APPLYING VIRTUAL REALITY TO TREAT VESTIBULAR DISORDERS OF VARIOUS ETIOLOGY

R E P O R T

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C O N T E N T S

INTRODUCTION

Benign paroxysmal positional vertigo (BPPV) is the most common cause of vestibular vertigo accounting for approximately 20-30% of diagnoses in specialized dizziness clinics and affecting more than 2% of population[1].

Each patient experiencing BPPV can cost up to 2000 US dollars[2] for the country despite it being one of the easier disorders to diagnose and treat. The problem lies in the inability of medical doctors to routinely use effective treatment methods, such as the Epley maneuver, which can significantly reduce treatment costs and duration.

Moreover, virtual reality (VR) is becoming more popular in our daily lives and is starting to make some impact in treating various disorders or provides additional tools in rehabilitation process.

To minimize the cost of BPPV treatment and improve wellbeing of patients we raised the following objectives:

1) Survey medical doctors specialized in neurology about BPPV and their experience in treating the disorder;

2) Develop VR software that allows patients to perform the Epley maneuver;

3) Perform a pilot study of the VR software with healthy volunteers to evaluate its usability and possible adverse effects.

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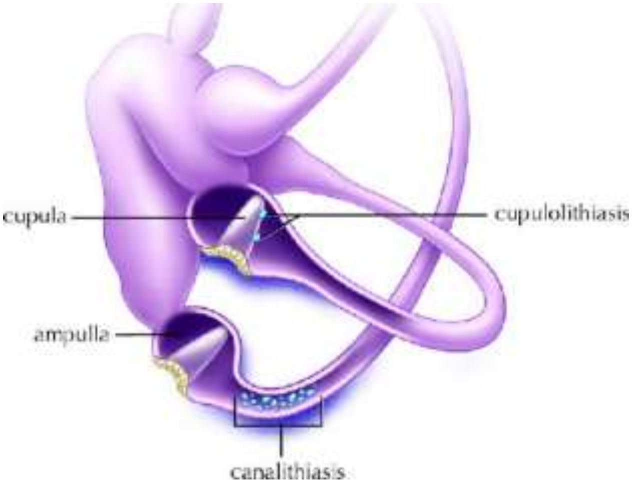
[1] Epidemiology of benign paroxysmal positional vertigo: a population based study. M von Brevern, A Radtke, F Lezius, M Feldmann, T Ziese, T Lempert, H Neuhauser (2007) http://jnnp.bmj.com/content/78/7/710.full.pdf

[2] Li CJ, Epley J, et al. Cost-effective management of benign positional vertigo using canalith repositioning. Otolaryngol Head Neck Surg (2000) 122:334–339

L I T E R A T U R E R E V I E W

2. 1. Benign paroxysmal positional vertigo

BPPV is a disorder arising in the inner ear. Its symptoms are repeated episodes of positional vertigo, that is, of a spinning sensation caused by changes in the position of the head[3]. The provocative positions usually trigger specific eye movements (i.e., nystagmus). There are 2 coexisting pathophysiologic mechanisms[4]:



http://www.ncbi.nlm.nih.gov/pmc/articles/PMC202288/figure/f4-16/

Canalithiasis (literally, "canal rocks") – the condition of otoliths residing in the canal portion of the semicircular canals.

Cupulolithiasis (literally, "cupula rocks") – otoliths adhered to the cupula.

These otoliths are responsible for sensitivity to head positions and when dislocated to semicircular canals cause dizziness.

Symptoms of BPPV include nausea, vomiting, visual disturbances and vertigo – illusion of spinning or swaying movement.

BPPV can significantly affect patient's quality of life and is a burden to society. In more than 85%[5] of affected individuals, BPPV leads to medical consultation, interruption of daily activities or sick leave. Only about 8% of patients receive effective treatment and the time period between the first symptoms and successful treatment can reach up to 92 weeks[6].

On the other hand, BPPV has a characteristic symptom – specific eye movement provoked by Dix-Hallpike test, which makes it easy to diagnose. Also, there are several maneuvers (including Epley maneuver) that can reposition the otoliths and relieve the symptoms within minutes with up to 90% effectiveness[7].

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[3] Bhattacharyya N, Baugh RF, Orvidas L, Barrs D, Bronston L, Cass S, Chalian A, Desmond A, Earll J (2008). "Clinical practice guideline: benign paroxysmal positional vertigo" (PDF). Otolaryngol Head Neck Surg 139 (5 Suppl 4): S47–81.

[4] http://emedicine.medscape.com/article/884261-overview

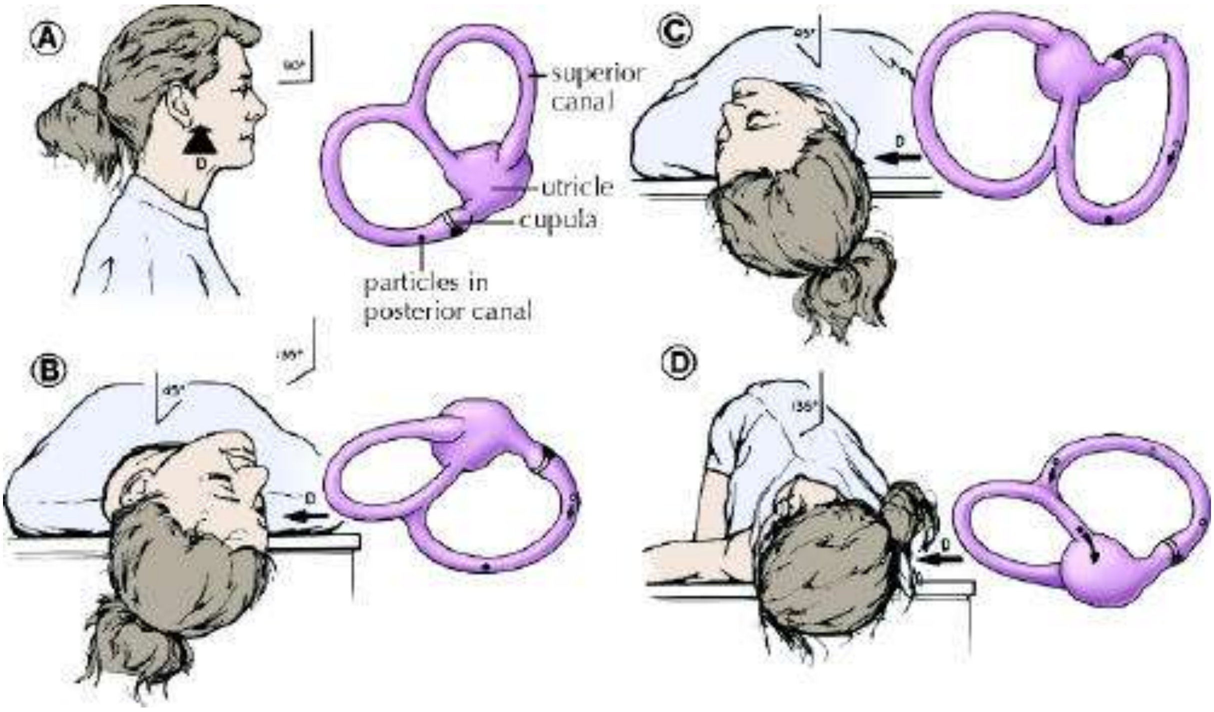
[5] Epidemiology of benign paroxysmal positional vertigo: a population based study. M von Brevern, A Radtke, F Lezius, M Feldmann, T Ziese, T Lempert, H Neuhauser (2007) http://jnnp.bmj.com/content/78/7/710.full.pdf

[6] Fife D FitzGerald JE. Do patients with benign paroxysmal positional vertigo receive prompt treatment? Analysis of waiting times and human and financial costs associated with current practice. Int J Audiol (2005); 44:50–7

[7] Efficacy of the particle repositioning menoeuvre for posterior canal BVVP http://www.ncbi.nlm.nih.gov/pmc/articles/PMC202288/table/t2-16/

2. 2. Epley maneuver

It is one of the repositioning maneuvers used to treat BPPV. It works by allowing free floating otoliths to be relocated, using gravity, back into the utricle, where they can no longer cause dizziness, therefore relieving the patient of bothersome vertigo.



http://www.ncbi.nlm.nih.gov/pmc/articles/PMC202288/figure/f8-16/

To perform the Epley maneuver the patient must complete the sequence of positions[8] starting from upright sitting posture with the head rotated 45 degrees towards the affected ear. Then the patient moves to 5 different positions with the series of movements of the head or the whole body. The maneuver takes up to 5 minutes to complete and can be used to treat BPPV in both ears.

Video “Epley maneuver to treat BPPV vertigo”: https://youtu.be/9SLm76jQg3g

Other repositioning maneuvers are available to treat BPPV (e.g. Semont[9], Brand-Daroff), but there is no significant difference in effectiveness[10] of these methods.

[8] http://emedicine.medscape.com/article/884261-treatment

[9] http://www.webmd.com/a-to-z-guides/liberatory-maneuvers-for-vertigo-semont-maneuver

[10] Single treatment approaches to benign paroxysmal positional vertigo. Herdman SJ, Tusa RJ, Zee DS, Proctor LR, Mattox DE Arch Otolaryngol Head Neck Surg. (1993 Apr); 119(4):450-4.

2. 3. Using virtual reality in medicine

The classical therapeutic approach for vestibular disorders relies on vestibular rehabilitation and symptomatic medication. Vestibular rehabilitation can improve static and dynamic balance and ultimately result in an increase of self-confidence and quality of life of sufferers[11].

However, many factors may negatively affect the outcome of vestibular rehabilitation, including incorrect performance of the exercises and the necessity of active efforts and interest from the patient[12]. Thus, more efficient and cost-effective therapeutic tools are yet to come for vestibular rehabilitation. In this context, virtual reality-based treatment could represent and interesting potential candidate.

Virtual environments are interactive simulations of real world generated by computers and presented to users through media of varying degrees of complexity (e.g., head-mounted display). Although the suitability of virtual reality in balance training of participant with vestibular disorders has already been demonstrated[13], no general recommendations on how to perform virtual reality-based vestibular rehabilitation are available.

The present meta-analysis[14] demonstrates the promising potential of virtual reality-based treatment for peripheral vestibular disorders. Despite significant differences in terms of protocol used and outcomes evaluation, all studies demonstrated that virtual reality-bases rehabilitation strategies had a positive effect and were seemingly well tolerated. Virtual reality-based rehabilitation represents a potentially promising new avenue to reduce the costs of peripheral vestibular disorders rehabilitation, as long as intervention protocols are standardized, side effects are documented and the profiles of patients susceptible to benefit from virtual reality-based rehabilitation are defined.

2. 4. Simulator sickness questionnaire

Using visual simulators can result in simulator sickness, which involves symptoms similar to those of motion-induced sickness. We must consider that simulator sickness tends to be less severe and originates from elements atypical of conditions that induce motion-induced sickness, thus using Motion Sickness Questionnaire can be misleading or irrelevant for simulator sickness.

In order to evaluate the side effects of using virtual reality, Simulator Sickness Questionnaire (SSQ) was developed. The SSQ provides straightforward computer or manual scoring, increased power to identify "problem" simulators, and improved diagnostic capability[15].

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11 N. A. Ricci, M. C. Aratani, F. Dona, C. Macedo, H. H. Caovilla,´and F. F. Gananc ̧a, "A systematic review about the effects of the vestibular rehabilitation in middle-age and older adults," *Revista Brasileira de Fisioterapia*, vol. 14, no. 5, pp. 361–371, 2010.

12 D. E. Bamiou and L. M. Luxon, "Vertigo: clinical management and rehabilitation," in *Scott-Brown's Otorhinolaryngology, Head and Neck Surgery*, M. Gleeson and L. M. Luxon, Eds., pp. 3791–3817, CRC Press, New York, NY, USA, 7th edition, 2008.

13 H. S. Cohen, "Disability and rehabilitation in the dizzy patient," *Current Opinion in Neurology*, vol. 19, no. 1, pp. 49–54, 2006

14 Mathieu Bergeron, Catherine L. Lortie, and Matthieu J. Guitton, "Use of Virtual Reality Tools for Vestibular Disorders Rehabilitation: A Comprehensive Analysis" Hindawi Publishing Corporation, Advances in Medicine Volume 2015, Article ID 916735, 9 pages

15 Robert S. Kennedy, Norman E. Lane, Kevin S. Berbaum & Michael G. Lilienthal "Simulator Sickness Questionnaire: An Enhanced Method for Quantifying Simulator Sickness" The International Journal of Aviation Psychology Volume 3, Issue 3, 1993 pages 203-220

Sample SSQ Scoring Worksheet

#	Symptom	Severity				Value	Ns	Os	Ds	N	O	D
1.	General discomfort	None	Slight	Moderate	Severe	1	*	*		1	1	
2.	Fatigue	None	Slight	Moderate	Severe	1		*			1	
3.	Boredom	None	Slight	Moderate	Severe							
4.	Drowsiness	None	Slight	Moderate	Severe							
5.	Headache	None	Slight	Moderate	Severe	0		*			0	
6.	Eye strain	None	Slight	Moderate	Severe	1		*			1	
7.	Difficulty focusing	None	Slight	Moderate	Severe	1		*	*		1	1
8a.	Salivation increased	None	Slight	Moderate	Severe	0	*			0		
8b.	Salivation decreased	None	Slight	Moderate	Severe							
9.	Sweating	None	Slight	Moderate	Severe	1	*			1		
10.	Nausea	None	Slight	Moderate	Severe	0	*		*	0		0
11.	Difficulty concentrating	None	Slight	Moderate	Severe	1	*	*		1	1	
12.	Mental depression	None	Slight	Moderate	Severe							
13.	"Fullness of the head"	None	Slight	Moderate	Severe	0			*			0
14.	Blurred Vision	None	Slight	Moderate	Severe	1		*	*		1	1
15a.	Dizziness with eyes open	None	Slight	Moderate	Severe	0			*			0
15b.	Dizziness with eyes closed	None	Slight	Moderate	Severe	2			*			2
16.	*Vertigo	None	Slight	Moderate	Severe	1			*			1
17.	**Visual flashbacks	None	Slight	Moderate	Severe							
18.	Faintness	None	Slight	Moderate	Severe							
19.	Aware of breathing	None	Slight	Moderate	Severe							
20.	***Stomach awareness	None	Slight	Moderate	Severe	0	*			0		
21.	Loss of appetite	None	Slight	Moderate	Severe							
22.	Increased appetite	None	Slight	Moderate	Severe							
23.	Desire to move bowels	None	Slight	Moderate	Severe							
24.	Confusion	None	Slight	Moderate	Severe							
25.	Burping	None	Slight	Moderate	Severe	0	*			0		
26.	Vomiting	None	Slight	Moderate	Severe							
27.	Other											
	Total									3	6	5

Weights: N = 9.54, O = 7.58, D = 13.92, T = 3.74

N = 3 * 9.54 = 28.62
O = 6 * 7.58 = 45.48
D = 5 * 13.92 = 69.60
T = (3 + 6 + 5) * 3.74 = (14) * 3.74 = 52.36

2. 5. Dizziness handicap index

Dizziness handicap index (DHI) is one of the most used standardized scale created in 1990[16]. It can be used to evaluate the impact of most forms of dizziness. Bigger score indicates bigger significance of the disability caused by a disorder and greater impact on the daily routine.

Scientific research describes usability of DHI to determine to effectiveness of both pharmaceutical treatment and vestibular rehabilitation exercises[17].

The scale consists of 25 questions about patient's symptoms and experiences of the previous month. Questions are grouped in 3 categories and can give a total score ranging from 0 (no dizziness) to 100 (severe dizziness and disability[18]).

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[16] Jacobson GP, Newman CV, The development of the Dizziness Handicap Inventory. Arch Otolaryngol Head Neck Surg, 1990 Apr; 116 (4) : 424-7.

[17] Alsalaheen BA, Mucha A, Morris LO, Whitney SL, Furman JM, Camiolo-Reddy CE, Collins MW, Lovell MR, Sparto PJ. Vestibular rehabilitation for dizziness and balance disorders after concussion. J Neurol Phys Ther. 2010 Jun;34(2):87-93.

[18] Whitney S.L., Wrisley D.M., Brown K.E., Furman J.M., Is perception of handicap related to functional performance in persons with vestibular dysfunction? Otol. Neurotol., 25 (2004), pp. 139–143

M E T H O D S

Objective no. 1 - Survey medical doctors specialized in neurology about BPPV and their experience in treating the disorder

To determine possible relevance of our app in the health care community and gain insight on knowledge and attitudes towards benign paroxysmal positional vertigo (BPPV) and its treatment options, we conducted an anonymous paper-and-pencil questionnaire of Lithuanian neurologists and other health care professionals. It consisted of 15 questions on respondents' demographic data, clinical practice, experience with BPPV, and preferred diagnostic and treatment methods for this condition. As neurologists were the target group for our investigation, the questionnaire was primarily carried out during specialty conferences and meetings. Statistical analysis of questionnaire data was carried out with R statistics package[19] (R Core Team, 2015).

Objective no. 2 – Develop VR software that allows patients to perform the Epley maneuver

We chose to use the Unity Engine for our app, because of its versatility, ease of use, and cross-platform support, which allows us to make the app more accessible to the public.

Hardware used:

1. Samsung Gear VR powered by oculus
2. Samsung Galaxy S6

http://www2.pcmag.com/media/images/485051-gear-vr.jpg?thumb=y&width=740&height=426

Objective no. 3 – Perform a pilot study of the VR software with healthy volunteers to evaluate its usability and possible adverse effects.

To determine the user friendliness and possible virtual reality induced side effects, we conducted a pilot study of our app. Self-reported healthy volunteers not suffering from BPPV or other balance related conditions were invited to participate in virtual reality experiment where they were asked to perform tasks (Epley maneuver) following the directions of our app. The participants then were asked to complete a questionnaire on the accessibility of the app and Simulator Sickness Questionnaire (SSQ) (Kennedy, 1993) which is one of the most popular tools to assess simulator induced side effects. In addition to questions on participant's general health, SSQ has a list of control symptoms administered before and after exposure to stimulation. Symptoms are evaluated on a 4-point scale from 0 to 3, and divided into nausea, oculomotor, and disorientation subscales. Subscale scores are calculated by multiplying raw scores of each subscale by a respective scaling factor. Total score is computed by adding raw scores of each scale together and scaling by a factor of 3.74. Statistical analysis of SSQ and user friendliness questionnaire data was carried out with R statistics package[19] (R Core Team, 2015). SSQ was translated into Lithuanian language.

[19] R Core Team (2015). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. URL https://www.R-project.org/.

R E S U L T S

Objective no. 1 - Survey medical doctors specialized in neurology about BPPV and their experience in treating the disorder

In total, we surveyed 88 health care professionals. Their demographic details are provided in table 1.

Based on the respondents' answers, majority of them (40 (46.51 %)) encountered 50 or more patients with BPPV in their clinical practice. However, such result could be explained by relatively high average age (42.86 (± 14.12) years) and long clinical experience (16.52 (± 13.87) years) of the surveyed group. Health care professionals were also asked about their subjective opinion on the prevalence of BPPV in outpatient and emergency care settings. Most of the respondents (29 (33.72 %)) think that patients with BPPV account for 10 % to 25 % of all dizziness and vertigo patients in outpatient care setting, and 34 (38.64 %) believe the same to be true in emergency care setting.

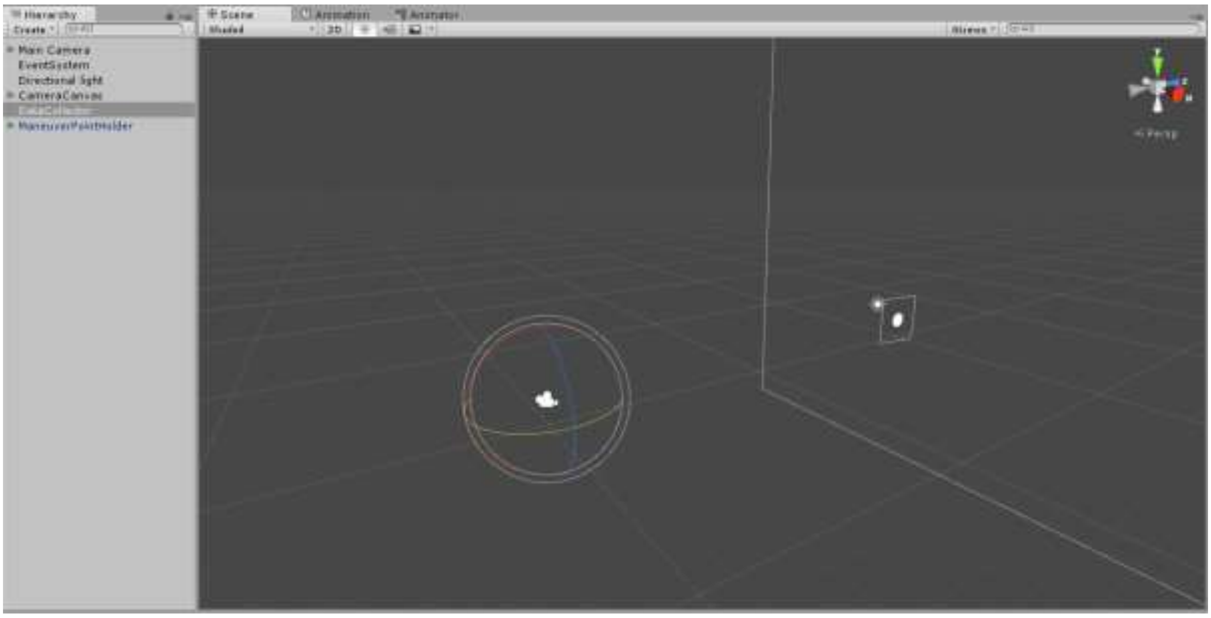
Table 1. Demographic data of surveyed health care professionals

		Female	Male	Total
No of respondents		71 (80.68 %)	17 (19.32 %)	88
Age, yrs (± SD)		42.10 (± 14.07), n = 67	46.00 (± 14.34), n = 16	42.86 (±14.12), n = 83
Occupation	Neurologist	44 (61.97 %), n = 71	13 (76.47 %), n = 17	57 (64.77 %), n = 88
	Neurology resident	13 (18.31 %), n = 71	1 (5.88 %), n = 17	14 (15.91 %), n = 88
	Other	14 (19.72 %), n = 71	3 (17.65 %), n = 17	17 (19.32 %), n = 88
Involved in clinical practice		67 (95.71 %), n = 70	16 (94.12 %), n = 17	83 (95.40 %), n = 87
Clinical experience, yrs (± SD)		15.59 (±13.74), n = 62	20.33 (±14.23), n = 15	16.52 (± 13.87), n = 77

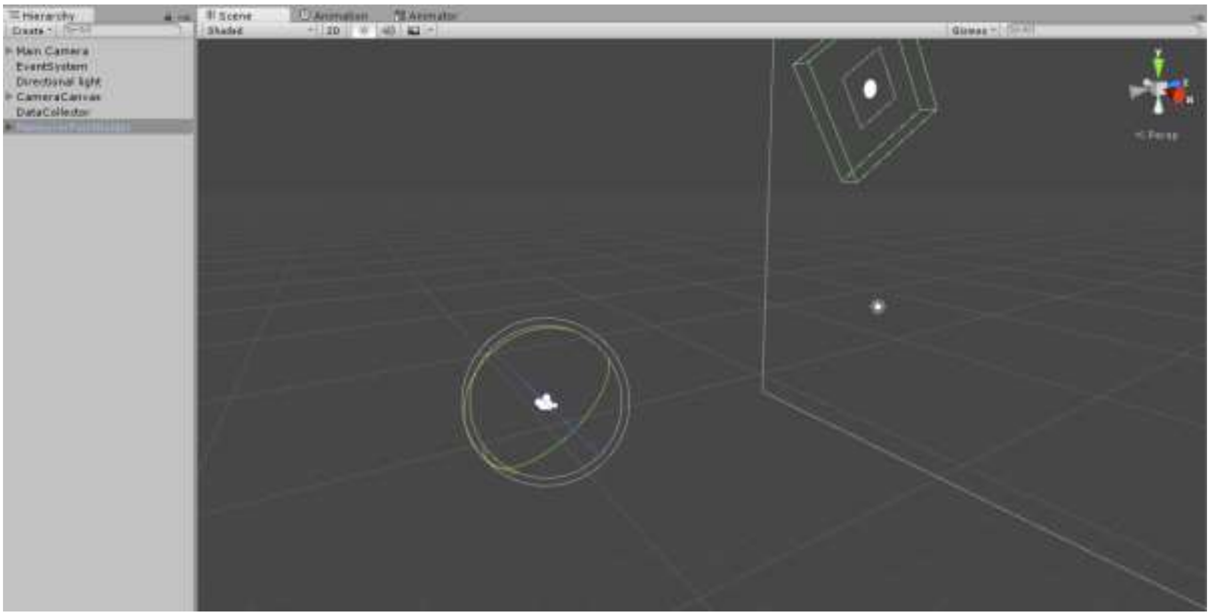
Our questionnaire also showed that positional maneuvers are popular tool in BPPV diagnosis, with just 19 (21.84 %) of the respondents never using them to diagnose BPPV. Main reasons for not applying positional maneuvers in clinical practice included time constrains (30.77 %), fears to worsen patient's condition (30.77 %), and lack of knowledge on their techniques (26.92 %). Among maneuvers used for treating BPPV, Epley maneuver was the most popular one (65.91 %), whereas, betahistine was the most popular pharmacological treatment option (71.59 %).

Objective no. 2 – Develop VR software that allows patients to perform the Epley maneuver

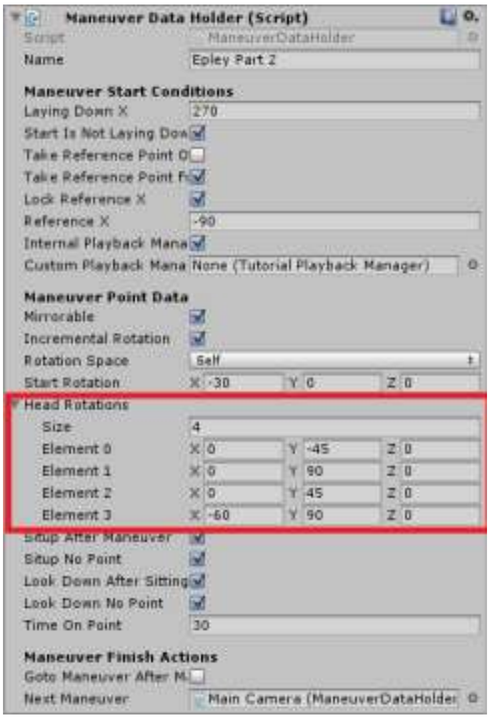
One of the biggest challenges was to figure out how to place the points in the precise rotation. As Unity uses a so called “Hierarchical” object placement, which works in a way that all the child objects of one parent belong to a separate local coordinate system, we figured to use a dummy object placed at the location of the user’s camera which would contain the actual point object placed in front of it (Ex. 1), and then rotate the dummy to the required rotation to rotate the whole matrix and thus place the point at the required position and angle. (Ex. 2)



Ex. 1



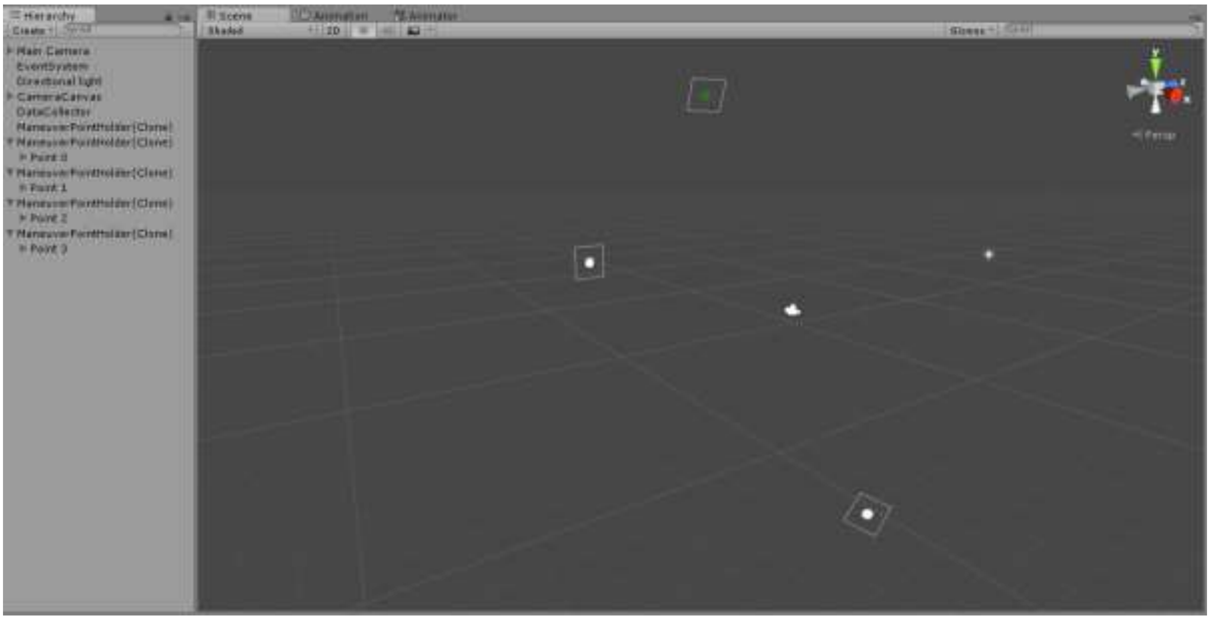
Ex. 2



Ex. 3

After the stage was set for testing, we realized that placing the points, changing the rotations and adding other maneuvers would be difficult, so we developed the system – dynamic placement of the points.

The points and other data specific to a maneuver is defined in a separate container for each maneuver implemented into the app (Ex. 3), which allows for easy modification and iteration of the maneuver, and makes the addition of other maneuvers really easy. After the maneuver is loaded, the points are spawned into the scene and rotated according to the settings (Ex. 4). The script has no hard coded values, all the maneuver options can be changed in this container, so it requires no coding skills for someone to change or add a new maneuver to the app. Also, as the code uses the maneuver data from the containers, and you can define a sequence of maneuvers, there is practically no limitations for implementing any maneuver.



Ex. 4

The maneuver to start can be selected from a user interface that contains all the possible options, which is displayed when the app starts. The maneuver is then loaded, and a narrative tutorial is played for the user. It is easy and intuitive to follow the directions not only because of the narrative, but also a number of additional tools:

1. The points are colored differently to prevent the user from looking to the same point twice;
2. If you look away from the point for an extended period of time, an informational message is played after you completion of the maneuver, to advise repetition because of critical number of imperfections.

Objective no. 3 – Perform a pilot study of the VR software with healthy volunteers to evaluate its usability and possible adverse effects.

In total, 15 volunteers participated in our study. Their performance was filmed for our future reference (example: https://youtu.be/8-8ZefqlF7Q). The demographic details of the participants are provided in table 2.

Table 2. Demographic data of healthy volunteers involved in the pilot study

		Female	Male	Total
No of respondents		10 (66.67 %), n = 15	5 (33.33 %), n = 15	15
Age, yrs (± SD)		20.50 (± 1.58)	19.20 (± 0.84)	20.07 (± 1.49)
Occupation	Non medical student	2 (20 %), n = 10	1 (20 %), n = 5	3 (20%), n = 15
	Medical student	8 (80 %), n = 10	4 (80 %), n = 5	12 (80 %), n = 15

Participants were asked to rate the apps' user friendliness based on a number of statements on various aspects of the app. Their answers were later ranked on a scale from 0 to 5 where 1 corresponded to "completely disagree", 5 to "completely agree", whereas 0 meant "hard to tell". Based on the volunteers' responses, the app scored relatively high on user friendliness with the average score of 4.19 (± 0.44) across all categories. The app scored the highest on categories related to spoken commands, and lowest on design, easiness and discomfort of performing the tasks. The later points might be due to the fact that *Epley* maneuver requires to hold one's head in unusual positions for extended periods of time. A more detailed breakdown of the results is provided in table 3.

Table 3. The average scores of user friendliness questionnaire across all categories

Statement	**Average score (± SD)**
The text of the app was easy to read	4.07 (± 1.28)
The text of the app was understandable	4.33 (± 1.35)
Visual clues were understandable	4 (± 1.07)

Visual clues helped to perform the tasks	4.47 (± 0.83)
I liked the design of the app	3.67 (± 1.23)
Spoken commands were clear and understandable	4.4 (± 0.63)
Spoken commands could be heard clearly	4.93 (± 0.26)
It was easy to understand spoken commands	4.87 (± 0.35)
The device fit comfortably	4.27 (± 1.22)
The device did not fall from the head	4.07 (± 1.49)
It was easy to perform the tasks	3.53 (± 1.60)
I did not experience any discomfort while performing the tasks	3.73 (± 1.16)

We also asked the participants to share their recommendations for the app via open-ended questions in the questionnaire. Most recommendations included concerns for better fitting device and more exciting app graphics and design.

However, it is interesting to note that although most of the participants claimed to have understood the commands, as we later saw in the filmed data, they failed to perform the tasks as expected. It leads us to assume that spoken commands, visual clues, and their timing in regards of each other should be improved to better user comprehension.

Out of 15 participants, 1 failed to complete the post stimulation part of the SSQ, therefore, was excluded from further data analysis. The participants rated their experience in virtual environment relatively high with 7.07 (± 2.84) points out of 10, on a scale where 1 corresponded to "poor" and 10 to "excellent". Out of 14 participants, 6 (42.86 %) reported getting or somewhat getting the feeling of motion during the stimulation. 3 (21.43 %) volunteers also reported unusual experiences during exposure, such as feeling tense, difficulties perceiving objects in 3D.

We used Wilcoxon signed-rank test to compare participants' symptom scores among different subscales, and total score pre- and post-exposure to virtual environment. We did not find any statistically significant differences between the results in any category (table 4). It should also be noted that some of the volunteers tended to score their pre-exposure symptoms higher as also evident from higher average scaled pre-exposure score in nausea subscale (10.90 vs. 6.13). This allows us to assume that, on average, virtual reality setting was tolerated relatively well among the volunteers. However, it is important to note that due to limited number of participants, hardly any conclusions should be drawn about the safety and possible side effects of the app, and user friendliness should be considered the primary focus of this study.

Table 4. Average scaled SSQ scores pre- and post-exposure to virtual environment

Scale	Average scaled score pre-exposure	Average scaled score post-exposure	p value
Nausea	10.90	6.13	0.1967
Oculomotor	12.45	13.54	1.000
Dizziness	10.94	23.86	0.1366
Total	13.36	15.38	0.6650

CONCLUTIONS

1. Health professionals often encounter cases of BPPV but around $^{1}/_{5}$ of them do not perform repositioning maneuvers because of included time constrains or lack of knowledge on their techniques;
2. Our app was relatively user-friendly and did not cause any significant adverse effects. However, more testing is needed since the number of participants was limited and filmed data suggest the need of clearer instructions and guidance.

Short-term goals:

1. Make improvements in our app:
   1.1. Clearer instructions;
   1.2. Additional visual clues to achieve more precise movements of test subjects;
   1.3. Better overall looks and design.
2. Test more healthy volunteers to make the app more understandable;
3. Begin testing with patients affected by BPPV and track their improvement and overall effectiveness of the app using Dizziness handicap index (DHI);
4. Establish partnership with international community of professionals specializing in vestibular disorders to get some input about the possibilities of improvement of the app and applying it into clinical practice.