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Virtual reality eye exercises application based on bates method: a preliminary study

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ABSTRACT

In many situations, ophthalmologists prescribe glasses and contact lenses as a treatment method for Myopia. The other way to cure myopia is by performing Lasik surgery or using advanced tools which takes a large amount of financial effort. Dr. William Horatio Bates proposed a promising method to cure myopia with an eye exercise approach, providing opportunities to enhance the availability of low-cost eye treatment that is not easily achievable with surgery and other expensive approaches. However, many myopia patients are still unaware of this method and have no idea how to use it in their daily lives. The rapid growth of virtual reality (VR) technology has shown that this technology offers an affordable and effective solution to provide better health services. This paper expands the result of an initial experiment aimed to validate the utilization of mobile VR technology to enhance the possibility of the Bates method implementation as a low-cost daily eye exercise tool. A direct diary study with 14 participants was carried out to explicitly investigate the feasibility of the proposed app. The result reveals that the proposed app could assist people with myopia when doing eye exercises and the result is quite promising in reducing the refractive levels with 0.13 diopter on average within 5 weeks period.

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1. INTRODUCTION

Refractive error known as myopia is a leading cause of visual impairment in the world and it is becoming more prevalent. Myopia is predicted to affect 52% of the world's population by 2050, with epidemic levels affecting 70 to 80% of young adults in Europe and East Asian nations like Taiwan, Japan, Hong Kong, and Singapore [1]–[5]. The main cause of Myopia is a problem in the refraction of light, when the accommodation is at rest, parallel rays of light from the space come to focus in front of the retina [6]. Due to the spasm of the ciliary muscles, close objects look clear to myopia patients, but distant objects appear blurred because the light is focused in front of the retina rather than on the retina [7].

Glasses, contact lenses, and refractive surgeries are the most used treatments to overcome refractive errors, but these methods are relatively expensive and do not naturally cure myopia [8]. In the field of vision therapy, eye exercises are frequently prescribed to treat myopia, visual acuity, ocular motility disorders, accommodative dysfunction, amblyopia, and visual field defects [9]. Medical doctors also recommend eye exercises to prevent vision problems and eye diseases like myopia and hyperopia [10], reduce eye fatigue [11], and improve visual acuity [12]. Recent studies have shown that various eye movements have a significant effect on refractive error. Because eye movements are effective in improving visual acuity levels in myopia, clinicians should consider using eye exercise to improve the visual acuity of adolescents with myopia [13], [14]. The Bates method, developed by New York ophthalmologist William Horatio Bates (1860–1931), is one of the most widely used eye exercises for alternative therapies. According to Dr. William Bates, the most important factor in achieving maximum visual acuity at various distances is to attain a state of full relaxation. Proper eye movements allow patients' eyes to rest, moisturize, and massage [15]. The Bates method includes palming, visualization, movement (or 'shifting'), and sunning. Blinking is one of the most important exercises in the Bates method. People with vision impairments use their eye internal and external muscles while reading and performing other daily activities [16]. However, most myopia patients don't really know the correct way to exercise and need a personal trainer to do the stuff. This condition may retard the progression of eye exercise in myopic individuals [17].

Virtual reality (VR) is a technology that typically provides interaction and immerses the user's senses in a computer-generated environment in a naturalistic fashion [18]. Head-mounted displays (HMDs) play an important role in VR implementation because these technologies can provide a natural three-dimensional visual experience in the way of interaction and communication with daily devices such as smartphones [19]. The emergence of VR offers new possibilities to leverage the usage of this technology in rehabilitation and therapy scenarios. Recent examples of including this technology in rehabilitation reveal that VR can address the limitation of real-life rehabilitation environment setting by providing a low-cost ideal virtual training environment for patients [20]-[23]. Hence, we intend to design a VR application that is feasible to support patients with myopia to conduct Bates eye exercises as an alternative tool to the classical Bates exercise rehabilitation.

In this paper, we explore individual responses and their insight into the usage of Bates eye exercises with VR to observe reactions from patients. Next, based on collected respondent data, we design an application prototype to meet the patient's requirements. The objective of this study is to investigate the feasibility of the proposed VR application to help patients with myopia do eye exercises in daily life so they can practice independently.

2. MATERIAL AND METHOD

This section outlines the serial methods we used to examine how users perceived and received the proposed minimum viable product. Considering contextual problems, VR technologies also introduce a change in the conventional eye exercise processes. We have focused on the implementation scenario of the Bates method in the VR interface. The process for conducting a retrospective diary study to gather requirements for the proposed app, the proposed system's concept, and the system design strategy are presented below.

2.1. Preliminary study and requirement elicitation

The essence of the Bates method is to find a way to train the eye muscles that ensure the functioning of the eye and ensure the possibility of creating proper conditions for human body regeneration. The Bates method has many techniques including palming, visualization, movement (or 'shifting'), and sunning. A preliminary study was conducted to quantify the capability of smartphone and mobile VR to implement the Bates technique, in particular, to identify the proportions of which techniques are feasible in mobile VR scenarios. Bates proposes several techniques for eye therapy through color, shape, depth, texture, and movement. These techniques seem like nourishment to the eye for normalizing the eyes condition [17]. Some of the existing methods which are proposed in the Bates method include head swing, palming, sunning, optical swing, and color day.

We conducted a field study by exploring individual responses about their awareness and knowledge of the Bates method. The subjects participating in the pilot study were people without visual impairments and those with myopia (nearsightedness) with various diopter levels including glasses and no glasses. Next, based on collected respondent data, we build a set of features, interfaces, and control mechanisms to implement the selected Bates method into the proposed app.

2.2. The VR compatibility scenario

The main function of the proposed system is based on selected exercises known from the Bates method literature, and the compatibility of virtual reality implementation. The concept of the proposed eye exercise app involves the use of a mobile virtual reality technology in which make Bates eye exercise methods are performed on a single smartphone. The objective of utilizing the mobile virtual reality implementation is to allow the Bates eye exercise can be accessed by anyone at any time and anywhere with a minimum cost. However, there may have been some threats and limitations to the development process. The variation of methods used plus the limited functionality of mobile virtual reality at this moment may only include a number of the Bates methods that would have been feasible for virtual reality implementation. Due to the limitation of smartphone and VR support, we can only implement head swing and optical swing. Table 1 shows the VR compatibility to support Bates methods implementation.

Table 1. VR compatibility of the features set

Method name	Description	VR Support	Reason
Palming	Close and massage the eyes to achieve eye relaxation	Not supported	When using HMD or CardBoard, users can't massage their eyes.
Sunning	Facing the sun with eyes closed and moving the face area side to side to distribute the sunlight	Not supported	It is impossible to simulate the sunlight using a smartphone
Colour day	Focus on 1 color in 1 day	Not supported	Can be implemented but it's impossible that the user will use HMD or CardBoard glasses for a full day.
Optical Swing	Roll your eyes vertically, horizontally, and diagonally without moving the head then rest your eye muscles by closing your eyes	Supported	Create a moving object that the user's eyes can follow.
Head Swing (Central Vision)	Train the eye muscles by using a moving focus pointer but without paying attention to the surroundings, so that the focus of the eye will be fixed on the pointer while the patient's head is following the pointer object.	Supported	Utilize the Gyroscope sensor to create a pointer that moves in the 3D axis.

The head swing and optical swing stimulate both activity and relaxation of the muscles responsible for controlling the accommodation of sight. The proposed application should provide a simulation between the eye and the observed virtual reality image so that the patient can implement head and optical swing in a simplified version.

2.3. Diary study of the eye's performance

The purpose of this study is to assess the viability of VR to support novice users' when doing the Bates Method on a daily basis, so the usability level of the proposed interactive app has become a crucial criterion. Usability testing is a crucial step in developing mobile applications when it comes to user experience. Performing usability tests while developing an application can have a number of advantages, such as improving the usability and quality of the software before it is released [24]. We measure the usability level of the proposed prototype which was developed with requirements and design scenarios in the previous phase. Introductory tasks coupled with a 30-days (5 weeks) retrospective diary were used to collect data about the participant's effect on the usage of the proposed app. The participants were suggested to try the proposed app in the morning, and again in the evening.

Slovin's formula was used to determine the sample size of participants [25]. With N being the population size and e is the margin of error, the amount of N=100 and error tolerance e=25%=0.25 was given in (1).

$$n = \frac{N}{1 + N\,e^2} = [13.79] \approx 14 \quad (1)$$

The 14 participants had at least some familiarity with VR apps for HMDs and Android mobile applications. They were divided into two groups: myopic individuals without glasses and myopic individuals wearing glasses. Additionally, they are familiar with measuring their current refractive error and are aware of their current diopter level, which enables them to validate the accuracy of the proposed application result during testing. Their performance on the evaluation tasks was observed while they were using the proposed VR app, and any issues that emerged were noted and highlighted.

3. RESULTS AND DISCUSSION

As part of the feasibility test of our VR approach to provide an intuitive implementation of the Bates method for a wide range of users, we implemented several case studies on top of an android platform as a minimum viable product. In the following, we introduce the main feature of the proposed application prototype like eye exercises functionality, and a feature to calculate the diopter level to investigate the usability of the proposed application. The result and the possible issues in the implementation phase will be presented as:

3.1. Prototype implementation

The mobile application prototype was built for Android-supported devices based on the insight that we have on the conceptual system design. The main feature of this app is to provide a virtual environment for conducting compatible Bates exercise methods. Users need to use the HMD with their smartphone to practically use the apps. When the user opens the application and selects a specific exercise mode, for example, the head swing, the application provides a history log to the user so they can use this application to track the exercise progression for every period. When the user clicks the start exercise button, then the application will present step-by-step guidance on how to proceed with the selected exercise. Then the VR mode will show up on the screen with the actionable exercise instruction. The screen flow for user interaction is depicted in Figure 1.

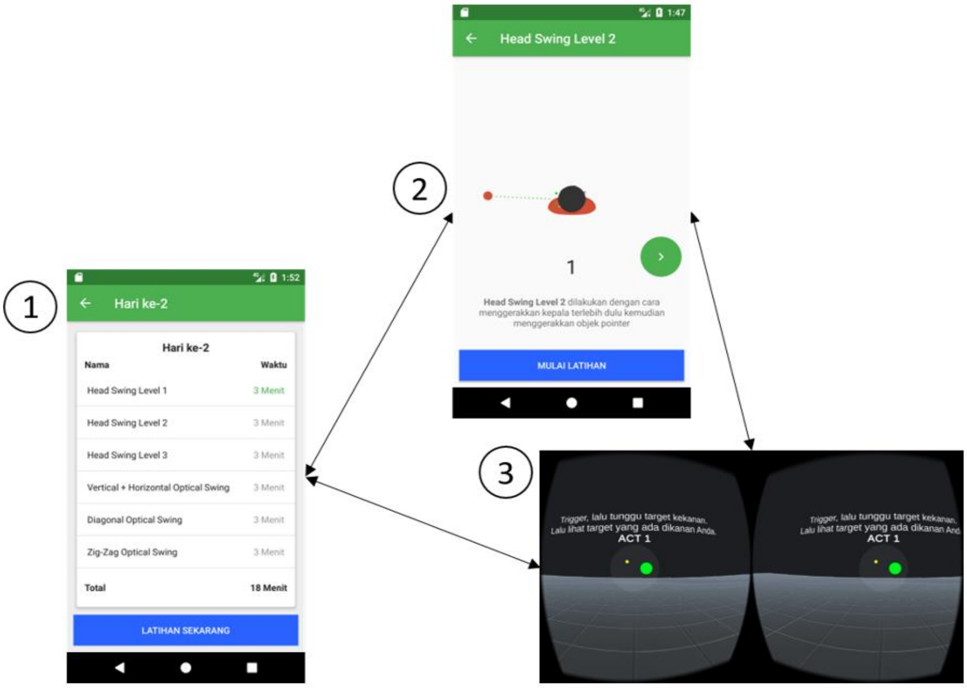

Figure 1. The screen flow of using the VR mode exercise

The proposed application should convert the raw distance data to a diopter value in order to accurately display a diopter level to the user. In order to determine the blur line's distance, this application uses a front-facing camera to capture real-time images of the user's face and then automatically determine the user's eye position. The diopter calculation module's comprehensive documentation can be found in [26], [27]. After computing the diopter level using the distance data, the application displays the results to the user. Figure 2 displays the entire process flow.

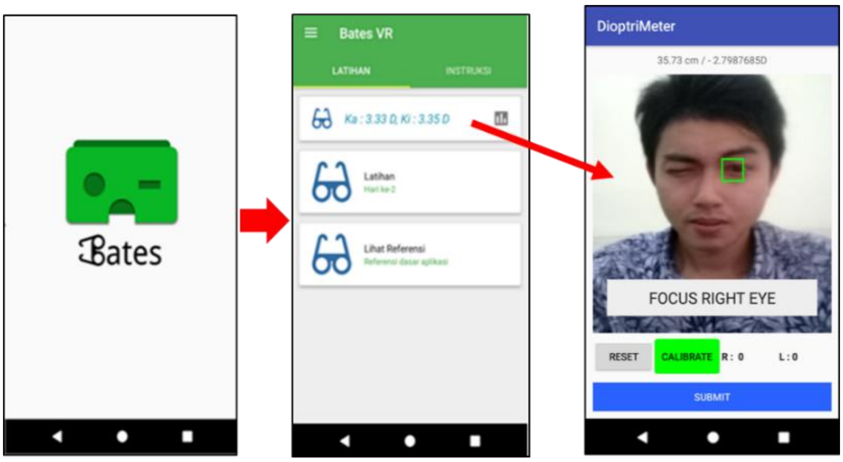

Figure 2. Automatic diopter measurement feature

3.2. Eye performance evaluation result

The study aims to evaluate the feasibility of the Bates method implementation in a VR environment for people with myopia prevalence. Innovative technologies should be a great tool to support the user's action in order to enhance their visual abilities. The 14 participants were involved, and they were asked to do several task scenarios with the proposed app as described in Table 2. Fourteen healthy subjects (7 males and 7 females) aged 21–42, participated in the non-equivalent control group experiment. They were categorized as myopia but not wearing glasses, and myopia with glasses. Using information from introductory tasks, each participant has a 30-days (5 weeks) retrospective diary evaluation, and to avoid adaptation times, the proposed app was personalized with the devices the participants owned. The participants were suggested to try the proposed app in the morning, and again in the evening.

Table 2. The task scenario for the diary study

Task description	Scenario
Head swing level 1	1. Focus your gaze on the pointer object. 2. When the pointer moves to the right, followed by moving your eyes up to 75 degrees without moving the head. 3. Once the pointer stops on the right, turn your head until the pointer is in the center of the view. 4. Press the virtual reality restart button and focus your eyes until the pointer is at the starting point without moving your head. 5. Once the pointer is at the starting point, move your head back to the starting position.
Head swing level 2	1. Focus your gaze on the pointer object. 2. Move your head 75 degrees to the right 3. Press the virtual reality restart button and focus your eyes on the pointer until it reaches the center of the screen view. 4. Move your head to the starting position. 5. Restart the processes
Head swing level 3	1. Focus your gaze on the pointer object. 2. As the pointer moves to the right, move the head to the left until 45 degrees. 3. Press the virtual reality restart button and move your head to the initial position following the pointer in the opposite direction.
Vertical horizontal optical swing	1. Focus on the center of the screen. 2. Press the start button and focus your eyes on a vertically moving object. 3. When the pointer stops moving, close your eyes for 10 seconds and take deep breaths to relax. 4. Press the restart button and focus your eyes on a horizontally moving object.
Diagonal optical swing	1. Focus on the center of the screen. 2. Inside the app, press the start button and focus your eyes following on a pointer object that moves diagonally. 3. When the pointer stops moving, close your eyes for 10 seconds and take deep breaths to relax. 4. Press the restart button and focus your eyes on an object that moves diagonally.
Zig-zag optical swing	1. Focus on the center of the screen. 2. Inside the app, press the start button and focus your eyes on an object that moves horizontally in a zigzag way.

A direct dairy study was conducted to explicitly access the effect of the proposed app to support the Bates exercise method. An online questionnaire was designed to be completed on participants' devices, with responses saved at each step to allow for sequential or end-of-day completion. The trial environment in the diary study when participants use the proposed app is depicted in Figure 3. The boarding page of the user to see the particular exercise instructions are shown in Figure 3(a) and Figure 3(b) is the exercise process in the testing environment. The result of the field trial which shows the diopter level range for each participant and the comparison result from week 1 to week 5 is shown in Table 3.

As previously stated, the evaluation's outcomes can tell us whether the suggested app is helping to improve the Bates exercise tasks' user experience. Participants completed the experiment task relatively in different amounts of time over the course of one week in the preliminary study, which did not take into account the usage time for carrying out each scenario with the apps. Although after five weeks of doing exercise, no significant differences in myopia levels were found between the participants, the exercise results are quite promising, within 5 weeks participants gain less diopter level with 0.13 diopter on average. The fact that the diopter gap between week 1 and week 5 of the app measurement had a small standard deviation (SD) indicates that the suggested application can provide participants with consistent results in terms of reducing refractive levels. The participant also states about eye fatigue indication after using VR in long usage scenarios with HMD. The participant comments are relevant to the existing studies which point to substantial limitations of VR in long-term use outside of eye exercise activities [28], [29]. The most interesting and unique insight of our evaluation is that participants in general state that the proposed app's intuitive presentation makes them feel like doing eye exercises can be simpler, faster, and more enjoyable, and they can track their eye health on an individual basis.

(a) (b)

Figure 3. Screenshots of VR mode (a) head swing instruction and (b) head swing exercise

Table 3. The results of the diary evaluation

No	Participant	Eyes	Week 1 (Diopter)	Week 2 (Diopter)	Week 3 (Diopter)	Week 4 (Diopter)	Week 5 (Diopter)	Gap (Week 1 – Week 5)
1	Participant 1	R	-2.99	-2.96	-2.94	-2.9	-2.82	0.17
		L	-2.89	-2.86	-2.78	-2.74	-2.71	0.18
2	Participant 2	R	-2.49	-2.44	-2.42	-2.42	-2.33	0.16
		L	-2.47	-2.45	-2.42	-2.38	-2.36	0.11
3	Participant 3	R	-1.5	-1.5	-1.47	-1.45	-1.4	0.1
		L	-1.5	-1.5	-1.47	-1.44	-1.38	0.12
4	Participant 4	R	-1.29	-1.27	-1.26	-1.22	-1.18	0.11
		L	-1.29	-1.29	-1.28	-1.24	-1.21	0.08
5	Participant 5	R	-2.88	-2.85	-2.84	-2.8	-2.78	0.1
		L	-2.9	-2.87	-2.83	-2.82	-2.79	0.11
6	Participant 6	R	-2.02	-1.95	-1.94	-1.94	-1.86	0.16
		L	-2.03	-1.99	-1.97	-1.97	-1.87	0.16
7	Participant 7	R	-2.24	-2.21	-2.13	-2.06	-2.03	0.21
		L	-2.21	-2.18	-2.17	-2.16	-2.11	0.1
8	Participant 8	R	-1.72	-1.69	-1.67	-1.59	-1.53	0.19
		L	-1.73	-1.71	-1.7	-1.64	-1.6	0.13
9	Participant 9	R	-2.45	-2.39	-2.37	-2.34	-2.31	0.14
		L	-2.71	-2.69	-2.67	-2.65	-2.62	0.09
10	Participant 10	R	-2.2	-2.2	-2.19	-2.15	-2.1	0.1
		L	-2.48	-2.46	-2.44	-2.42	-2.4	0.08
11	Participant 11	R	-1.33	-1.3	-1.28	-1.27	-1.24	0.09
		L	-1.34	-1.33	-1.3	-1.27	-1.23	0.11
12	Participant 12	R	-2.42	-2.4	-2.38	-2.35	-2.34	0.08
		L	-2.72	-2.66	-2.55	-2.46	-2.36	0.36
13	Participant 13	R	-2.69	-2.67	-2.65	-2.62	-2.61	0.08
		L	-2.46	-2.44	-2.42	-2.4	-2.35	0.11
14	Participant 14	R	-1.69	-1.67	-1.59	-1.53	-1.49	0.2
		L	-1.71	-1.7	-1.64	-1.6	-1.47	0.24
			Mean of Gap/Deviation					0.138/0.006

4. CONCLUSION

The preliminary study of the idea to implement the Bates method into mobile VR shows that the proposed apps make eye exercise become simpler and less time-consuming by only using a smartphone and simple HMD tools like cardboard. In our five-week diary study, we found that the proposed app could assist people with myopia when doing eye exercises with the Bates method and the result is quite promising in reducing the refractive levels in a short period of time. The eye fatigue indication issues when using VR with HMD in long-term scenarios also can be considered a new challenge to the next phase of the proposed approach. Although no significant reduction in the index of refraction was observed in this study, we conclude that the work is feasible for future implementation based on this preliminary evaluation.

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