

## Measuring Neck Abnormalities for Preliminary Assessment of Neck Pain Disease using Virtual Reality

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**Abstract:** Neck pain is an increasingly prevalent issue in the general population, leading to a growing incidence of chronic cases and potential future health risks. The economic impact is significant, as individuals with neck pain often cease working due to discomfort. Traditional assessments of treatment effectiveness involve the measurement of neck deformity and movement, typically requiring expensive and limited Cervical Range of Motion (CROM) equipment found primarily in large hospitals. The challenges posed by the COVID-19 outbreak further hinder access to such evaluations. This study proposes the development of a Virtual Reality (VR) application designed to measure neck movement range, enabling users to self-administer assessments under the guidance of the VR application. The VR application development process commences with storyboard creation, all components were designed and creates models object using Blender. The development of VR applications for angle measurement follows the storyboard, was executed using the Unity program. Prioritizing user satisfaction, the application capitalizes on the proven accuracy and reliability of VR devices. Usability experimental focused on user independence, with participants autonomously following instructional videos. Noteworthy user satisfaction, reflected in an average score of  $4.36 \pm 0.52$ , underscores the potential of the VR application in addressing neck pain symptoms. The study emphasizes

meticulous design considerations, including character and scene elements, aiming to enhance user engagement and immersion in the virtual environment. Users demonstrated focused attention during the measurement process, unaffected by external factors.

## 1. Introduction

Neck pain is a symptom caused by defects in the cervical spine joints, neck muscles, and shoulder blade muscles. It is prevalent in the general population and tends to increase annually (Guo *et al.*, 2023). Incorrect postures in everyday life have been a long-standing cause of neck pain (Nainate, 2020). Individuals experiencing neck pain may also encounter complications such as a fear of movement, which can significantly impact their daily lives. If neck pain becomes chronic, it may lead to other future health issues, such as rheumatoid arthritis, osteoporosis, etc. (Sarig Bahat *et al.*, 2018). Additionally, this symptom can affect other mental illnesses, such as stress-related disorders.

According to the Global Burden of Disease (GBD) report, an estimated 124 million cases of neck pain increased worldwide from 1990 to 2017 (Sarig Bahat *et al.*, 2018). Neck pain is a symptom that is commonly attributed to musculoskeletal system and connective tissue disorders. Many patients suffer from the disease, which is ranked 3rd out of 10 in the 2021 annual case report by the Ministry of Public Health of Thailand (Strategy and Planning Division. Ministry of Public Health, 2019). According to studies on

the prevalence of neck pain at the Faculty of Medicine, Chiang Mai University, and medical colleges in Malaysia, 65% of personnel and 1% of students, respectively, experienced neck pain from long periods of computer use (Punwaree, Klaphajone, & Kovindha, 2009; Alshagga *et al.*, 2013). In 2011, a study at Thammasat University found that 46% of undergraduate students between the ages of 18 and 25 had neck pain (Kanchanomai *et al.*, 2011). Subsequently, a study at government health facilities in Yala Province, Thailand, found that a total of 136 people had neck, back, or shoulder pain (Ahmadmusa, 2020). Today, neck pain is the most common health problem among students in the 4th and 5th years of the Faculty of Allied Health Sciences at Naresuan University (Lertsinthai *et al.*, 2020). These studies suggest that neck pain is a prevalent problem that can affect people of all ages, from teenagers to working adults. Therefore, neck pain treatment is crucial and should be widely available.

Furthermore, the increasing number of patients with neck pain has an indirect impact on the economy because they must stop working due to pain (Kazeminasab *et al.*, 2022). The assessment of treatment effectiveness involves the measurement of neck deformity and movement, which necessitates the use of cervical range of motion (CROM) equipment, as shown in Figure 1. However, CROM equipment is not only expensive but also limited in availability, typically found only in large hospitals. The challenges have been exacerbated by the COVID-19 outbreak,

further complicating access to evaluations for neck pain utilizing such equipment in hospitals (Parasate *et al.*, 2022).

The medical field has adopted virtual reality (VR) technology to treat the symptoms of various diseases. VR headsets take users out of the real world by immersing them in a simulated environment, as shown in Figure 2. These VR headsets contain sensors that can track various types of movement, including head tracking, which utilizes gyroscopes, accelerometers, and magnetometers (Freeman *et al.*, 2017). The accuracy of these sensors has been demonstrated in a study conducted by Xu *et al.* (2015).

The VR Oculus Rift presents only a slight degree of deviation when compared to the motion tracking system (Xu *et al.*, 2015), and the VR device can be seamlessly integrated with sensors on mobile phones through the app. Furthermore, a study by Chang *et al.* suggests that the measurement of neck angles using a goniometer sensor from a mobile phone is highly reliable (Chang *et al.*, 2019).

In 2021, Yan *et al.* (2021) concluded that VR can still measure neck angles with an expected deviation of no more than 2 degrees compared to measurements with goniometers. Along with the accuracy between VR and medical devices for measuring the angle of neck movement such as CROM, according to the Santos-Paz study, VR is still very accurate, but the size of VR devices is

large and expensive (Santos-Paz *et al.*, 2022). Addressing this concern, Trinidad-Fernández *et al.* developed an application for the VR Meta Quest 2 HMD device. They chose this device due to its affordability, popularity, and excellent quality and accuracy in measuring neck angles (Trinidad-Fernández *et al.*, 2023). VR applications for measuring neck movement, as discussed in the above articles, typically require expert guidance during usage.

Virtual reality (VR) applications developed for use with head-mounted displays (HMD) are typically customized to suit the specific application and intended purpose. Tao *et al.* (2021) conducted a literature review focusing on the design of VR applications within the healthcare domain. They asserted that effective VR application design enhances user comprehension, leading to increased user retention and repeated usage (Tao *et al.*, 2021). However, prolonged usage of VR applications with HMDs can have adverse effects on user health, including eye strain, dizziness, and the potential for neck injuries. Therefore, it is imperative for VR applications to be meticulously designed to mitigate these health-related concerns.

VR demonstrates high accuracy and reliability when compared to medical measurement devices. VR is becoming exponentially more popular, and most people are aware of this technology. Additionally, the equipment used for measuring neck movement angles, CROM is both expensive and limited in quantity, often only available

in larger hospitals. This means that a physical therapist or specialist must be present while using the equipment. COVID-19 has made it even more difficult to access neck pain assessment using such devices at hospitals.

This study aims to develop a VR application for initial neck injury assessment, leveraging the accuracy and reliability of VR equipment. Therefore, the focus of this research is on designing the application to be user-friendly with the goal of achieving user satisfaction. The application is designed and developed for users to utilize independently, aiming to alleviate the workload of experts and the limitations of CROM devices.

## 2. Materials and Methods

### 2.1 VR Device

There are now several varieties of VR technologies, which are grouped into three categories (Heizenrader, 2023). Firstly, Non-Immersive VR: this type of virtual reality is often integrated into daily activities, such as gaming on platforms like PlayStation. Users may not be fully aware that they are experiencing VR. While interacting with the virtual environment through a screen, they control characters without physically entering the virtual world. Secondly, Semi-Immersive VR: this category provides a 3D-viewable



Figure 1. Cervical Range of Motion (CROM)

virtual world. Users can manipulate the virtual environment using a computer mouse, but their body movements are not tracked and replicated within the virtual space. Thirdly, Fully Immersive VR: this is the most advanced form of VR, offering users a complete and immersive experience. Users can move their bodies within the virtual world through motion detection technology. High-resolution head-mounted display (HMD) glasses and various VR controllers are essential for optimal vision and interaction.

In this study, we utilized fully immersive VR through the PICO 4 VR device (PICO, 2023), which is conducive to application development due to the availability of an SDK (Software Development Kit) for creating applications. The device is reasonably priced, making it a cost-effective choice compared to other VR models. Additionally, the device boasts a balanced design where its weight is symmetrically distributed towards the back. This design facilitates prolonged usage as the weight is concentrated towards the front only, and a cushion supports the entire device, both in the front and back, reducing discomfort for the user. The PICO 4 weighs a light 350 grams and offers adjustable pupil distance to accommodate individual user needs.



Figure 2. VR device (PICO 4)

It also features tracking and positioning sensors, including optical sensors on the sensor board, an AKM Semiconductor three-axis, six-axis MEMS gyroscope, and an accelerometer from TDK-InvenSense.

## 2.2 VR Application Design

The VR application has been designed to align with the process of measuring neck pain levels using the CROM device, as illustrated in Figure 3.

The initial phase of the physical therapy assessment for neck abnormalities involves the completion of a visual analog scale questionnaire (VAS). This instrument prompts the assessor to delineate their pain level on a horizontal 10-centimeter line, the parameters of which range from no pain on the left end to excruciating pain on the right, as illustrated in Figure 4. Subsequently, the measurement of CROM device will be conducted to quantify angles in six distinct directions: Flexion, Extension, Right Lateral

Flexion, Left Lateral Flexion, Right Rotation, and Left Rotation. The data obtained from both the VAS questionnaire and CROM device are subsequently utilized to comprehensively evaluate the assessor's neck condition.

Furthermore, a well-designed VR application has a positive impact on user usability, reducing the occurrence of discomfort during device utilization, such as neck strain and eye fatigue from prolonged VR usage. Deserver's study (Park, Lee, & Ko, 2013) suggests that VR game design should include a user guide to provide users with a foundation and understanding of how the game works for a more enjoyable experience. Another interesting aspect of VR is its ability to immerse users in a simulated reality, creating a more engaging and realistic experience. Therefore, based on the above conclusions, our study designed a VR application featuring a step for measuring neck pain levels in alignment with CROM device and designed

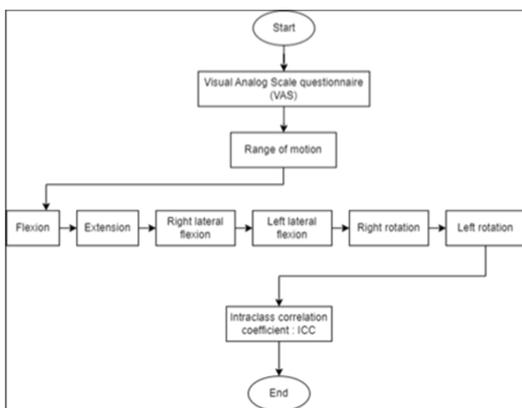


Figure 3. CROM procedure to measure neck abnormalities

Volunteer ID: \_\_\_\_\_

**Visual Analog Scale questionnaire (VAS)**  
Pain level questionnaire for use in screening for research

On a scale from 0 to 10, where 0 means no pain at all, and 10 means the worst pain imaginable, please mark X on the line below to indicate the average level of pain you experienced in the past 1 week.

0-----10  
No painPain full

Results : ( ) Pass ( ) Fail

signature: \_\_\_\_\_  
Date: \_\_\_\_/\_\_\_\_/\_\_\_\_

Figure 4. CROM procedure to measure neck abnormalities

the internal environment to be interesting and user-friendly.

Storyboarding is a crucial aspect of application development as it provides a visual representation of the application’s direction. It allows for a comprehensive view of the development path, showcasing the overall picture of its progression. Moreover, it outlines the work process in a step-by-step manner, facilitating easy editing and incorporation of additional components within the application.

In this study, the storyboard of the application has been designed, comprising key scenes as follows: user guidance, VAS

measurement, measurement of CROM in Flexion and Extension directions, and measurement of CROM in Right Lateral Flexion and Left Lateral Flexion directions. The procedural steps for each scene adhere uniformly to the guidelines derived from VAS and CROM measurements, as outlined in Table 1. Place tables at the top or bottom of pages. Avoid placing them in the middle of pages. Table heads should be above the tables. Insert tables after they are cited in the text. Use 9-point Calibri for Table labels as shown in Table 1.

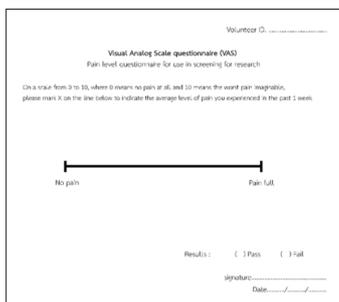
**Table 1.** Storyboard for VR application

1. Introduction	
Physical therapist	VR Application
<p>Explain details about the process of assessing neck pain levels.</p>	
	<p>Introducing the Application Functionality: Upon clicking "Enter," a video showcasing the entire operational process, including equipment usage and necessary user actions, will be displayed on the introduction page. Additionally, users have the option to pause and repeat the video for enhanced comprehension and convenience.</p>

**Table 1.** Storyboard for VR application (cont.)

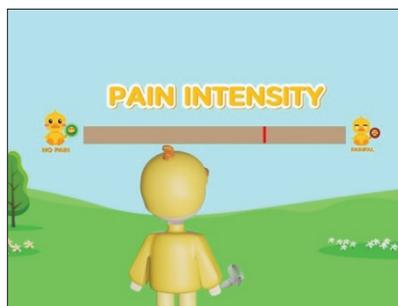
**2. Visual Analog Scale questionnaire (VAS)**

**VAS**



In the process of utilizing VAS measurement, users are instructed to mark symbols on a 10-centimeter straight line on paper. The positioning of the mark corresponds to the intensity of pain experienced by the user at the specific moment of assessment.

**VR Application**



The design for measuring pain levels involves a horizontal straight line similar to VAS. Users can use the controller to mark their pain level, following the same conditions as VAS. After the user makes their selection, an auditory signal will notify them of the chosen pain level.

**3. Measure the angle of neck movement in the directions of extension and flexion**

**CROM**



During the measurement process in this particular direction, the assessor is seated and wearing the CROM device. They are instructed to elevate and lower their head while the physical therapist orchestrates the movement to gauge the angle. It is imperative for the physical therapist to initially set the starting angle and posture to 0 degrees, ensuring consistency across all measured directions. This meticulous approach is essential to prevent inaccuracies in the subsequent measurements.

**VR Application**



Design a central red dot, configuring angles to 0 degrees in all directions (x, y, z). Following this, create a duck model to symbolize the user's head, dynamically orienting itself based on the user's head movements in all directions. The measurement process includes integrating a guiding pipe to demarcate the permissible range of movement, directing users to maneuver the duck within the confines of the pipe. It is imperative to ensure that the duck, representing the user's head, remains within the pipe before angle measurement, as deviation may result in inaccurate angle measurements. After conducting angle measurements in each direction using VR, a display screen will present the obtained angles and the duration of use.

Table 1. Storyboard for VR application (cont.)

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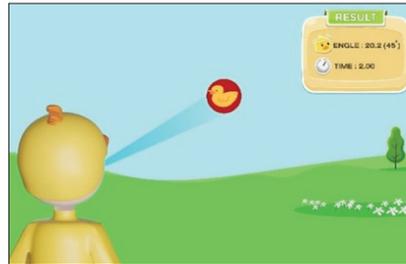
4. Measure the angle of neck movement in the directions of right lateral flexion and left lateral flexion

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CROM



VR Application



To measure lateral flexion, the assessor is instructed to tilt their neck to the left and then to the right. Before commencing the measurement, the physical therapist must ensure that all measured directions are set to 0 degrees to ensure accuracy. Once the lateral flexion movements are complete, the physical therapist should verify that the readings for all other directions remain at 0 degrees to prevent any errors in the assessment.

The measurement in this section is designed with a single central red point and no pipes, allowing users to tilt their necks left and right. The duck must not exceed the designated red point to ensure accurate angle measurement.

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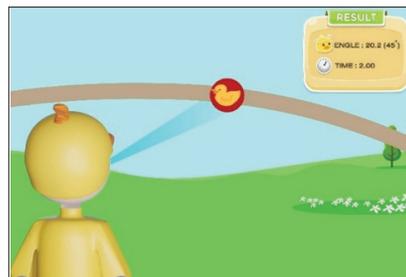
5. Measure the angle of neck movement in the directions of right rotation and left rotation

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CROM



Application



This phase of angle measurement involves instructing the assessor to turn the neck both left and right. It is essential to ensure that all directional measurements are initially set to 0 degrees before initiating the movement. Following the completion of the neck movement, the physical therapist must verify that the measurements for other directions remain at 0 degrees to avoid potential errors.

The measurement of this angle will be designed similarly to the measurement steps for Flexion and Extension but with a change in the orientation of the tube from vertical to horizontal for guiding left and right neck rotations.

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### 2.3. Satisfaction Assessment

Utilizing the precise head movement tracking features of VR devices, this research focuses on designing and developing user-friendly VR applications. To assess the user-friendliness of the developed VR application, a questionnaire will be employed in this study. The questionnaire aims to evaluate user satisfaction and collect feedback on various aspects of the application's usability.

This study examined the satisfaction levels of VR application usage among voluntarily participating health-conscious individuals, encompassing both females and males aged between 20 and 59 years. The sample size consisted of 50 participants, excluding individuals experiencing neck pain, those with recent neck or back surgeries, or any other discomfort related to the neck. The selection of the sample was based on the COSMIN methodology for evaluating the content validity of Patient-Reported Outcome Measures (PROMs) User Manual version 1.0. (Terwee *et al.*, 2018).

Satisfaction Assessment Form: The questionnaire will be organized into four sections for a comprehensive evaluation. These 4 sections include sections 1 VR design 4 questions: 1) Patterns of using the application with realistic technology devices that are easy to use. 2) The design of the application is beautiful and interesting. 3) The colors in the application design. 4) The font style and size are appropriate., sections 2 application usability 2 questions: 1) The speed of using the

application with realistic technology devices. 2) The arrangement of menus or categories is appropriate., sections 3 model and animation design 3 questions: 1) 3D modeling and animation styles suitable for the content. 2) The 3D model and animation are interesting and beautiful. 3) 3D modeling and animation convey accurate meaning and are easy to understand., and sections 4 The effectiveness of utilizing applications with VR devices 5 questions: 1) VR device are user-friendly and convenient. 2) The sound of the subtitles is clear. 3) The content is well-organized. 4) The content is explained clearly. 5) The content is easy to understand. Participants will rate their satisfaction levels on a rating scale from 1 to 5, where 1 denotes very unsatisfied, 2 denotes unsatisfied, 3 denotes moderate satisfied, 4 denotes satisfied, and 5 denotes very satisfied. The evaluation of satisfaction with VR applications will entail computing both the mean and standard deviation of satisfaction scores. This approach aims to offer a concise overview of the average satisfaction level among participants while also providing insights into the range of variability in the satisfaction scores.

The analysis will employ the mean and standard deviation (SD) to assess the level of satisfaction among the participants. The results will be compared against predefined criteria for interpretation: a score range of 4.51-5.00 indicates very satisfied, 3.51-4.50 indicates satisfied, 2.51-3.50 represents moderate satisfaction, 1.51-2.50 implies unsatisfied, and 1.00-1.50 represents very

unsatisfied. Specifically, in the context of user application satisfaction assessment, it is essential to ensure that the mean score is at least 3.51, and the standard deviation is not less than 1.00 (Collado-Mateo *et al.*, 2020).

### 3. Results and Discussion

#### 3.1 VR Application

VR application development, the BLENDER program is utilized to craft models in alignment with the intended application format. These model files are then imported into the Unity Engine for further development, given its widespread usage as a game development platform, commonly employed for VR games and applications. Integration of sensors into Unity for VR games allows for the incorporation of various sensor types. To enhance user interaction, motion tracking features such as head tracking are implemented within the Unity engine. This enables users to explore virtual environments by tracking head movements effectively, thereby facilitating the creation of three-dimensional games in

diverse formats. In the VR application, an initial video will serve as an introduction, providing users with step-by-step guidance on the measurement procedures for values such as the Visual Analog Scale (VAS) and various angular metrics. The primary objective is to acquaint users with the assessment process and anticipate the forthcoming steps, encompassing detailed instructions on utilizing the controller in conjunction with the interactive elements of the game, as shown in Figure 5. After the introductory video, users will proceed to measure their pain levels using the Visual Analog Scale (VAS). On the user interface (UI) page, a horizontal straight line, similar to the CROM measurement, will be displayed. Figure 6 illustrates the VAS measurement process. Users will be prompted to select the point on the line that corresponds to the severity of pain they are experiencing at that moment.

The next step involves measuring head movement in all six directions. A red circular spot, denoting 0 degrees in the x, y, and z axes, serves as the focal point for each

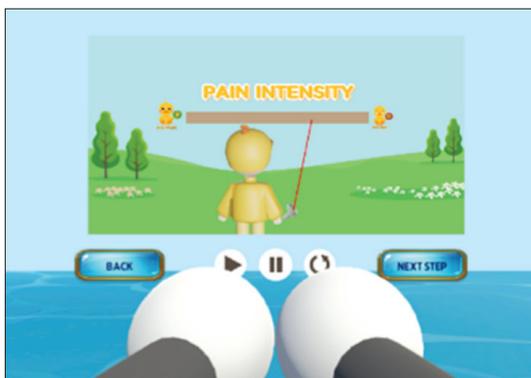


Figure 5. Video screen for introducing the usage of the VR application

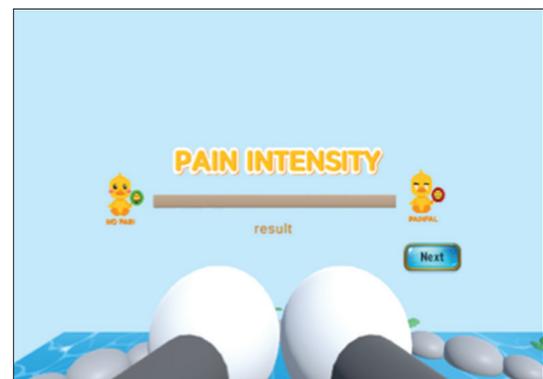


Figure 6. VAS measurement in the VR application

direction. A duck model is used to simulate user head movements. The user is prompted to perform the motion to evaluate neck pain. The VR application will provide audio cues indicating the direction before each the measurement. Additionally, the user is instructed to align their head with the line of sight or guide tube to maintain proper posture in each direction, as shown in Figure 7.

The VR application is designed to utilize the left controller for start and stop the measurement of the range of head movement. Simultaneously, it captures the time taken for each movement. The outcomes, comprising the measurable degrees of motion, along with the corresponding durations, are then displayed on the screen. Users can subsequently press the button on the right controller to enter the angle measurement in other directions. This process is repeated

until users have measured the range of head movement in all six directions, including Flexion (Figure 7(a)), Extension (Figure 7(b)), Right Lateral Flexion (Figure 7(c)), Left Lateral Flexion (Figure 7(d)), Right Rotation (Figure 7(e)), and Left Rotation (Figure 7(f)).

### 3.2 Satisfaction Assessment Results

The effectiveness of the VR application was evaluated through user testing, as shown in Figure 8. During user testing, participants were provided with VR headsets and instructed to interact with the application. Their feedback was collected to assess the usability, effectiveness, and overall experience of the VR application. From the user satisfaction assessment of the application, the mean and SD values were presented and separated into 4 categories, as shown in Tables 2- 5.

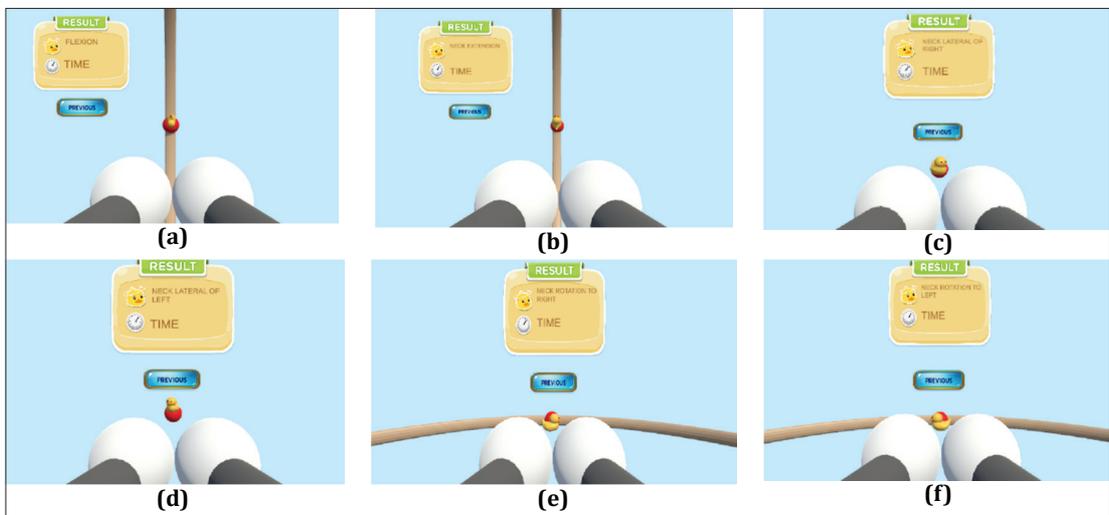


Figure 7. Measurement of head movement in all 6 directions



Figure 8. User testing with VR application

Table 2. VR Design satisfaction

Question	Mean ± SD	Level
1. Patterns of using the application with realistic technology devices that are easy to use.	4.28 ± 0.76	Satisfied
2. The design of the application is beautiful and interesting.	4.34 ± 0.82	Satisfied
3. The colors in the application design.	4.44 ± 0.70	Satisfied
4. The font style and size are appropriate.	4.24 ± 0.82	Satisfied
<b>Average</b>	<b>4.33 ± 0.66</b>	<b>Satisfied</b>

Table 3. Application usability satisfaction

Question	Mean ± SD	Level
1. The speed of using the application with realistic technology devices.	4.32 ± 0.74	Satisfied
2. The arrangement of menus or categories is appropriate.	4.38 ± 0.75	Satisfied
<b>Average</b>	<b>4.35 ± 0.68</b>	<b>Satisfied</b>

**Table 4.** Model design and animation satisfaction

Question	Mean ± SD	Level
1. 3D modeling and animation styles suitable for the content.	4.4 ± 0.70	Satisfied
2. The 3D model and animation are interesting and beautiful.	4.36 ± 0.88	Satisfied
3. 3D modeling and animation convey accurate meaning and are easy to understand.	4.36 ± 0.66	Satisfied
<b>Average</b>	<b>4.37 ± 0.63</b>	<b>Satisfied</b>

**Table 5.** The effectiveness of utilizing applications with VR devices

Question	Mean ± SD	Level
1. VR device are user-friendly and convenient.	4.06 ± 0.77	Satisfied
2. The sound of the subtitles is clear.	4.26 ± 0.85	Satisfied
3. The content is well-organized.	4.52 ± 0.61	Very satisfied
4. The content is explained clearly.	4.54 ± 0.61	Very satisfied
5. The content is easy to understand.	4.56 ± 0.67	Very satisfied
<b>Average</b>	<b>4.39 ± 0.57</b>	<b>Satisfied</b>

### 3.3 Discussion

In the usability testing of the application, it was observed that users have the ability to watch an instructional video explaining how the application operates and can follow the steps autonomously. Those who participated in the testing phase conveyed a notable satisfaction level in all aspects, reflected by an average score of  $4.36 \pm 0.52$ . Throughout this study, careful attention was given to crafting character and scene designs, aiming to elicit excitement and interest, thereby fostering a heightened sense of immersion into the virtual world. Furthermore, users exhibited focused attention during the measurement process, undisturbed by external factors.

However, the researchers have received user suggestions regarding the design of the VR application. It is recommended to adjust the size of the animation to be larger. In terms of application usability, it should be designed to be user-friendly. Additionally, regarding the efficiency of using applications with virtual reality technology, feedback suggests that controlling the controller remains difficult to use.

### 3.4 Limitations and Future Works

Although user satisfaction with the use of the application is at a high level, there are still limitations to the VR application. These include the necessity of calibrating the VR equipment accurately before proceeding

with various measurements to minimize angle measurement errors. It is also crucial to align the gaze with the application. This research employed measurements and satisfaction evaluations for participants with good health. Consequently, the derived satisfaction level can only be extrapolated to this specific demographic and cannot be directly compared with the satisfaction levels of individuals experiencing genuine neck injuries. Despite the VR application demonstrating reliable accuracy in angle measurements, there exists a slight deviation when compared to CROM device.

Based on the above limitations, we will focus on developing VR applications that can measure degrees more accurately and reliably compared to standard tools in the medical field and test them with a sample group of people with real neck pain.

#### 4. Conclusion

Neck pain, arising from issues in cervical spine joints, neck muscles, and shoulder blade muscles, often results from prolonged incorrect postures in daily life. The traditional method of measuring neck deformities and assessing treatment levels involves expensive and limited cervical range of motion (CROM) device, primarily available in large hospitals and it is necessary to have experts in using the equipment. Therefore, this study has developed Measuring Neck Abnormalities for Preliminary assessment of neck pain disease using virtual reality (VR). VR technology, known for its sensors

and tested accuracy, is reliable in measuring neck angles. The primary focus of this study is on the design of the application, aiming to ensure user satisfaction and usability. Users should be able to operate it independently, with efforts made to minimize any potential impact on their health. User satisfaction, based on a sample of 50 users without neck pain, indicated satisfied (average score of  $4.36 \pm 0.52$ ). However, this study necessitates a comparative analysis of precision measurement and device reliability between VR and CROM to validate accuracy. This verification is crucial for determining the potential future usability of the VR application.

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