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RESEARCH ARTICLE

Assessing the Impact of Enriched Virtual Reality on Motivation and Engagement in Stroke Rehabilitation

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ABSTRACT Virtual reality is highly recommended for stroke rehabilitation as it was found to aid in recovery and can motivate users. While there are various virtual reality rehabilitation studies, the impact of virtual environments on rehabilitation has been less studied. This study investigates the added value of an enriched virtual environment on motivation and engagement in stroke rehabilitation. We conducted a validity study on healthy participants (N=25) in two environments: enriched virtual reality and non-enriched virtual reality. Our hypotheses are: 1) An enriched virtual environment with multisensory feedback, gamification, and adaptive function adds value to user motivation and engagement by increasing interest/enjoyment, perceived choice, value/usefulness, and relatedness of the application. 2) Motivated and engaged users spend more time or score more points in the application. The key findings of this study are that intrinsic motivation is higher in the enriched virtual environment (EVE) compared to the non-enriched virtual environment (NEVE). There are significant differences in motivation between these two environments. Furthermore, results show that more participants are engaged in the enriched virtual environment, spending more time, and scoring higher (Spearman's $\rho = 0.809$).

INDEX TERMS Engagement, enriched virtual environment, motivation, stroke rehabilitation, virtual reality.

I. INTRODUCTION

Almost two decades ago, interaction methods were the primary concern of virtual reality (VR) rehabilitation. Interaction modes of VR were limited to devices such as joysticks, gamepads, and 3D mice. Such interaction modes raised concerns as there was a constraint in achieving the objective of fostering natural interaction during rehabilitation [1], [2], [3]. Significant associated problems were learnability and workload. Indeed, cognitively deficient users need to learn to interact with the devices to be able to benefit from VR-based rehabilitation. Replicating interactions comparable to the real world in a virtual environment (VE) would have remained a concept without technological advances in VR. Therefore, in the past, more focus was placed on the conceptual and technological advancement of VR technologies. The aim was to achieve the technological ability to design usable interfaces to fit the purpose of learnability and usability.

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TABLE 1. VR rehabilitation approaches and interventions, Burdea [5].

Approach	Intervention
VR-augmented rehabilitation	VR is used to enhance conventional therapy and is supplementary
VR-based	VR replaces conventional rehabilitation totally
Telerehabilitation	Intervention as at different places or at a distance

Currently, the concept of natural interaction is possible in VR with the advancement of technology, and the focus of study has shifted from developing the technology to applying it in other disciplines and treatments. Keshner et al. [4] reported a rapid growth in studies of the involvement of VR in rehabilitation. Instead of developing specific tools and VR technology to facilitate rehabilitation, the use of the same set of VR technologies can be applied to a multitude of different rehabilitation techniques. Furthermore, VR can emulate and represent the real world in a simulated environment. With VR, users can go beyond reality and the capabilities that are possible in the real world within a safe and controlled environment.

Burdea [5] claimed that virtual rehabilitation has the potential to solve issues such as the cost of rehabilitation, monitoring issues for home rehabilitation, compliance with training schedules, and the unavailability of therapists in some rehabilitation centers. A shift from conventional therapy to a VR approach is not intended to totally replace conventional therapy, which has been proven to be effective for patient recovery but rather to act as a complementary rehabilitation approach for patients. Dias et al. [6] claimed that VR applications meet fundamental rehabilitation principles such as task-oriented training, biofeedback, stimuli-rich environments, and motivation.

According to Burdea [5], there are three approaches to rehabilitation through VR as shown in Table 1. The table lists three approaches to VR rehabilitation and how VR is implemented as a rehabilitation intervention for each approach.

A VR-augmented rehabilitation approach is supplementary to conventional therapy. Therapists may use this approach to enhance conventional therapy conducted for the patient. According to Luis et al. [7], traditional interventions of conventional therapy are proven effective in re-learning motor skills for post-stroke patients. However, the authors claimed that conventional rehabilitation techniques are limited to rehabilitation with inanimate objects and interaction that is bounded by safety and specific commands. Besides the cognitive aspect of receiving rehabilitation, VR environments are found to be complementary to physical training for an optimal rehabilitation plan for patients with multiple sclerosis. The advantages of VR-augmented rehabilitation have been discussed by Long et al. [8]. The authors stated that supplementary VR training provides more options for patients, which sub sequentially enhances participation in daily training.

Participation and adherence to daily training are essential to recovery. Intense and repetitive rehabilitation benefits motor function improvements as claimed by Thomas et al. [9], de Sousa et al. [10], and Hammerbeck et al. [11]. However, Hammerbeck et al. [11] have disclosed that patients found repetitive arm training boring. Due to the high intensity and repetitiveness, patients participating in long-term rehabilitation are inclined to get tired and consider therapy monotonous [12]. For stroke patients in long-term rehabilitation, repetitive movements while doing mundane tasks frequently cause boredom and a loss of interest in continuing rehabilitation [13].

VR has the potential to address these issues by enhancing the user experience. Poupyrev et al. [14], Weiss et al. [15], Chessa and Solari [16], and Lee et al. [17] highlight the potential of VR to enhance mundane and boring tasks by providing a more engaging and immersive experience. The application of VR in rehabilitation has proven to be particularly effective in addressing the mundanity of rehabilitation [18] due to its ability to provide an immersive, interactive, and engaging experience [19].

To provide solutions for engaging rehabilitation, studies [20], [21], [22], [23], [24], and [25] investigated the efficacy and effectiveness of VR for stroke rehabilitation by focusing on designing serious games with various interaction methods, such as principles of video games design (e.g., evaluation for playability, usability, and engagement), integration with robots, design of training scenes and rehabilitation scenarios. However, there is a lack of studies that compare the effects of how VEs were designed on the motivation and engagement of patients toward VR stroke rehabilitation.

In this study, we compared a virtual environment designed with multisensory feedback, gamification, and adaptive feedback to a virtual environment without these elements to investigate the added value of enriched virtual environments on motivation and engagement of users. This validity study involved healthy participants as a benchmark for future studies.

II. RELATED WORK

A. STROKE AND STROKE REHABILITATION

Brain cells depend on oxygen and glucose to produce energy to carry out functions. These two elements are transported by blood in arteries leading to and within the brain. A blockage by a blood clot or narrowing of the arteries can cut off blood supply to the brain, leading to a stroke. Brain cells deprived of oxygen and glucose will eventually die; consequently, affected areas of the brain will lose their ability to function. This occurrence is referred to as a stroke. When a stroke happens, common disabilities faced by affected areas of the brain are related to memory loss and loss muscle control.

Typically, stroke rehabilitation starts as soon as 24 to 48 hours (about 2 days) after a stroke occurrence, depending on the patient's condition. Immediate stroke rehabilitation will increase the chance of the patient regaining lost functions and skills. Rehabilitation aids patients in relearning skills and improving functions so they can regain independence. The process of rehabilitation aims to treat most function lost, by improving functional and intellectual capacities, and re-educating motor cognitive functions [12], [26]. The main purpose of rehabilitation is to improve the quality of life by recovering limbs so activities of daily living (ADL) can be resumed. According to guidelines by John Hopkins Medicine [27], The National Institute of Health and Care Excellence (NICE, UK) [27], and the Ontario Stroke Network [28], stroke rehabilitation should be intensively prescribed to stroke patients daily. The recommended schedule and intensity for individual rehabilitation sessions should be from 45 minutes to 3 hours, daily, at least five times a week. However, various reports from hospitals [20], [29], [30], [31] found discrepancies in the actual duration of therapy and planned therapy sessions. Regardless of stroke severity, on average, patients received 22 to 32 minutes of the minimum 45 minutes of planned rehabilitation. Therefore, patients received less than a quarter hour of daily rehabilitation on weekdays. Hence, patients are encouraged to exercise independently during their own time to increase rehabilitation time.

For some patients, a shorter length of daily intensive rehabilitation for a few weeks is adequate to restore motor skills and achieve independence. However, patients' conditions such as severity and other health complications may prolong the journey to recovery and independence. After being discharged from the hospital or rehabilitation center, patients continue rehabilitation at home and are encouraged to attend periodic therapy sessions with therapists. At home, patients are expected to continue rehabilitation with their caregivers' supervision. In most cases, the caregivers are the adult children of the patient. Traditionally, patients and caregivers are prescribed written guides, often including pictorials as prescription of exercises at home. With the lack of supervision by doctors and therapists, patients might not be fully adherent to the rehabilitation schedules and activities due to a lack of self-willingness, or the lack of time spent by caregivers in assisting and monitoring patients. The findings by [32] described the issues of home rehabilitation such as lack of instruction from therapists, patients tending to slack off, and lack of correction for movements.

Yoshida et al. [33] interviewed healthcare professionals working with stroke patients. In the interviews, these healthcare professionals often ascribed motivation to a patient's attitude towards rehabilitation. In other words, an initiative-taking attitude is associated with motivation while a passive attitude indicates a lack of motivation. Furthermore, the study found that compliance with rehabilitation is indicative of motivation; meanwhile, lack of motivation is often due to noncompliance. Patients with high motivation were more likely to regard rehabilitation as important for recovery and to adopt an initiative-taking attitude in rehabilitation [34].

In the same study, Yoshida et al. interviewed stroke patients on their motivation to rehabilitate. The outcome of the survey showed that patients' view on motivation towards rehabilitation aligned with those of the healthcare professionals. Patients reported that they are more likely to put effort into and behave proactively towards rehabilitation when motivation is high. During periods of high motivation, they are more likely to initiate self-training or demand harder training from therapists.

B. STROKE AND STROKE REHABILITATION MOTIVATION AND ENGAGEMENT

Patients are expected to be engaged in their rehabilitation to ensure adherence and maintain ongoing rehabilitation, given that motivation and engagement are closely related concepts. Marcum [35] proposed reinforcing the concept of motivation, which usually relies on manipulation and control, with engagement, which emphasizes self-determination, interest, enjoyment, participation, and challenge. Cabot [36] distinguishes motivation as— "wanting to do" and engagement as— "doing it". Therefore, patients should be actively participating in and anticipating rehabilitation.

The self-determination theory on motivation [37], [38] states that motivation can be caused by internal factors (e.g., intrinsic motivation) as well as external factors (e.g., extrinsic motivation). Factors such as the need for self-control and personal fulfillment contribute to intrinsic motivation. Extrinsic motivation is influenced by factors such as gaining rewards, avoiding punishments, and garnering public approval.

Motivation is often described as an important determinant of rehabilitation outcomes [39], as it has been implied to be a link between cognition and motor performance [40]. A patient's adherence to rehabilitation can benefit from the effects of motivation on stroke rehabilitation [41].

In rehabilitation, engagement refers to a patient's deliberate effort to work towards recovery by participating fully in therapies [42]. Engagement of stroke patients in learning is an essential part of achieving active learning [43] which can lead to successful recovery. Engaging in stroke rehabilitation allows reducing disability after a stroke by improving lost functions, increasing motivation, increasing rehabilitation speed, and enhancing the ability for home rehabilitation [44], [45], [46]. Other authors [47] found that interactivity is critical for engagement, and feedback is crucial for active participation.

The design of video games, often associated with good user engagement [48], may offer insights into designing motivating and engaging VR stroke rehabilitation applications. Swanson and Whittinghill [39] highlight the use of video game-based interventions as a promising tool for increasing patients' motivation to participate in rehabilitation. Elor et al. [49] discussed how immersive VR, combined with physical and emotional intelligence, can enhance physical rehabilitation by addressing issues such as lack of engagement. In the context of rehabilitation (but not specifically stroke), Palaniappan et al. [50] found that VR exergaming can gauge motivation and engagement. A comparison made by Syed et al. [51] on neurologically deficient patients revealed that VR rehabilitation is more effective in improving motivation and functional tasks than conventional therapy. The positive effects on motivation and the functional context of VR rehabilitation were also discussed by Matijević [52]. Through several VR minigames for stroke patients, Dias et al. [6] highlighted the importance of VR in increasing motivation for repetitive movements.

III. GOALS AND METHODS

In this work, we investigate the added value of an enriched virtual environment (multisensory feedback, gamification, and adaptive function) on motivation and engagement. For this purpose, we have developed VR applications, namely EVE and NEVE, based on a pick-and-place activity and conducted a user study following an experimental research study design.

A. HYPOTHESIS

Our hypotheses are:

- An enriched virtual environment with multisensory feedback, gamification, and adaptive function adds value to the motivation and engagement of the user with the applications by increasing interest/enjoyment, perceived choice, value/usefulness, and relatedness of application.
- Motivated and engaged users spend more time or score more points in the application.

B. PARTICIPANTS

Twenty-five participants participated in this single-masked research study. All participants (N = 25) in this validity study are nursing students (21 female, M = 29.36, SD = 10.09, range 19–51).

While the aim is to promote the design of motivating and engaging VR rehabilitation for stroke patients, the experiment was done on healthy subjects to evaluate the feasibility of the applications, adopting the method conducted by [53] following a well-established development approach in medical-oriented human-computer systems. According to [54], feasibility studies are frequently conducted in preparation for a randomized controlled trial (RCT) to address uncertainties and allow researchers to optimize the intervention or conduct of the trial. As an example, the study with healthy subjects is critical to validate [55] that the immersive VR motor learning applications affect motivation and engagement positively and has no negative side effects such as excessive cyber-sickness in users. Furthermore, Satava et al. [56] in their proposed taxonomy of metrics for evaluating surgical abilities and skills, focused on the concept of validity. In this study, we consider the concept of content validity of the taxonomy in assessing the accuracy and relevance of the content proposed (rehabilitation activity) and performed by the expert (trainee nurses) based on detailed examination of the system content. The sample size of twenty-five participants was justified as sample sizes for qualitative feasibility studies are small and typically require between 5 and 20 individuals as participants [57].

The school had previously informed the participants that they would be participating in studies with VR. However, they were not informed of the specific activities within the experiment. The experiment took place at the nursing school. Before the start of the study, each participant was briefed again on the protocol and their tasks. However, the objectives, hypotheses, and expected outcomes of the study were not communicated to avoid biased answers and behaviors. If the participants decided to continue with the study, they were required to fill in the demographic questionnaire with their basic information, acknowledgment of receiving the briefing, and participation agreement.

After participants consented to participate in this study, they could begin the experiment. A within-subject design was chosen, with one factor: the type of environment, with two scenarios: enriched (EVE) and non-enriched (NEVE) environments. The presentation of each scenario for every participant was alternated to reduce bias (i.e., half of the participants started with the EVE and half with the NEVE).

C. MEASURES

The data gathered in this study are related to the participants' motivation and engagement. The measures were used to determine participants' motivation and engagement towards VR rehabilitation in different environments and scenarios. In the environments developed for the study, elements of multisensory feedback, gamification, and adaptive functions are incorporated. Gamification uses game elements in a non-game context, in this case, stroke rehabilitation therapy. According to Kang and Tan [58], through games, users can experience pleasure and feelings of competence, contributing to increased intrinsic motivation towards the activity.

Intrinsic motivational information can be gathered through the Intrinsic Motivation Inventory (IMI) survey. The IMI is a validated psychometric tool to assess individual's subjective experience related to tasks or activities they engage in. It is a self-reported instrument where participants provide their own perceptions and assessments of their motivational experiences using a Likert scale. IMI consists of forty-five items (questions) under seven subscales representing the factors contributing to intrinsic motivation. The tool is very flexible because users can construct appropriate questions for the experiments based on the available questions. To score the

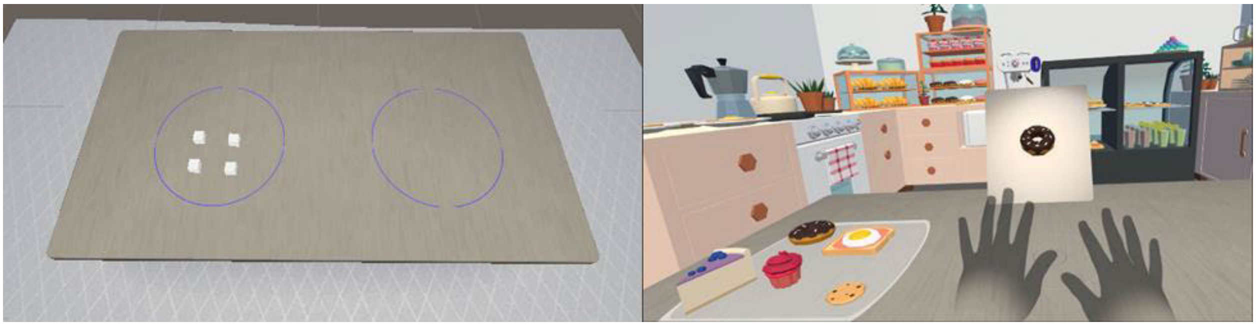

FIGURE 1. (a). Screenshot of Non-enriched Virtual Environment (NEVE) (b). Screenshot of Enriched Virtual Environment (EVE).

result of the IMI questionnaire, the score of items labelled with (R) should be subtracted from eight and the resulting number is the score. Then, subscale scores are calculated by averaging all the items on the subscale. In this study, we use the results of the IMI subscale scores to gain insight into the intrinsic motivation of participants in two different virtual environments and scenarios of the same stroke rehabilitation activity.

Besides measuring intrinsic motivation with the IMI, we also measure motivation and engagement with scores, levels, and time spent integrating with the application. While scores and levels in gamification and adaptive functions are associated with extrinsic motivation, research has found that they do not inherently affect intrinsic motivation. Mekler et al. [59], found that scores and levels did not necessarily affect intrinsic motivation in non-game contexts. The authors assumed that these elements function as progress indicators, guiding and enhancing user performance, and their implementation is a viable means to promote specific user behavior in non-game contexts.

According to Brigham [60], engagement in gamification is the level of involvement, interest, and interaction that individuals have with game-like elements in non-game contexts. Engagement is often measured by time spent, volume of contributions, and frequency of visits to the software [61]. Research by Cheung et al. [62] and Boyle [63] suggests that the time spent on a game can be an indication of engagement. Other factors, such as the design and implementation of gamification elements, the individual's motivation, and the specific context, also play a significant role in determining the level of engagement [64]. The score was found to be an indication of engagement, as a higher score indicates higher engagement [65]. Therefore, score, level, and time were measured and validated with correlation tests.

D. SYSTEM DESIGN

The rehabilitation exercise for this study was developed by a participatory design involving doctors, therapists, and nurses working closely with stroke patients. The participatory design method was chosen to establish the correct rehabilitation activities as well as to ensure that the virtual environments are safe and suitable for stroke patients to perform motor rehabilitation exercises in. Discussions were conducted to elicit information from the professionals. Demonstration sessions were conducted to verify and validate the developed applications with the professionals.

As a result, two task-specific fully immersive VEs as shown in Figure 1a and Figure 1b, were developed in the Unity 3D game engine (editor version 2021.3.17f1). The fully immersive VEs run on the Meta Quest 2 head-mounted display (HMD) and Oculus App Version 56.0.0.109.155.

The scenarios replicated the ''pick and place'' activity of conventional therapy. The VEs use hand-tracking instead of controllers for the pick-and-place gestures, allowing users to move their hands and fingers when grabbing and releasing game objects in the virtual world. The first scenario was a NEVE. In the NEVE, two rings were displayed on a table, and cubes were placed within the boundaries of one of the rings. Participants were tasked with moving all the cubes from one ring to the other repeatedly. No elements of multisensory feedback, gamification, or adaptive function were implemented in this scene.

The second scenario was an enriched VE (EVE) where the virtual world was visually loaded with visual and auditory stimuli as the ambiance and as a means of feedback to the participants own action, as well as with elements of gamification (points and levels) and an adaptive function in the game (increasing difficulty based on the user's performance). The core task for participants remained the same, which was to pick and place an object in a ring on the table. As a task, participants were given specific instructions through randomized photos shown in the VE. When game objects were picked and placed, audio was played corresponding to the action. If the correct game object was placed in the ring, a positive sounding audio clip was played and text showing praise was displayed to the participant. Otherwise, the participant was warned with a short beep sound and encouraging feedback through text. Each correct step was awarded points that were displayed in the VE. When a participant scored fifty points, the level was completed, and the participant was challenged with the next level. There was no maximum score on level 6, therefore, participants could keep playing in the level until the allocated time ran up or until they decided to stop. The difficulty increased due to the different placements of game

FIGURE 2. Levels in Enriched Virtual Environment (EVE).

objects at each level. As the game progressed, the placement of game objects demanded more effort by participants to move horizontally, vertically, and diagonally, as seen in Figure 2. The activities of the rehabilitation are based on solving and sensing with the progression or completion as the accomplishment element to encourage the desire to continue interaction with the rehabilitation application [66].

E. EXPERIMENT PROTOCOL

At the start of the study for the EVE and NEVE, participants were given a demo on navigating in the VE. They were allocated 5 minutes to interact with each application. However, they were allowed to quit at any time within the allocated time. Next, they were asked to put the head-mounted display (HMD) on. Participants were required to locate their hands in the VE and were given a chance to try to pick and place game objects with their virtual hand. The countdown of the timer (five minutes for each scenario) started when the participant started moving their hand in the VE. Participants were allowed to continue playing until the time was up or to stop at any time they wished to. Upon finishing the interaction with each VE, the participant was required to fill in an Intrinsic Motivation Inventory (IMI) [67] questionnaire as shown in Table 2. Each questionnaire took 2-3 minutes to complete.

Out of the seven subscales in the IMI, five were chosen for their relevance to the expected outcomes of the study along with their corresponding relevant item(s). The function of each subscale is as described: interest/enjoyment is the only subscale that assesses (a self-report measure of) intrinsic motivation, while the other subscales (e.g., perceived choice, pressure/tension) are either positive or negative predictors of both self-reported and behavioral measures of intrinsic motivation. The value/usefulness subscale is related to the internalization and self-regulation regarding activities that could improve intrinsic motivation. Finally, the relatedness subscale determines the value of intrinsic motivation when participants interact with the applications.

IV. RESULTS AND DISCUSSION

A. MOTIVATION

To estimate the reliability and internal consistency of the modified IMI questionnaire from the data of the surveys on both VEs using Cronbach's Alpha, the initial values of Cronbach's Alpha were 0.51 (EVE) and 0.87 (NEVE). Due to the poor reliability of the EVE IMI questionnaire, an elimination was made to ensure the reliability of the applied questionnaire. After removing the pressure/tension subscale, the final Cronbach's Alpha values were 0.78 (EVE) and 0.93 (NEVE), which indicate that the questionnaire used to evaluate both VEs is acceptable and has excellent reliability. Table 3 shows the IMI questionnaire after elimination and its results.

On a scale of 1-7, the average subscale scores ranged from 3 to 7. The range indicates that for some subscales, participants felt less positive about the VE in the context of the subscales. The subscale scores of the EVE were found to be higher than those of the NEVE.

The result of the interest/enjoyment subscale is a measure of intrinsic motivation. The result of this study showed that participants scored high for EVE (6.09) and lower for NEVE (4.35). The results indicated that both environments provided some extend of interest and enjoyment but undergoing the "rehabilitation" with EVE was more enjoyable and interesting.

As the participants were healthy subjects and did not need rehabilitation, the perceived choice subscale is interesting to discuss. The subscale's outcome can predict the willingness of future users to undergo rehabilitation on either of the VEs. Both EVE (4.94) and NEVE (4.50) scored moderate to

TABLE 2. Selected subscales and items from Intrinsic Motivation Inventory (IMI).

Intrinsic Motivation Inventory	
Subscale	**Item**
Interest/Enjoyment	This activity was fun to do
	I thought this was a boring activity (R)
	This activity did not hold my attention at all (R)
	While I was doing this activity, I was thinking about how much I enjoyed it
Pressure/Tension	I was very relaxed on doing these (R)
	I was anxious while working on this task
	I felt pressured while doing theses
Perceived Choice	I did this activity because I wanted to
	I did this activity because I had to
Value/Usefulness	I would be willing to do this again because it has some value to me
Relatedness	I'd like a chance to interact with this application more often
	I'd really prefer not to interact with this application in the future (R)

TABLE 3. Result of IMI Questionnaire.

	E-VE		NE-VE	
Subscale/Item	Mean (s.d)	Score (1-7) (s.d)	Mean (s.d)	Score (1-7) (s.d)
Interest/Enjoyment	6.09 (1.18)		4.35 (2.09)	
• This activity was fun to do		6.28 (0.74)		4.24 (2.13)
• I thought this was a boring activity (R)		6.56 (0.65)		4.56 (1.89)
• This activity did not hold my attention at all (R)		6.12(1.62)		4.88 (2.20)
• While I was doing this activity, I was thinking about how much I enjoyed it		5.40(1.22)		3.72 (2.09)
Perceived Choice	4.94 (2.12)		4.50 (2.26)	
• I did this activity because I wanted to		5.44 (1.87)		4.72 (2.26)
• I did this activity because I had to (R)		4.44 (2.31)		4.28 (2.32)
Value/Usefulness	4.76 (1.77)		3.68 (1.91)	
• I would be willing to do this again because it has some value to me		4.76 (1.81)		3.68 (1.95)
Relatedness	5.64 (1.56)		4.54 (2.07)	
• I'd like a chance to interact with this application more often		4.96 (1.67)		3.84 (1.97)
• I'd really prefer not to interact with this application in the future (R)		6.32 (1.14)		5.24 (2.01)

high average scores. The scores of the items evaluated in the subscale showed that participants continued to interact with the VEs more likely due to their own choice and less likely because they felt obligated to do so. Hence, it was predicted that the application of an enhanced virtual environment will motivate users to start rehabilitation on their own time and at their own will. Nonetheless, this result accounts for healthy participants with normal cognitive abilities and cannot be confirmed for stroke patients.

While rehabilitation activities are not of any value for the healthy participants, results for the value/usefulness subscale are moderate to high for EVE (4.76) but low to moderate for NEVE (3.68). The mean scores showed that after interacting with both environments, participants found that the activity was somewhat valuable and useful for them. In this context, while the average score of EVE is not much higher than that of NEVE, enriched environments containing multisensory feedback, gamification, and adaptive functions do impart

TABLE 4. Test of Difference of Interest/Enjoyment Subscale.

Test of difference of Interest/Enjoyment subscale		
Item	Wilcoxon Signed-Rank Statistic	p-value
This activity was fun to do	1.50	0.00022438
I thought this was a boring activity (R)	0.00	0.00011661
This activity did not hold my attention at all (R)	17.00	0.0142008
While I was doing this activity, I was thinking about how much I enjoyed it	9.50	0.00052188

TABLE 5. Test of difference of perceived choice subscale.

Test of difference of Perceived Choice subscale		
Item	Wilcoxon Signed-Rank Statistic	p-value
I did this activity because I wanted to	16.00	0.02014611
I did this activity because I had to (R)	47.00	0.45207114

value to the users, although, initially, they do not necessarily need rehabilitation.

Finally, the subscale of relatedness was evaluated. Once again, the mean score of EVE (5.64) is higher than that of NEVE (4.54). One of the objectives of this subscale is to measure interaction. An initial deduction based on the mean score showed that participants are more likely to feel a connection with the EVE application than with the NEVE. From this subscale and its scores, it is also relevant to claim that multisensory feedback, gamification, and adaptive functions engage users and make them feel connected to the application and that it relates to them.

B. TEST OF DIFFERENCE BETWEEN TWO VES BASED ON EACH SUBSCALE ITEM

The average IMI scores of the EVE across all subscales appear to be higher than those of the NEVE. However, to obtain a more accurate difference between the two environments, we conducted inferential tests of the subscales. The Wilcoxon Signed-Rank (WSR) test determined the significant difference in the IMI subscales between the two VEs, with alpha $\alpha = 0.05$. For subscales with more than one item, a WSR was performed on each item. The overall difference for each subscale was determined by the condition: all (p-value $< \alpha$).

1. Test of difference of Interest/Enjoyment subscale:

- H_{01} = There is no significant difference in the Interest/Enjoyment subscale between Enriched Virtual Environment and the Non-enriched Virtual Environment.
- H_{A1} = There is a significant difference in the Interest/Enjoyment subscale between Enriched Virtual Environment and Non-enriched Virtual Environment.

Table 4 shows a significant difference in the interest/enjoyment subscale between EVE and NEVE. The p-value of each item was calculated to be less than the level of significance, $\alpha = 0.05$. The results show that the null hypothesis, H_{01} should be rejected, which means that the application of an enriched virtual environment in repetitive stroke rehabilitation activities is more motivating than a non-enriched environment.

2. Test of difference of Perceived Choice subscale:

- H_{02} = There is no significant difference in the Perceived Choice subscale between the Enriched Virtual Environment and the Non-enriched Virtual Environment.
- H_{A2} = There is a significant difference in the Perceived Choice subscale between the Enriched Virtual Environment and the Non-enriched Virtual Environment.

There is no significant difference in the perceived choice subscale between EVE and NEVE, as shown in Table 5. The condition to reject the null hypothesis is that all p-values $< \alpha$. However, the p-value of the second item in the subscale is greater than 0.05, leading to a failure to reject the null hypothesis for the overall subscale. Nonetheless, the p-value of the first item on the subscale is $< \alpha$, consequently proving that there is a significant difference between EVE and NEVE and supporting the statement in the discussion of the IMI score result.

3. Test of difference of Value subscale:

- H_{03} = There is no significant difference in the Value subscale between the Enriched Virtual Environment and the Non-enriched Virtual Environment.
- H_{A3} = There is a significant difference in the Value subscale between the Enriched Virtual Environment and the Non-enriched Virtual Environment.

Table 6 indicates that there is a significant difference in the value/usefulness subscale between EVE and NEVE. The p-value of each item was calculated to be less than the level of significance, $\alpha = 0.05$. The result concludes that the null hypothesis, H_{03} should be rejected, meaning that the application of enriched virtual environments in repetitive stroke rehabilitation activities is more meaningful than in non-enriched environments.

4. Test of difference of Relatedness subscale:

TABLE 6. Test of difference of Value/Usefulness subscale.

Test of difference of Value/Usefulness subscale		
Item	Wilcoxon Signed-Rank Statistic	p-value
I would be willing to do this again because it has some value to me	37.00	0.010443111003860028

TABLE 7. Test of difference of Relatedness subscale.

Test of difference of Relatedness subscale		
Item	Wilcoxon Signed-Rank Statistic	p-value
I'd like a chance to interact with this application more often	8.00	0.00101374
I'd really prefer not to interact with this application in the future (R)	30.00	0.02544051

- H_{04} = There is no significant difference in the Relatedness subscale between the Enriched Virtual Environment and the Non-enriched Virtual Environment.
- H_{A4} = There is a significant difference in the Relatedness subscale between the Enriched Virtual Environment and the Non-enriched Virtual Environment.

There is a significant difference in the relatedness subscale between EVE and NEVE in table 7. The p-values of each item were calculated to be less than the level of significance, $\alpha = 0.05$. The result concludes that the null hypothesis, H_{04} should be rejected. The application of enriched virtual environments in repetitive stroke rehabilitation activities is more relatable than in non-enriched environments.

C. SCORE, LEVEL, TIME

Figure 3 shows the amount of time spent on the EVE compared to the NEVE by each participant. Time duration is presented in seconds for accuracy. The range of time spent on the EVE is 1 minute 14 seconds–5 minutes, while in the NEVE the range of time spent is 34 seconds–5 minutes. The average time spent is 4.04(1.17) minutes on the EVE and 2.79(1.76) minutes on the NEVE.

Based on further analysis, twelve participants spent less than 2 minutes on NEVE, while only eight participants spent 5 minutes on NEVE. To be precise, six participants spent less than a minute on NEVE. On the other hand, ten participants spent between 2–3 minutes and fourteen participants spent 5 minutes on EVE. No participants spent less than 1 minute on this environment.

To identify if there is a significant difference between the time spent in EVE and NEVE, a paired t-test was applied. The hypotheses are as below:

- H_{05} = There is no significant difference between the Enriched Virtual Environment and the Non-enriched Virtual Environment times.
- H_{A5} = There is a significant difference between the Enriched Virtual Environment and the Non-enriched Virtual Environment times.

The results of the paired t-test showed that the Wilcoxon Signed-Rank Test value is 26.0 with a p-value of 0.0055. As the p-value is less than the level of significance, $\alpha = 0.05$, the null hypothesis is rejected. This shows that there is a statistically significant difference between the time spent on EVE and on NEVE. Participants spend significantly more time in EVE compared to NEVE.

From the outcome of time spent data, a general deduction on the engagement of participants with the environments was made. It is fair to deduce that EVE motivates participants to actively participate in repetitive tasks for a longer time compared to NEVE. To support this statement, Spearman's Rank Correlation test was conducted.

The outcomes are presented in Table 8. From these tests, we can conclude that the longer a participant spends interacting with the application, the higher their score are. Moreover, score and level could influence the engagement of participant in the application as well.

The maximum score for each level is 50 points; upon achieving 50 points, players are awarded a level up. This mechanism is applied to five levels, rounding the scores to be 250 points. No maximum score was set for level 6 to observe participants' engagement with the environment; however, the baseline was decided to be of 50 points. Thus, the minimum score for the completion of six levels was approximated to be 300 points. The visualization of the scoring scheme is tabulated in Table 9.

Twenty-two participants scored more than 300 points by completing all six levels. Only three participants quit the rehabilitation activity before reaching level 6. However, they reached at least level 4 on the EVE. Fourteen participants scored more than 300 points (min: 400, max: 1390) and reached the maximum time on the session (5 minutes). Eight participants scored more than 300 points (min: 370, max: 520) in less than 5 minutes and decided to stop the rehabilitation activities.

The eight participants were faster at reaching the final level, but the fourteen participants spent more time and scored higher than the eight participants. The correlation of scores and time spent on the VE can illustrate insights into the engagement and motivation of participants with the VE. Participants who spent less time can be categorized as

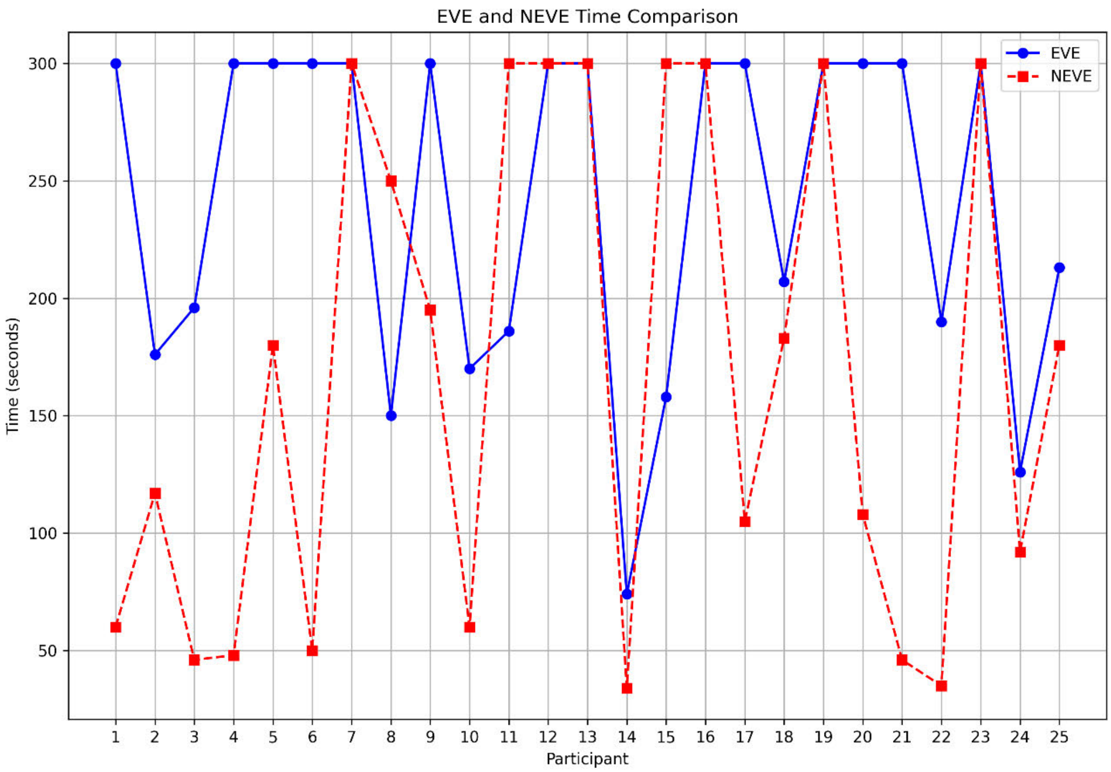

FIGURE 3. Overview of time spent by every participant in EVE and NEVE.

TABLE 8. Spearman's rank correlation coefficient.

Spearman's Rank Correlation Coefficient		
Spearman Rank Correlation between	Spearman's ρ	Correlation
Time Spent and Score	0.809	Very strong relationship
Time Spent and Level	0.560	Strong relationship
Score and Level	0.565	Strong relationship

TABLE 9. Maximum score and total accumulated score possible for each levels.

Level	Maximum score of level	Total accumulated score
Level 1	50	50
Level 2	50	100
Level 3	50	150
Level 4	50	200
Level 5	50	300
Level 6	No maximum score	>300

motivated to reach the next level quickly. When they realized that there was no more level-up reward after scoring points, the participants stopped interacting with the application. However, the fourteen participants were more engaged in the activities and were more persistent in spending more time doing repetitive activities in the virtual environment despite not being rewarded with new levels.

The analysis of the IMI questionnaire and the test of differences showed that the EVE, which includes elements of multisensory feedback, gamification, and adaptive functions was perceived as more motivating than the NEVE, which lacks such features. Higher average scores on all IMI subscales predicted a positive outlook on the effect of motivation and engagement (value/usefulness and relatedness subscales) of a VE that incorporates these three elements in the design of repetitive stroke rehabilitation in VR. The design of the environment without the three elements, although having decent scores in the IMI, is predicted to enhance motivation and engagement less. This statement is based on comparing the time spent on EVE and NEVE by the participants of validity studies. More participants were not motivated and engaged enough to persistently spend more time doing the repetitive activities in NEVE. The result of time spent on EVE in relation to scores achieved provides insight into how participants interact with the application's environment. Since the number of participants that spent more time and scored higher on EVE is greater, it is possible to approximate that an environment with elements of multisensory feedback, gamification, and adaptive function indeed enhances motivation and engagement.

D. IMPLICATION OF STUDY

- STROKE REHABILITATION

Assuming motivation as a general concept [53], we treated the result to be projected similarly for stroke patients. This study offers some preliminary insights into the prediction of the added value of enriched virtual environments for stroke rehabilitation. Key implications discovered through this study includes:

a) Enhanced rehabilitation outcomes and increased patient compliance.

In the context of rehabilitation, specifically stroke rehabilitation, multiple studies have reported demotivation as a deterrent factor from continuing rehabilitation [13]. *This issue* hinders patients from achieving improved motor recovery and self-independence. Previous studies [4], [14], [16], [17] highlighted that VR has the potential to improve the feeling of boredom when undergoing boring tasks by providing a more engaging and immersive experience.

In this study, we have found that VR, with the implementation of enhanced environments, addresses the issues of patients' non-compliance with rehabilitation. Motivation reflects the patient's positive attitude towards rehabilitation. When motivation is high, patients report that they are more willing to do rehabilitation exercises. This study showed that enriched virtual reality stroke rehabilitation positively impacts motivation and engagement. Thus, ensuring the completion of the prescribed therapy regimen. Motivation to comply with the rehabilitation exercises leads to improved motor and function recovery which are important for ensuring that the goal of self-independence can be achieved by patients. Increased patient compliance may also result in shorter recovery time as patients are motivated to do more and are willing to spend more time on rehabilitation exercises in their own time.

b) Training and education.

As stakeholders both in the healthcare sector and in this study, medical practitioners can benefit from the research in VR stroke rehabilitation. Through this study, medical practitioners can rediscover the importance of motivation and engagement for stroke rehabilitation. Besides, they can gain new skills and methods for using VR as the tool for rehabilitation, improving patient care.

c) Applications in other domains.

Findings from this study may be applicable to other domains, especially areas involving physical therapy and learning. The importance of motivation and engagement in encouraging continuous and prolonged learning should be investigated further.

- INTERFACE AND INTERACTION DESIGN

In the context of Human-Computer Interaction (HCI), this study raises some important implications for the design of motivating and engaging applications. Emphasis should be placed on immersive experience and emotional engagement.

The results of this study show that enriched virtual reality produced higher engagement compared to non-enriched virtual reality. This finding implies that VR stroke rehabilitation applications should be designed to be highly immersive, applying elements such as multisensory feedback to fully engage patients and prolong their interaction time within the VR rehabilitation application. Sensory feedback must be meaningful to ensure the motivation and engagement of patients. Motivating aspects of interactive feedback such as praise, positive sound feedback, and uplifting music, are essential for retaining patients in the application. As shown in the results, these types of interactive feedback engage users to play longer and do more rehabilitation exercises in the application. Therefore, more studies should investigate the significance of the user interface and interaction on the user experience of VR stroke rehabilitation applications. Design elements should evoke positive emotions to enhance user engagement.

V. CONCLUSION AND FUTURE WORKS

With the potential of VR stroke rehabilitation to promote motivation and engagement, a validity study was conducted to investigate the added value of enriched virtual environments in VR. The enriched virtual environments with the inclusion of multisensory feedback, gamification, and adaptive feedback were assessed against a virtual environment without those elements. Healthy participants (N= 25) participated in the study and performed rehabilitation activities in two virtual environments (EVE, NEVE). Intrinsic Motivation Inventory (IMI) showed high scores for interest/enjoyment, perceived choice, value/usefulness, and relatedness subscales for EVE. To evaluate the difference, the Wilcoxon Signed-Rank test was applied. Results demonstrate that there are significant differences between the two VEs, regarding motivation, with EVE being more motivating. The final analysis was based on the scores achieved, levels reached, and time spent on the application. A comparison of the time spent in the application between EVE and NEVE indicates that more time was spent on EVE than on NEVE.

An initial assumption that we can make based on the outcomes is that an enriched virtual environment adds value to motivation and engagement in VR stroke rehabilitation. The scores and levels were then compared against time in EVE to determine the engagement of participants in terms of their persistence in performing more repetitive rehabilitation activities.

Results showed that more participants completed the maximum stipulated time, although they had reached the highest level possible. The outcomes of this validity study enabled us to predict that stroke patients with higher cognitive abilities will produce comparable results to the healthy participants from this validity study.

The positive findings from this study can spur further research and development on enhancing, retaining, or generating the feelings of motivation and engagement in VR rehabilitation in general, and specifically for stroke rehabilitation. Therefore, besides researching the efficacy of VR in rehabilitation of motor skills, research should also consider the user experience and how to elevate it to enhance rehabilitation and increase patient compliance.

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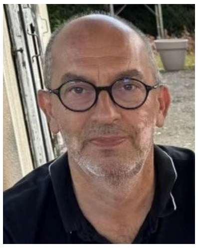

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