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The Effects of Two Game Interaction Modes on Cortical Activation in Subjects of Different Ages: A Functional Near-Infrared Spectroscopy Study

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ABSTRACT Increasing age and various pathological factors lead to cognitive function decline among the elderly. The most serious cognitive dysfunctions among the elderly include mild cognitive impairment (MCI), Alzheimer's disease (AD), and vascular dementia (VAD). Cognitive training is an effective approach to mitigate the decline in cognitive function. Recent studies have confirmed that emerging training methods using new technologies, such as virtual reality (VR) and mobile phones, can be used effectively for cognitive training. This study used functional near-infrared spectroscopy (fNIRS) to compare the brain activation of young and elderly people during VR and mobile phone training when performing a cognitive training game. fNIRS has been shown to be an effective tool for monitoring cognitive decline. In the current study, the MMSE scale was used to measure cognitive performance and fNIRS was used to measure brain activation among 20 youth (mean age 25.33±1.59 years) and 17 elderly people (mean age 63±4.35 years). The results showed that the mobile phone game produced significant activation of the prefrontal lobe (PFC) and the VR game produced significant activation of the parietal lobe (MC). The average MMSE scale score of the elderly group was lower than that of the young group and was strongly correlated with PFC activation. This study confirms that elderly people have reduced cognitive function compared to young people. The results indicate that mobile phone games have a positive training effect on reducing cognitive decline, and that VR is a suitable means for cognitive function training among the elderly.

INDEX TERMS Virtual reality, functional near-infrared spectroscopy, cortical activation, game experience, cognitive decline.

I. INTRODUCTION

With the rapid increase in the global aging population, the number of people over the age of 60 is predicted to double in 2050 from 900 million in 2015, and the global percentage of people aged over 60 is predicted to increase from 12% to 22% [1]. The decline in cognitive ability that sets in with aging is a major challenge faced by the elderly. Based on the degree of cognitive decline, many elderly people will end up suffering from mild cognitive impairment (MCI), Alzheimer's disease (AD), vascular dementia (VAD), or other cognitive impairment symptoms. Cognitive ability is a generalization of multiple cognitive fields and their interactions [2]. Moreover, cognitive decline may be the result of damage to multiple fields or to a specific field. The extent of damage is different, and the decline in cognitive ability changes accordingly. Existing experimental studies have examined age-related decline in multiple cognitive domains, including attention, memory, response, and learning [3]–[5]. With the aging population, the scale of cognitive decline among the elderly is predicted to increase. To date, an effective system or model for cognitive training has not been developed, with the current approaches relying on repetitive traditional training methods that focus on memory and attention. With emerging technologies such as virtual reality (VR) and smartphones, there exists a potential for

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cognitive training models to break from tradition and harness new development opportunities.

VR technology is a computer simulation technology that enables people to enter and experience complete immersion in artificially-created virtual worlds. In recent years, VR has developed rapidly, with the emergence of 5G high-speed transmission, the Internet of Things, artificial intelligence, mobile high-performance graphics computing, and other technologies [6], [7]. At the same time, the application of VR in the field of brain function training has attracted increasing attention [8]. Compared with traditional rehabilitation, VR is a multisensory, pleasant, and targeted training method. A recent study demonstrated that an intervention using VR technology was beneficial for the rehabilitation of patients with cognitive dysfunction and movement disorders [9]. Moreover, in an experimental study [10], a wireless functional near-infrared spectroscopy (fNIRS) instrument was used to evaluate a VR neurorehabilitation system. This study found that the VR neural network neurorehabilitation system could activate the action observation system. In clinical treatment, many doctors have also begun to use sensory stimulation in VR as a tool to perform targeted brain training [11]. Together, these studies highlight the potential of VR technology and the unlimited possibilities for cognitive function training.

With the popularization of the Internet, people's dependence on smartphones has surpassed that on traditional PCs. Mobile phones are no longer just used for communication and entertainment [12]. Although research on the use of mobile games for cognitive function training was slow to take off, over the past few years, a large number of mobile games have been developed to assist with cognitive function training. For example, one experimental study reported that the combination of cognitive and sports rehabilitation training was more effective than either alone [13]. Further, mobile phone games have been reported to significantly alleviate cognitive decline [14]. Although several existing studies demonstrate the utility of mobile games as a means of cognitive function training, it is still necessary to investigate their rationality and influence of mobile phone games. While many studies have shown a positive impact of VR and mobile games on cognitive training, the existing research lacks objectivity, physiological evaluation of the brain, and evaluation of cognitive training in young and elderly people. An objective data collection and evaluation system will provide empirical support for the development and design of cognitive games.

Various neuroimaging technologies are available for detecting physiological changes in the brain, including magnetic resonance imaging (MRI), electroencephalography (EEG), positron emission tomography (PET), and single photon emission tomography (SPECT). In order to detect the effect of VR games and mobile phone games on brain activation, the current study used fNIRS. Compared with other existing brain imaging technologies, fNIRS is not sensitive to fake and inferior motion trajectories, can be used on various people in various situations, and is conveniently mobile [15]. It is a new type of brain imaging technology based on the neurovascular coupling mechanism; it detects the relationship between the metabolic activity of neurons and the oxygenated hemoglobin content in blood vessels. It employs the information obtained on the changes in oxygenated proteins and deoxygenated hemoglobin in the cerebral cortex to describe brain activity [16]. Furthermore, fNIRS has been shown to be one of the safest and most reliable tools for brain function neuroimaging and has been widely applied in the field of human brain function research [17].

Although relevant studies have confirmed that emerging training methods such as VR and mobile phones have a relatively perceptible effect on the recovery of cognitive functions, many challenges still persist. First, games for cognitive training are still in their infancy and there is no standard training process. Second, the current evaluation of the effects of these training methods is not accurate enough to form a corresponding evaluation system. Third, the existing training methods do not distinguish between the cognitive training needs of people of different ages and cannot be used to conduct targeted training.

To address these gaps, the current study used fNIRS technology to examine the effects of VR games and mobile games on young and old people, focusing on the cognitive (prefrontal cortex; PFC) and motor (motor cortex; MC) areas of the brain. Cognitive function and differences activated in the brain regions during the performance of the two games were compared between the two groups of subjects. We made the following predictions.

(1) Mobile phone games may produce a stronger activation of the cognitive area (PFC) than VR games, and the functional connection strength of each brain area may be stronger when playing mobile games than when playing VR games. VR games may produce stronger activation of the MC than mobile phone games.

(2) The training effect of mobile phone games may be greater in youth and VR may be more effective for cognitive training of the elderly.

(3) There may be differences in the activity of the cerebral cortex with age, as reflected in the cognitive decline among the elderly.

Cognitive decline among the elderly is an early symptom of AD; hence, early intervention training is particularly important. The aim of this study was to determine the game methods that are most useful for the elderly, so that targeted training of cognitive function can be conducted to improve the cognitive status of the elderly.

II. MATERIALS AND METHODS

A. SUBJECTS

20 healthy young people and 17 healthy elderly people were recruited for this experiment. None of the subjects suffered from any cardiovascular or cerebrovascular diseases, neurological diseases, mental diseases, or other motor dysfunctions. The subjects displayed no symptoms of 3D vertigo. Information on the sample is provided in Table 1. Before the

TABLE 1. Summary of sample information.

Parameter	Youth Basic information	The aged Basic information
Age（years）	25.33±1.59	63±4.35
Height（cm）	172.11±8.04	165.93±6.82
Weight（kg）	70.94±15.77	67.26±7.99
Body mass index	23.73±3.97	24.55±2.50
MMSE score	27.81±1.07	26.33±0.94

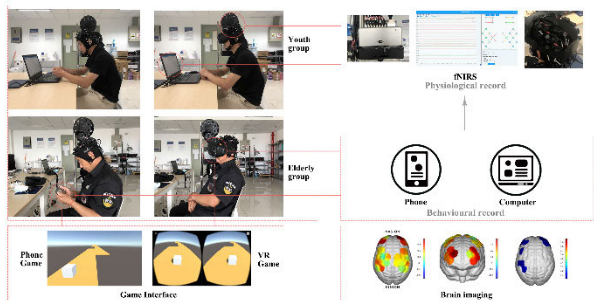

FIGURE 1. Flow chart of the experimental set-up.

formal experiment, the participants were familiarized with the experimental content and process. Due to head movement or noise from thick hair affecting the signal light of the probe, data from 4 young and 2 elderly subjects were abnormal and were, therefore, excluded from the study. The data from the remaining 31 subjects were analyzed. The research was conducted in the Design Research Laboratory of the School of Mechanical Engineering, Shandong University. All subjects agreed to participate and signed an informed consent form. The research was approved by the Academic Ethics Committee of Shandong University and the study was conducted in accordance with the ethical standards stipulated in the 1975 Declaration of Helsinki (revised in 2000) [18].

B. EXPERIMENT GAME AND VR EQUIPMENT

It is now known, from studies, that game players are better than non-game players in cognitive abilities [19], including attention, memory, and calculation abilities [20], [21]. Although action video games can improve cognitive function more overall, different types of games correspond to training specific areas of cognitive function. The game type designed in this paper is based on the perspective of the first person to carry out the role-playing game of moving and avoiding obstacles. The running speed is accelerated with the passage of playing time, and the number of obstacles increases. Through visual stimulation, the player's attention, judgment, and analytical ability are obviously trained.

We designed the Avoid falling game (Afg) to be compatible with two interactive technologies—mobile phones and VR. The main task in the game is to control the blocks to maintain normal progress, avoid missing the ground, and prevent falling. The specific operation steps of the VR version of the Afg and the ordinary mobile version are discussed next. The VR version of the game is played by inserting the corresponding VR glasses into the mobile phone. The participant shakes their head to the left or right to move the game character left or right, respectively. For the mobile phone version, both hands are used to control the phone with gravity sensing to play the game; the character is moved left or right by tilting the mobile phone left and right with both hands.

The VR equipment used in this study was the VRG brand (Haofengyuan Technology Co., Ltd.), which supports 5.7-inch smartphones and myopic users below 800°. The equipment dimensions are 190 mm × 100 mm × 110 mm. The product functions with both glasses and normal vision. The dual adjustment system interactively adopts remote control through a combination of hand and head control. The mobile device used was a Huawei brand Meta8 model, with a 6-inch FHD screen, an Android operating system equipped with a Kirin 950 processor, and a 4000 mAh super-capacity battery to maintain long-term battery life. The experimental setup is shown in Figure 1.

C. EXPERIMENTAL PROCEDURE

The fatigue in the task may have a certain impact on the experimental results. Moreover, according to related research [22], the stability of data can only be ensured when the static state exceeds 5 minutes. In order to better avoid fatigue among the participants due to the long task duration, this experiment set the total task duration of each stage to 7 minutes and 20 seconds and provided the subjects with sufficient rest during the interval between the two tasks to help them recover their mental and physical calm.

This experiment was divided into two phases. Each phase involved a 440 s paradigm experiment. In both phases, the subjects were required to wear earphones (Apple Airpods pro), with the earphones on noise reduction mode throughout the experiment. It was also necessary to maintain a quiet environment and ask the subjects to reduce the frequency and amplitude of physical movements in order to reduce noise in the fNIRS signal. Before the experiment, the subjects were trained to use the equipment proficiently and the researchers ensured that they understood the experimental process. All subjects were required to sit in a relaxed position to calm their mood and complete the MMSE scale. Then, the mobile game experiment phase was carried out. For this phase, the subjects wore the fNIRS equipment and earphones and then performed the experimental paradigm (rest 20 s, play 40 s, rest 20 s) seven times. After resting for 10 minutes, they performed the VR game experiment wearing the VR equipment, fNIRS equipment, and the in-ear headsets (Apple Airpods pro); the VR paradigm was the same as the mobile phone paradigm (rest 20 s, play 40 s, rest 20 s) and was repeated seven times. The experimental paradigm is depicted in Figure 2.

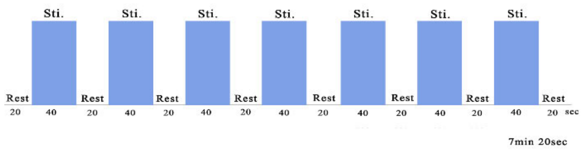

FIGURE 2. Schematic diagram of the paradigm experimental process.

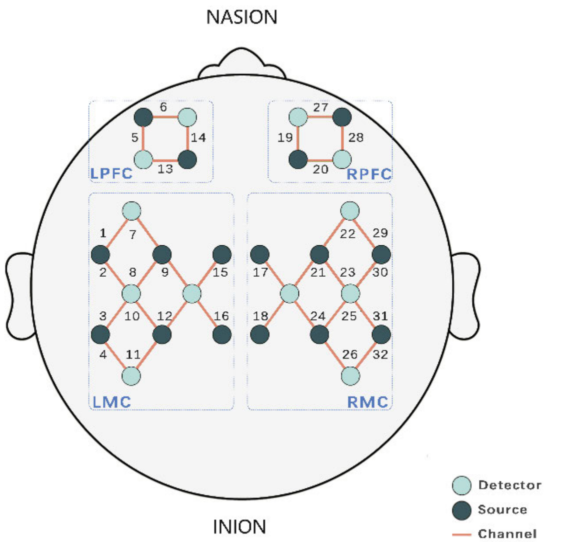

FIGURE 3. Arrangement of source optodes (Gray dots), detector optodes (Green dots), and measurement channels (Orange rectangle) over the prefrontal cortex and motor cortex based on the international 10/10 system. The four cerebral cortical areas are separated by the blue frames: LPFC,RPFC, LMC, and RMC.

D. fNIRS CONFIGURATION

We used a multi-channel near-infrared system (Nirsmart, Danyang Huichuang Medical Equipment Co., Ltd., China) in this experiment [23]. The sampling frequency was set to 10 Hz. Two kinds of near-infrared light of different wavelengths (760 nm and 850 nm) were used to detect oxygen and hemoglobin (HBO2) concentration changes. According to the requirements of the internationally-accepted 10/20 electrode distribution system, the device's 16 signal emission sources and 12 detectors were divided into 32 channels, which were arranged over the right prefrontal cortex (RPFC), left prefrontal cortex (LPFC), right motor cortex (RMC), and left motor cortex (LMC). A flexible headgear holder was used to fix the distance between the emitter and scalp, control the environment light during the experiment, and reduce the impact of excessive light on the experimental data. A brain location map is shown in Figure 3.

E. ANALYSIS OF fNIRS DATA

NIR spark was used to analyze the experimental data obtained from the near-infrared brain function imager. The data were preprocessed in six steps. 1) The required experimental time segment is selected, the redundant time period is removed, and stitching processing is performed. 2) The algorithm recognizes the artifacts based on the input parameters and automatically retrieves the interval of possible artifacts in the data. A 0.5 s sliding time window is used to check all time intervals for the detected artifacts and the data is corrected by spline interpolation. 3) Strong conversion into optical density is ensured. 4) A Butterworth filter is used for band-pass filtering. 5) The initial time of the hemodynamic response function (HRF) is set to -2 s and the end time to 40 s (retaining the baseline state as "-2–0 s", the time of single block mode as "0–40 s"); 6) the modified Beer-Lambert law is used for calculations; the formula is as follows:

$$OD^{\lambda_i} = In\frac{I_{Oi}}{I_i} = \left(\varepsilon_{HBO}^{\lambda_i} C_{HBO} + \varepsilon_{HBR}^{\lambda_i} C_{HBR}\right) L_{\lambda_i} \quad i = 1, 2, 3 \tag{1}$$

$$L_{\lambda_i} = r \times DPF^{\lambda_i} \quad i = 1, 2, 3 \tag{2}$$

$$\Delta OD^{\lambda_i} = \left(\varepsilon_{HBO}^{\lambda_i} \Delta C_{HBO} + \varepsilon_{HBR}^{\lambda_i} \Delta C_{HBR}\right) \times r \times DPF^{\lambda_i} \quad i = 1, 2, 3 \tag{3}$$

OD is the optical density, I_{Oi} is the intensity of incident light with a wavelength of λ_i, I_i is the corresponding scattered light intensity, $\varepsilon_{HBO}^{\lambda_i}$ is the light absorption coefficient of HBO (oxygenated hemoglobin) with a wavelength of λ_i, L_{λ_i} is the optical path, r is the distance between the light source and the detector, DPF is the optical path difference factor and is wavelength dependent, and $\Delta C_{HBO} \cdot \Delta C_{HBR}$ represent the concentration changes of oxyhemoglobin and deoxyhemoglobin, respectively. From (1) and (2), equation (3) can be obtained and the equation of 3 wavelengths can be obtained from this; then, the equation can be solved for $\Delta C_{HBO} \cdot \Delta C_{HBR}$.

After preprocessing the original experimental data, a generalized linear model (GLM) was used to analyze the HBO time series data using the following formula:

$$Y = X\beta + \varepsilon \tag{4}$$

where ε is a random error term and is generally assumed to be a normal random variable with zero mean and variance of σ^2 and independent of each other.

u is the mean value of the dependent variable and is generally interpreted as the form of the sum of the response variables:

$$u = X\beta \tag{5}$$

β is the linear combination parameter to be estimated.

Objective function: the objective of estimating the parameters, or the minimum deviation, or the unbiased minimum variance, etc. Again, the least squares and maximum likelihood are generally used.

GLM establishes the ideal HRF for each experimental paradigm and then calculates the degree of match between the experimental HRF value and the ideal HRF value, denoted by β. The estimated value of the HRF of the HBO signal is often reported as a β value representing the peak of the HRF function as a reflection of the channel cortical activation level [24].

Through Pearson correlation analysis, the functional connection strength between each channel was studied. Pearson's correlation coefficients range from $(-1, +1)$. When $R_{a,b} > 0$, it means that the two variables are positively correlated; when $R_{a,b} < 0$, the two variables are negatively correlated; the closer $R_{a,b}$ is to 0, the weaker the linear relationship between the two variables. The formula is as follows:

$$R_{a,b} = \frac{cov(A, B)}{S_a S_b} = \frac{E(AB) - E(A)E(B)}{\sqrt{E(A^2) - E^2(A)}\sqrt{E(B^2) - E^2(B)} } \tag{6}$$

Cov(A, B) represents the covariance of A and B; E(A) and E(B) represent the mean values of A and B, respectively; S_a and S_b represent the variance of A and B, respectively. A correlation coefficient $R_{a,b}$ of 0.8-1.0 indicates a very strong correlation, 0.6-0.8 a strong correlation, 0.4-0.6 a moderate correlation, 0.2-0.4 a weak correlation, and 0.0-0.2 a very weak correlation or no correlation.

F. STATISTICAL ANALYSIS

IBM SPSS was used (v.23.0) for statistical analysis, data mining, and predictive analysis. First, the Shapiro–Wilk test was used to examine whether the experimental data were normally distributed. If the data obeyed the requirements of the normal distribution, the paired samples t-test was used to compare whether the difference between the mobile game and VR game experiment data was statistically significant ($P < 0.05$) was taken to indicate that a difference was statistically significant.

III. RESULTS

A. ANALYSIS OF INTRA-PHASE ENCEPHALIC REGION ACTIVATION

The β values of the 32 channels were analyzed. When young people used the VR game, the highest value was 1.8432 in the LMC and the lowest value was −3.2593 in the RMC. During the mobile game, the highest value was 3.2687 in the RMC and the lowest value was −1.4572 in the RMC. For elderly people, during the VR game, the highest value was 3.9416 in the LPFC and the lowest value was -3.0742 in the RMC; during the mobile game, the highest value was 1.8619 in the RMC and the lowest value was −1.6139 in the RMC. The numerical analysis of the β values of each brain area is shown in Figure 4.

Figure 5 presents the cortical maps corresponding to the two games. The higher the $\boldsymbol{\beta}$ value of the channel, the redder the channel; the lower the $\boldsymbol{\beta}$ value, the bluer the channel.

B. ANALYSIS OF BETWEEN-PHASE BRAIN REGION ACTIVATION

The Shapiro-Wilk test revealed that the data were normally distributed. Thus, paired-samples t-tests were performed. The results revealed that, for the young age group, channel 4 ($t = 2.152$, $p = 0.048$), channel 5 ($t = -2.436$, $p = 0.028$), channel 6 ($t = -3.151$, $p = 0.007$), channel 13 ($t = -3791$, $p = 0.002$), channel 14 ($t = -3.208$, $p = 0.006$), channel 19 ($t = -3.301$, $p = 0.005$), channel 20 ($t = -2.858$, $p = 0.012$), channel 25 ($t = 2.493$, $p = 0.025$), channel

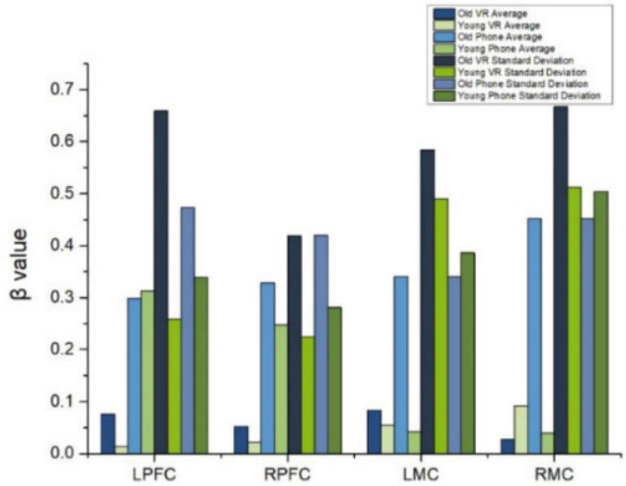

FIGURE 4. Comparison of the median and standard deviation of β values in each brain area between the two groups.

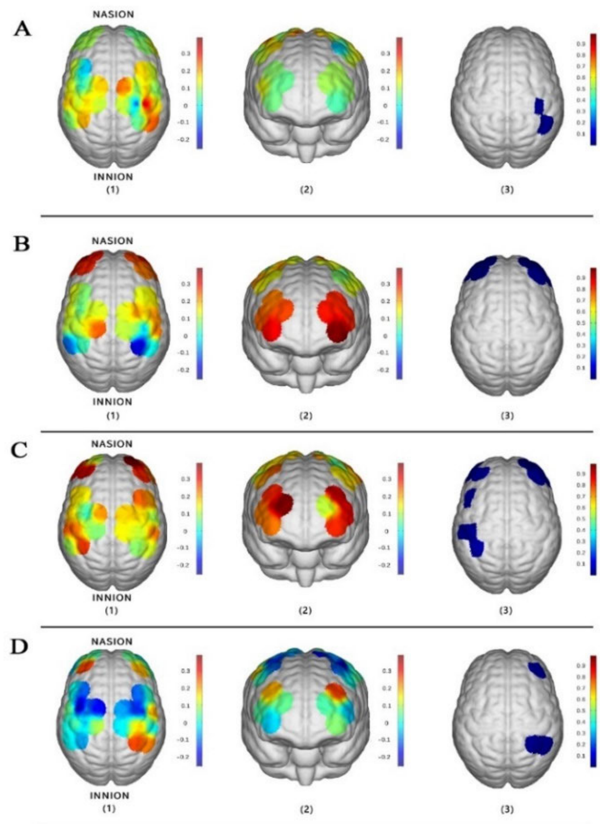

FIGURE 5. A) The brain activation state of the youth group in VR games; B) The brain activation state of the youth group in mobile games; C) The brain activation state of the elderly group in mobile games; D) The brain activation state of the elderly group in VR games. 1)The changes of β value in the motor area; 2) The changes of β value in the cognitive area; 3)The changes of β value in baseline activation.

26 ($t = 2.457$, $p = 0.027$), channel 27 ($t = -3.673$, $p = 0.002$) ($p < 0.05$) exhibited significant differences between the game types. During the VR game, channels 4, 25, and 26 exhibited enhanced activation compared to during the mobile game, while channels 5, 6, 13, 14, 19, 20, and

TABLE 2. Two sets of significant channel paired sample tests.

Youth	Average value	Standard deviation	t	Degree of freedom	Significance
Youth group					
VR4 – PH4	0.2190	0.4071	2.152	15	0.048*
VR5 – PH5	-0.2565	0.4211	-2.436	15	0.028*
VR6 – PH6	-0.4465	0.5668	-3.151	15	0.007**
VR13 – PH13	-0.2393	0.2525	-3.791	15	0.002**
VR14 – PH14	-0.2531	0.3157	-3.208	15	0.006**
VR19 – PH19	-0.2635	0.3194	-3.301	15	0.005**
VR20 – PH20	-0.1859	0.2603	-2.858	15	0.012*
VR25 – PH25	0.5586	1.0964	2.493	15	0.025*
VR26 – PH26	0.3233	0.5263	2.457	15	0.027*
VR27 – PH27	-0.3165	0.3447	-3.673	15	0.002**
Elderly group					
VR5 – PH5	0.4417	0.5842	-2.928	14	0.011*
VR7 – PH7	0.3325	0.5530	-2.329	14	0.035*
VR15 – PH15	0.4932	0.6942	-2.751	14	0.016*
VR19 – PH19	0.4229	0.6215	-2.636	14	0.020*
VR27 – PH27	0.3398	0.5214	-2.524	14	0.024*
		P < 0.05 *		P < 0.01**	

27 exhibited enhanced activation during the mobile game compared to the VR game. For the elderly subjects, channel 5 ($t = -2.928$, $p = 0.011$), channel 7 ($t = -2.329$, $p = 0.035$), channel 15 ($t = -2.751$, $p = 0.016$), channel 19 ($t = -2.636$, $p = 0.02$), and channel 27 ($t = -2.524$, $p = 0.024$) ($p < 0.05$) exhibited statistically significant differences. Channels 5, 7, 15, 19, and 27 were enhanced during the mobile game compared to the VR game. These results are shown in Table 2.

It can be seen, combining the comparison of the significant channel paired sample test results with the median of the corresponding channels, that the median values of channels 5, 6, 13, 14, 19, 20, and 27 in the youth group were significantly greater during the mobile game than during the VR game, while for channels 4, 25, and 26, the median values during the VR game were significantly larger than those during the mobile game. In the elderly group, the median values of channels 5, 7, 15, 19, and 27 were significantly greater during the mobile phone game compared to the VR game, while the median values of channels 4, 25, and 26 were significantly greater during the VR game compared to the mobile game. Figure 6 shows the median β values of each significant channel when the youth group and the elderly group used the mobile game and VR game, respectively.

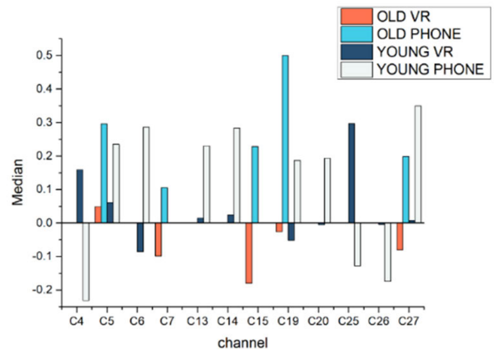

FIGURE 6. Comparison of the median of significantly activated channels between the youth group and the elderly group.

TABLE 3. Summary of Pearson correlation analysis between MC and PFC channels during the two games in the young and elderly groups.

	VR				Phone			
	0. 4–0. 6		0. 6–1. 0		0. 4–0. 6		0. 6–1. 0	
Youth group								
Positive channel					1–6	1–13	13–25	
					2–13	2–14		
					3–13	3–14		
					3–28	7–20		
					9–19	9–28		
					14–25	25–28		
Negative channel	6–16	2–28			1–28	16–19	1–20	18–19
					18–27	18–28		
Elderly group								
Positive channel			13–15		1–5	1–6	1–14	1–27
					1–20	7–13	5–18	6–18
					7–14	7–27	25–28	
					10–19	10–20		
					25–27			
Negative channel	6–15	11–13	11–20	15–20				
	11–28	13–24	24–28	25–28				
	13–29	15–19	28–29					
	15–28	19–29						
	21–27	28–31						

C. ACTIVATION CORRELATION ANALYSIS BETWEEN THE MC AND PFC

Pearson correlation analysis between the MC and PFC channels during the performance of the two games was conducted. The results revealed that the number of medium-degree positive correlations, strong positive correlations, medium-degree negative correlations, and strong negative correlations in each channel during the mobile game in the youth group was greater than the number of significant positive correlations during the VR game. As shown in Table 3, in the elderly group, the number of moderate negative correlations and strong negative correlations during the VR game was significantly higher than that during the mobile game, and the number of moderate positive correlations and strong positive correlations during the mobile game was higher than that during the VR game.

D. ACTIVATION CORRELATION ANALYSIS MC

Pearson correlation analysis was carried out between the channels of the LMC and RMC during the two games. The

TABLE 4. Summary of Pearson correlation analysis between LMC and RMC channels during the two games in the young and elderly groups.

	VR				Phone			
	0. 4−0. 6		0. 6−1. 0		0. 4−0. 6		0. 6−1. 0	
Youth group								
Positive channel	4−21	4−24	7−31	4−26	1−25	2−32	3−17	8−17
	12−18	15−22	16−21	16−26	3−23	3−25	8−23	8−30
	21−14				3−30	4−26	9−17	12−21
					7−25	7−29	15−17	16−18
					8−21	8−29	16−31	
					9−26	9−32		
Negative channel					11−18	11−23		
					11−25	12−25		
Elderly group								
Positive channel	2−18	3−18	4−18	10−18	3−32	1−25	7−30	11−18
	7−17	7−21	11−18	11−29	11−21	11−24	11−26	15−21
	7−31	8−12	15−18		15−17			
	10−24	11−24						
	12−17	12−26						
Negative channel	7−25		24−31		12−24			
	2−18	3−18	4−18	10−18	3−32	1−25	7−30	11−18
	7−17	7−21	11−18	11−29	11−21	11−24	11−26	15−21
	7−31	8−12	15−18		15−17			
	10−24	11−24						

results revealed that the number of medium-degree positive and strong positive correlations in each channel during the mobile game in the youth group was significantly greater than during the VR game, and the number of medium-degree negative and strong negative correlations in each channel during the VR game was significantly greater than during the mobile game. The number of medium positive correlations, strong positive correlations, and medium negative correlations in each channel during the VR game in the elderly group was significantly greater than during the mobile game. These results are shown in Table 4.

E. ACTIVATION CORRELATION ANALYSIS PFC

Pearson correlation analysis was performed between the channels of the LPFC and RPFC during the two games. The results revealed that the number of medium-degree positive correlations and strong positive correlations in each channel during the mobile game in the youth group was significantly greater than during the VR game. The number of strong positive correlations in each channel during the VR game in the elderly group was significantly greater than during the mobile game, and more moderately correlated channels were observed during the mobile game. These results are shown in Table 5.

F. ANALYSIS OF MMSE SCORES AND CORRELATION ANALYSIS BETWEEN MMSE SCORES AND THE PFC

The MMSE scale is the most widely used cognitive function test scale; it screens the subject's orientation, memory, comprehension, application, language reading, and writing abilities [25]. Before the experiment, the MMSE scale was administered to the two groups to judge the cognitive status of each subject. MMSE scale scores from 27-30 indicate normal cognition, scores from 21-27 indicate mild cognitive impairment, scores from 10-21 indicate moderate cognitive impairment, and scores from 0-10 indicate severe cognitive impairment. The results showed that the average score of the elderly group was lower than that of the young, indicating that the elderly group had poorer cognitive function than the young group.

TABLE 5. Summary of correlation analysis between LPFC and RPFC channels during the two games in the elderly group and the youth group.

	VR				Phone			
	0. 4−0. 6		0. 6−1. 0		0. 4−0. 6		0. 6−1. 0	
Youth group								
Positive channel	5−23		19−27		5−27	5−28	6−20	6−28
					13−19	13−20	13−27	13−28
					14−27			
Elderly group								
Positive channel	6−20		5−27	6−28	5−27	6−19	5−6	5−14
			13−19	13−20	6−20	14−18	5−18	6−14
			13−28	14−19	14−19	14−20	6−18	19−20
			14−20		14−27	20−27	19−27	
					20−28	27−28		

Pearson correlation analysis between the MMSE scale scores and the average cognitive area (PFC) β of the youth group and the elderly group revealed a significant positive correlation in the youth group (R = 0.624, Sig.2-tailed=0.01) and the elderly group (R = 0.771, Sig.2-tailed=0.001). Both correlations were strong.

IV. DISCUSSION

In this study, fNIRS equipment was used to monitor the activation of brain regions and the strength of functional connections between channels in a sample of young people and elderly people when engaged in a VR game and a mobile game. The positive effects of these games on the training of the PFC and MC were estimated in this study. The results revealed that the elderly group had a lower MMSE scale score than the young and both groups exhibited a strong positive correlation between MMSE scores and PFC activation. Further, the mobile game activated the cognitive areas of the brain in both groups more perceptibly, while the VR game activated the elderly more significantly than the mobile phone game. The strength of the functional connection between each brain area was higher during the mobile game relative to the VR game, while the brain signals and the functional connection strength of each brain area were generally lower among the elderly compared to those of the young group.

fNIRS is one of the most reliable brain function imaging techniques [26], [27], with its stable signal and convenient set up for experimental monitoring [15]. The HBO signal is the parameter used to explore brain nerve changes during fNIRS [28], [29]. It was observed that fNIRS indirectly records changes in brain nerve activity by detecting changes in brain HBO signals and then calculating changes in cerebral cortex hemodynamics [30]. The analysis of the experimental data in this paper is based on the analysis and processing of the β value [24]. The β value can reflect changes in the cerebral cortex nerve activity on the side of measurement and is suitable for analysis and discussion.

The LPFC and RPFC brain areas of the young group were significantly activated during the mobile game while the LPFC, RPFC, LMC, and RMC brain areas of the elderly group were significantly activated. Comparison of the groups for the mobile phone game indicated that the young group and the old group exhibited activation in the same brain areas in the PFC. The observed activation is consistent with the findings of a previous experimental study that used nuclear magnetic resonance (MRI) to monitor the effects of mobile games on brain cognitive function training. This prior study found that the game training mode was more conducive to brain cognitive training [31]. Here, we found that mobile games in the elderly group also produced significant activation of the MC. This may be because fine hand movement functions (such as pinching and pressing) and gross hand movement functions (holding, gripping) decline with age ()()[32]; thus, when the elderly used the mobile phone, their MC was activated due to the extra effort required to move their hands. Since mobile phones are convenient and time-sensitive and are a permanent fixture in modern life, they should be further explored as tools for cognitive and motor function training [33], [34].

The RMC of the young and elderly groups was obviously activated during the VR game. At the same time, the PFC was also significantly activated in the elderly group. This may be because elderly people have never been exposed to VR-related training before [9]. In the comparison of activation between the groups, the VR game produced significantly more activation of the MC. This is consistent with results when using MRI and EEG equipment to monitor the effect of VR on nervous system training in previous studies [35], [36]. Thus, it appears that VR is more effective for training brain motor functions and has potential for use in brain cognitive function training [37].

The difference between the two-game operation modes was a fundamental factor for the differences in the experimental data. The mobile game is mainly based on hand movements, whereas the VR game is based primarily on torso movements. fNIRS monitors the influence of different actions on brain activation. Hand movements can fully mobilize the mutual cooperation of various brain areas [38]. Improvements to hand coordination in training can effectively improve cognitive training.

This study found that activation of the PFC and MC regions in the elderly group was lower than that observed in the youth group. This result may be related to the corresponding changes in cerebral blood vessels with age. Several studies have used various diagnostic tools to study the brains of the elderly, including single photon emission tomography (SPECT), transcranial Doppler ultrasound (TCD), nuclear magnetic resonance (MRI), and fNIRS, and have found that regional cerebral blood flow (CBF), brain tissue oxygenation, brain autoregulation, and the cerebrovascular carbon dioxide response (CC2R) change with age [39]–[41]. Further, compared with younger subjects, elderly subjects have lower baroreceptor sensitivity and lower average cerebral blood flow velocity (bfv) [42], [43], which may also be a factor in the observed differences between the groups here.

The human brain is composed of multiple brain regions with different functions. These brain regions share information with each other to mediate and coordinate performance of a task. Pearson correlation analysis was performed to examine changes in the activation of various brain regions and the relationship between MMSE scale scores and PFC brain area signals during the mobile game and VR game, in each group. According to the basic principles of brain rehabilitation [44], the vascular coupling and system adjustment mechanisms determine the strength of the functional connection between brain areas, that is, the cooperative ability of the brain areas.

The strength of the functional connection between each brain area was significantly greater during the mobile game than during the VR game. The postures of the subjects were different during the two games due to the different interaction modes of the two games. According to an EEG study, different actions lead to different effects on the cerebral vascular system, with differing hemodynamic responses mediated by the sympathetic, parasympathetic, and somatosensory nerves [45]. The directional coupling strength between the LPFC and RPFC in the elderly group was significantly enhanced compared with the youth group. The PFC plays a key role in complex cognitive behavior [46]. Thus, this result suggests that cognitive function damage causes the PFC brain area to work harder to complete cognitive tasks, increasing the strength of the neural coupling between the LPFC and RPFC [47]. These results also further illustrate that frontal lobe function is related to normal aging and degenerative changes. In the comparison of the LMC and RMC functional connection strength, there was no significant difference between the two groups. In the comparison of the MC and PFC, the number of negative correlation channels in the elderly was increased significantly and the number of positive correlation channels was much lower than that in the youth group. This may be due to the increase in blood vessel stiffness with age and the deterioration of myogenic regulation in the elderly group. The ability to regulate exercise also decreases with age, which affects elderly people's ability to cooperate with cognitive functions [48].

Analysis of the MMSE scale scores indicated that the average score of the elderly group was lower than that of the youth group. This indicates that the elderly group had reduced cognitive function compared with the youth people. Analysis of the correlation between MMSE scale scores and the PFC revealed that MMSE scores were significantly positively correlated with PFC activation, which demonstrates the relationship between the PFC and cognitive function [49]. Moreover, the lower β value in the PFC also confirms the reduced cognitive ability of the elderly group. These findings are consistent with those of a prior study that used fNIRS in the CT treatment of female patients with cognitive impairment [50].

V. LIMITATIONS

There were several limitations related to sample themes and game types in the experiments, caused by the covid-19 epidemic. In the future, we propose to recruit the same number of young and old people and also maintain the same ratio of men to women and the same level of education for both young and old. Similarly, in the game design, we will take into account the habits of different age groups to increase the content of the scene, improve the game mechanism, and help the participants get a better sense of immersion to enhance the training effect. We will minimize the limitations of subsequent experiments through strict screening of subjects, controlling the experimental environment, and iterating the game.

VI. CONCLUSION

In this study, fNIRS was used to monitor brain signals during mobile and VR game tasks among elderly and young people. The average MMSE score of the elderly group was lower than that of the young group. The cognitive function of the elderly group was lower than that of the young group. Studies suggest that cognitive training using such games can slow down cognitive decline. Here, the positive training effect of the mobile phone game produced obvious activation in the PFC of the two groups, and the cognitive training effect was more significant, stimulating the strength of the functional connections between different brain regions. The VR game improved brain activation in various regions in the elderly group, and this may be helpful for the prevention of neurological disorders in the elderly and in their rehabilitation. The training effect was stronger among the elderly than in young people. These research results verify the presence of cognitive decline among the elderly. The results suggest that different cognitive training results are achieved with differing cognitive training games and among people of different ages. These results can be used to inform different cognitive training-related products for people of different ages.

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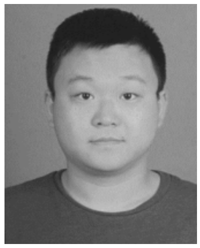

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