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Neglect, virtual reality and music therapy: *A clinical report*

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Abstract
Neglect is typically experienced after suffering from a stroke. Despite various rehabilitative interventions used in treatment for neglect, there is no consensus about the most effective intervention or treatment. Virtual Reality (VR) combined with music therapy practices may offer a promising intervention for use during neglect rehabilitation. This review summarises evidence of existing interventions and assessments used for post-stroke and neglect rehabilitation on patients in VR and music therapy research. Non-systematic searches of the PubMed and PsycINFO databases were conducted to retrieve relevant articles. Overall, literature found in small studies suggests promising findings for symptom reduction during neglect rehabilitation through the use of VR and Musical Neglect Training interventions. This was coupled with a demonstration of feasibility and safety. Novel evidence is found in stimulation of specific neurological regions in neglect patients during exposure to a VR intervention. However, larger trials with consistent assessments are needed to arrive at generalisations. Based on the evidence reviewed, the article explores intersections of VR and music therapy interventions with the purpose of neglect rehabilitation.

Keywords: ***Stroke; neglect; rehabilitation, music therapy, virtual reality***

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Introduction

Focus of the Review

Despite various rehabilitative interventions used for treatment of neglect, there is no consensus about the most effective intervention or treatment [1]. Given the lack of research exploring the combined use of VR and auditory cues to neutralise neglect bias, a review identifying and describing interventions and assessment in VR and music therapy research applied to stroke and neglect populations would provide an understanding of whether or not such an intervention is applicable for treating neglect. Therefore, this review summarises evidence of existing interventions and assessments used for post-stroke and neglect populations in VR and music therapy research.

PRODUCTION NOTES:

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The Neglect Syndrome

Neglect is a common result of a right hemispheric stroke in the brain. This affects approximately 60% to 70% of stroke populations. [2,3,4] State that neglect is caused due to damage to the multisensory cortex, where the auditory and visual input combine to construct spatial representations of our body's position in relation to our environment. Neglect may also be referred to as hemineglect, spatial neglect, visuospatial neglect, visual neglect, unilateral spatial neglect (USN), paresis, and hemiparesis. [5] indicate the frequency of patients suffering with neglect in the United States is estimated to be from 13% to 81% in populations who have experienced a right hemisphere stroke. They also describe rates in other countries that exist at approximately 50% of the stroke population.

Areas of Functioning Affected by Neglect

Neglect can affect various areas of functioning. Often the functions affected include impaired neurological performance, motor performance of the limbs and perception. According to [6], the distinct deficit in patients experiencing neglect is an orientation bias to the right. There are two categories of neglect that affect functioning. These categories are: 1) how neglect affects behaviour (e.g., physical sensation, and motor movement) and 2) how much it disrupts perception (e.g., personal awareness or spatial awareness) [1,7,8,9]. In a recent review, neglect is described as causing comorbid visual conditions such as strabismus, greatly increasing the risk of a fall [10]. There is further evidence that patients suffering from neglect cannot accurately perceive time. This is known as time discrimination [11], which causes disruptions to visual attention when directing it over time [12]. Furthermore, neglect weakens the accuracy in perceiving sounds when audio tones are presented in the neglected area, e.g., the left ear [13,11,14]. Due to the combined auditory (perception of sounds) and visual (directing visual attention) impairment caused by neglect, these disabling effects can impede patient participation and adherence to rehabilitation programs. It may also decrease patient independence in activities of daily living (ADL). Furthermore, patients with neglect report higher scores for depression than non-neglect patients [15].

Neglect Rehabilitation and Recovery

Following neglect, rehabilitation and recovery is needed by patients. Differences between rehabilitation and recovery are important to outline. [16] defines rehabilitation "as any aspect of stroke care that aims to reduce disability and promote participation in activities of daily living" (p. 239). [16] also describes rehabilitation as being a "process… to prevent deterioration of function, improve function, and achieve the highest possible level of independence" [16, p. 239]. Recovery associated with neglect is defined as "improvement across a variety of outcomes, beginning with biological and neurologic changes manifesting as improvement on performance and activity based behavioral measures" [16, p. 239].

Typical neglect rehabilitation is closely related to stroke practices, and may involve its associated interventions. These may be the following, but not limited to: a) Physical interventions, such as muscle strengthening, repetitive task training, constraint induced mobility therapy, mirror therapy, gait rehabilitation and botulinum toxin; b) Regenerative interventions, such as cognitive rehabilitation, non-invasive brain stimulation, neuromodulators and drugs to enhance motor recovery; c) Remote rehabilitation interventions, such as telerehabilitation, biotechnology and wearable sensors, and brain-computer interfaces; and d) Intervention technologies for rehabilitation such as robotic devices, VR and electrical stimulation [17].

Neuroplastic Changes post-stroke and Musical Stimuli

A fundamental aspect of post-stroke and neglect rehabilitation is inducing neuroplasticity. Neuroplasticity is generally understood as the capability of the nervous system to respond to intrinsic and extrinsic stimuli through reorganization of its structure, function and connections [18, 19]. Evidence for understanding neuroplasticity and the nature of how the brain functions when exposed to musical stimuli has been found through studies engaging in music, actively or passively, as well as the use of music-based interventions on various populations [20, 21]. The multisensory and multimodal actions of music engagement and music-making activate various neural pathways in the brain - this multi-modal aspect of music may be the reason for its role in supporting plastic changes in the nervous system [19]. Recently, music-based interventions have been used in the rehabilitation of traumatic brain injury [22] and stroke [23, 24].

Neurological Music Therapeutic Approaches

In recent years, music therapy practices have been researched, developed and applied to stroke and neglect rehabilitation. [25] states that "music therapy is a systematic process of intervention wherein the therapist helps the client to promote health, using music experiences and the relationships that develop through them as dynamic forces of change (p. 20)". According to the American Music Therapy Association [26] music therapists assist the following client populations: developmental and learning disabilities; Alzheimer's and other aging related conditions; substance abuse problems; brain injuries; physical disabilities; acute and chronic pain. An accepted model put into practice within music therapy and neuroscience is Neurologic Music Therapy (NMT) [27].

Music listening and musical activities such as playing an instrument, induce neural plasticity in various brain regions, with an emphasis in frontotemporal areas [3, 28, 29, 30, 31]. Examples of effective music listening have been reported in the recovery of discharged patients after different types of major surgery. This is measured via indicators such as pain and anxiety level, use of analgesics and patient satisfaction [32], providing support that music may also enhance neurological rehabilitation [3]. Evidence exists for the use of auditory stimuli as an effective training stimulus during the rehabilitation of neglect. Significantly, the use of auditory stimuli enhanced visual perception during neglect rehabilitation studies [33, 34].

Based on the data of NMT, Musical Neglect Training (MNT) has been developed for patients with visual neglect [27, 35]. MNT is a (NMT) technique employed by music therapists that uses active musical exercises with participants. In the exercises, participants are required to play musical patterns (that can be melodic or rhythmic) on musical instruments that extend to the neglected visual field. The musical patterns should be well known to the participants to drive an attentional search in applying and completing music-related events in the neglected field.

VR Rehabilitation

VR is a technology that has been researched and subsequently utilised as an intervention for stroke and neglect rehabilitation. VR systems rely on computer hardware and software in creating and mediating interaction between the user and the virtual environment [36]. VR rehabilitation typically involves providing its user with visual-audio stimuli presented through a head-mounted device (HMD) to foster real-time feedback. Feedback can also be provided through the patient's senses (e.g., by movement, touch, or sound) [37, 38] by means of using different interaction devices. Thus, the patient can interact with these virtual environments utilizing different input (e.g., joysticks, cameras, sensors or haptic devices) [38].

VR rehabilitation has been noted for its ecological validity, with the technology's capability to simulate realistic environments in which stimulus control can support consistent repetitive delivery that is hierarchical [39]. Specifically, the feedback stimuli delivered by VR can appear graded and manipulated across multiple sensory modalities (e.g., audio, visual and tactile), as well as tailored to the goals of the patient, therapist and functional capability of the patient. VR application design and research with clinical populations has been focused on developing functional activities which can be completed safely. The activities are monitored with degrees of accuracy using kinematic tracking (i.e., motion capture) found in VR systems to provide a naturalistic record of the patient's bodily movement.

Limitations to VR rehabilitation are found in aspects of development and user experience. For example, finding the most suitable manner to use and interact with VR during rehabilitation is usually costly and time-consuming, depending on user testing [39]. VR applications may also lack clinical ease of use, with back-end data extraction providing raw data that is sometimes not accessible to healthcare teams. Then, there is the problem with VR's main stimulus delivery device, the HMD. While HMDs provide rich immersive experiences and stereoscopy, they are sometimes difficult for the user to use, tethered to a system by cable and provide a limited field of view. Side effects after using HMDs include, *cybersickness* and *aftereffects*. Cybersickness is a form of motion sickness, with reported symptoms in nausea, vomiting, eyestrain, disorientation, ataxia, and vertigo [40]. Aftereffect symptoms include flashbacks, drowsiness, fatigue, and perceptual-motor disturbances [41, 42, 43]. User eyestrain and headaches are also reported after using HMDs. The use of headphones with HMDs has also been reported as uncomfortable to wear for some users.

VR Intervention Use for Neglect Populations

VR interventions for neglect rehabilitation have been developed, with studies tracking the upper-limbs of the patient using motion-capture technology related to task cueing stimuli [44]. The therapeutic goals associated with these interventions varied widely, with some using prism adaptation methods [45] removing parts of the ipsilesional visual field to promote contralesional orientation [46], and having patients reach for objects on the ipsi- and contralesional spatial side [47, 48]. In [47, 48], therapist support was given to some patients while they used the VR interventions. [44] writes that much of the visual stimuli used in these VR interventions was simple, using block shapes and colour to represent environments or task-related items the patient would interact with virtually.

VR and MNT Adjunct Use

Given that neglect is typically a multisensory phenomenon, [6] recommends using sensory signals from different modalities to counteract the rightward bias in neglect patients. Adjunctive use of VR rehabilitation with MNT tasks may provide a music therapist and/or multidisciplinary healthcare teams with an effective multi-modal tool to include during neglect rehabilitation. This is because of VR's multi-modal capability that includes immersion in a virtual environment via visual and audio stimuli, access to motor tasks in games with applications simulating realistic bodily movement associated with ADL, a safe environment to practice rehabilitation, and its kinematic tracking capability using motion capture technology that may be applied to patient assessment.

Methodology

To construct this narrative review, non-systematic searches of the PubMed and PsycINFO databases were conducted to retrieve relevant articles, using English language restrictions. The data search included terms for virtual reality, neglect, music therapy, and rehabilitation.

Selection Criteria

1. Study Type: Published peer reviewed primary studies.
2. Study Group: Patients (>18 years old) in a general hospital, family medicine clinics, sports medicine clinics, chiropractor clinics, physiotherapy clinics and/or

rehabilitation clinics, with a diagnosis of neglect, hemineglect, spatial neglect, paresis and hemiparesis, using established diagnostic criteria.
3. Study Intervention: VR practice delivered/accompanied by specialists in physical medicine, rehabilitation, paediatricians, orthopaedics and physiotherapists. Music Therapy delivered by a Music Therapist (defined by possession of professional Music Therapy qualification and/or registered with the appropriate governing body).
4. Study Outcomes: Changes in stroke or neglect symptoms as measured by validated rating scales, clinical study report, case study report.

Articles deemed relevant to all authors, including randomized controlled pilot trials, VR rehabilitation effects on ADL studies, observational case studies, a neurologic music therapy study, VR rehabilitation used adjunctly with physiotherapy, VR rehabilitation used with fMRI studies and feasibility trials were included. Data were examined and reviewed based on their clinical relevance.

Results

Topics and Study Designs

The study design results show one pre- and post- test design, three between group designs, two case studies, one between group design and within subject's design, and one quasi-experimental design: Non-equivalent control group design, one two-arm pilot RCT clinical trial. The largest study population includes 36 participants with the smallest study population including one participant (one case study). Information about the study designs and populations are summarised in table 1.

Table 1. *Summary of the 9 studies reviewed, their objectives/goals, interventions, study designs, and study outcomes reported. Note the asterisks (*) indicate intervention, assessment, and follow-up periods.*

Study Title	Author(s) and Reference	Study Objective/Goals	Intervention	Study Design	Number of Participants	Outcomes
Musical Neglect Training for Chronic Persistent Unilateral Visual Neglect Post-stroke	Kang and Thaut [49]	Spatial Neglect Symptoms	Musical Neglect Training *6-weeks follow up	Pre- and Post-Test Design	2	AT, LB *1-week follow-up
Rehabilitation in Chronic Spatial Neglect Strengthens Resting-state Connectivity	Wåhlin, Fordell, Ekman, and Lenfeldt [50]	Stroke severity, Awareness of physical sensation, Unilateral Neglect severity, Neglect severity, DAN Analysis, Brain Functional Anatomy	RehAtt®	Between Group Design	13	fMRI *1-week before intervention *1-week after intervention SCT, LB, BTT, VET, RBIT (VR-DISTRO). *1-2 weeks between assessments *1-week follow-up
Increase of Frontal Neuronal Activity in Chronic Neglect Training in Virtual Reality	Ekman, Fordell, Eriksson, et al. [51]	Stroke severity, Unilateral Neglect severity, Neglect severity, Awareness of physical sensation, Attention Behaviour	RehAtt®	Between Group Design	12	CBS, SCT, LBT, VET, BTT, PCT *PCT 1-2 weeks between sessions * fMRI scan 1-week before intervention and 1-week after intervention

Differing Effects of an Immersive Virtual Reality Programme on Unilateral Spatial Neglect on Activities of Daily Living	Yasuda, Muroi, Hirano, Saichi, and Iwata [52]	Visual Neglect severity, Unilateral Neglect severity, Stroke severity	Immersive VR programme	Case Study	1	LCT, LB, CBS.
Increasing Upper Limb Training Intensity in Chronic Stroke Using Embodied Virtual: A Pilot Study	Perez-Marcos, Chevalley, Schmidlin, et al. [53]	Motor Impairment, Awareness of physical Sensation, Safety of intervention, Patient Motivation	Mind-Motion ™ PRO	Between Group Design	10	FMA-UE, AROM, Muscle Strength, Functional Independence, Pain ratings, Safety and Acceptance of Technology, Tolerance to VR Intervention, Adverse Event Monitoring, Self-evaluation, Acceptance of technology, Motivation
Use of Virtual Reality In Improving Poststroke neglect: Promising Neuropsychological and Neurophysiological Findings From a Case Study	De Luca, Lo Buono, Leo, et al. [54]	Cognitive Impairment, Motor Impairment, Attention Behaviour	Bts-Nirvana System	Case Study	1	MMSE, Repeatable Battery for Neuropsychological Status, BIT, TCT.
Virtual Reality Application for the Remapping of Space In Neglect Patients	Ansuini, Pierno, Lusher, and Castiello [55]	Unilateral Neglect severity, Stroke severity	Hollow Box, Computer Monitor, DataGlove.	Between Group Design, Within Subjects Design	9	AT, SCT.
Virtual Reality Games as an Adjunct in Improving Upper Limb Function and General Health among Stroke Survivors	Ahmad, Singh, Nordin, Nee, and Ibrahim [56]	Motor Impairment, Patient Motivation, Patient functional independence, Stroke severity	Virtual Reality Games	Quasi-Experimental Design: Non-equivalent Control Group Design	36	FMA-UE, WMFT, IMI, IADL, SIS.
Feasibility, Safety and Efficacy of a Virtual Reality Exergame System to Supplement Upper Extremity Rehabilitation Post-Stroke: A Pilot Randomized Clinical Trial and Proof of Principle	Norouzi-Gheidari Hernandez, Archambault, Higgins, Poissant, Kairy [57]	Motor Impairment, Strokeseverity	Jintronix System	Two-arm pilot randomized clinical trial, pre-post follow-up design.	18	FMA-UE, BBT, SIS, MAL. *Baseline *Post-intervention *4-weeks follow up

Assessments

In all of the studies reviewed, various assessments are used to assess the patient's presence or severity of stroke and neglect symptoms. The different methods of assessment used are outlined below under the following categories: brain activity, computerised measures, standardized health measures and kinematic Tracking. Brain Activity was inclusive of Computed Tomography (CT), Magnetic Resonance Imaging (MRI), Functional Magnetic Resonance Imaging (fMRI).

The Standardized Health Measures included Activities of Daily Living (ADL), Albert's Test (AT), Behavioural Inattention Test (BIT), Barthel Index (BI), Catherine Bergego Scale (CBS), Fugl Meyer Assessment of Upper Extremity (FMA-UE), Functional Independence Measure (FIM), Intrinsic Motivation Inventory (IMI), Line Bisection Task (LB), Line Cancellation Test (LCT), Mini Mental State Examination (MMSE), Montreal Cognitive Assessment (MoCA), Motor Activity Log (MAL), Muscle Strength, Stroke Impact Scale (SIS), Trunk Control Test (TCT), Visual Extinction Test (VET), Wolf Motor Function Test (WMFT).

The Computerised Measures were Posner Cueing Task (PCT), Star Cancelation Test (SCT), Extinction Test (ET), Baking Tray Task (BTT), Rehabilitation Gaming System (RGS). Kinematic Tracking showed VR motion capture, Active Range of Motion (AROM).

Rehabilitation Strategies

Rehabilitation strategies are referred to as the processes to how interventions function and what neurological and behavioral mechanisms they aim to engage during rehabilitation [49, 51, 57]. There are two different post-stroke rehabilitation strategies. These are known as top-down and bottom-up. Top-down examples involve visual scanning training and visuomotor imagery therapy, while bottom-up techniques involve arm activation and prism adaptation training. Many of the existing top-down and bottom-up strategies and techniques have not demonstrated significant clinical efficacy, specifically for persons suffering with visual neglect [58, 59, 49]. Hence, there is a need for novel interventions to be used for neglect rehabilitation purposes.

One study [51] reveals what areas in the brain are typically stimulated most with top-down and bottom-up rehabilitation techniques. For instance, the Dorsal Attention Network (DAN) is a goal driven network, controlling spatial attention and stimulus selection and these are occupied with top-down rehabilitation strategies. On the other hand, the Ventral Attention Network (VAN) is described as a stimulus driven network, involved in reorientation, alerting responses and vigilance, and therefore, it is occupied with bottom-up rehabilitation strategies.

Interventions

In all of the literature reviewed, the two primary types of interventions used are VR and music therapy (specifically the MNT method of Neurologic Music Therapy). Some of the interventions are used as a primary mode of rehabilitation e.g., MNT in [49], VR in [55], VR in [52], and some of the interventions are used adjunctly with other modes of rehabilitation such as physiotherapy [57, 56] and standard cognitive therapy [54].

Descriptions of VR Applications, Devices and Games

Table 2. *A description of the VR applications, devices and games used from the literature reviewed. The table reads horizontally from the authors (researchers who applied the VR applications) to the VR applications and games used in the studies, to descriptions of the studies.*

Authors	VR Applications and Games	Descriptions
Ahmad, Singh, Nordin, Nee, and Ibrahim [56]	VR Games with Cy-Wee Z Game Controller	VR Games (including Mosquito Swat, Music Catch, Rebounce, Bejewelled, Balloon Popping, 10-pin Bowling, Air Hockey, Mah-Jong, and Solitaire) with Cy-Wee Z Game controller. The game controller is equipped with accelerometer, gyroscope and magnetic sensors enabling display of free movement in 3-dimensional space and capacity to detect depth.

Ansuini, Pierno, Lusher, and Castiello [55]	DataGlove	A VR controller (called DataGlove) with a computer program designed to allow neglect patients to reach and grasp an object, while simultaneously enabling the patients to observe the grasping of the virtual object in VR by a virtual hand. The virtual hand was controlled by their real hand which was placed in the DataGlove.
De Luca, Lo Buono, Leo, et al. [54]	Bts-Nirvana	Bts-Nirvana is a VR system connected to a projector or a big screen, reproducing a series of exercises. The system analyzes the patient's movements to create interactivity. Audio-visual stimuli produced from the system are presented on both sides of the virtual environment.
Ekman, Fordell, Eriksson, et al. [51]	RehAtt®	RehAtt® involves the patient to complete intense scanning activities, with levels of the game adjusted according to the patient's difficulty. The RehAtt® environment is also enhanced by sound, visual and vibrotactile stimuli which are integrated in the game. The patient's contralesional hand controlled the 3D game using a force-feedback robotic pen.
Norouzi-Gheidari, Hernandez, Archambault, Higgins, Poissant, Kairy, [57]	Jintronix	The Jintronix application is used by therapists to record a patients' physical activity and adjust the difficulty of a motor task.
Perez-Marcos, Chevalley, Schmidlin, et al. [53]	MindMotion PRO™	A VR-based system used for rehabilitation of the upper limbs after brain damage. Exercises of the MindMotionTM PRO™ are presented in game-like scenarios designed to increase patients' motivation and therapy dose. A motion tracking camera and touch with an embedded computer is included. The 3D motion tracking camera captures participant's movements, and quantifies upper limb and trunk joint angles using passive colored markers
Yasuda, Muroi, Hirano, Saichi, and Iwata [52]	Immersive VR Program (including a motion-tracking device called Leap Motion)	The Immersive VR program is a 3D room environment, in which a desk is seen. In front of the desk a virtual screen is placed and seven visual stimuli. Three objects are placed on the table in the VR space. The patient moved their right hand freely and was able to see their hand in the VR space. When the VR hand touched an object, the object turned red. To draw attention to the left side in the VR environment, they included a moving slit and slowly drew the projected image seen by the patient towards the left.

MNT Method of Neurologic Music Therapy

MNT emphasizes left-field visual processing by using musical exercises on music making equipment. MNT uses active musical exercises structured in pitch, time and tempo, using musical equipment purposefully configured to focus active attention toward the neglected field [49]. Theoretically, the combination of spatial orientation and motor execution in the perceptual and physical set up of MNT is a crucial component of the intervention, as it addresses these processes together.

In the study by [49], participants sat in a chair and played tone bars placed on the desk by using their non-paretic arm (right arm). The first tone bar (D) was placed toward the centre of the participants, (which was also aligned with the midsection of their faces). Following this, two tone bars (B, C#) were set to the right side before starting a scale or triad in order to begin the playing movement from right to left side. The participants followed five protocol levels by playing three ascending scales to full scale. A hi-hat cymbal was placed in the final position to provide a strong sound for completion of the pattern. In each pattern, the cymbals' edge matched the end of the very last tone bar's edge. The researcher was positioned on the patients non-neglect side (their right side) to provide instruction and play a keyboard accompaniment for each pitch. The participants repeated these patterns five times before moving to the next level.

Intervention outcomes

Musical Neglect Training Outcomes

MNT was used on two individuals with chronic visual neglect. These participants underwent six individual MNT sessions. Two standardized health measures were used on the participants, the AT and Line Bisection test [49]. The AT tests for visuo-motor neglect, while the Line Bisection test tests for egocentric perceptive neglect. The findings show significant improvements from pre- to post- intervention on one outcome measure, which was the AT, indicating improvement in visuo-motor neglect.

VR Rehabilitation with Daily Living Outcomes

[52] tested VR technology on a patient with near and far spatial neglect, evaluating if the VR application had an effect on the patient's ADL. They reported an improvement on post-stroke symptoms in tests assessing near and far space neglect (LB, and LCT) in their single participant. However, the study found no change in the patients' CBS scores that were used as a measure of ADL throughout the intervention period. The results of the study suggest the participant unsuccessfully translated visual search task skills used in spatial detection to ADL, thus the VR intervention had little effect on ADL. Despite this, the results in symptom improvements of the study are described as replicating previous findings, indicating the immersive VR intervention is beneficial for performing visual search tasks in cases of far space neglect.

VR Rehabilitation with Neurological Outcomes

[51] used functional magnetic resonance imaging (fMRI) scanning before and after patients used a VR intervention designed for neglect rehabilitation with the aim to evaluate if clinical improvements could be seen in chronic neglect after rehabilitation sessions. In addition, the team aimed to evaluate if such changes were represented by changes in neurological attention networks and in other areas.

Following a neuroimaging evaluation, results from the study indicate that regions of a neglect patient's brain are affected in a potentially beneficial way after training using a multisensory VR intervention for rehabilitation. Specifically, results show an increase in the neglect participants' task-evoked brain activity after the VR intervention was used for rehabilitation sessions. The brain regions activated include the prefrontal and temporal cortex during attentional cueing. Correlations were also found between brain and behavioural changes during use of their VR intervention and monitoring via fMRI scanning. The data show blood oxygen level-dependent signal (BOLD) signals in the brain increase as their patients (who have neglect) use their VR intervention for rehabilitation. This neurological activity correlated with behavioural improvements, reporting increased cue-induced focus of attention, found in the prefrontal cortex, bilateral middle and superior temporal gyrus after 15 hours of training.

The same team [50] used fMRI scanning to explore neural mechanisms associated with recovery and neglect. They present data on resting-state functional connectivity within the DAN in chronic neglect patients undergoing rehabilitation using VR, aiming to improve left-side awareness. The fMRI results from this study indicate that as patients completed training using a VR intervention, a region responsible for saccadic eye movements to the left became more integrated with the left posterior parietal cortex. In addition, fMRI scanning showed results indicating a longitudinal increase in interhemispheric functional connectivity between the right frontal eye field and left intraparietal sulcus following VR rehabilitation. Further analysis revealed that VR rehabilitation influenced DAN connectivity more than other networks. This is highlighted as potentially a new mechanism that can be used during the rehabilitation of patients with visuospatial neglect.

VR with Motor and Physical Rehabilitation Outcomes

[53] investigated upper limb function using VR as an intervention for post-stroke rehabilitation. The study reported findings in a high-efficiency rate (the relationship between the time of a therapy session and the time spent in active therapy) of 86.30% in favour of the VR intervention, as well as improvements in FMA-UE and AROM scores of the patient. No changes were found in the patient's functional independence. FMA-UE was tested at post-intervention and AROM was observed at follow-up. The results of this study conclude that task-specific VR training may be advantageous for motor recovery in stroke survivors.

To investigate upper limb motor function in stroke survivors, VR was used by [57]. They reported outcomes favouring the VR technology (M = 1.0%, 5.5%, and 6.7% between the intervention and control group, post-intervention) when compared to traditional stroke therapy (e.g., physiotherapy and occupational therapy). Furthermore, the study reported VR gamification technology as feasible and safe during post-stroke rehabilitation.

[56] studied the use of VR games (including Mosquito Swat, Music Catch, Rebounce, Bejewelled, Balloon Popping, 10-pin Bowling, Air Hockey, Mah-Jong, and Solitaire) applied adjunctly to traditional stroke therapy (e.g., physiotherapy) on a stroke population. The results report no significant difference between VR and traditional therapy interventions (e.g., physiotherapy).

VR with Cognitive Rehabilitation Outcomes

[54] used a VR system called Bts-Nirvana on a single patient suffering with USN. [55] demonstrated a significant improvement on a USN patients' motor and cognitive function. In addition, a minor improvement in the patients' mood is found, with a reduction in depression.

Discussion

Focus of the Study and Commentary

The focus of this review was to summarise evidence of existing interventions and assessments used for post-stroke and neglect populations in VR and music therapy research. The review includes studies that employed VR and MNT as interventions for post-stroke and neglect rehabilitation. In general, the authors came to similar conclusions as shown in other studies in this field [1, 7], with the exception of the fMRI scanning of neglect patients during the use of VR [51, 52]. This review is in line with [1] and [7] commentaries regarding the use of novel interventions in post-stroke rehabilitation studies. They argued that promising findings are found in smaller trials but appear more difficult to reproduce in larger ones. Such findings are abundantly clear in this review, where pilot studies, case studies and feasibility studies were reviewed but larger studies could not be identified. For instance [57, 56, 53, 54, 55], all produce positive findings in safety and feasibility regarding the use of VR for stroke and neglect rehabilitation. Yet, the efficacy of their interventions requires further investigation in larger trials. This finding is also emphasised in the MNT study. The number of participants involved in the studies was relatively small, with a maximum participant total of 36. In addition to small sample sizes, most of the study designs pose challenges to the integrity of the findings. Furthermore, no large scale RCT was reviewed.

This review highlights promising neurological outcomes seen in [51] and [50] studies, finding stimulation of specific neurological regions during exposure to a VR intervention in neglect patients. Specifically, [51] found the neurological activity in the prefrontal cortex, bilateral middle and superior temporal gyrus correlate with behavioural improvements, transferring to increased focus of attention. While [50] reported DAN activity of neglect patients as being positively influenced during exposure to VR rehabilitation, transferring to saccadic eye movement to the left becoming more integrated with the left posterior parietal cortex. [7] points out that such data is crucial for future study due to a lack of understanding of the neurological mechanisms that can be exploited during neglect rehabilitation. Yet, the sample sizes used in these studies are small, and the challenge remains to investigate their results in a larger trial. It is also unclear if the patients reported outcomes specific to the intervention used in both studies (i.e., RehAtt®).

The heterogeneity of the interventions reviewed during neglect rehabilitation make it difficult to assess their evidence with clarity, echoing findings from [1] scoping review. The lack of consistent selection of assessments used make it difficult to evaluate which intervention was most effective on its population and why. Indeed, the studies reviewed had a reliance on standardized assessments which are not neglect specific. This confirms findings from [7] review, that the general lack of common standards in this field obscures its findings.

Study Goals and Outcomes

Another reason for the lack of high-quality evidence could be that the goals of the studies were not consistently aligned in reducing disabilities and improving independence. Instead, they were focused on aspects pertaining to the feasibility (if the interventions functioned correctly or not) in using the interventions in post-stroke and neglect rehabilitation. [58] argues that the focus of studies in post-stroke rehabilitation should be in reducing disability and improving independence, rather than testing if interventions function or not. To demonstrate this, [52] reports that VR tasks used for neglect did not transfer to improvements in ADL outcomes, yet argued for the feasibility of their Immersive VR Program when used with neglect patients. Thus, the efficacy of the VR application is not promising when associated with daily living outcomes.

On the other hand, the review broadly points to preliminary evidence that VR used as an adjunct intervention for neglect rehabilitation with physical and occupational therapy practice is beneficial. This is indicated in the studies conducted by [56, 57, 53] who combined VR with physiotherapy, occupational therapy and physical therapy rehabilitation, producing positive therapeutic outcomes.

Exploring VR's purpose as an Adjunct Intervention in Music Therapy Practice

For VR to be used as an adjunct intervention during neglect rehabilitation by music therapists, its relevance for music therapy practice requires further examination. First, the lack of clinical evidence from this review to support the inclusion of VR technology with established music therapy practices, does not imply immediate adoption by music therapists. This suggests that acknowledgment of this review's results are used as a preliminary guideline to how VR can be applied to outcomes associated with music therapy practice. Second, the clear benefits in using VR adjunctly with music therapy practices must be developed. Third, using VR adjunctly with music therapy practices must be done in a safe and feasible manner. In order to investigate this, music therapy must be placed in a multidisciplinary context, acknowledging the healthcare practices which have previously used VR for different purposes. Therefore, the remainder of this review will briefly explore potential intersecting areas of research, as indicated from the results in relation to VR and music therapy rehabilitation, which may be applied to neglect rehabilitation.

Intersecting Purposes in VR and Music Therapy Interventions

Based on this review's findings, we explore how VR and music intervention purposes intersect in similar areas during neglect rehabilitation, such as the music therapist utilising VR for assessment purposes. We also discuss the multimodal capabilities of both interventions. Specifically, we consider VR's kinematic tracking capability as a motor assessment instrument that can be utilised by the music therapist, as this provides clinical data regarding the patient's limb movement based on practice. Furthermore, the multimodality of the intervention can be given importance due to its support in rehabilitating the multiple areas of dysfunction caused by neglect [9, 12, 8, 6, 11, 10].

Assessment

As indicated by use of the MindMotion PRO™ by [53], quantitatively tracking a neglect patient's kinematic behaviour (e.g., motor movement of the limbs) to audio stimulus during VR usage provides feedback about the patient's limb movement. This could be applied to music therapy sessions, measuring the range of motion and training intensity during music therapy sessions in order to provide real-time feedback to support music therapists regarding intervention outcome. Specifically, this feedback supports an accuracy in motor assessment, allowing for the therapist to observe the effects (or lack of) of the audio stimulus on a patient's motor movement during, between and after sessions.

Multimodality

A multimodal approach to rehabilitation sees multiple approaches contributing to a therapeutic process. Multimodality highlights the multidisciplinarity of a rehabilitative protocol or treatment plan. By focusing on common aims of each discipline, or how the work towards these aims can contribute to one another, treatment becomes streamlined and cooperative. If therapists could combine the use of VR and MNT during neglect rehabilitation, there is the possibility to address neurological, physical, and perceptual needs of a patient simultaneously within one therapy session.

Initially, thorough assessment would be needed to determine the suitability for such an intervention. This would likely require involvement of physical therapy, occupational therapy, and music therapy. It is possible with future research that a specific multidisciplinary assessment tool be established for use of this intervention specifically, to determine patients' suitability. When considering implementation of this intervention, it is feasible to consider that with the proper safe-guards and training in place, this proposed method of rehabilitation could be implemented as an adjunct intervention for rehabilitation by music therapists, physical therapists, or occupational therapists. This aspect would need to be addressed in future research, in formal development and evaluation of the clinical protocol. Some of these safe-guards are embedded in the VR application experience, which allows the user to safely participate in task-based activities without the risk of dysfunctional movement within a real-world setting as well as the considerations of cybersickness and aftereffects [40, 41, 42, 43]. However, future training among professionals will be crucial, especially regarding safety in physical rehabilitation, competence training in using VR in practice, needed when using music interventions.

For the patient, the collective work towards common aims and a streamlined process seen in a multimodal approach to rehabilitation could result in fewer appointments over time. This would ideally result in cost savings for the patient, in addition to the reduced time spent in, and traveling to, appointments.

Intersecting Purposes Outside this Review

Evidence not accounted for in the outcomes of this review includes intersecting purposes between VR and music therapy interventions associated with restoring function in damaged areas of the brain caused by the stroke with motivating task-based activity. Both interventions contain purposeful activity (task-based or movement induced) by focusing attention or inducing movement toward the left side of the patient (e.g., inducing patient motor movement to the left side, having the patient look toward the left side, or play musical tone bars toward the left side) to make rehabilitation enjoyable, as well as maintain patient adherence to the rehabilitation. This psychosocial aspect of patient adherence and motivation to rehabilitation is regularly discussed in the background literature of the articles reviewed, but not accounted for in the study outcomes. Therefore, we discuss patient adherence and motivation to neglect rehabilitation below as an intersecting purpose of VR and music therapy interventions for neglect rehabilitation.

Task-based activity, Patient Adherence and Motivation to Neglect Rehabilitation

The experience of music is known to have not only an emotional role, but also a motivational role. The music component itself in music therapy practice has been proven to contribute to specific motivating neurobiological systems and mechanisms, activating the dopaminergic mesolimbic system, while regulating mechanisms in memory, attention, executive functions, mood and motivation [3, 60]. Dopamine plays a significant role in the neurobiological workings of reward, learning, and addiction. Naturally occurring rewards, such as positive music experiences, activate these dopaminergic systems and contribute to one's attention and learning [62]. Furthermore, the multimodal activity of music through engagement or creation supports plastic changes in the nervous system [19, 23, 24].

Following this, the music component within an intervention is a large part of what motivates the patient to complete a task, work towards goals, and/or to actively participate in the work with the music therapist. Much like the inclusion of VR in neurological rehabilitation, music interventions also provide an added purposefulness to the activity. A patient's motivation towards rehabilitation exercises is critically important, as these exercises can seem repetitive, and at times uncomfortable. Adding a purposeful element to the rehabilitative exercises contributes to patient motivation [62].

As illustrated in this review, both VR and music therapy interventions produce recovery in domains afflicted by neglect, with VR providing some evidence in improving patient adherence to treatment. It is conceivable then, that by combining a purposeful music intervention with an already motivating rehabilitation environment by using VR, that rehabilitation and progress towards aims may be somehow streamlined or further beneficial for patients and healthcare systems alike.

Limitations

As previously outlined, there are challenges to generalising the findings from this review, due to small trials, small sample sizes, heterogeneous assessments, goals, and outcomes. This implies the need for caution when interpreting any evidence reviewed for use in clinical settings. Similarly, some of the studies reviewed here are not directly applied to the treatment of neglect but are primarily investigating feasibility of the interventions.

Due to the narrow scope of this review, there are many opportunities for further inquiry. This includes understanding in greater detail the function of neurological mechanisms of neglect patients when exposed to VR and music, and then designing interventions around beneficial neurological exploitation. There is a need for a rigorous practical understanding of how to use VR in neurologic music therapy settings, and the development of a formal clinical protocol will be needed. Furthermore, the costs of VR equipment may also burden some music therapists and multidisciplinary teams, and how these equipment costs can be justified without rigorous clinical evidence remains unclear.

Conclusion

In this review, the use of VR during stroke and neglect rehabilitation produces findings regarding feasibility and safety, however the clinical findings are ambiguous. Larger trials with similar assessments are needed to arrive upon generalisations. Promising neurological outcomes were found in stimulation of specific neurological regions during exposure to a VR intervention in neglect patients. Specifically, neurological activity in the prefrontal cortex, bilateral middle and superior temporal gyrus was associated with increased focus of attention during VR rehabilitation. In addition, saccadic eye movement to the left became more integrated with the left posterior parietal cortex during VR rehabilitation.

Based on the review's findings, the authors explored how VR and music-based interventions purposes intersect in similar areas used for neglect rehabilitation. These are in assessment, patient adherence and motivation to treatment, as well as the multimodal capabilities of both interventions. Using VR and music-based interventions adjunctly for neglect rehabilitation is theoretically promising, and development of a clinical framework to practically use these interventions with neglect patients is suggested.

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