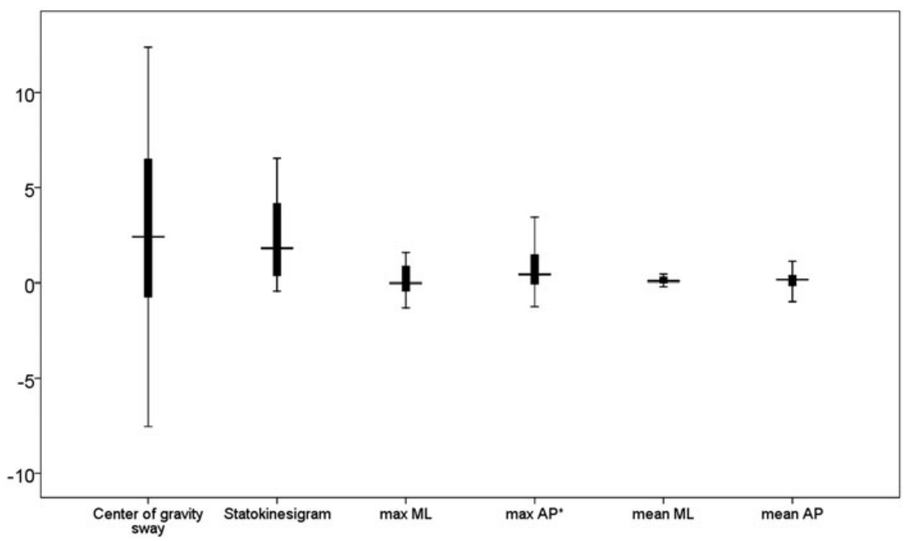

Figure 2. Changes in balance indices in patients with Ménière's disease ($N = 36$) following virtual reality training system vestibular rehabilitation.

Discussion

Vestibular rehabilitation can help patients with chronic imbalance. However, rehabilitation exercises are repetitive and boring basic movements that may impair patients' motivation to adhere to the plan. Moreover, when patients self-administered these exercises, rehabilitation by using traditional protocol might be limited because of insufficient flexible adaptive and customizing capability. Three-dimensional, virtual reality, animation game-based technology enables the hierarchical delivery of stimulus challenges encountered in realistic environments or daily living at various difficulty levels; the system can also facilitate customizing the patient's balance performance progress.[18] Game-based, virtual reality technology has been used for neurological and musculoskeletal rehabilitation. However, few studies have reported using this approach to evaluate balance improvement.

In the present study, patients with chronic imbalance caused by active Ménière's disease exhibited improvements in extension and coordination exercises after virtual reality vestibular rehabilitation (Table 2). Improvement in center of gravity sway and meanML was greater in patients in early stages with milder functional impairment at baseline than in those in the late stages of Ménière's disease. In addition, mild functional disability predicted improvement in the statokinesigram and maxAP.

A study reported improvement in balance after vestibular rehabilitation.[1] Vestibular rehabilitation exercises were originally designed for patients with stable uncompensated vestibular diseases. Wrisley et al. [19] and Gottshall et al. [20] have demonstrated that physical therapy can improve balance both subjectively and objectively in patients with dizziness.[14]

All patients experienced fluctuating disequilibrium symptoms at the time of recruitment. The study proves that symptoms of imbalance can be alleviated with progressive, structured exposure to movements that provoke symptoms. Patients in the early stage of Ménière's disease may experience less unsteadiness between attacks and have greater baseline balance than do patients in the late stages of Ménière's disease. Therefore, the degree of improvement after vestibular rehabilitation was greater in the early stage of Ménière's disease. The functional disability of Ménière's disease was a predictor of treatment outcomes.

Vestibular rehabilitation can reduce the fear associated with episodic vertigo and can improve patients' confidence in their ability to maintain balance.[12] The protocol design in the present interactive vestibular rehabilitation exercises comprised six sessions. The preliminary data (six sessions in 4 weeks) exhibited a trend in the rehabilitation effect, and a dose-effect relationship might be observed with more training sessions.

The limitations of the present study include the high percentages of older patients (most patients were aged >60 years) and patients with comorbid conditions. Underlying comorbid diseases may cause additional dizziness, imbalance, or limb weakness; these diseases may not abate with rehabilitation and may interfere with kinesthetic learning and progress achieved through rehabilitation exercises.[21] Furthermore, we did not evaluate whether improvements in balance were maintained after the completion of rehabilitation; therefore, we could not evaluate the post-intervention functional status in this short-term follow-up study. Additional studies having a long-term follow-up period should be conducted, and the correlation between subjective symptoms and objective balance measures should be evaluated in the future.

Conclusion

The present results suggest that chronic imbalance caused by uncompensated Ménière's disease can be improved through three-dimensional, virtual reality vestibular rehabilitation. The interactive three-dimensional, virtual reality, game-based vestibular rehabilitation exercises can assist patients with Ménière's disease who have mild disability and cannot benefit from drugs or surgery. The system enables hierarchical and customized delivery of realistic environmental stimuli adapted to patients' balance improvement. A home care model, once established in the future, can significantly reduce the transportation, training, and supervision cost for both the patients and the healthcare providers.

Disclosure statement

The authors report no conflicts of interest. The authors alone are responsible for the content and writing of this article.

Funding information

This study was supported by the National Central University – Cathay General Hospital Joint Research Fund (102NCU-CGH-04).

References

[1] Hillier SL, McDonnell M. Vestibular rehabilitation for unilateral peripheral vestibular dysfunction. Clin Otolaryngol. 2011;36:248–249.

[2] Badke MB, Miedaner JA, Shea TA, et al. Effects of vestibular and balance rehabilitation on sensory organization and dizziness handicap. Ann Otol Rhinol Laryngol. 2005;114:48–54.

[3] Pavlou M, Lingeswaran A, Davies RA, et al. Simulator based rehabilitation in refractory dizziness. J Neurol. 2004;251: 983–995.

[4] Eleftheriadou A, Skalidi N, Velegrakis GA. Vestibular rehabilitation strategies and factors that affect the outcome. Eur Arch Otorhinolaryngol. 2012;269:2309–2316.

[5] Cooksey FS. Rehabilitation in vestibular injuries. Proc R Soc Med. 1946;39:273–278.

[6] Schubert MC, Whitney SL. From Cawthorne-Cooksey to biotechnology: where we have been and where we are headed in vestibular rehabilitation? J Neurol Phys Ther. 2010;34: 62–63.

[7] Corna S, Nardone A, Prestinari A, et al. Comparison of Cawthorne-Cooksey exercises and sinusoidal support surface translations to improve balance in patients with unilateral vestibular deficit. Arch Phys Med Rehabil. 2003;84: 1173–1184.

[8] Whitney SL, Sparto PJ, Hodges LF, et al. Responses to a virtual reality grocery store in persons with and without vestibular dysfunction. Cyberpsychol Behav. 2006;9:152–156.

[9] Gottshall KR, Sessoms PH, Bartlett JL. Vestibular physical therapy intervention: utilizing a computer assisted rehabilitation environment in lieu of traditional physical therapy. Conf Proc IEEE Eng Med Biol Soc. 2012;2012:6141–6144.

[10] Sparrer I, Duong Dinh TA, Ilgner J, et al. Vestibular rehabilitation using the Nintendo® Wii balance board: a user-friendly alternative for central nervous compensation. Acta Otolaryngol. 2013;133:239–245.

[11] Rendon AA, Lohman EB, Thorpe D, et al. The effect of virtual reality gaming on dynamic balance in older adults. Age Ageing. 2012;41:549–552.

[12] Yeh SC, Chen S, Wang PC, et al. Interactive 3-dimensional virtual reality rehabilitation for patients with chronic imbalance and vestibular dysfunction. Technol Health Care. 2014;22:915–921.

[13] Clendaniel RA, Tucci DL. Vestibular rehabilitation strategies in Meniere's disease. Otolaryngol Clin North Am. 1997;30: 1145–1158.

[14] Gottshall KR, Topp SG, Hoffer ME. Early vestibular physical therapy rehabilitation for Meniere's disease. Otolaryngol Clin North Am. 2010;43:1113–1119.

[15] Committee on Hearing and Equilibrium. Committee on hearing and equilibrium guidelines for the diagnosis and evaluation of therapy in Menière's disease. Otolaryngol Head Neck Surg. 1995;113:181–185.

[16] Takagi A, Fujimura E, Suehiro S. A new method of statokinesigram area measurement. Application of a statistically calculated ellipse. In: Igarashi M, Black OF, editors. Vestibular and visual control on posture and locomotor equilibrium. Basel: Karger Publishers; 1985. p. 74–79.

[17] Paillard T, Costes-Salon C, Lafont C, et al. Are there differences in postural regulation according to the level of competition in judoists? Br J Sports Med. 2002;36:304–305.

[18] Kasse CA, Santana GG, Scharlach RC, et al. Results from the balance rehabilitation unit in benign paroxysmal positional vertigo. Braz J Otorhinolaryngol. 2010;76:623–629.

[19] Wrisley DM, Whitney SL, Furman JM. Vestibular rehabilitation outcomes in patients with a history of migraine. Otol Neurotol. 2002;23:483–487.

[20] Gottshall KR, Moore RJ, Hoffer ME. Vestibular rehabilitation for migraine-associated dizziness. Int Tinnitus J. 2005;11: 81–84.

[21] Whitney SL, Wrisley DM, Marchetti GF, et al. The effect of age on vestibular rehabilitation outcomes. Laryngoscope. 2002;112:1785–1790.