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Role of Computerized Software, Artificial Intelligence, and Virtual Reality in Cognitive and Neuromotor Rehabilitation Therapy after Brain Injury

Presha Goel[1], Manoj K Bajaj[2]

Abstract: ***Rehabilitation of impaired cognitive functions that occur because of an acute insult to the brain or through progressive neuronal degeneration is an active area of research. Neuronal injury may result in deficits affecting cognition or neuromotor function, thus affecting activities of daily living. Conventionally, cognitive rehabilitation has been provided by trained therapists through paper-pencil tasks, while motor rehabilitation has been managed through physiotherapy. However, with easy and widespread access to computer software through mobile phones, tablets, and personal computers, computer-assisted rehabilitation has been gaining a strong footing. Artificial intelligence (AI) has been used by researchers to design tasks to improve patients' cognition and keep them engaged, and virtual reality-based exercises are being used for neuromotor rehabilitation. AI-based robotic exoskeletons and robotic-assisted gait training have been reported to improve the mobility of patients. This review assesses the status of computer-assisted cognitive rehabilitation and its role in the recovery of patients with acquired neuronal injuries.***

Keywords: brain injury, neurodegeneration, cognitive rehabilitation, neuromotor rehabilitation, computer assisted rehabilitation

1. Introduction

Rehabilitation of impaired cognitive functions that occur because of an acute insult to the brain or through progressive neuronal degeneration is an active area of research. Since the nature of the insult, or the specific area of the brain that has been affected, determines the type and degree of deficit, the rehabilitation process needs to be tailored accordingly. These deficits may include those related to attention, memory, perception, comprehension, action-oriented processes related to conceptualization, planning, organization, and execution of a task, as well as neuromotor deficits resulting in limitation of mobility.[1, 2] These disturbances may affect interpersonal communication and activities of daily living (ADL).

The goal of cognitive rehabilitation is to improve the functional capacity of an individual by enhancing the person's ability to process and interpret information. It aims to address attention, memory, executive functions, and pragmatic communication through one-to-one sessions. There are two main approaches to cognitive rehabilitation therapy (CRT): the restorative and the compensatory approach.[3] Through the restorative approach, CRT aims to reinforce and restore impaired functions through the repeated exercise of standardized cognitive tests of increasing difficulty while targeting specific domains. The compensatory approach teaches alternate ways for compensating. For example, effective use of electronic memory devices, or reminders to compensate for memory deficit.[4]Although this has conventionally been done through paper and pencil tasks, i.e., conventional cognitive rehabilitation (CCR), there is an increase in interest in computer assisted cognitive rehabilitation (CACR).

For cognitive rehabilitation therapy (CRT) to be effective, a multidisciplinary approach is required encompassing interventions through other specialists such as speech, occupational and physical therapists to address other activities of daily living that may need improvement.4 Further, cognitive behavioral therapy (CBT) is also required for the treatment of psychological disturbances that are often associated with brain injury.[5] As noted by Silver et al cognitive rehabilitation is best suited when the recipient is well-motivated and has a mild to moderate degree of cognitive impairment.[6]

In this evolving field of CRT, newer approaches are being tried by therapists for optimal outcomes. This article aims to review the literature regarding computer assisted approaches to cognitive and neuromotor rehabilitation and the role of artificial intelligence (AI) and virtual reality (VR) in assessing as well as treating various deficits that may be associated with brain injury or neurodegenerative diseases such as multiple sclerosis, Parkinson's disease, and Alzheimer's disease.

Cognitive assessment

An essential part of rehabilitation is an accurate, objective assessment of the cognitive deficit. Hanley et al have studied the potential clinical utility of a quantitative electroencephalographic (EEG)-based Brain Function Index (BFI) to measure the presence and severity of functional brain injury. They found that BFI scaled with the severity of functional impairment in patients with brain injury (BI), and therefore, it could serve as a quantitative marker of brain function impairment. Using Artificial intelligence (AI), this algorithm has been further developed to differentiate between functional abnormalities and structural injury.[7]

Similarly, CANTAB mobile testing app developed by Cambridge Cognition™ is a digital memory assessment tool that can objectively test deficits in memory. It can diagnose patients with neurocognitive dysfunction and dementia at an early stage while reassuring healthy patients about the absence of disease.[8]

Another such test is the computerized neuropsychological test (CNT, Maxmedica, Seoul, Korea). It tests for five components: Verbal memory, visual memory, attention, visuomotor coordination, and higher cognition functions. It has been found to have good diagnostic accuracy and is being consistently used.[9] Along similar lines, Repeatable Battery for the Assessment of Neuropsychological Status Update® (RBANS® Update) is a digital, individually administered battery to measure cognitive decline or improvement that can be administered in a tele-practice context.[10]

Cognitive Rehabilitation

Computer assisted cognitive rehabilitation (CACR) is not a new concept. A historical perspective of CACR has been provided by Bill Lynch (2002) in which he linked the origin of CACR to the use of video games as therapeutic recreation in the late 1970s.1[1] These computer-generated games, which provide digital experiences referred to as virtual realities (VR), provide a controlled environment for performing engaging and customizable rehabilitation activities. The inclusion of VR in rehabilitation can result in better functional outcomes, including the recovery of the damaged neural tissue through neuroplasticity and neurogenesis, thus at least partially compensating for some of the functional alterations resulting from the injury.[11, 12]

For this review, we will refer to two types of VR which can be differentiated by the intensity and quality of feelings elicited in the user – non-immersive and immersive VR.1[2] Non-immersive VR is the type that we encounter while using computers, tablets, smartphones, or other electronic devices. Since the virtual world is displayed on the monitor and the user interacts with it through input devices such as keyboards, monitors, or joysticks, there is simultaneous awareness of the physical surroundings as well as the virtual world is displayed on the monitor. The following section deals with CACR delivered through interactive software programs of non-immersive variety.

Bonnechère et al studied the role of computerized cognitive games to prevent cognitive decline due to decreased mental and physical activity in healthy aging. They reported that significant improvement occurred in processing speed, working memory, executive function, and verbal memory, although attention and visuospatial abilities were not significantly benefitted.1[3] Kim et al used *RehaCom®* software for CACR in their RCT which was conducted among 32 patients with acute brain injury either due to stroke or trauma and compared the results with therapist-driven cognitive rehabilitation (TCR). In the CACR group, 30 minutes of cognitive training using RehaCom was performed 5 times a week for 2 weeks. Each session was supervised by a trained therapist who provided instructions, the first time each module was performed. Further intervention by the therapist was restricted only to the events when the patient was unable to complete the module appropriately. On the other hand, in the TCR group, the therapist walked the patient through manual tabletop activities designed to improve multiple neurocognitive domains, like in the CACR group. The frequency and duration of sessions were the same, but the therapists were free to intervene intuitively to any extent during the session. The researchers reported that while both groups showed significant improvement in tests for complex attention and executive function, the TCR group showed significant improvement in the additional executive function tests related to phonemic fluency and semantic fluency. On the other hand, the CACR group showed significant improvements in the additional complex attention tests-symbol search, and digit symbol coding.[14]

Similarly, by using the visual exploration training through *RehaCom®* (Hasomed GmbH; Magdeburg, Germany) program, Lee et al reported that CACR resulted in improvement in static balance among the elderly, which can help in the prevention of injuries due to fall.[15]

De Luca et al have explored the role of CACR to improve visuospatial and executive functions in Parkinson's disease using the *ERICA* platform (www.erica. giunti. it)-an Italian computerized cognitive tool, aimed at improving cognitive domains related to attention, memory, spatial cognition, and verbal and non-verbal executive functions. The software offers a wide repertoire of exercises from which a therapist can choose the ones that they wish to include in a patient's treatment plan. These exercises promote motivation by engaging the patient in playful tasks and encouraging awareness of performance through audio-video feedback. In this randomized trial, De Luca et al found that although an improvement was seen in both sets of patients – those undergoing CCR as well as those undergoing CACR, significantly higher improvement was observed in attention, orientation, and visual-spatial domains in the CACR group.[16]

Similarly, in a randomized control trial (RCT) involving patients with Multiple Sclerosis with mild to moderate cognitive impairment, De Luca et al reported that compared to the conventional therapy, CACR using the *ERICA* software resulted in a higher improvement in memory, attention, and processing speed.[17]

In an RCT conducted by Marin et al, CRT using paper-and-pencil training over 24 weeks was compared to CACR using *Constant Therapy App®* in patients with Alzheimer's disease in the early stages of cognitive impairment and mild dementia. They reported that patients in the CACR group showed greater adherence to therapy than the CCR group and had greater improvement in performance over time.[18]

Various other AI-based commercially available programs and apps such as *Brain HQ®, and Brain Function Therapy®* have also been used by researchers to assess the effect of CACR on patients with acquired brain injury.

Neuromotor rehabilitation

Technologies based on Immersive Virtual Reality (VR) have steadily gained ground in neuro-rehabilitation. In immersive VR, the person enters the virtual world with the help of specialized hardware, such as a head-mounted display, a bodysuit, data gloves, and an immersive room, and lives in virtual reality for that duration of time.[19] The purpose is to sustain the illusion that the virtual world is the actual real world. Sensors attached to the bodysuit can monitor the person's movements. Electroencephalographic cap can be used to track brain activity, thus, generating and recording a large amount of data, which can be analyzed to tailor therapy.

One such example is *BTS Nirvana*, a medical device engineered by *BTS Bioengineering* that uses immersive VR for neuro-rehabilitation of motor and cognitive functions of patients with acquired neurological deficits. It creates a virtual 'sensory room' for the patient to provide an immersive, stimulating experience, making the rehabilitation process more effective by involving the subject. Exercises can be adapted to a specific patient's abilities. There is a real-time adjustment of the patient's environment in accordance with the patient's behavior, thus providing strongly stimulating audio-visual feedback. By using this system, patients can be rehabilitated more effectively under the supervision of a therapist.[20]

In a randomized controlled trial designed to study the efficacy of BTS-Nirvana in comparison to traditional cognitive rehabilitation therapy, De Luca et al reported that while both treatment groups showed a significant improvement in cognitive functioning and in mood, only the virtual reality group showed a significant increase in selective attention, and cognitive flexibility and shifting, thus leading to better cognitive and behavioral outcomes.[21]

Gamified neurore habilitation mobile therapy systems, developed at *MindMotion*™ provide VR-based motor-cognitive training through motivational games and empowerment techniques. This invention promotes functional improvements by using motion capture technology and an AI-based algorithm. According to the developers, the system focuses on the bio-psycho-social aspects of cognition, emotions, and positive experiences and therefore addresses multiple aspects of rehabilitation for a sustained and long-term effect. It provides rehabilitation exercises for the upper limbs, trunk, and lower limbs. Audio-visual feedback and graphic movement representations for patients keep them engaged and motivated. Simultaneous capture and analysis of data regarding patient performance help medical professionals to tailor therapy.[22, 23]

Effective balance rehabilitation requires frequent repetition of challenging exercises.[24] In a Cochrane review, Laver et al concluded that VR-based exercise-oriented games "exergames" can increase the training dose and deliver good results when used synergistically with conventional therapy by inducing neurogenesis and neuroplasticity.[25] To guide clinicians in the selection of patient-focused VR-based balance exercises, Wiskerke et al conducted a Rasch analysis[26] to determine the optimal VR exergame approach for balance therapy in persons with neurological disorders such as stroke and multiple sclerosis. Using the Rasch analysis, they could identify a hierarchical order of VR-based exercises for persons with low to moderate balance ability.[27]

Brain-computer interfaces (BCIs) have been shown to promote motor rehabilitation by pairing movement-related activity of the brain with the congruent somatosensory feedback through electrical stimulation, thus inducing neural plasticity. [28] This is the principle behind gait training and VR-based balance exercises by using robotic exoskeletons (RE) for helping patients with lower limb weakness to walk as well as helping patients with upper limb weakness to gain functionality.[28]

Limb weakness may be a common sequela of vascular or traumatic brain/spinal cord injury. Studies suggest that robotic-assisted gait training in persons suffering from acquired brain injury is statistically more likely to recover independent walking as compared to those who do not use RE.[29, 30] During RE-supported movement, nerve signals are sent from the brain to the muscles producing biosignals that the robot suit can perceive through the sensors on the skin. As a result, the exoskeleton moves at the same time as the muscles, thus supporting weakened muscles to produce movement that might not be possible otherwise.[31] Use of robotics in rehabilitation could also improve activities of daily living that require similar motor skills, thereby enhancing cognitive rehabilitation.[32]

Two REs have been approved for rehabilitation of brain/spinal cord injury patients who have an inability/difficulty with walking-*ReWalk*and*Ekso*. Both these products are available for neurorehabilitation under the supervision of a therapist and have enabled patients to gain some functionality and adapt themselves better to activities of daily living. However, the cost is a limiting factor for the widespread use of an RE.[31]

In their paper, Jochumsen et al have described the setup for induction of neural plasticity by pairing a BCI setup with a low-cost 3D-printed wrist exoskeleton. The electrical encephalographic potential generated by an imaginary movement can send a wireless signal to the Arduino on the wrist exoskeleton through a paired personal computer running on OpenViBE. The movement of the wrist exoskeleton is executed through an electrically powered linear actuator control board.[33]

With the ongoing research in this field, there is hope for customizable low-cost robotic exoskeletons to rehabilitate patients suffering from neural injury.

Is Computer Assisted Cognitive and Neuromotor Rehabilitation Effective?

A systematic review of the available literature is difficult because of the heterogeneity in the study protocols and results. However, most reviews have reported at least a partial benefit associated with computerized rehabilitation.

Bogdanova et al reviewed the use of computerized treatment as a rehabilitation tool for attention and executive function in adults who suffered an acquired brain injury. They reported that preliminary evidence suggested improvement in attention and executive functions in patients undergoing CACR.[34]

Maggio et al (2019) reviewed the growing role of virtual reality in the therapy of brain-injured patients. They concluded that rehabilitation through new VR tools focused on cognitive and neuromotor rehabilitation could affect patient outcomes positively, by boosting motivation and participation. They reported that VR can enhance the effects of conventional therapy by promoting longer training sessions and by reducing hospital stays because of the availability of home-based therapy using VR.[35]

In their review, Tosto-Mancuso et al (2022) commented that although rapid development of gamified neurorehabilitation technologies has taken place in the past decade, clinical adoption remains limited. While the authors insist that there is a need to address feasibility and deployment strategies, they also note that wider use of computerized exercise-based therapies will help in the detection of additional benefits of gamification.[36]

Nedergård et al conducted a systematic review to summarize the evidence for the effect of robotic-assisted gait training (RAGT) on biomechanical measures of gait. Using a random-effects model for gait speed, cadence, step length (non-affected side) and spatial asymmetry, they concluded that there was no significant difference between the RAGT and comparator groups. However, stride length, step length, and temporal asymmetry improved slightly more in the RAGT groups.[37] Further, Schwartz et al noted that longer duration and a higher intensity of RAGT seemed to have a beneficial effect on the final functional ambulation outcomes.[38]

Finally, Perez-Marcos et al propose virtual reality (VR) as the appropriate medium to design long-lasting effective treatments for motor-cognitive neurorehabilitation through motivational games, and empowerment techniques. They insist that through VR, the therapist can integrate evidence-based neurorehabilitation techniques and neuroscience principles into motivating training approaches that promote self-management by empowering patients to own their recovery process.[39]

2. Conclusion

Cognitive and neuromotor rehabilitation is shaping up in this day and age of artificial intelligence and machine learning. While CACR should not be taken as a substitute for the rehabilitation delivered by a trained therapist, these modalities can definitely be used as an additive to enhance the intensity of therapy, induce the necessary modifications and variations, as well as encourage prolonged and continued therapeutic support for better long term outcomes.

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