

Article

A Preliminary Investigation of Thai Clinical Attitudes Towards VR Adoption in Upper-Extremity Rehabilitation: Patient Usability and Clinician Perceived Usefulness

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Abstract

Virtual reality (VR) has shown promising potential for upper-extremity rehabilitation; however, its successful integration into clinical practice depends not only on therapeutic effectiveness but also on the acceptance of the technology by patients and healthcare professionals alike. Despite growing international research in this area, there is limited evidence on clinical attitudes toward VR rehabilitation in Thailand and other middle-income settings. This study investigates Thai patients' and clinicians' perceptions of VR for upper-extremity rehabilitation through two complementary studies focusing on perceived usability and usefulness. The first study evaluated the perceived usability of a VR rehabilitation game using the System Usability Scale (SUS) among 40 first-time VR users divided into younger and senior groups. The younger group reported a higher average SUS score (64.6) than the senior group (55.4). While both groups generally perceived VR rehabilitation positively, senior participants expressed greater concern regarding system complexity, consistency, and the need for technical assistance. Nevertheless, the findings indicate that VR remained an acceptable rehabilitation approach even among elderly first-time users in a population with relatively lower technological readiness. The second study explored clinicians' perceptions of utilizing VR-generated movement data to support rehabilitation decision-making. Five rehabilitation professionals evaluated the potential usefulness of VR data visualizations for diagnosis and treatment monitoring. Clinicians generally perceived VR data as valuable, particularly for tracking rehabilitation progress rather than diagnostic decision-making. Feedback from interviews also highlighted practical considerations for future implementation, including the importance of normative data, simplified visualization formats, and the feasibility of clinical workflows. By combining patient usability perspectives with clinicians' evaluations of clinical usefulness, this research provides a broader understanding of the factors influencing VR adoption for upper-extremity rehabilitation in Thailand. The findings contribute contextual evidence from an underrepresented healthcare environment and offer insights relevant to the future deployment of VR-assisted rehabilitation systems in similar socio-economic settings.



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conditions of the [Creative Commons](#)[Attribution \(CC BY\) license](#).**Keywords:** digital adoption; rehabilitation; user perception; human factors; VR

1. Introduction

Rehabilitation is a significant medical process that involves a vast number of patients, such as patients who have undergone a significant operation, sensory loss, a stroke, a serious accident, or a brain injury [1].

Upper-extremity (UE) or upper-limb (UL) rehabilitation is a form of musculoskeletal rehabilitation that focuses on the recovery of the upper body musculoskeletal system, including the arms, shoulders, and hands. In stroke patients, the prevalence of hand and arm abnormalities and control regression is as high as 60% [2]. In addition, therapy is typically required for patients who have undergone spinal cord injury or thoracic or arm surgery, such as those who have undergone breast cancer surgery [3].

Field research in Thailand has revealed that a common obstacle that hinders the efficacy of rehabilitation therapy is patient cooperation, which is adversely affected by negative emotions such as depression, anxiety, unhappiness, fear, illness-related concerns, and lack of motivation [4]. Furthermore, an examination of physiotherapy workforce production in Thailand revealed a shortage of physical therapists (PTs), with their distribution geographically skewed towards the central region of the country [5,6].

Virtual reality (VR) is a highly promising technology that has garnered significant attention for its potential to facilitate upper-limb rehabilitation. In recent years, several literature reviews have been published that compile high-quality research on the efficacy of VR solutions for upper-extremity rehabilitation [7–9].

The primary goal of prior research on virtual reality (VR) in rehabilitation has been to evaluate its effectiveness relative to more traditional medical approaches. The results of these studies suggest that virtual reality (VR) exergaming may have effects that are either equivalent to or superior to those of conventional therapy alone [10–12]. VR exergaming programs were determined to be more effective than home exercise programs in a separate benchmarking study [13].

Another extensively pursued research objective has been to examine users' psychological states during VR rehabilitation sessions. Research has demonstrated that VR interventions can substantially enhance motivation and compliance with rehabilitation programs. For instance, Chen et al. found that spinal cord-injured patients who utilized a VR-based system spent a significantly longer time attending rehabilitation sessions in comparison to a conventional practice [14]. In the same study, certain patient mood indicators showed improved outcomes, including a significant decrease in tension and increases in commitment and serenity [14]. Another study indicated that enjoyment is widely recognized as a motivational factor that fosters engagement throughout treatment [15], while a separate study showed that excitement is also a significant motivator [16]. Additionally, the degree of immersion is associated with the impact of virtual reality. Liu et al. (2019) found that a more immersive environment has a greater impact on users' motivation to engage with the system [17].

Recent research has increasingly focused on the practical implications of VR adoption in real-world healthcare contexts, particularly on the attitudes of patients and healthcare professionals toward VR technologies. VR technology has become more prevalent in clinical settings. However, it is still not mainstream in therapy and is more commonly used in healthcare for research or pilot testing. Attitudes towards VR can be a key factor in determining how willing the public and healthcare professionals are to adopt it for clinical use.

Previous research has examined patients' attitudes toward adopting virtual reality for therapeutic purposes, including the study by Gomez Bergin et al. (2024), which introduced the attitudes towards virtual reality therapy (AVRT) measure [18]. AVRT was used to evaluate public perceptions of people using VR for psychological therapies. Gomez Bergin

et al. (2024) [18] also found that a positive attitude towards adopting the technology was associated with factors such as familiarity with the technology and a belief that the technology is a cost-effective solution. The willingness of healthcare professionals to use VR in therapy has also been investigated from clinicians' perspectives. The results indicate that therapists generally perceive VR as beneficial and believe it has promising applications in healthcare settings [19,20]. The benefits of VR are widely acknowledged by healthcare professionals for the following applications: clinical simulations, clinical education, and physical therapy [20].

Beyond examining individual user or clinician perceptions, recent eXtended reality (XR) rehabilitation research has increasingly emphasized developing broader rehabilitation frameworks and architectures that integrate immersive technologies, patient monitoring, clinician supervision, and rehabilitation workflows. For example, Marullo et al. (2025) combined XR technologies with clinical oversight and data-driven rehabilitation processes [21]. Similar studies have highlighted the importance of integrating technical systems, patient engagement, and healthcare decision-making within a unified rehabilitation ecosystem. While these studies provide valuable architectural and implementation perspectives, relatively little attention has been given to the early-stage adoption factors that influence whether patients and clinicians are willing to use such systems in practice.

This study contributes to both academic research and healthcare practice by applying VR technologies to upper-extremity rehabilitation. The present study addresses this gap by developing a VR rehabilitation prototype, conducting usability evaluations with prospective users, and interviewing clinicians about the usefulness of VR-generated rehabilitation data. By combining end-user usability assessment and clinician evaluation within a single investigation, the study provides complementary insights into factors that may influence the adoption of VR-based rehabilitation technologies.

The significance of this work lies in its focus on the early-stage adoption of VR-based rehabilitation technologies and their potential integration into clinical practice. Furthermore, there remains a notable lack of evidence regarding attitudes toward VR adoption for upper-extremity rehabilitation within the Thai healthcare context. By focusing on this population, the study provides context-specific insights that may inform future implementation strategies, system refinement, and policy development.

Successful implementation of VR rehabilitation technologies depends on both patient acceptance and clinician adoption. Therefore, understanding the perspectives of both stakeholder groups is essential before large-scale deployment in clinical practice. Accordingly, this study was designed around two complementary research questions: (RQ1) How do younger and older users perceive the usability of the proposed VR-based rehabilitation system? (RQ2) How do rehabilitation clinicians perceive the usefulness and potential clinical applicability of the movement metrics generated by the system? Together, these two investigations provide a preliminary understanding of VR adoption from both end-user and clinical stakeholder perspectives and offer complementary evidence regarding factors that may influence the adoption of VR-based rehabilitation technologies.

2. Study 1: Perceived Usability of VR to Thai Prospective Patients

This research aimed to examine perceived VR usefulness among potential patients. This experiment aimed to examine the attitudes of two primary demographics: seniors and younger individuals. "Perceived usability" is the average assessment of ease of use, derived from post-task self-reported data, to evaluate the overall user experience over time [22].

Flavián (2006) found that users' trust in the system is likely to increase significantly and be associated with higher engagement when they perceive the system as usable [23]. In

UE rehabilitation, when therapeutic technology is used, usability is a major determinant of readiness to undertake treatment [24]. Several methods, such as CSUQ, UMUX, AltUsability, and SUS, have been proposed for measuring perceived usability [25–27]. Therefore, we decided to use the SUS to measure perceived usability among prospective patients after VR exposure.

The SUS is a 10-question survey instrument developed by Brook (1996) [28] to measure the usability of products and services. It has 10 alternating positive- and negative-formulated statements that respondents subjectively evaluate to assess a system's usability [29]. The typical approach of using SUS to test usability begins by establishing a test environment that facilitates participants' experience of products or services. Then, the participants rate their level of agreement with each statement in the SUS questionnaire using a Likert scale. Some statements in SUS indicate that participants have a positive perception of the product/service, while others indicate a negative perception. The next step involves computing and interpreting the aggregate score. Figure 1 illustrates the conventional version of SUS.

The System Usability Scale

No.	Questions	1	2	3	4	5
1	I think that I would like to use this system frequently.	☐	☐	☐	☐	☐
2	I found the system unnecessarily complex.	☐	☐	☐	☐	☐
3	I thought the system was easy to use.	☐	☐	☐	☐	☐
4	I think that I would need the support of a technical person to be able to use this system.	☐	☐	☐	☐	☐
5	I found the various functions in this system were well integrated.	☐	☐	☐	☐	☐
6	I thought there was too much inconsistency in this system.	☐	☐	☐	☐	☐
7	I would imagine that most people would learn to use this system very quickly.	☐	☐	☐	☐	☐
8	I found the system very awkward to use.	☐	☐	☐	☐	☐
9	I felt very confident using the system.	☐	☐	☐	☐	☐
10	I needed to learn a lot of things before I could get going with this system.	☐	☐	☐	☐	☐

Figure 1. SUS questionnaire adapted from [30].

2.1. Methodology

Participants were recruited through convenience sampling from the local community and university network. Interested individuals were screened against predefined inclusion and exclusion criteria prior to participation. Participants were eligible for inclusion if they were aged 15 years or older, were able to understand and follow study instructions, and had no prior diagnosis known to affect upper-extremity movement. Individuals were excluded from participation if they had severe visual impairment, vestibular disorders, a history of upper-limb injury, or any condition that would contraindicate the safe use of virtual reality equipment.

This research recruited 40 people aged 18 to 82 for the usability test session. Participants were categorized into two age groups: Group A, including seniors aged 59 to 82 years, and Group B, consisting of younger individuals aged 18 to 24 years. Each participant engaged in the Shooting Virtual Reality Game [31] for about 5 min. The Shooting Virtual Reality Game is a VR application designed to facilitate workouts targeting upper-extremity muscles through three distinct methods that replicate arm and hand movements in daily activities. Upon completing the game, users were requested to complete the SUS questionnaire, which has been translated into Thai.

2.2. Results

2.2.1. Demographic

The demographic data of Study 1 are summarized in Table 1. Group A consisted of 20 participants (4 male, 16 female) aged 59 to 82 years. Additionally, none of the participants had any prior exposure to computer games. None of the participants had encountered this

device previously. There were 20 participants in Group B, with 18 males and 2 females, aged 18 to 24 years. All participants had 2 to 15 years of experience playing computer games. Eight participants recognized this device but had not yet used it, while twelve participants were unaware of it and had never used it.

Table 1. Demographic details of participants in Study 1.

Group	N (M:F)	Min	Max	Avg. Age
A	20 (4:16)	59	82	69.29
B	20 (18:2)	18	24	20.00

2.2.2. Results of Usability Tests

Table 2 presents an overview of the SUS scores for Group A and Group B. The findings indicate that the average SUS score for the older group was 55.4, whereas the younger group's score was higher at 64.6. Analyzing the Min, Max, and standard deviation (SD) of SUS in both groups, the senior group exhibited greater variability in attitudes toward VR usability, as reflected by the SD.

Table 2. SUS scores.

Group	Mean	Median	Min	Max	SD	95% CI
A	55.4	55	27.5	80	12.3	[49.6, 61.1]
B	64.6	62.5	50	85	10.5	[59.7, 69.5]

To determine whether the observed difference in SUS scores between age groups was statistically significant, an independent-samples *t*-test was conducted. Preliminary assessment indicated that SUS scores were approximately normally distributed within both groups. The analysis revealed that younger participants ($M = 64.6$, $SD = 10.5$) reported significantly higher SUS scores than senior participants ($M = 55.4$, $SD = 12.3$), $t(38) = 2.56$, $p = 0.015$. The mean difference between groups was 9.25 points (95% CI [1.92, 16.58]). The effect size was large (Cohen's $d = 0.81$), indicating a substantial difference in perceived usability between the two age groups.

Figure 2 shows the average SUS score per question in both groups. Both prospective patient groups have generally similar attitudes toward VR usability, as evidenced by their scores. The "simple-to-use" (Q3) score was significantly high, indicating a positive attitude toward the VR testing system among participants in both groups. In contrast, the younger group rated the VR-based testing game as consistent (Q6) and "easy to learn" (Q7). In the senior group, the score suggests that participants had a more negative attitude toward the tested VR system in certain respects. The seniors agreed that a technical person's assistance is necessary (Q4) and that the individual must first understand the system before using it (Q10).

2.3. Discussion

A usability assessment of a VR game system for rehabilitation, performed with prospective Thai patients who were all first-time users, demonstrated the potential for adoption of the solution. Figure 3 illustrates the visualization of the SUS scores from this study, plotted against the approximate distribution from over 5000 global tests as reported by [32], incorporating the "grade scale" established by [33]. The older group's average SUS score of 55.4 equates to a "D" grade, while the younger group's score of 64 is within the "C" grade range. Both parties consider virtual reality a feasible technique for rehabilitation.

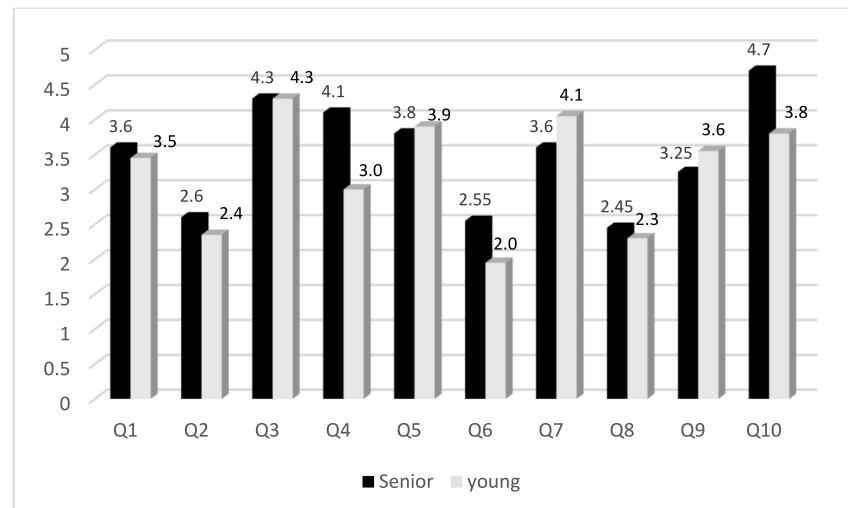


Figure 2. Comparison of SUS score by question between the two groups.

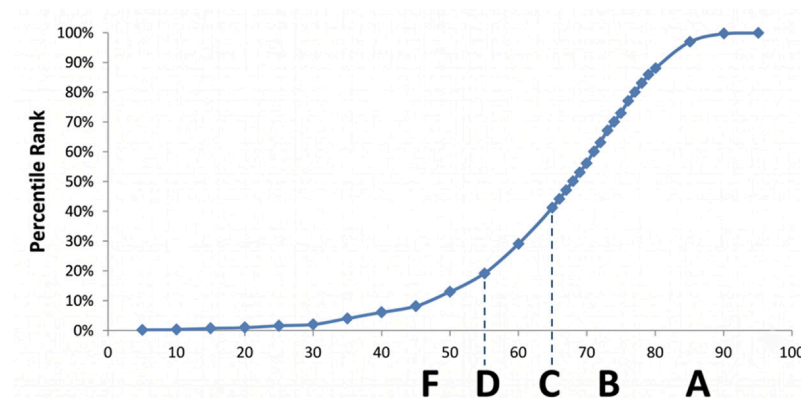


Figure 3. SUS scores by grade.

A comparison of the SUS scores with previous research on VR technologies for UE rehabilitation is shown in Table 3. The findings from this Thai study ($n = 40$), reporting lower SUS scores (64.6 for young adults and 55.4 for seniors) compared to studies in the Republic of Korea (SUS 71.0, $n = 5$ [34]), China (SUS 90.50, $n = 15$ [35]), Spain (SUS 86.25, $n = 5$ [36]), and Austria (SUS 69, $n = 6$ [37]), suggest potentially lower perceived usability in the Thai context. However, the scores remain above the commonly accepted minimum threshold for acceptable usability. The discrepancy may be attributed to several factors. For example, unlike the other studies that focused on clinical populations (stroke patients, breast cancer patients, and physiotherapy specialists), this research uniquely examines a healthy population, including a significant elderly cohort—a demographic absent from prior investigations.

Table 3. A comparison of the SUS scores with previous research.

Author	Participant	Country	N	SUS
Lee et al., 2016	Stroke patients	Republic of Korea	5	71.0
Zhou et al., 2021	Breast cancer patients	China	15	90.50
Rojo et al., 2022	Physiotherapist specialist	Spain	5	86.25
Baranyi et al., 2024	Healthy user	Austria	6	69
This study	Young healthy group	Thailand	20	64.6
This study	Senior healthy group	Thailand	20	55.4

Several factors may also contribute to the lower SUS scores observed in this study. An additional contextual factor that may influence user perceptions is the broader level of digital technology adoption within a country. International indices such as the IMD World Digital Competitiveness Ranking and the Network Readiness Index indicate differences in digital readiness among countries included in previous studies [38,39]. However, the present study did not directly measure participants' digital literacy or technology readiness. Therefore, any relationship between national digital readiness indicators and SUS scores should be interpreted cautiously. Future studies should incorporate direct measures of digital literacy and technology acceptance to better understand their influence on perceived usability.

Also, although all VR games share the same purpose of supporting physical therapy in rehabilitation, their designs differ in detail. Complications in interaction, game rules, and multi-sensory feedback affect players' adaptation to the system and result in varying levels of perceived usability, as indicated by the SUS scores. It should also be noted that the SUS assessment for this project occurred in the first phase, following the release of the first prototype. Design issues may persist, necessitating improvement; enhancing this vital aspect of the design should yield a higher SUS score.

A closer look at the System Usability Scale (SUS) scores for each group at the question level reveals two significant behavioral implications that differentiate the senior group from their younger counterparts. Firstly, participants in the older group had higher expectations of consistency aspects in user interface (UI) design than the younger group (Question 6). This heightened expectation may arise from an awkward experience when engaging with the VR system, possibly due to biological constraints in seniors, whose cognitive abilities are typically reduced [40,41]. Also, empirical research on VR engagement among the senior group has revealed that senior users perceive VR controllers as nonintuitive [41]. In addition, younger users, who may be more accustomed to rapidly evolving technologies, might prioritize novelty and functionality over consistency. Research has shown that, when comparing attitudes toward adopting emerging digital solutions between older and younger users, only the older user group perceived ease of learning as a significant factor influencing the acceptance decision [42].

In addition, the lower scores on Questions 4 and 10 of the SUS suggest that the senior group is less confident in operating the VR-based system independently; these low scores should not impact clinical operations if VR is employed as a therapeutic device for admitted patients. In a healthcare setting, physical therapy sessions are usually led by a physical therapist (PT) and hospital staff. Therefore, the impact of this concern is likely to be minimized. Nevertheless, the results of this research indicate that additional attention and potential further research are required to enhance the design of VR-based interventions for the purpose of implementing them in emerging therapeutic concepts in rehabilitation, such as tele-rehabilitation [43] or home-based rehabilitation [44], in which patients, relatives, and private caregivers are likely to conduct the treatment sessions from a distance.

An important limitation of this study is that age and gaming experience were highly confounded. All younger participants reported extensive gaming experience, whereas none of the older participants had prior gaming experience. Consequently, differences in usability ratings may reflect not only age-related factors but also familiarity with gaming and interactive technologies. Future studies should recruit participants with varying levels of gaming experience across age groups to isolate the independent effects of age and familiarity with technology.

A further limitation of Study 1 is that the usability evaluation was conducted using healthy volunteers rather than patients undergoing upper-extremity rehabilitation. This decision was made because the study was intended as an early-stage usability assessment

of the first prototype before undertaking more resource-intensive clinical evaluations. Consequently, the findings primarily reflect the usability perceptions of potential users interacting with the system under controlled conditions and may not fully represent the experiences of individuals with motor impairments. Therefore, the results should be interpreted as preliminary evidence of usability and acceptance, rather than as evidence of usability in clinical rehabilitation populations. Future studies should evaluate the proposed system with actual rehabilitation patients to establish ecological validity and determine whether the usability findings observed in healthy participants are maintained in real-world rehabilitation settings.

3. Study 2: The Perceived Usefulness of VR Data for Clinical Decision-Making

The attitudes of healthcare staff toward adopting virtual reality for upper-extremity rehabilitation were examined by assessing the perceived utility of VR technology in facilitating clinical decision-making. Perceived usefulness is a fundamental concept in technology acceptance research, especially within the Technology Acceptance Model (TAM) framework. The term was originally defined as the degree to which a person believes that using a particular system would enhance their job performance [45]. Unlike assessments of patient attitudes, which aim to assess how VR is perceived as a usable technology among existing, widely available VR solutions, the use of tracked data logs from VR to support clinical decision-making is a relatively emerging concept. The study was designed to evaluate the perceived usefulness of the proposed innovative solution from the clinician's perspective. A demonstration of how VR data could be used to interpret physical therapy outcomes was presented to assess clinicians' perceptions of VR as a viable technology for clinical applications.

3.1. Methodology

The overview procedure for conducting this experiment was as follows.

1. A virtual reality environment was established. For the VR system, an Oculus Rift Version 1 was employed. Movement coordinates were recorded by connecting the VR system to the Unity platform. Additional C# modules were created to extract stored coordinates from Unity.
2. One participant was recruited to assume the role of a VR user and role-play as a patient. Additionally, clinicians were recruited through purposive sampling from the Department of Rehabilitation at the Faculty of Medicine, Chiang Mai University. Potential participants were identified based on their professional experience in upper-extremity rehabilitation. They were invited directly to participate in the study, which used VR-derived data to inform their decision-making.

Since Study 2 was designed as an exploratory proof-of-concept to gather preliminary expert perspectives rather than to estimate population-level opinions, a small group of clinicians with relevant rehabilitation experience was recruited.

This sample size is also consistent with recommendations from early-stage evaluation research, which suggests that as few as 5 participants can identify major usability issues and provide valuable formative feedback during the initial stages of system development [46]. Accordingly, the clinicians' evaluations should be interpreted as an initial expert appraisal intended to inform future development rather than as a statistically generalizable assessment of clinician attitudes.

3. A role-play patient was requested to execute tasks based on the Fugl-Meyer Assessment, while the VR system monitored and recorded the movements in a coordinate format. Figure 4 conceptually illustrates the experimental configuration of Study 2.

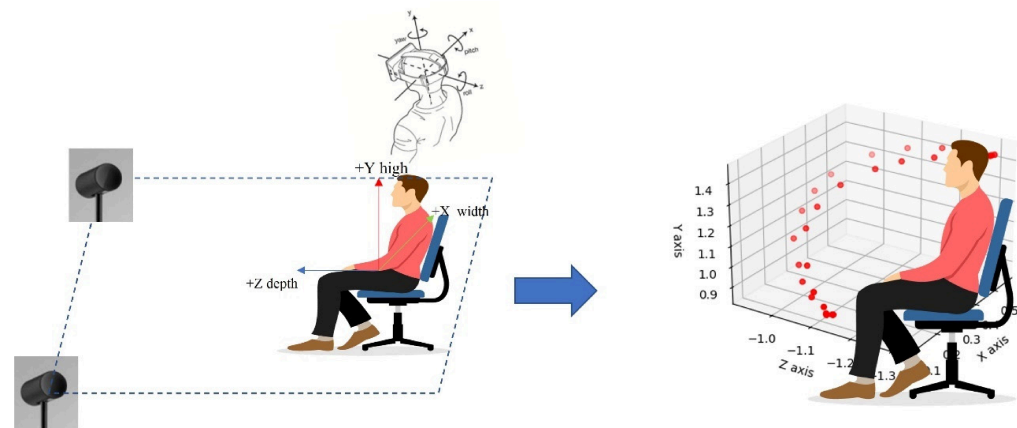


Figure 4. Experimental set-up for Study 2.

4. We demonstrated a method for utilizing VR data logs to assist clinicians in decision-making, as illustrated in Figure 5. The collected data are presented as a graph to depict the velocity of movement over time. The X coordinate represents time, while the Y coordinate signifies the distance measured from the body.

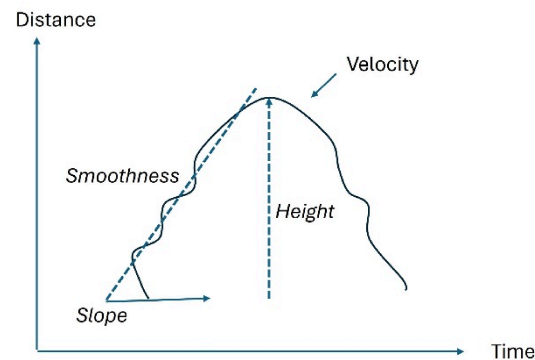


Figure 5. The graph and its properties are presented to clinicians to support decision-making.

5. After that, a follow-up interview was carried out. The interview served a dual purpose. The first objective was to investigate clinicians' attitudes toward virtual reality (VR)-based treatments, specifically whether they recognize any benefits associated with the approach. "In what ways do you believe the virtual reality-based intervention can be beneficial for the treatment of UE?" (Question 1). The second objective was to determine whether graph visualizations derived from virtual reality data logs could provide clinical decision support in two scenarios: (1) identifying abnormal movement patterns between mobility-impaired and non-mobility-impaired individuals (diagnosis), and (2) visualizing treatment progression (progress tracking).

The slope, smoothness, and graph height are three graph attributes that can be used to describe the quality of UE movement. The objective was to investigate clinical attitudes that can be utilized to substantiate clinical decisions. The following questions were asked:

"Can slope be used to identify mobility impairment as a diagnostic tool? (Q2)", "Can slope be used to determine how well a patient has recovered? (Q3)", "Can the graph smoothness be used to identify mobility impairment as a diagnostic tool? (Q4)", "Can the graph smoothness be used to determine how well a patient has recovered? (Q5)", "Can the graph height be used to identify mobility impairment as a diagnostic tool? (Q6)", and "Can the graph height be used to determine how well a patient has recovered? (Q7)". For each attribute, we plotted graphs from two datasets on the same x- and y-axes to enable comparison.

6. Following the interviews, clinicians' responses were analyzed using a qualitative categorization approach. Responses to Questions 2–7 were classified into three categories: positive, conditional, and negative. Positive responses indicated clear agreement with the proposed use of the visualization metric. Conditional responses reflected agreement contingent upon additional information, validation, or specific clinical circumstances. Negative responses indicated disagreement with the proposed use.

In addition, open-ended responses from Question 1 and participant remarks were analyzed thematically to identify recurring perceptions regarding the clinical applicability of VR-derived movement data. Thematic analysis was used to preserve the nuances of clinicians' opinions and avoid the oversimplification of conditional responses.

3.2. Results

3.2.1. Demographic

The study recruited experienced clinicians from the Department of Rehabilitation, Faculty of Medicine, Chiang Mai University, as volunteers to investigate the perceived utility of VR data for clinical decision-making. The demographic details of the clinicians participating in this experiment are presented in Table 4.

Table 4. Demographics of clinicians who participated in Study 2.

No.	Occupation	Gender	Experience (Years)
1	Occupational therapist	Female	20
2	Physiotherapist	Male	22
3	Orthotist	Female	12
4	Rehabilitation doctor	Male	25
5	Rehabilitation doctor	Male	20

3.2.2. Data as a Tool for Decision-Making

As mentioned in points 4 and 5 in Section 3.1, data from the VR data log were utilized to generate graphs for discussion with clinicians to assess their perceived usability of the approach. The study proposes three methods to elucidate the differences between two mobility patterns. The participant was instructed to execute movements in two patterns designed to influence the chosen attribute. For the slope attribute, the participant was instructed to demonstrate movement at three distinct speeds; the results indicate that faster movements yield a steeper slope, as illustrated in Figure 6.

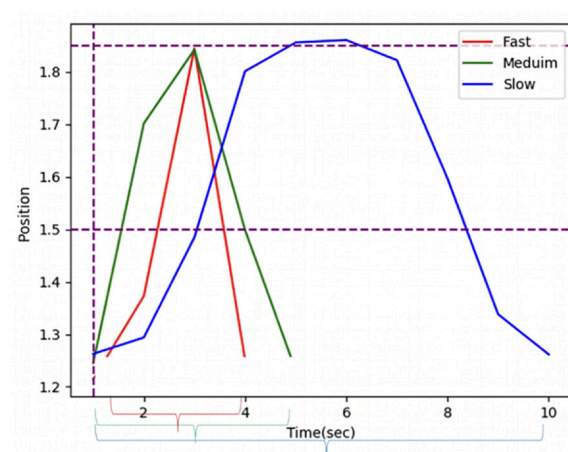


Figure 6. A comparison of the movement speed through the graph slope.

The smoothness of the motion graph was the second aspect used. Figure 7 illustrates the graph smoothness by showing that right-handed participants performed the movement and then repeated it with their left hand. The results indicate that the right-handed movement produced a smoother graph. Finally, the graph height was used to illustrate the participant's regular movement compared with that of the mobility-impaired participant, who simulated being able to reach only part of the target. Figure 8 illustrates that the completed movement to the target generates a higher graph than the incomplete movement.

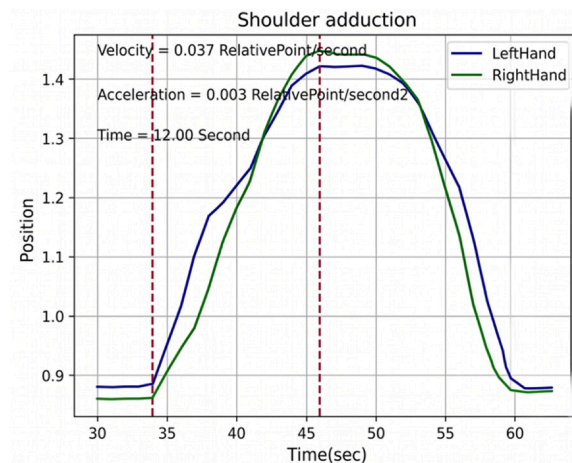


Figure 7. A comparison of the smoothness of the movement.

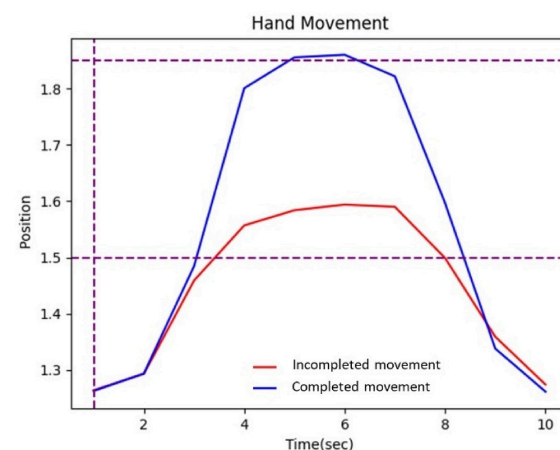


Figure 8. A comparison of different graph heights from complete/incomplete movement.

3.2.3. Perceived Usefulness of the Clinician

The clinicians' responses are summarized in Table 5, while the recurring themes identified from the open-ended comments are presented in Table 6.

Table 5. Clinicians' responses to the proposed visualization metrics.

Visualization Metric	Positive	Conditional	Negative	Main Concerns
Slope for diagnosis	1	4	0	Useful primarily in obvious cases; normative reference values needed
Slope for progress monitoring	5	0	0	None reported
Smoothness for diagnosis	4	1	0	Applicability may vary across clinical conditions
Smoothness for progress monitoring	5	0	0	None reported
Height for diagnosis	5	0	0	None reported
Height for progress monitoring	5	0	0	None reported

Table 6. Emergent themes from clinicians' feedback.

Theme	Frequency	Representative Concern
Objective assessment	5	Quantitative data may reduce subjective judgment
Need normative reference data	3	Healthy reference values are required
Real-world validation	2	Clinical movement patterns differ from demonstrations
Additional contextual information	1	Graphs should be interpreted alongside the clinical context
Syndrome-specific applicability	1	Some indicators may not generalize to all conditions

As shown in Table 5, clinicians generally expressed positive attitudes toward using VR-derived movement metrics for rehabilitation assessment and monitoring. Across all evaluated metrics, no participant expressed outright disagreement. Instead, responses were either positive or conditional, suggesting overall acceptance of the proposed approach while highlighting several considerations for future clinical implementation.

The strongest agreement was observed for the use of movement metrics in rehabilitation progress monitoring. All clinicians strongly endorsed the use of slope, smoothness, and movement height to track patient improvement over time (Table 5). These findings suggest that quantitative movement indicators may be perceived as particularly valuable for longitudinal assessment during rehabilitation.

In contrast, responses related to diagnostic applications were more cautious. As shown in Table 5, four of the five clinicians provided conditional responses regarding the use of graph slope for diagnostic purposes. The conditions most frequently mentioned involved the availability of normative reference values, additional contextual information, and further validation under real-world rehabilitation conditions. This finding suggests that clinicians may view the proposed metrics as supportive indicators rather than standalone diagnostic tools.

Thematic analysis of the open-ended responses identified five recurring themes (Table 6). The most prominent theme concerned the potential for a more objective rehabilitation assessment. Clinicians frequently indicated that numerical movement representations could supplement traditional observational assessment and reduce subjective interpretation. One clinician noted:

“Using numerical data can reduce bias and make decisions more scientific.”

Another frequently occurring theme involved the need for normative reference datasets (Table 6). Several clinicians emphasized that comparisons with healthy reference populations would facilitate interpretation of movement characteristics and improve confidence in clinical decision-making. As one participant commented:

“Normative data are needed to distinguish patients from healthy individuals.”

Additional themes included the need for real-world validation, contextual clinical information, and evaluation across diverse clinical conditions (Table 6). These observations indicate that clinicians generally recognize the potential value of VR-derived movement data but also identify several requirements that should be addressed before routine clinical deployment.

Taken together, the quantitative response patterns presented in Table 5 and the thematic findings summarized in Table 6 suggest that clinicians perceive considerable promise in the proposed approach, particularly for monitoring rehabilitation progress. However, future development should focus on establishing normative datasets, validating the approach with real patient populations, and integrating additional clinical context to support interpretation and decision-making.

3.3. Discussion

From the qualitative feedback analysis of clinicians' perceived usability of data from the VR solution to support decision-making in rehabilitation treatment, it was noted that clinicians generally agreed and provided positive, supportive feedback on the approach, indicating high perceived usability. Moreover, clinicians showed enthusiasm by proposing solutions to fill the gap in the demonstration and raised some practical constraints during the interviews. These responses can provide significant insights into their levels of interest, whether expressed positively or negatively. Research indicates that when participants are eager to provide feedback, it often reflects a deeper engagement with the technology in question. For instance, Apergi et al. (2021) highlight that personalized feedback is crucial for maintaining engagement with technology, suggesting that when users are willing to provide feedback, it indicates their active involvement and interest in the technology [47]. This aligns with findings from Freedberg et al., who emphasize that feedback—both positive and negative—can significantly influence engagement and learning outcomes, suggesting that the nature of feedback shapes users' perceptions and willingness to interact with technology [48].

In terms of clinical application, clinicians preferred to use VR data logs for monitoring treatment progress rather than for diagnosis or screening to initiate treatment. This finding aligns with the literature, which shows that several studies integrate VR technology into clinical practice to track progress and monitor improvements in patient outcomes during rehabilitation. For example, a study on the use of VR for upper-limb rehabilitation found that clinicians could monitor the intensity and frequency of patients' exercises through VR systems, enabling data-driven adjustments to therapy [49]. This capability is particularly beneficial in tailoring rehabilitation programs to meet individual patient needs, thereby enhancing the overall effectiveness of the rehabilitation process [50]. The data collected from the VR-based therapy data log provides clinicians with insights into patient preferences and performance, which can inform future rehabilitation strategies and improve patient-centered care [51]. Regarding the literature on the application of VR data logging for diagnostics, to the best of our knowledge, no evidence has been reported. This study did not investigate clinicians' perspectives on this aspect in sufficient detail. However, the less favorable reliance on scientific data logs collected from VR in the diagnosis process may be associated with the findings of a prior study, which found that diagnosis decisions on who should receive stroke rehabilitation were often made based on experience, emotion, and subjective factors rather than using scientific guidelines and evidence [52].

Although the investigation of data visualization for VR rehabilitation decision-making was not the main focus of this research, and visualization was used primarily to provide an example of how VR data might be used to support clinical decision-making, the results from the interviews with medical staff provide some initial findings for further study in this aspect.

This study partially investigated the potential of kinematic representations for visualizing rehabilitation progress. 2D graphs were used to visualize velocity through the slope; the smoothness of the graph represents the smoothness of motion, and the graph height shows the range of movement. Although the range of motion was cited as the best outcome from the evaluation, it is too soon to conclude that this variable is the most effective indicator of rehabilitation outcomes. The main purpose of showing mobility outcomes in a 2D graph in this research was to demonstrate, as a proof of concept, that VR data logs can be visualized to support clinical decision-making. Research on the most effective visualization solution is comprehensive and requires further study in future work to answer this question. However, some findings from this research provide a clue and strong evidence that research to identify an optimum visualization solution should be

conducted by separating the concern between kinematic variables and the approach used to visualize the result. For example, clinicians expressed a lack of agreement with using the slope of the graph to provide velocity information for decision-making, but they did not oppose using the velocity variable and suggested that the results be presented numerically instead. To improve the completeness of this research, it should have begun with a research question, such as which kinematic variables are meaningful, and then investigated the best way to visualize the results. Additional research has indicated that clinicians' ability to interpret data from external devices can markedly affect their readiness to integrate that technology into clinical practice [53].

There are several limitations of Study 2 that should be noted here. Firstly, the small sample size and recruitment from a single institution limit the generalizability of the findings. The results should therefore be interpreted as preliminary evidence of clinician perceptions rather than representative of the broader rehabilitation community.

A further limitation of this study is that the movement demonstrations presented to clinicians were generated from simulated movement patterns performed by a single researcher rather than collected from actual rehabilitation patients. This approach was intentionally adopted during the proof-of-concept stage to facilitate preliminary exploration of clinician perceptions regarding the proposed visualization concept. Consequently, the demonstrations may not fully reflect the variability, complexity, and compensatory movement behaviors commonly observed in clinical rehabilitation populations. Therefore, the findings should be interpreted as evidence of perceived clinical potential rather than evidence of clinical effectiveness. Future studies should evaluate the proposed approach using data collected from patients with varying levels of motor impairment to establish clinical validity and generalizability.

4. General Discussion

This research investigates the use of virtual reality technology for upper-extremity rehabilitation from the perspectives of potential patients and healthcare professionals. Evaluating the perceived usability of VR technology from the patient's perspective in Thailand, a finding not previously documented, poses a more challenging experimental condition than other studies due to the population's lower technological readiness. Nonetheless, the results demonstrate that VR remains a viable technology, even among elderly populations. Because gaming experience and age were not independently controlled in this study, they do not necessarily indicate inferior usability; rather, they highlight the importance of considering both population characteristics and cultural context when evaluating and comparing usability scores across populations.

From the clinicians' perspective, there is extensive support for using VR data logs to assist in rehabilitation decision-making, particularly for treatment tracking. Constructive feedback regarding system modifications and critical concerns was elicited to inform future research deployment and enhance the system's practicality.

Consequently, synthesizing the findings from the two experiments yields a comprehensive perspective on VR adoption for UE rehabilitation in Thailand, indicating that patients should be receptive to engaging with VR-based treatment. At the same time, clinicians would likely use VR data logs to support clinical decision-making. The insights gained have potential applications beyond Thailand, offering strategies and frameworks that could benefit similar contexts and middle-income settings, thereby expanding the reach and applicability of VR technology in healthcare across diverse socio-economic contexts.

From a practical implementation perspective, these findings suggest that VR systems may be most effectively deployed as complementary tools integrated within existing rehabilitation workflows rather than as replacements for conventional clinical assessment.

The clinician feedback further highlights the importance of providing interpretable movement metrics, contextual patient information, and normative reference datasets to facilitate clinical adoption.

The findings also provide insight into the challenges of implementing VR rehabilitation technologies in countries with moderate levels of digitalization. Although participants generally responded positively to the proposed system, successful deployment may depend on factors such as user familiarity with digital technologies, clinician training, availability of technical support, hardware acquisition and maintenance costs, and integration into routine clinical practice. Addressing these challenges may improve the feasibility of adopting VR-based rehabilitation systems in resource-constrained healthcare environments.

Beyond Thailand, the lessons learned from this exploratory investigation may offer useful considerations for other middle-income countries and regions undergoing similar digital transformation. In this regard, the study contributes preliminary evidence regarding both patient acceptance and clinician adoption of VR-based rehabilitation technologies, thereby supporting future efforts toward broader implementation and clinical validation.

In this phase of the discussion, it is essential to recap the limitations of our two experiments and the potential for further research to overcome them. As an example, the first experiment failed to incorporate a qualitative data gathering strategy to supplement the SUS analysis with user insights into perceived usability. We oversimplified the process in Study 2 by immediately assessing the clinical relevance of the graph attributes to decision-making when evaluating the benefits of VR data log utilization. The assessment should be divided into two components: the motion attributes that are significant for clinical decision-making and the visual format in which they should be represented.

5. Declaration of Ethical Statements

The research contained two main nonintervention studies. Study 1 aimed to investigate individuals' attitudes toward a VR-based rehabilitation system. The study was organized in a casual, open public setting, inviting individuals who were interested and willing to try the technology and participate in the survey. Participation was entirely voluntary, and all participants had the right to withdraw at any time without any consequences.

Study 2 included interviews with clinician collaborators to gather insights on the perceived usefulness of our approach. These interviews were characterized as discussions aimed at understanding personal views and experiences. All participants were informed about the nature of the discussion and its purpose within the research context.

We assured participants that participation was voluntary and that clinicians retained the right to withdraw at any stage without repercussion. Conversations were treated confidentially, and identifying information was removed to protect participants' privacy. The findings will be used solely for research purposes, and we value the contributions and perspectives of our clinician collaborators.

Author Contributions: Conceptualization, N.C.; Methodology, N.C.; Software, S.U.; Validation, N.C.; Formal analysis, S.U.; Investigation, N.C.; Resources, S.U.; Data curation, S.U.; Writing—original draft, S.U. and N.C.; Writing—review and editing, N.C.; Visualization, S.U.; Supervision, N.C.; Project administration, N.C. All authors have read and agreed to the published version of the manuscript.

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Institutional Review Board Statement: Ethical approval was waived because this was a nonintervention study that aimed to investigate individuals' perceptions of VR adoption for rehabilitation. The study was organized in a casual, open public setting, inviting individuals who were interested in and willing to try the technology and participate in the survey. Participation was entirely voluntary, and all participants had the right to withdraw at any time without any consequences.

Informed Consent Statement: Informed consent was obtained from all subjects involved in the study.

Data Availability Statement: The original contributions presented in this study are included in the article. Further inquiries can be directed to the corresponding author.

Conflicts of Interest: The authors declare no conflicts of interest.

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