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Correlation between virtual reality's intervention and monitored brain activity: A systematic review

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Abstract: *While conducting dual-task training on patients with neurological disorders, it is crucial to comprehend brain activity changes during performance. Therefore, this systematic review's goal is to examine the literature on the usage of virtual reality in patients with postural and cognitive dysfunctions while assessing areas of brain activity through a non-invasive neuroimaging tool - fNIRS. We conducted research using PubMed, CINAHL, EMBASE, SCOPUS, Science Direct databases, Web of Science, PsycINFO, and Association for Computing Machinery (ACM) Digital library. Keywords were 'VR' OR 'virtual reality' AND 'dual-ask' AND 'fNIRS' or 'Functional Near-Infrared Spectroscopy'. Search of the literature revealed a total of three articles, which investigated exercising programs' effects on motor and cognitive function improvement while monitoring brain activation with fNIRS in older and young adults. All three studies showed improvement in cognition after performing VR tasks and its correlation with cortical activation after VR intervention. Future studies should include more longitudinal studies to explore the potential mechanism of VR and more studies on different types of neurological diseases.*

Keywords: Cognitive-motor Intervention; Dual-task; Neuroimaging; Virtual Reality; Systematic Review

1. Introduction

Cognitive functions are the foremost multiplex functions of the brain, with the assistance of which the method of reasonable information of the world is fulfilled [1, 2]. But as people age, their brains do too, and this natural process results in cognitive decline [3, 4]. Due to the increasing trends in life extension and maturation of the world population, which can increase the risk of frailty, cognitive impairments are increasingly important to international society [5]. Slowness and muscle weakness are characteristics of frailty in aging people [6], which can lead to unstable gait and falls [7]. Therefore, it is very important to find a way to stop cognitive damage from occurring.

Virtual reality (VR) is a form of computer equipment that provides a live, interactive simulation of the actual world [8] and allows to isolate a person from a normal sensory environment to the precise specifications of the computer programmer, where an individual can move around and interact [9]. Nowadays VR technologies are often used in gaming and entertainment areas. However, even if games have become a field for expanding the capabilities of innovative equipment [10, 11], the potential of using VR in various fields of human activity should not be underestimated. These technologies find their application in many directions, like education [12], the military [13], and healthcare because they help to save time, economic and human resources. For healthcare direction, such applications of VR technologies like exergames, become popular in neurological rehabilitation. For example, Zeigelboim et al. (2021) study used exergames to help Parkinson Disease's people in neurorehabilitation [14]. They improved independence through the improvement of daily assignments in Parkinson Disease's patients by using Nintendo Wii devices, including a Wii controller and Wii Balance Board (Nintendo Co, Ltd., Kyoto, Japan). The patients performed 20 VR sessions with four balance games and after

performing them, it showed that such games were more efficient in improving independence, confidence, and balance in PD patients. Another study investigated the effect of exergames on cognitive functioning through meta-analysis [15]. Thirteen studies were analyzed and found results suggested that exergaming could not only improve cognitive functions in people with neurological illnesses but also be used as a dual-task method to develop motor skills (balance and walking ability) [16].

Dual-task (DT) is a way to estimate the effect of divided attention on an external cause of attention (e.g., gait or cognitive task) and a primary task [17]. Therefore, it is often used to investigate how attention affects balance and posture in various age and population groups [18]. Dual-task training has been shown in several studies to enhance both cognitive and motor function in patients with neurological illnesses, using virtual reality [19, 20]. Fishbein. et al (2019) used VR in stroke patients for applying dual-task performance in improving walking and balance [19]. Killane. et al (2015) investigated whether integrated motor-cognitive virtual training enhances dual-tasking and gait in PD patients [20]. Other studies presented that post-stroke patients could improve their balance and other walking factors by dual-tasking while utilizing a treadmill and virtual reality (VR) surroundings [21, 22]. While conducting dual-task training on patients with neurological disorders it is crucial to comprehend which brain activity changes happen during the performance.

In 1977 Jobsis described that one of the most promising and non-invasive neuroimaging tools for evaluating how well the brain dynamics is functional Near-Infrared Spectroscopy (fNIRS) [23]. The working characteristics of the fNIRS are based on the penetration effect of light with a wavelength from 650 to 1000 nm through the human body's tissue and the skull into the brain [24] and absorption by natural chromophores: oxygenated hemoglobin (HbO2), deoxygenated hemoglobin (Hb) and cytochrome oxidase [25]. Infrared radiation comes from the source through a fiber optic cable (optode) to skin sensors [26] located symmetrically with respect to the midline and consisting of an emitter and a transmitter placed between 3.5 and 6 cm away from one another. The beam of light from the transmitter penetrates through the soft tissues of the head and the bones of the skull into the parenchyma of the brain and, while being reflected and scattered, hits the emitter. The concentration of chromophores: HbO2, Hb, and cytochrome oxidase is a variable value and directly depends on the level of saturation and tissue metabolism [26]. One study investigated the hemodynamic connections of walking while carrying out two tasks in young and older adults [27]. The findings of this investigation revealed that only during visually challenging dual-task walking did prefrontal stimulation in the younger group differ from the older participants. As an indicator of cognitive effort, while walking, Mirelman et al. (2014) noticed a graded response and concluded that dual-tasking enhanced prefrontal region brain activity in young adults [28]. In addition, according to one study, there were no variations in PFC activity at every stage of cognitive demand, however, there was an activity in the right hemisphere throughout the continuous n-back task during the DT than during the single cognitive (SC) condition [29].

While analyzing studies about ways of improving cognitive impairments and functional disability in patients with different neurological disorders, we noticed, that there are a lot of studies using VR technologies in dual-task training [14], [19-22] and dual-task interventions by applying fNIRS to measure brain activation during a dynamic movement [27-29]. However, not many studies have appeared with the concurrent application of virtual reality in dual-task training with the measurement of brain activity through fNIRS. Therefore, we set the main goal of our systematic review to look at the literature on the usage of virtual reality on patients with postural and cognitive dysfunctions while assessing areas of brain activity through a non-invasive neuroimaging tool – fNIRS.

2. Methods

2.1 Data Search process

This study searched for research papers published in academic journals from 1969 to 2023. We used Pubmed, CINAHL, EMBASE, Web of Science, SCOPUS, Science Direct, PsycINFOand, Association for Computing Machinery (ACM) Digital library databases for searching data for our systematic review. Keywords were 'VR' OR 'virtual reality' AND 'dual-ask' AND 'fNIRS' or 'functional Near-Infrared-Spectroscopy'. Inclusion criteria were implemented. Also, the reference record of the relevant papers was scrutinized for any new suitable studies. EndNote X9 software was used for software management.

2.2 Inclusion and Exclusion criteria

Studies of all kinds, that examined how playing a particular genre of VR exercise game during DT affected brain activity in older and younger adults using the neuroimaging technology – fNIRS, were included. 1) Studies that focused on recovery from traumatic brain injury, 2) research protocols, 3) animal studies, 4) studies that looked at the effects of drugs and alcohol on DT, 5) conference papers, and 6) studies on research methodologies were all excluded from consideration.

2.3 Quality assessment and the risk of bias

Two authors, based on the inclusion criteria, reviewed the titles and abstracts before extracting them for full-text review. If there were divergent opinions, the third reviewer's opinion and the consensus were used to resolve the differences. Applying the Critical Appraisal Skills Programme instrument (CASP), the level of quality of each study was evaluated [30]. The tool's questions concentrate on the methodological components of qualitative thinking about deciding whether the chosen investigative procedures were satisfactory and whether the conclusions are clearly stated and insightful [31].

2.4 Analysis of the results of extracted study

After extracting data were reported in Table 3: author of study and publication year, study design, participant characteristics (number of subjects), physical and cognitive interventions, study period, type of fNIRS, dependent variables and outcomes, and main results of each study.

3. Results

3.1 Data Search Results

As a result of the first eight database searches, 1027 documents were searched. The initial selection eliminated redundant papers (n = 174) and papers unrelated to fNIRS (n = 64), VR (n = 163), and a dual-task (n = 169) were eliminated. In addition, we removed the Symmetric review or meta-analysis study (n = 116) and removed the studies that were not suitable for the study design (n = 311).

There was a total of 30 studies that required full text confirmation, and three papers were selected as a result, excluding studies that were not related to the research design (n = 3), fNIRS (n = 3), VR (n = 4), and Dual task (n = 17). Figure 1 depicts the method used to choose studies. The PRISMA flow chart was used for the process of literature selection. Finally, three papers were decided on.

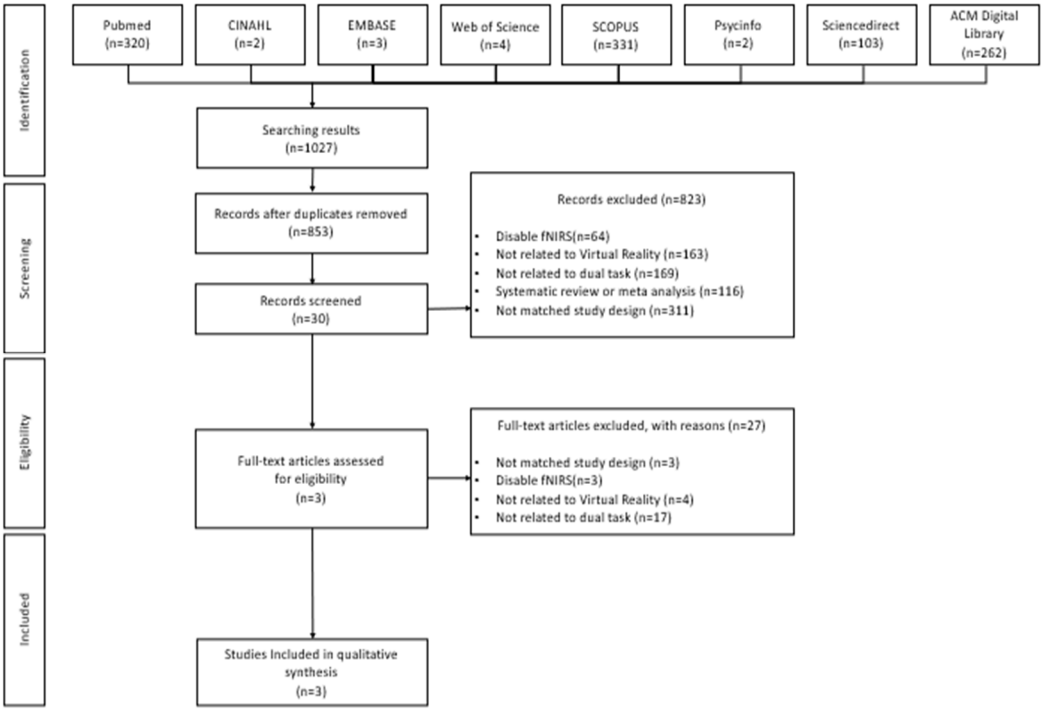

Figure 1. PRISMA flow diagram

3.2 Quality assessment

To estimate the methodological attribute of retrieved articles, the CASP checklist was used. Liao et al. (2021) used the CASP randomized controlled trial checklist, and the other studies used the CASP case-control study checklist. In Liao et al. (2021) study, double blinding was not possible, and in the study of Rond et al. (2021), cases were not recruited in an appropriate manner, potential confounding factors were not considered, and the intervention effect was insufficient. On the other hand, in the study of Zheng et al. (2022), all checklist items were satisfied. All selected studies reported on clearly focused research questions and the generalizability of results [Table 1], [Table 2].

Table 1. Result of CASP Checklist (Randomised Controlled Trial)

NO.	Questions	Liao et al (2021)
1	Did the study address a clearly focused research question?	Y
2	Was the assignment of participants to interventions randomised?	Y
3	Were all participants who entered the study accounted for at its conclusion?	N
	Were the participants ‘blind’ to intervention they were given?	Y
4	Were the investigators ‘blind’ to the intervention they were giving to participants?	N
	Were the people assessing/analysing outcome/s ‘blinded’?	Y
5	Were the study groups similar at the start of the randomised controlled trial?	N
6	Apart from the experimental intervention, did each study group receive the same level of care (that is, were they treated equally)?	Y
7	Were the effects of intervention reported comprehensively?	Y
8	Was the precision of the estimate of the intervention or treatment effect reported?	Y
9	Do the benefits of the experimental intervention outweigh the harms and costs?	Y
10	Can the results be applied to your local population/in your context?	Y
11	Would the experimental intervention provide greater value to the people in your care than any of the existing interventions?	Y

Y: Yes, N: No, CT: Can ’t Tell, E: Enough, NE: Not Enough

Table 2. Result of CASP Checklist (Case Control Study)

NO.	Questions	Rond et al (2021)	Zheng (2022)
1	Did the study address a clearly focused issue?	Y	Y
2	Did the authors use an appropriate method to answer their question?	Y	Y
3	Were the cases recruited in an acceptable way?	N	Y
4	Were the controls selected in an acceptable way?	Y	Y
5	Was the exposure accurately measured to minimise bias?	N	Y
6	(a) Aside from the experimental intervention, were the groups treated equally?	E	E
	(b) Have the authors taken account of the potential confounding factors in the design and/or in their analysis?	N	Y
7	How large was the treatment effect?	NE	E
8	How precise was the estimate of the treatment effect?	E	E
9	Do you believe the results?	Y	Y
10	Can the results be applied to the local population?	Y	Y
11	Do the results of this study fit with other available evidence?	Y	Y

Y: Yes, N: No, CT: Can ’t Tell, E: Enough, NE: Not Enough

3.3 Results of the extracted study

All three of the chosen studies focused on how exergaming therapies affected the development of physical and cognitive skills in both older and younger individuals while analyzing brain activation with fNIRS. (Table 3) [32-34].

Rond et al. (2021) examined how a weight-shifting game affected cerebral function in young adults (YA) and older adults (OA), as measured by fNIRS [32]. The key findings of this study were that OA showed reduced serial subtraction task and diminished game performance and higher HbO2 levels in the frontal eye fields (FEF) and the left prefrontal cortex (PFC) during a wasp game single-task (STwg) than in YA, because of age-related compensatory neural recruitment. Also, HbO2 levels were lower in all investigated regions of interest (ROIs) during DT in OA, except for the right PFC, because of the increased task load of DT. Due to OA's increased reliance on this cortical region, which is in control of goal-directed activity, YA demonstrated reduced activation in HHb alterations of the left supplementary motor area (SMA) during DT. Since the fact that OA displayed more degraded brain activity than YA, these findings are interpreted as a competitive decline in neural activity, which confirms the age-related decline in game performance when distractions are added to a difficult balance game. In addition, the limitations of this study were not taking into account participants' physical activity levels, which has been displayed that affect fNIRS feedback in both YA and OA, not using a power-based and pragmatically determined sample size, not using the wasp game calibration's functional stability limits, and not using an fNIRS setup that included channels with short separations that account for extra-cerebral components [32].

The second study, Liao et al. (2021), employed a randomized control trial study to ascertain the effects of an exergaming program and combined physical exercise (CPE) on older individuals' cognitive ability [33]. Compared to the CPE group, the EXER group demonstrated improved verbal and working memory (CCVLT) scores in addition to improved scores in global cognition (MoCA). However, after training, participants in both groups displayed in fNIRS decreased hemodynamic changes in the frontal granular cortex, which might be elucidated as an indicator of ameliorated neural efficiency given that the PFC might require less energy to carry out the same cognitive task more successfully. The results of the fNIRS experiment revealed a relationship between the lower prefrontal cortex (PFC) activation in both groups and improved global cognition performance. Limitations include the lack of follow-up evaluation, which makes it impossible to assess the long-term benefits of both exercise games and cognitive performance enhancement (CPE), as well as the fact that participants' hemodynamic responses were only assessed in the prefrontal cortex of the brain. However, the authors did find alterations in other brain regions [33].

Zheng et al. (2022) studied NIVR-Exergames and a resistance band through a crossover study stretching program, which were evaluated for their effectiveness in enhancing motor cognition in young adults, where fNIRS was used to track the activation of six regions of interest (ROIs) both before and after exercise [34].

According to the study's findings, the NIVR-Exergame task helped ROIs respond immediately and significantly stimulated the bilateral premotor cortex (PMC), which is involved in learning, motor planning, and controlling motion [35]. Additionally, both groups — the resistance-band stretching task group and the NIVR-Exergame group — demonstrated stimulation of the right supplementary motor region (SMA), which is essential for the execution of independent motion. Moreover, the results also demonstrated that the NIVR-Exergame task initiated the dorsolateral prefrontal cortex (DLPFC), which is connected to cognitive, affective, and sensory processing. However, there was not a significant distinction between Baseline and Post-task 1 between either group's reaction time (RT) or an accuracy rate of 2-back (AR). Because the participants were healthy and young, the effect of exercise on cognitive enhancement was not as evident as it would be in participants with low implementation, who are more affected by exercise factors. Therefore, NIVR-Exergames can develop the stimulation of SMA, PMC, and DLPFC in young persons while paired with demanding motor and cognitive activities in order to improve motor and cognitive function in those with neurological diseases. Also, the authors noted that cognitive distraction and dual-tasking are significant limitations to daily life activities and that high degrees of task complicatedness can be contraindicated in OA related to the possibility of negatively affecting connections between cognitive and motor neural networks [34].

Table 3. Characteristics of the extracted study

Author (year)	Design	Participants	Intervention		Period	Times	Type of fNirs	Dependent variable & Outcomes	Main results
			Physical	Cognition					
Rond et al (2021)	Cross-sectional, single-task (wasp game, serial subtraction), dual-task (combination of both single-tasks)	Seventeen young adults and seventeen older adults	Wasp game (participants had to hit as many wasps as they could while being displayed by a red ball in the center of the area)	Serial subtraction (YA and Oa were asked from the starting number to subtract sevens and threes)	3 blocks, five trials per block	Five trials with 30s of baseline task and 40s of active task	LABNIRS	CoM,MiniBEST,MoCA, Flanker, Set-Shifting, SS JLO HbO_{2}, HHb	1) While performing both tasks OA showed reduced serial subtraction task and diminished game performance than YA 2) HbO2 levels were higher in the left PFC and FEF during STwg in OA and no changes in YA 3) HbO2 levels were lower in all investigated ROIs during DT in OA, except for the right PFC

									4) When a distraction was added to a hard balance game, OA had impaired brain activity compared to YA
Liao et al (2021)	Single-blind, parallel, randomized control trial	46 participants, aged 65-90 years old	Resistance exercise Aerobic exercise Tai chi and balance exercise	Window cleaning (moving to clean a window at a specific location), Firework hitting (igniting the firework at a given location), Goldfish grasping (catching the fish in given location) exercises	12 weeks	Three times 60-minutes per week	OEG-16	MoCA, EXIT-25, CCVLT, CWT, TMT part B, *n*-back test, fNIRS	1) Significant effects on executive function and attention regions in both groups and improved scores in the global cognitive domains for the EXER group 2) Increases in verbal and working memory scores in the EXER group 3) The correlation between lower PFC activation in both groups and higher scores in the global cognition category
Zheng (2022)	Cross-sectional	15 young participants, aged 18-24 years old	During game "Just Dance" participants played "snake" role and tried to	The letters (A-H), which appeared at random, had to be rememb	12 weeks	3 times per week	CW-fNIRS	BMI, SBP, DBP HR, GLM beta values in diffe	1) The NIVR-Exergame task was beneficial for the ROIs' quick response

	maintain the current position of the feet	ered by the participants, who had to press a response button (“F”-the same, “J”-otherwise) to compare the letters with those that would display at an interval ahead of them	rent ROI, RT of 2-back and AR of 2-back	2) The NIVR-Exergame task engaged the bilateral PMC 3) The right SMA was stimulated by both the resistance-band stretching job and the NIVR-Exergame 4) DLPFC was turned on via the NIVR-Exergame task 5) There was not a significant distinction between Baseline and Post-task 1 in RT and AR 6) There was not a significant difference in blood pressure in the male groups; it rose during Post-task 1 and fell during Post-task 2 in the female groups

*Note: YA: Young Adults, OA: Old Adults, CoM: Center of Mass, MiniBEST: Mini Balance Evaluation Systems Test, MoCA : Montreal Cognitive Assessment,

SS: Serial Subtraction, JLO: Judgement of Line Orientation, HbO_2: Oxygenated, HHb, Deoxygenated hemoglobin, PFC: Pre-frontal cortex, FEF: Frontal eye fields, STwg: Single-Task wasp game, ROI: Region of interest, DT: Dual-Task, EXIT-25: The Executive Interview 25, CCVLT : Chinese Version of California Verbal Learning Test, CWT: The Chinese version of the Stroop Colour and Word Test, TMT: Trail Making Test, fNIRS: functional near-infrared spectroscopy, BMI: Body Mass Index, SBP: Systolic Blood Pressure, DBP: Diastolic Blood Pressure, HR: Heart Rate, GLM: General Linear Model,

RT: Reaction Time, AR: Accuracy Rate, NIVR, PMC: Premotor Cortex, SMA: Supplementary motor area, DLPFC: Dorsolateral Prefrontal Cortex

4. Discussion

We intended to present information about some research that utilized virtual reality to benefit patients with postural and cognitive dysfunctions while assessing areas of brain activity through a non-invasive neuroimaging tool - fNIRS in our systematic review. All three studies showed improvement in cognition after performing VR tasks and its correlation with cortical activation after VR intervention.

It has been suggested that VR training could be used as a kind of therapy for patients with motor and cognitive declines. By having patients engage in multisensory training, VR rehabilitation therapy for motor and cognitive disorders is intended to enhance the neural plasticity of the brain [36]. Thomson et al. (2014) studied the integration of motion-controlled virtual reality games among stroke patients in improving an upper limb function [37]. They used VR games, because they could provide task-specific repetition, grading, and motivational training with real-time multimodal performance and movement feedback for stroke neurorehabilitation [38]. VR systems was used on Parkinson's disease patients in the Barry et al., (2014) study to amplify gait and balance [39]. For cognitive rehabilitation, VR can activate areas of the brain by way of offering patients particular scenarios or tasks to accomplish [40] or by providing patients with situations that they cannot encounter in real-time through visuals [41]. Therefore, all 3 analyzed studies after intervening in VR games showed improvement in motor and cognitive functions.

Since the 1980s Functional Near-Infrared Spectroscopy (fNIRS) was developed and operated in neuroscience studies. It is a method of neuroimaging that controls changes in the circulation and oxygenation of the blood in the brain wielding near-infrared light. It is non-invasive and portable, making it an attractive option for studying brain function in real-world settings. The advantages of FNIRS include its non-invasive nature, portability, and ability to measure changes in brain activity in real time. The disadvantages include the limited depth of penetration (up to about 2 centimeters) and potential for interference from sources such as movement or skull bone. The limited depth of penetration caused by the inability of penetrating deeper within the brain parenchyma (the depth of penetration is 1.5-2.5m), implies that fNIRS cannot be used to interrogate the white matter, basal ganglia, cerebellum, or brainstem. Therefore, only cortical activity can be examined with it. Another limitation of fNIRS is the potential for interference from sources. One interference is the hair, that might block the passage of light between the source and the scalp. Another interference is due to the free movements of participants, which can be prevented by fastening the holder to the head. The monitoring and provision of augmented feedback regarding cortical activation regions during therapy have been proposed as a role for the still-evolving application of fNIRS in VR therapy [36]. There is an area of study focusing on the impact of dual-task training on cognitive capacity using fNIRS (functional Near-Infrared Spectroscopy) as an outcome measure. The results of these studies are varied, some studies have observed improvements in cognitive function as an outcome of dual-task training, while others have not found any appreciable effects. In some research, fNIRS was applied to record task-specific outcomes in brain hemodynamics that occur during motor activities in a virtual reality environment [42, 43]. Due to fNIRS's capacity to identify changes in cortical regions, it can provide data on the degree of activation, which general practitioners can utilize to plan a therapy progression [36].

Brain cognitive-motor activation areas include Prefrontal Cortex (PFC) [44], Premotor Cortex (PMC) [45], Supplementary Motor Area (SMA) [46], and Dorsolateral Prefrontal Cortex (DLPFC) [47]. An aging-related reduction in prefrontal activity during cognitive function in older individuals was suggested by a prior fNIRS study [48]. In order to minimize age-related brain alterations, older people engage in bilateral or opposing areas. [49]. It suggests, that even with the right PFC's higher activation of the left PFC during the perception performance, hemisphere specialization of some sort is still evident [49], which explains a correlation between decreased activation in older adults' prefrontal cortex (PFC) and increased scores in the area of general cognitive ability [33]. Grafton et al. (2007) and Ehrsson et al. (2007) pointed that PMC is processing information for planning purposes [50] and both the performance of physical tasks and the mediation of complicated motor skills [51]. The SMA is engaged in establishing new motor systems and carrying out volitional activities that preserve postural balance [52], which was suggested in Hiyamizu et al. (2014) and Herold et al. (2017) studies.

They found an increase in HbO_2 in SMA post-training during balance learning, highlighting the use of higher cortical processes [53, 54]. During Lin et al. (2011) study OA indicated higher SMA and PMC brain activity [55] which was explained that because of the aging brain enhanced activation of the cortex as a method of adaptation to make up for its diminished effectiveness [56]. Woollacott & Shumway-Cook. (2002) signified that the DLPFC is associated with postural control's processing of sensory signals and allocation of attentional capacity [57] and plays a part in evaluating fresh data and developing new motor behaviors [58]. According to one study, the DLPFC, a region associated with working memory activity, had increased blood oxyhemoglobin needs during dental procedures, which is related to a stronger inclination for conscious control of motions [59]. Moreover, while performing more difficult sensory assignments, older adults demonstrated increased bilateral DLPFC activation, which is indicated that to maintain balance performance, OA have an expanded allocation of mental abilities that is compensatory in nature [60]. Therefore, the implementation of VR games might stimulate the activation of SMA, PMC and DLPFC brain areas, providing a way of improving balance control in patients with cerebrospinal nervous system disorders.

There are three papers analyzed in this study, and the limitation is that the number of studies is small and various information cannot be reflected. However, this study is meaningful in presenting the information because VR intervention methods have been actively conducted most recently, and there was not a lot of research on the correlation with monitored brain activity. Overall, it is likely that specific training protocols, subject populations, and task demands used in each study play a role in the observed effects. Additionally, fNIRS has limitations as a measure of brain function, and results should be accurately interpreted. To control the robustness and generalizability of the dual-task training's impact on cognitive abilities as measured by fNIRS, more research is required. Future research should explore the possibility of increasing neural plasticity in OA through balance games with or without a DT and consider whether these results would improve balance and reduce falls in daily life. Also, a true control group to determine the effects of Kinect-based exergames directly more thoroughly on cognitive activity, and conductivity of exergames to the understanding of the influence of the combination of motor and cognitive function is needed.

5. Conclusions

Dual task performance, or the capacity to carry out two things at once, is important because it reflects an individual's cognitive control and ability to allocate attention effectively. It is a key factor in evaluating cognitive function and can provide insight into an individual's capacity to perform everyday multi-tasking-intensive activities like driving and talking on the phone or working on the computer and holding a conversation. Additionally, research has shown that dual task performance declines with age, making it an important measure of age-related changes in cognitive function. This systematic review provided information on studies about the effectiveness of dual-tasking VR interventions on brain activity in improvements of global cognition and maintaining balance. We recommend that future studies should include more longitudinal studies to explore the potential mechanism of VR and more studies with different types of neuro system disorders.

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