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Development of Virtual Reality Based Left Brain System

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Abstract - This paper proposes a virtual reality based Left Brain System named BrainUp World to improve left brain thinking. The left-brain system was employed with mobile virtual reality technology, hand motion tracking and haptic feedback system. The implementation of these systems is to enhance the experience and sense of embodiment. BrainUp World includes virtual reality-based brain training games to improve a person's attention level, reasoning skill, auditory cognition, arithmetic skill, sequencing skill and memory. The hand tracking system was utilized with an IR camera to capture the hand orientation and return the gesture data to the VR application. A low-cost and lightweight haptic glove was invented which provides the sense of touch using vibrations while interacting with VR contents. An experimental study was conducted to assess the efficacy of BrainUp World compared to traditional PC-based training approaches. Participants were randomly assigned to either the VR-based or PC-based training group and underwent 6 different games to test a person's attention level, reasoning skill, auditory cognition, arithmetic skill, sequencing skill, and memory. The results revealed a statistically significant improvement in left brain function in the VR-based training group compared to the PC-based group, with a T-score growth of 4.73. Analysis using ANOVA confirmed the significance of this difference (p-Value = 0.04). Notably, the study also identified age-related differences in thinking fluency, highlighting the importance of personalized cognitive training interventions. In conclusion, BrainUp World demonstrates the potential of VR technology in promoting left brain development, as evidenced by empirical findings from the conducted study. By offering immersive and interactive cognitive training experiences, VR-based systems hold promise for enhancing various aspects of cognitive function associated with left hemisphere dominance. Further research in this area is encouraged to explore the full potential of VR-based interventions for cognitive enhancement.

Keywords— Left Brain, Training, Virtual Reality, Leap Motion, Haptic Glove

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1. INTRODUCTION

In contemporary society, the demand for peak cognitive performance is ubiquitous, spanning professional, educational, and personal spheres Many individuals struggle with cognitive challenges such as reading, remembering, problem-solving, or paying attention in their daily life. Hence, people are advocated to stay their brain healthy through neuroplasticity training [1]. The Human brain can be described as being divided into two parts

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which are the left and right hemispheres. This brain's two hemispheres function differently and people normally can be categories as a left-brained or right-brained person according to which side of their brain is dominant [2, 3]. In general, the left-brained person has an analytical and methodical thinking style while the right-brained person is more creative or artistic [4]. A brain thinker or brain-balanced person can unleash the full potential of the brain in terms of study and working efficiently.

Every person needs to keep their mind clear every day to ensure that the brain works in the best performance [5]. There are several ways to train the mind such as quick games, brain teasers, and logical quizzes that can be conducted anywhere and by anyone. Our Intellectual performance or cognition is based on the function of our brain. In our old age, it often happens that we lose certain skills especially in the case of neurological diseases [6]. To restore these functions, it is a great challenge to the clinic and researcher. In this context, Virtual Reality (VR) technology has emerged as a compelling solution, offering unique advantages in cognitive training and rehabilitation[7]. VR's immersive nature transcends the constraints of traditional two-dimensional interfaces, providing users with a multisensory, three-dimensional environment conducive to active learning and engagement. This immersive quality enables the creation of virtual scenarios that closely mimic real-world contexts, fostering meaningful skill transfer and generalization. Moreover, VR applications can be tailored to individual needs and preferences, offering personalized and adaptive training experiences. Leveraging VR technology to develop brain training applications offers new opportunities for immersive and engaging cognitive interventions

In this project, a series of applications to train the left brain thinking by using the wearable VR technology were aims to developed. This VR System will be integrated with a hand tracking function [8] to immerse the user in a virtual scenario to further improve the brain training efficiency and experience [9]. Participants will be experimented with the game focused on activities associated with the left hemisphere of the brain, emphasizing mathematics, logical thinking, arithmetic skills, reasoning, and analytical time sequence processing. A comparative analysis between PC-based and VR-based training methods was conducted to assess the differences in training outcomes. Additionally, the study investigated potential age-related differences in learning during the training process.

2. LITERATURE REVIEW

This section mainly focuses on the relevant background study for this project. This review will compare the existing VR based cognitive training and haptic glove system. Furthermore, this section explains the advantages and limitations of different kinds of haptic glove designs as well as the reasons for choosing them.

2.1 Research on VR Based Training

A VR experiment of industrial shutdown maintenance using Functional near-infrared spectroscopy (fNIRS): In this research, a VR system was developed to simulate normal and stressful scenarios in a power plant. The worker's problem-solving skill in a stressful scenario is hard to predict and evaluate since not every time that the power plant will shut down. Therefore, this research proposed a neurophysiological approach with the aid of VR to simulate a stressful scenario to evaluate a worker's work performance and stress index. In the meantime, fNIRS was applied to collect the user's brain waves from their responses.

During the experiment, the participants were required to complete the given task for a short duration in the virtual world. At first, the participant was asked to memorize some instructions for pipe maintenance and then perform it in a normal and stressful situation. Meanwhile, the participant was asked to equip the fNIRS device and ensure all the probe was connected properly. The output of this experiment shows that stressful training has a stronger influence on the participants' neural connection. This research paper also suggested some supervised machine learning classification models that use the fNIRS data to examine the participant's task performance. The researcher has identified the approach was able to obtain the best accuracy which reached 80.38% in classifying participants' task performance.

VR-based cognitive-motor training for middle-aged adults at high Alzheimer's disease risk: This design was aimed at middle-aged adults to prevent dementia through VR cognitive-motor training. The project was started with some inclusion criteria to filter the participant for the experiment. The age of the participants should be around 40 to 65 and at least one of their parents with Alzheimer's disease (AD). Then, the participants who fulfilled the requirement were given the first physical evaluation followed by neurocognitive measurement and brain imaging measures. After that, the participants were randomly assigned into 4 separate groups for different types of training. The training is divided into VR training with a treadmill (VR+T); VR training without treadmill (VR-T); scientific TV documentary with a treadmill (TV+T) and Usual activities (no-contact control).

Participants in group 1 (VR+T) received a VR-based task that showed on a screen while walking on a treadmill. The treadmill was motion commanded to synchronize with the virtual scenario, and motion detection system. Special cameras and markers are also mounted to the participant's right and left hands respectively to track the hand movement. The identical set of VR tasks was applied to group 2 (VR-T) training as well, but the participant was just standing on the treadmill. Participants in group 3 (TV+T) were instructed to watch an episode of a scientific documentary without being involved in VR-based training. For group 4, participants were engaged in their daily activities during the 12 weeks. The VR-based training included five main training tasks for the participant to complete. These tasks train up participants' sustained attention, working memory, selective attention, convert rule deduction, and planning in a virtual supermarket.

Cognitive training is very common, and it can be conducted in a very simple way. However, simple cognitive training cannot obtain a good training output. Therefore, VR-based technology provides a valuable contribution to these fields by virtualizing cognitive training. VR uses the latest technology to simulate environments, objects, or situations. Furthermore, VR training produces a sense of embodiment. It makes the participant feel immersed in the VR environment. With this immersive experience, the efficiency of training would accelerate improved [10], [11].

Regarding the benefits of cognitive training, the older participants involved in this (ACTIVE) training were showed multiple long-term benefits, including the benefits that related to driving performance [12], daily functional abilities [13], and most notably, dementia onset.

2.2. Research on Haptic Glove

Soft Robotic Hand Rehabilitative Exoskeleton for Stroke Patients: This study has proposed a design of robotic hand orthosis for stroke patients. From statistics, stroke is one of the serious diseases that 5.9 million cases of death were reported in 2010. It is a disease that would cause a person to lose strength and dexterity in some parts of their body, especially their hand. This may cause it difficult for people to grasp and release an object, and even affect them in doing daily tasks. Hence, the researchers have conducted this preliminary investigation on soft robotic hand exoskeleton to support the rehabilitation of stroke patients.

According to a report, costly rehabilitation equipment or treatment causes the majority of stroke patients to be unable to access quality care. However, traditional physical therapy rehabilitation is labor-intensive which needs one-by-one therapist-patient treatments. To overcome these issues, many researchers has put their effort into robot-assisted therapy. They would like to investigate a solution that has lower costs and can meet the demands of rehabilitation. Existing rehabilitation assistive devices that exist in the market or the research stages, which are made up of rigid links that needs precise attachments at finger joints [14, 15]. The heavy and bulky design makes it inconvenient to use. Rigid rehabilitation is also prone to get injured due to misalignment between the rigid link of a robot and a human finger. As a similar issue arises, the researchers start to put their effort into soft robotic exoskeletons development.

This study has investigated that typical soft exoskeleton that fabricated using soft lithography methods require technical knowledge and higher cost to produce. The adoption of the 3D printing technique makes prototype fabrication cheaper and faster. Fused Deposition Modelling (FDM) was suggested due to its ability to print by using soft flexible materials and short fabrication time. In this paper, they present a design of FDM 3D printed soft robotic hand orthosis.

The proposed design used the pneumatic pressurization approach to strengthen grasping force. Thus, the patient can grasp things easily by equipping the designed glove. The soft exoskeleton will bend during pneumatic pressurization of the inner chamber of the actuator. In short, the researcher investigated that FDM-based soft 3D printing is a good method to fabricate a soft robotic hand exoskeleton. Their design, including the control system of the waist belt is lightweight which resolves the portability issues. The pneumatic control system does not produce any noise when in use, it produced a peak of 74.5 dB of noise in a 57.0dB ambient environment. The study also proved PIY glove was able to archive 41.8N of maximal grip force.

Fine Tactile Representation of Materials for VR: With the development of VR technology, various assistive device [16, 17, 19] has been invented to immerse the user in the VR environment. VR glove is one of the famous devices in VR interactions. The VR glove was not commonly used due to the costliness and the inconvenience of wearing them. Thus, this study presented a preliminary design of a low-cost and lightweight haptic glove that enables the user to feel the sense of touch using vibration haptic feedback technique while interacting with VR contents. The proposed haptic glove provides the texture haptic according to the material of the object touched in VR. They conducted several experiments to express the material in the form of vibration. Five vibration motors were attached to the glove which was used to realize the vibration on the five fingers. The strength of the vibration motor can be manipulated by pulse width modulation (PWM).

Besides, they further developed an algorithm to analyze the material texture based on the image and convert it into frequency components. With the utilization of the algorithm, they can analyze the material from the image and assign a vibration strength of the motor relatively. The control system is built up by an Arduino board, Bluetooth module HC-06, and five vibration motors. The HC-06 Bluetooth module was used to send the corresponding signal to the PC.

User evaluation was conducted to investigate the user's sense of immersion. A questionnaire was distributed to users for collecting their feedback after use. The question in the questionnaire is more toward the comfortability and portability of gloves. The survey got an average score of 4.5 out of 5. In short, the use of haptic vibration can provide a realistic sense of touch and minimize the weight of the haptic glove. This concept is applicable in this project due to its size and a high degree of coordination with the Leap Motion Controller.

2.3. Comparison between Research Approaches

VR is still considered an early-stage technology, but it is a potential technology for future system integration. For example, turning a very complex and requires a high budget of training into a virtual immersive training. By completing the research over some cognitive training approaches, the results showed VR-based training provides an immersive training experience. Table 1 shows that VR-based cognitive training with supporting devices obtained a more immersive training experience.

Table 1. Comparison of Cognitive Training

	VR-training of Industrial Shutdown Maintenance	**VR-Based Cognitive-Motor Training for Middle-Aged Adults**
Platform	VR	VR, TV
Supporting Device	No	Yes (Treadmill)
Immersion	Immersive	Most Immersive
Interaction	Yes (HTC Controller)	Yes (Undisclosed)

By completing the research over some existing haptic gloves, the result showed tactile vibration with integrated VR design provided a more immersive experience. The tactile vibration glove has a lower cost and lighter weight compared with other haptic gloves. However, a soft robotic hand rehabilitative exoskeleton was specifically designed for stroke patients. The glove used the pneumatic pressurization approach to strengthen grasping force. The weight of the glove is relatively large due to the use of an actuator. Therefore, in the aspect of cost, weight, and immersion, tactile vibration is recommended to be applied in VR based integration system. Table 2 shows the comparison between haptic gloves

Table 2. Comparison between Haptic Gloves

	Soft Robotic Hand Rehabilitative Exoskeleton	**Fine Tactile Representation of Materials for VR**
Type of Feedback	Tension force	Tactile Vibration
Integration Design	No	VR
Immersion	Immersive	Most Immersive
Weight	Greater	Lesser

3. RESEARCH METHODOLOGY

This section explains the development of the VR based left brain training application and haptic glove. The section also explains how the experimental study is carried out

3.1. Design Consideration

Most of the braining training systems have faced the training adaptive and convenience problem which can cause discomfort to participants. Besides, a boring or complex training procedure may cause the participant losses their passion. Hence the time taken to complete the training will be increased and the effectiveness of brain training will be reduced relatively. Besides, a VR training system without any interaction between the real world and virtual world is difficult to immerse the participant in a situation. Moreover, cost-effectiveness, repeatability, and reproducibility of the system need to be considered as well. To resolve these problems, this paper would like to propose a VR-based left-brain training system. According to the problems stated above, some of the solutions have been figured out such as:

- Create an immersive Left Brain Training System by VR technology.
- Implement VR supporting devices such as an interactive haptic glove.
- Develop the application for the Android platform.

The VR-based brain training system aroused the users' interest and novelty to immerse themselves in training. Not only that, the feature of human hand simulation with haptic feedback will enhance the sense of embodiment of the user. To make this brain training system cost-effective, a VR application was developed for the Android platform. So, users can conduct brain training with their smartphone and mobile VR headset.

3.2. System Architecture

Figure 1 shows the system architecture of this project. The arrows represent the signal or data flow, and all the devices are connected via the corresponding terminal.

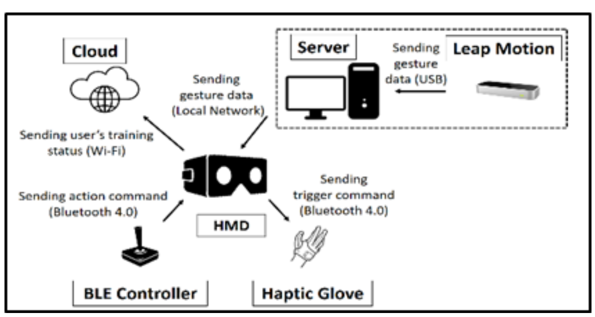

Figure 1. System Architecture

The VR-based brain training application was developed on the Android platform, named “BrainUp World”. The smartphone can be turned into a Head-Mounted Display (HMD) by inserting the phone into a mobile VR headset. The Leap Motion sensor has to mount onto the HMD, while it also needs to be connected to a PC server by using the USB cable. Besides, the HMD with installed VR application has to connect with the local network server to obtain the gesture data. The HMD and the PC that open the server must connect under the same network connection. Moreover, the developed VR application will process the gesture data and simulate a virtual hand in the virtual world. When the virtual hand is grasping the virtual object, the application will send a trigger command to the haptic glove and generate haptic feedback. A Bluetooth controller was wirelessly connected to HMD for action control. The user’s training status is observable in the application. The user can also upload their training score to the cloud for experimental study,

3.3. Haptic Glove

Computer-aided design software (Autodesk Inventor) was used to design the 3D architecture of orthosis that was used for the haptic gloves. Each designed part was printed by Fused Deposition Modelling (FDM) 3D printer. FDM is one of the popular manufacturing techniques in prototyping due to its fast-printing duration and lower cost. Figure 2 shows the schematic design of the haptic glove drawn.

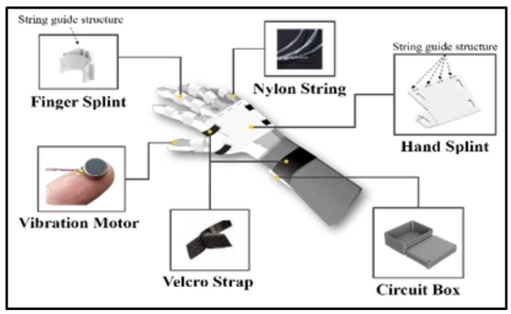

Figure 2. Schematic Design of the Haptic Glove

The designed orthosis consists of three parts: finger splint, hand splint, and circuit box. Every finger splint and hand splint were designed with a string guide structure. This allows the finger splints to be linked with hand splints through strings. The flexible string can generate tension force when the user has a grasping action. Nylon string with a 1mm diameter was selected as it can provide less tension force.

Table 3. Characteristic of different string tension

String tension	Power	Control	Durability	Feel
Low	Easy	Decrease	Increase	Increase
High	Hard	Increase	Decrease	Decrease

Table 3 shows the characteristic of different string tension. The reason for using nylon string is that it has a lower tension force. The lower tension force behavior makes it easy to control with lesser power, higher durability, and tension feel.

Every finger splint and hand splint are attached with a velcro strap. The velcro strap design allows the splint to be bounded on different sizes of hands. The side hole of the finger splint is the sewing point for fixing the velcro strap. Furthermore, the circuit box of orthosis has to be bounded on the forearm. The size of the circuit box is designed to well fit with the forearm. The purpose of the circuit box is to keep the Li-Po battery and Wemos D1 mini-module. Jumper wires are extended from the circuit box to supply power to every vibration motor.

The glove was modified into a double-layer structure. The first layer is used to place the user’s hand w.hile the second layer is used to mount the vibration motor and its connecting wire. The vibration motor and its connecting wire were fixed and enclosed to the second layer of the glove through sewing. Figure 3 shows the position of every vibration motor under the glove.

Figure 3. Vibration Motors' Position (Before Sewed)

The schematic of the haptic glove control system is illustrated in Figure 4. Wemos D1 mini module was used as a controller unit. It supports Wi-Fi and Bluetooth connection which is suitable in wireless project design. The most fascinating feature of the module is its size. After a survey, their size is the smallest among the microcontrollers with the same feature in the market. The size of the microcontroller is important so that it can be mounted on the user's forearm without any burden. Moreover, a 3.7V rechargeable Li-Po battery was used as a power source for the control unit and vibration motors. The part was designed to be as small as possible to maximize its portability. The size and weight of the circuit box are about 1.8cm × 4.8cm × 2.0cm and 57g respectively.

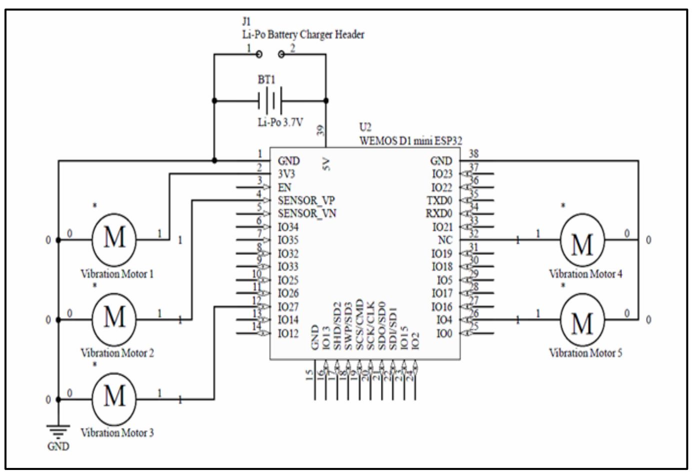

Figure 4. Schematic Diagram of Haptic Glove Control System

3.4. BrainUp World Left Brain Training Application

The VR-based left brain training application was named "BrainUp World". This name reflects the core objective of this application which is to train the brain in a VR world. This software is developed by using Unity engine and visual studio.

App Navigation Design: Navigation design consists of information architecture, interaction architecture, and user interface mapping. Figure 5 shows a user interface (UI) map that was created to support the construction of app navigation design.

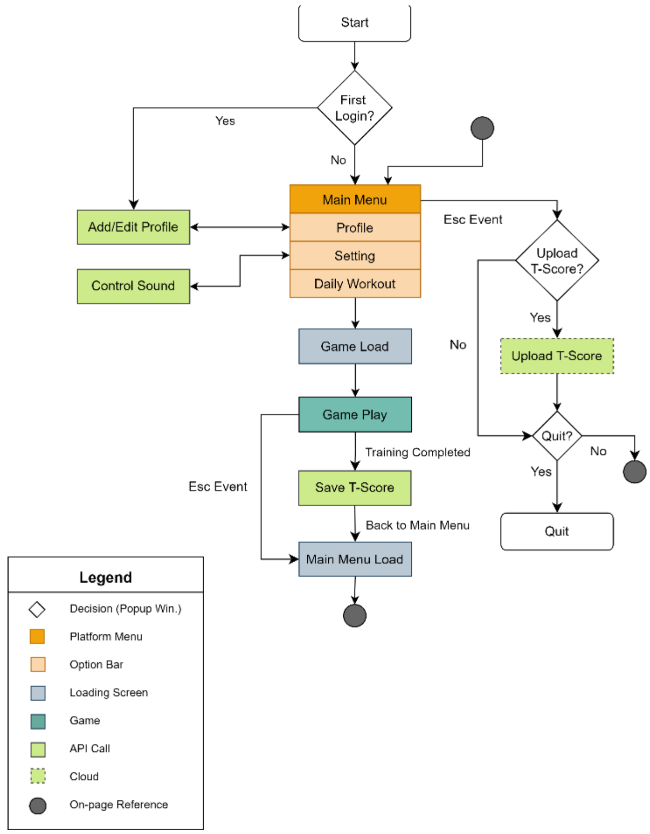

Figure 5. UI Map for Overall Navigation

The UI Map presented the navigation path of the whole application. The interaction architecture has been constructed through the event listener. Every component on the interface is interactive and has its destination. In this case, the user is unable to trigger any event because the phone is inserted in the HMD. The phone's screen is enclosed which cannot be touched. That's why a wireless controller is needed for navigation. Once the event listener detected an event from the controller, the application will run the assigned function from the script like switching the scene.

To make wireless controllers collaborate with the VR application, a reticle pointer from Google VR SDK has been used. There is a reticle pointer located at the center of the screen. The reticle pointer can be expressed like an invisible laser, and it will extend until it meets a target. When the pointer targets an object, it will expand into a circle for indication. Meanwhile, the user is required to press the confirm button from the controller to confirm the selection. The application will only be triggered when it receives the reticle point on-select event and the button press event from the controller.

The reticle point is always located at the center of the screen. It can target every virtual object under the vision. The visual orientation in the virtual world is synchronized in the real world. When the user moves their head around, the sensors (gyroscope) in the phone simultaneously detect head movements and translate them into the virtual world. This feature allows users to target every virtual object by moving their heads or looking at the target object.

Attention Training: Attention training mainly trains a person's ability to resist distracting information while solving the main task. Therefore, the training was designed in the following way. For example, such a task may require participants to read a letter (e.g. "Red") while its letters may be painted in a different colour (e.g. "Blue"). The participant needs to identify the word as "Red" and resist identifying it as "Blue". The participant has to pay attention to the colour of the displayed word, or its meaning without getting distracted. Figure 6 shows the sample question given during attention training.

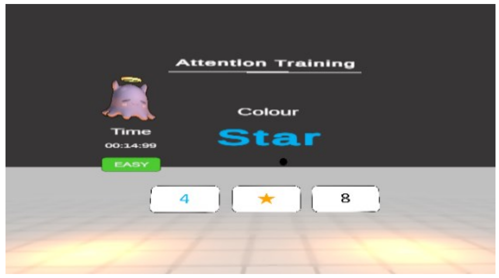

Figure 6. Sample Question in Attention Training

Figure 7 illustrates the overall flow of attention training, which is divided into three levels of difficulty. As the difficulty increases, so does the level of distraction presented during the training. In this context, 'Q' denotes the question number, while 'GLvl' represents the game level within the training.

At the first level, participants are presented with fixed questions, alternating between queries regarding color and meaning over three rounds. This structured approach makes the questions relatively easier to process due to their consistency. Moving to the second level, questions become more challenging as they randomly switch between color and meaning. The introduction of distraction elements, such as the word 'Star' highlighted in blue in Figure 6, adds complexity to the task. In the second level, distraction elements are fewer and less closely related to the meaning or color of the incorrect answer (e.g., '8'). However, in the third level, the number of distraction elements increases, and they become more closely aligned with the meaning or color of the incorrect answer (e.g., 'star shape with orange color')."

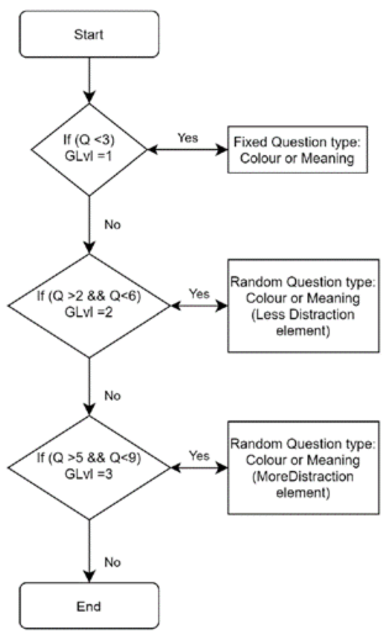

Figure 7. Flowchart of Attention Training

An automatic question-answer generation system has been created to support the framework of the training application. The objective of this system is to generate random questions without repetition during training. The random question will automatically pair with a goal answer as well.

Reasoning Training: Reasoning is referred to a skill that can support conclusions with logical reasons and evidence. Reasoning skills are important in comprehending, measuring, and accepting claims and arguments. Therefore, the reasoning training designed exercises the user's logical reasoning by placing the object in the right order. The hints will be given during the training. Users were allowed to select their preferred device to complete the training. The devices included a computer mouse and a haptic glove. If the computer mouse was selected, the user can pick up the object through the mouse or controller. However, it will require the user to open server software and connect the leap motion to the PC. The procedure to set up the connection will be discussed in the next section. Figure 8 shows the scene of reasoning training in medium difficulty.

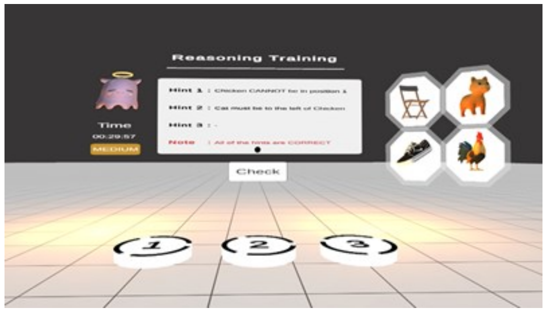

Figure 8. Scene of Reasoning Training

The user needs to place the correct object in the answer slots with a correct sequence. The hint is given to lead the user to place the correct object in the relevant answer slot. Users will use their reasoning skills to assume based on the hints given. The reasoning training is also divided into 3 difficulties. The number of answer slots is increased from 2 to 4 according to the training difficulty.

Auditory Cognition Training: Auditory cognition refers to the ability to receive and interpret information heard from the ears. The left-brain thinker is always good at understanding language, learning, and remembering verbal information. Therefore, auditory cognition training was designed to train user auditory perception by distinguishing the direction, intensity, and tone of a sound clip. The training is also divided into 3 difficulties.

In the first level of training, the user needs to recognize where the direction of the source sound comes from. The second level is sound intensity recognition training. There are two sounds played in different volumes. The user needs to differentiate which sound has higher volume or lower volume. The third level is tone recognition training. There are two different tones of sound (e.g. 200Hz & 210Hz) played, and the users will distinguish both options according to the question asked.

Arithmetic Training: Arithmetic training was developed as well to train a person's ability in calculation. Arithmetic skills are often used in daily life like giving customers the correct change or calculating discount price. Therefore, the training was designed to train users' basic arithmetic skills. The user will be asked to find the number pair that completes the equation. The sample question that will be asked in arithmetic training is illustrated in Figure 9.

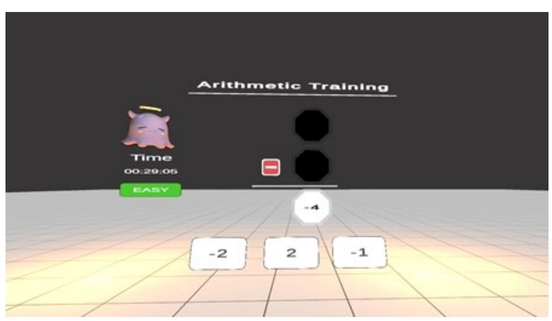

Figure 9. Scene of Reasoning Training

The training is divided into 3 difficulties while each difficulty includes 3 questions. To make the training more challenging, the difficulty is increased by question. The difficulty depends on the range of the randomly generated answer and operator. The bigger the range gap, the higher the number will be generated in the equation.

Memory Training: Memory training was developed to train a person's working memory and spatial recall skills. First, the training will generate a total of 9 interactive boxes. When the training starts, certain boxes will change colour, while the participant has to remember which boxes have changed colours. Then the participant needs to recall back and select the correct boxes. In the hard difficulty of training, the boxes will change colour in sequence, so that the participant has to remember the sequence as well. Figure 10 shows the scene of memory training.

Figure 10. Scene of Memory Training

The training was divided into 3 difficulties and each of them had 3 questions. In easy level, the program will show all the coloured boxes at one time. For medium level, the program will show the coloured boxes one by one with sequence. The coloured boxes will remain until all coloured boxes are shown. In hard difficulty, every coloured box will show up after about one second and turn back to the default colour.

Sequencing Training: Sequencing training is the last in the application. The sequencing training is aimed to train a person's planning ability. The rule of the training is that the user needs to connect all the nodes with only one stroke. The scene of sequencing training is illustrated in Figure 11.

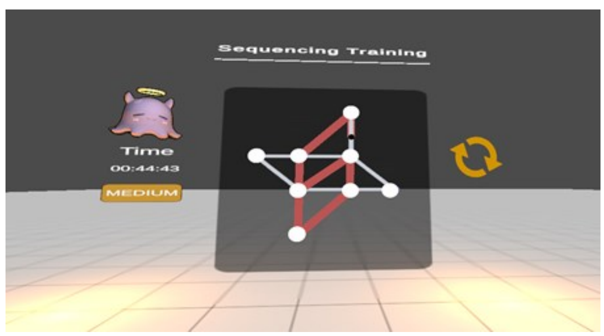

Figure 11. Scene of Memory Training

The question presented during the training is a photo. In the script, pre-programming is needed to record down all the locations of the nodes. When the question shows up, the photo will be presented, and every node will be covered by an interactive button. These buttons are arranged according to the location of the nodes recorded. Besides, if there is a button pressed, a red line will be rendered and follow the movement of the reticle pointer. Users may move their head to control the line movement. If there is another button pressed, a link will form between these two nodes and a new line will be generated and start at the last selected node.

The working principle of the program can be described as follows. First, each node from the photo was assigned a number. Every node has linked with another node and these linked nodes are denoted as children. Next, every node has a list to record its children's numbers. The node link diagram was illustrated in Figure 12.

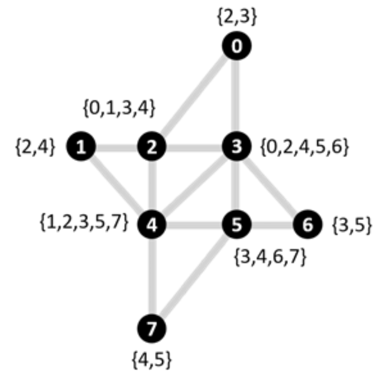

Figure 12. Node Link Diagram

These lists were becoming a reference for checking whether the connection is right or wrong. For example, if a user tries to connect node 0 and node 7, but the list of nodes 0 does not contain the child of 7, thus the program will refuse the connection. However, if the user connects node 0 and node 2, the program found that both lists have the number of each other's nodes, thus the program will allow the connection. Then, both numbers in the corresponding list will be removed. This means that the same connection can only be connected once.

This mechanism established the rule that allows the user to complete the connection with only one stroke. This rule has increased the difficulty of training which well-trained the user's plaining skill

3.4. PC Local Network Server

A PC or laptop was needed in this system to set up a local network server. This server is responsible for bridging the connection between the Leap Motion sensor and the developed mobile VR headset. Figure 1 shows the connection bridged between the Leap Motion sensor and a local network server used to transfer hand gesture data. The Leap Motion sensor first will capture the user's hand gesture through an IR camera. Then the captured image is sent to the PC through USB. The Leap Motion official software will convert these images into gesture data in the background. Therefore, a local network server software was developed to transfer these gesture data wirelessly to the phone VR application. A dynamic link library (DLL) called Coloreality.dll [18] was implemented into the development. At the recipient site (VR application) need to apply the prefab of Coloreality as well. The Coloreality prefab is mainly used to receive gesture data. In the end, these gesture data will be used for virtual hand simulation.

This software shows the connection status of Leap Motion with PC and server on GUI. The GUI will also show the host's IP address and the Port number. Any client who is going to connect with the host server needs to connect themselves with that IP address and port number. The server software also allows users to change the interval for gesture data transfer. Moreover, users can further fine-tune the simulation of virtual hands by scaling and modifying the position offset of virtual hands from PC server software. These offset data will be sent to the application and apply the change in virtual hand in real-time.

3.5. Experimental Study

An experimental study was carried out to investigate the differences between PC and VR-based training (Figure 13). This study applied a quasi-experimental research design to determine the differences between PC-based and VR-based training. There were 14 participants invited to participate in this experimental study, in which eight of participants were 10-23 years old, four of participants were 25-38 years old, and two of participants were 46-59 years old. User consents were collected before starting the experiment. Most of the training procedures are conducted in a contactless manner. This experiment was conducted over 3 weeks. The participants were divided into 2 groups, while each group was given different treatments.

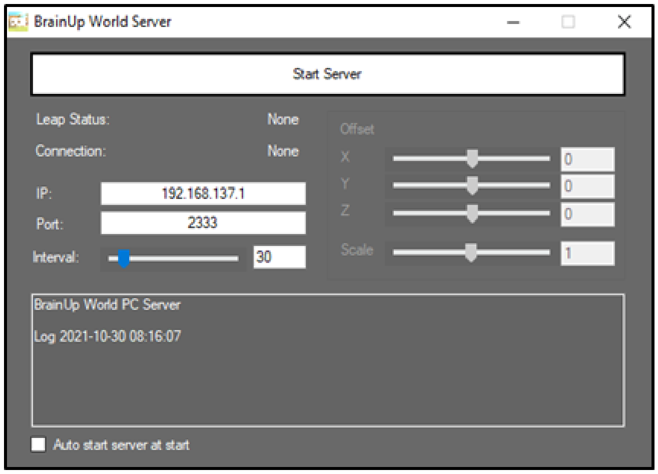

Figure 13. BrainUp World server software

For group A, participants need to conduct their training. The download link for the PC version of BrainUp World software was given. They will have to install it on their PC. For group B, all the devices including the VR headset, haptic glove, and controller were prepared for them before the training started (see Figure 14). They are given the same training duration, which is around 45 minutes. In this training session, they are required to get familiar with all the training. In the training assessment session, the participants will have to rerun all the training. Retry is not allowed during the assessment session. At the end of the training, a short interview was conducted. The participants had to answer the questionnaire that addressed their training experience.

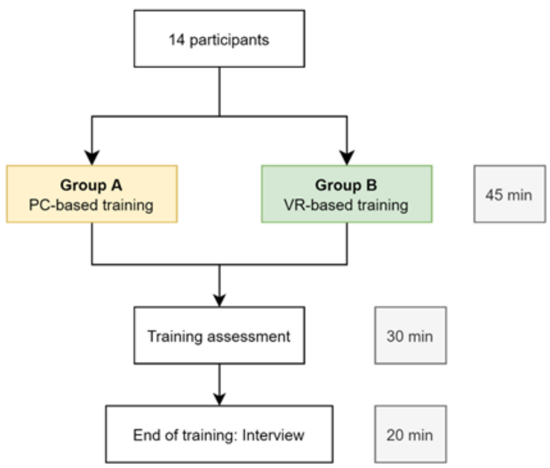

Figure 14. Experimental Design

4. RESULTS AND DISCUSSIONS

The prototype of the VR-Based Left-Brain Training System is illustrated in Figure 15. The overall size of the VR Headset is 14cm (Length)× 18cm (Width)× 11.5cm (Height). The main material of this VR headset is hard plastic and cushion. Figure 16 shows the ongoing VR-based left-brain training with the proposed VR system.

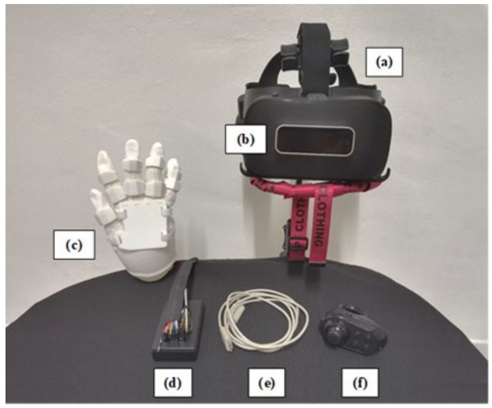

Figure 15. Prototype of VR-Based Left-Brain Training System (a) VR Headset (b) Leap Motion (c) Haptic Glove (d) Circuit Box (e) USB Cble (f) Bluetooth Controller

Figure 16. The Participant Using The Proposed VR System

4.1. Differences Between PC and VR-based Training

After three weeks of training have conducted, each participant's training report was constructed. The participants' reports are included in the appendix. The report calculated the mean score over these training weeks and examine the growth of T-score (Training Score) from the slope. Table 4 shows the T-score growth of every participant. The mean scores for the three weeks are detailed in the Appendix section.

Table 4. T-score Growth of Participant

	Age Group (yrs)			Mean
Training Group	10-23 yrs	25-38yrs	46-59 yrs	Growth
A(PC-based)	9.42	2.00	3.08	6.12
	9.75	3.75		
	8.33			
	6.50			
B(VR-based)	10.00	10.92	3.42	10.85
	12.67	7.75		
	14.42			
	16.75			

The total number of participants aged 10 to 23 years, 25 to 38 years and 46 to 59 years are 8, 4, and 2 respectively. To balance the training output of both groups, the participants were grouped evenly based on their age. As result shown in Table 4, the mean growth of PC-based and VR-based approaches are 6.12 and 10.85 respectively. The overall mean growth can be illustrated by the graph. Thus, the mean score for each training group per week was calculated. The mean growth for Training Group A and Training Group B is obtained by calculating the average scores for the 10 to 23 years, 25 to 38 years, and 46 to 59 years age groups, and then averaging these three values. Therefore, it is able to observe the significant gap in mean growth between Training Group A and B.

Figure 17 shows the overall changes in training performance of both training groups within 3 weeks. A trend line was created to form their linear equation. The differentiation of linear equations can determine the growth of the training performance of both training approaches across the weeks.

From the result shown in Figure 17, the participant who participated in PC-based training has obtained a 6.12 T-score (Training Score) growth for every training week. However, the participant who participated in VR-based training had a 10.85 T-score growth for every training week. This means the VR-based training obtains higher growth in training performance. This also can be inferred as PC-based training is easier to control which makes the initial training score higher. However, the training score obtained in week 3 for both training approaches is quite close. It was probably because of the experiment's ceiling effect

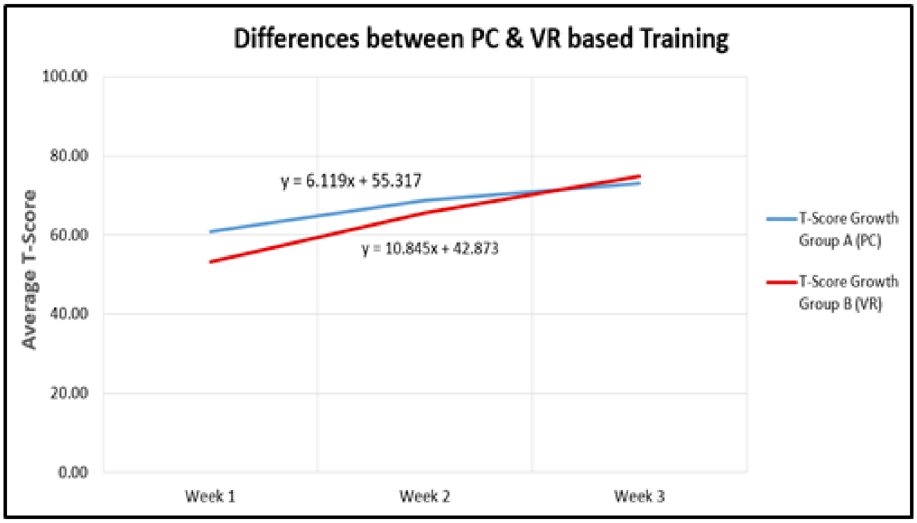

Figure 17. T-Score Differences

To further prove that VR-based training is better than PC-based training, an analysis tool called ANOVA was used. Analysis of variance (ANOVA) is commonly used to check whether two groups of data are significantly different from each other. Even though the T-score growth obtained from the mean calculation shows that VR-based training is higher than PC-based training, there is no standard provided to further prove the statement. Thus, ANOVA was used to prove or disprove whether VR- based training is more effective than PC-based training. This method can prove whether the sample groups are significantly different, by determining the p-value. If the p-value is less than the alpha level selected (0.05), it means a significant difference exists between the sample groups.

A one-way ANOVA was performed within group A and group B. Since, the participants were divided equally by age. Therefore, one-way ANOVA was used instead of two-way ANOVA. The steps for using ANOVA can be described as:

Step 1: Computer the Variance Between

$$SS_{between} = \sum n(\bar{x} - \bar{\bar{x}})^2 \quad (1)$$

Step 2: Computer the Variance Within

$$SS_{within} = \sum\sum (x - \bar{x})^2$$

$$S^2{}_{within} = \frac{SS_{within}}{n - k} \quad (2)$$

Step 3: Compute the Ratio of Variance

$$F = \frac{Variance_{between}}{Variance_{within}} \quad (4)$$

After F-ratio was computed, the p-value can be determined by using F-tables (k= 2, n= 14). Hence, if the p-value is smaller than the alpha level (0.05), it means a significant difference exists between the sample groups. Figure 18 shows the ANOVA report created by excel.

Anova: Single Factor

SUMMARY

Groups	Count	Sum	Average	Variance
PC-based Training	7	42.8	6.12	10.15
VR-based Training	7	75.9	10.85	19.4

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	78.26	1	78.26	5.3	0.04	4.75
Within Groups	177.34	12	14.78			
Total	255.6	13				

Figure 18. ANOVA Report

The factor of this ANOVA test is training approaches. As the highlighted cells in Figure 18 show, the p-value is smaller than the alpha level set (0.05). Besides. The F-value is higher than the F-critical values. This means that the factor has a significant effect on participants' training growth.

At the end of the training, the participants in group B were required to complete a questionnaire. The questions are described as in Table 5.

Table 5. Details of Questions for Group B

Questions	Details
Question 1	To give a rating according to the VR-based training experience.
Question 2	About whether the haptic glove is convenient to use.
Question 3	To rate the authenticity of the haptic glove based on its vibration intensity.
Question 4	About whether the question is easy or hard, and rate it according to the difficulty.
Question 5	Whether this proposed training helps you to improve your performance in daily life.

The first questionnaire question is to get the user feedback about the training experience by using VR whether the user is enjoying it or not. The second questionnaire question to get the user feedback about the haptic glove if it is suitable for the user to use. The third questionnaire question is to gather user feedback about the vibration intensity of the haptic glove when interacting with objects in VR, aiming to assess the realism of the haptic experience. The fourth questionnaire question assesses whether the in-game questions are too difficult for user to solve so the future work can increase or decrease the question difficulty. The fifth questionnaire question assesses the user improvement after using the VR application.

The result of the questionnaire is shown in Figure 19. Question 5 received the highest rating, which is around 4.8 out of 5. This means most participants in the questionnaire agree that the proposed training helps them to unleash their potential.

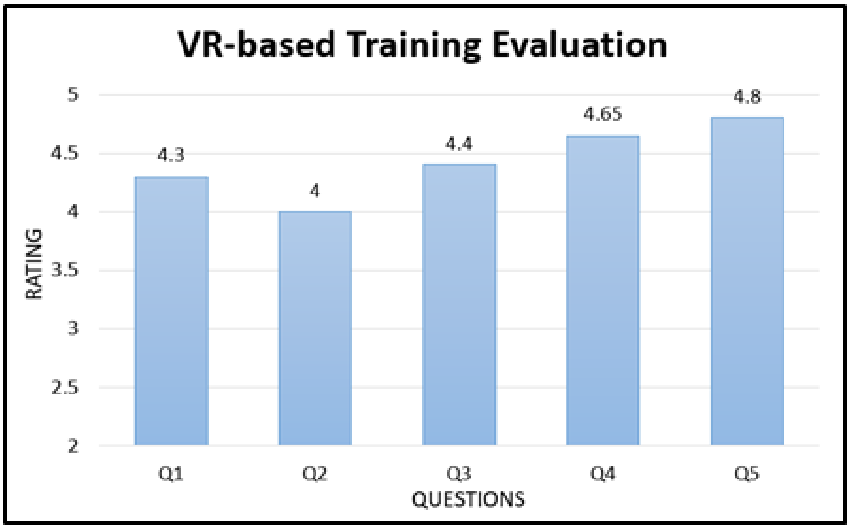

Figure 19. VR-based training evaluation on Group B

4.2. Age-related Differences in Learning

Therefore, this study aimed to determine age-related differences in attention, reasoning, auditory cognition, arithmetic, memory, and sequencing training. The data was collected from the same experimental group shown in Figure 14 earlier. In this study, the experimental group was no longer divided according to the training approach.

Figure 20 and Figure 21 show the result of the study. It clearly shows that a person's skill is decaying with age. The training score was calculated based on the accuracy and the response time of participants in answering questions. In the process of data analysis, it is found that the response time for the elder person is longer than the young person. This can be inferred as aging does affect the fluency of thinking.

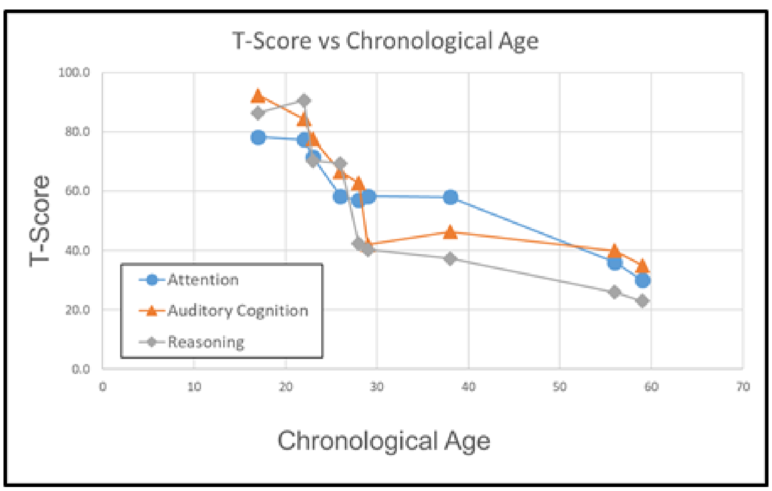

Figure 20. Age-related Differences in Left Brain Training 1

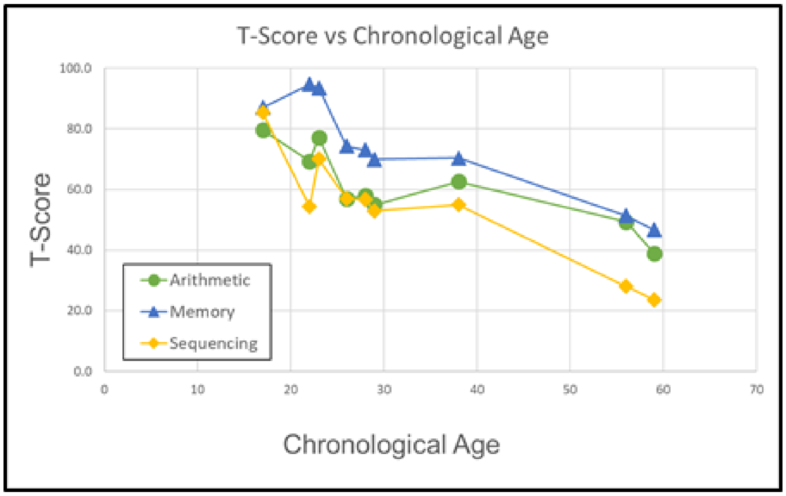

Figure 21. Age-related Differences in Left Brain Training 2

Overall, the result is not consistent with the prediction made initially. Since the elder adults were well performed in auditory cognition training. This can relate to the scoring system of the training. As mentioned earlier, accuracy and response time are carrying half of the mark respectively. During auditory cognition training, the time used to answer the question is relatively less, because the question asked is quite direct.

To further analyse the age-related difference in training, a quadrant chart was created to observe the overall training performance as shown in Figure 22. The dots represent the overall training performance obtained from the population of corresponding age. The x and y-axis are denoted as response time (s) and T-score respectively. From the chart, the performances of young adults are accumulated under the first quadrant (High Accuracy & Fast Response). Middle-aged adults show high accuracy and slow response. However, the performances of older adults fall under the last quadrant (Low Accuracy & Slow Response). There is a downward trend obtained from the result. The trend had concluded that the higher the age, the lower the accuracy, the longer the response time.

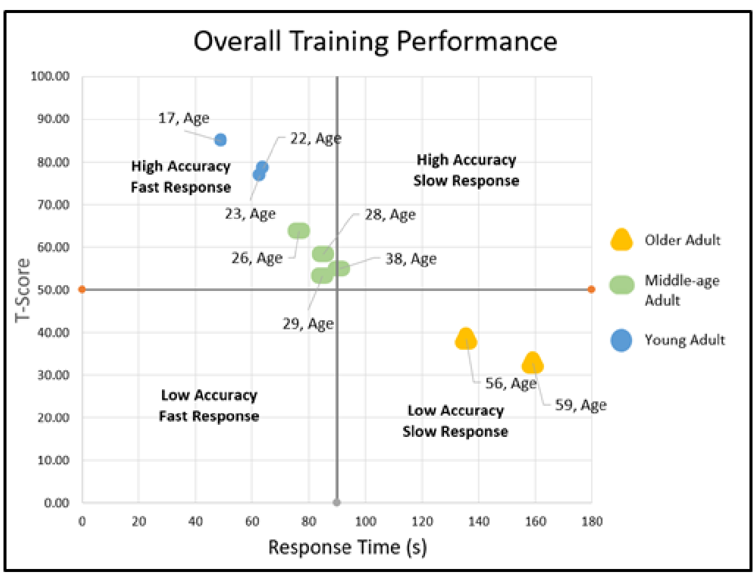

Figure 22. Overall Training Performance

4.3. Limitation

While the research offers valuable insight into performing brain training using VR system, certain limitations needed to be described. First, the study lacks specificity regarding the target participant demographic. This poses a limitation in ensuring the societal acceptance of the developed product. While our study did not define a specific user group, we recognize the importance of ensuring developer build system that can be acceptable by society for successful product adoption. Future research will aim to better define the target user demographic to improve the relevance and acceptance of the developed product within society. Secondly, the distribution method employed in this study did not explicitly consider the cognitive aspect of participants. This could have impacted on the balance of distribution and introduced potential biases in the measurement of results. Future research could benefit from incorporating cognitive factors into distribution strategies to enhance the fairness and representativeness of findings.

Another notable limitation concerns the reason the questionnaire was only used on Group B participants, rather than Group A. It's important to note that this study exclusively focuses on VR-based brain training. As such, the questionnaire and evaluation metrics were tailored primarily for participants undergoing VR-based training. We found that this limits the generalizability of the findings to other training modalities, such as PC-based training, and may restrict the applicability of the study's conclusions to a broader context. Future research needs to incorporate questionnaires for Group A to develop tailored questionnaires that align more closely with specific experiences and contexts of participants in different experimental conditions. Addressing these limitations will contribute to the development of more effective and widely accepted VR-based brain training systems

5. CONCLUSION

This paper has presented the design of a VR based left brain training system. The training application was developed on the android platform so that users can conduct brain training with their smartphone and mobile VR headset. The VR application had created 6 different games to test a person’s attention level, reasoning skill, auditory cognition, arithmetic skill, sequencing skill, and memory. Besides, an experimental study was conducted to evaluate the effectiveness of the proposed training approach.

A low-cost and lightweight haptic glove was invented which provides the sense of touch using vibrations while interacting with the virtual object. A survey was conducted to investigate the authenticity of the haptic feedback. It received an average rating of 4.4 out of 5 from the survey. The participants agreed with the necessity of the haptic glove which can bring the VR experience to a new level.

There was some implementation been changed for better functionality and performance. For example, the flex sensor was initially used in a hand tracking system. After several accuracy testing, this method was changed to use the Leap Motion sensor. Leap Motion sensor provided a higher accuracy rate in object grasping.

The experimental studies were conducted by using the proposed system. In the first experimental study, the difference between PC and VR-based training approaches was investigated. A VR-based training approach obtained 4.73 higher T-score growth for every training week. ANOVA analysis tool proved (p-value = 0.04) VR-based and PC-based training approaches are significantly different. In the second experimental study, the age-related difference in learning was investigated. The result shows, a person’s skill is decaying with age, and aging does affect the fluency of thinking

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AUTHOR CONTRIBUTIONS

Kok An Teo: Conceptualization, Data Curation, Methodology, Validation;
Kok Swee Sim: Project Administration, Supervision,
Chean Khim Toa: Writing – Original Draft Preparation;
Kai Liang Lew: Writing – Review & Editing.

CONFLICT OF INTERESTS

No conflict of interests was disclosed.

ETHICS STATEMENTS

Human subjects are involved and given consent before start of the experiment

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APPENDIX

Table A.1: Mean Scores at 1st Week

Training Group	Age Group (yrs) 10-23 yrs	25-38yrs	46-59 yrs	Mean Score (1st week)
A(PC-based)	68.17	56.17	35.33	60.86
	72.17	48.33		
	69.50			
	76.33			
B(VR-based)	75.83	53.17	29.33	53.24
	64.17	47.00		
	58.67			
	44.50			

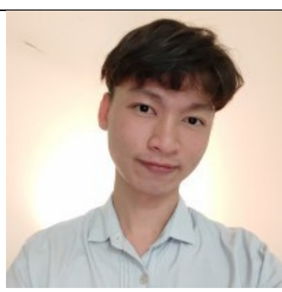
Table A.2: Mean Scores at 2nd Week

	Age Group (yrs)			Mean Score
Training Group	10-23 yrs	25-38yrs	46-59 yrs	(2nd week)
A(PC-based)	80.17	58.50	38.50	68.71
	84.50	55.17		
	75.83			
	88.33			
B(VR-based)	82.83	63.17	33.17	65.52
	76.00	55.33		
	81.83			
	66.33			

Table A.3: Mean Scores at 3rd Week

	Age Group (yrs)			Mean Score
Training Group	10-23 yrs	25-38yrs	46-59 yrs	(3th week)
A(PC-based)	87.00	60.17	41.50	73.10
	91.67	55.83		
	86.17			
	89.33			
B(VR-based)	95.83	75.00	36.17	74.93
	89.50	62.50		
	87.50			
	78.00			

BIOGRAPHIES OF AUTHORS



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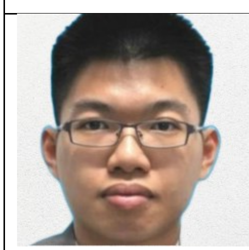	**KAI LIANG LEW** received the B. Eng.(Hons) degree and M.Sc. in Engineering from Multimedia University, Malacca in 2019 and 2022 respectively. He is currently taking Ph.D. degree in engineering in Multimedia University. His research interests include rehabilitation, deep learning and signal processing.