VR for Vocational and Ecological Rehabilitation of Patients With Cognitive Impairment: A Survey

Emilie Hummel, Mélanie Cogné, Marie Lange, Anatole Lécuyer,
Florence Joly, and Valérie Gouranton

***Abstract*— Cognitive impairment arises from various brain injuries or diseases, such as traumatic brain injury, stroke, schizophrenia, or cancer-related cognitive impairment. Cognitive impairment can be an obstacle for patients to the return-to-work. Research suggests various interventions using technology for cognitive and vocational rehabilitation. The present work offers an overview of sixteen vocational or ecological VR-based clinical studies among patients with cognitive impairment. The objective is to analyze these studies from a VR perspective focusing on the VR apparatus and tasks, adaptivity, transferability, and immersion of the interventions. Our results highlight how a higher level of immersion could bring the participants to a deeper level of engagement and transferability, rarely assessed in current literature, and a lack of adaptivity in studies involving patients with cognitive impairments. From these considerations, we discuss the challenges of creating a standardized yet adaptive protocol and the perspectives of using immersive technologies to allow precise monitoring, personalized rehabilitation and increased commitment.**

***Index Terms*— Virtual reality, cognitive rehabilitation, vocational rehabilitation, survey.**

I. INTRODUCTION

REHABILITATION of cognition and return-to-work support for cognitive impairment represent critical issues for patients suffering from brain disease or injury [1]. Cognitive functioning may hinder an essential part of work abilities and constitutes a very contemporary research subject [2]. Cognitive domains are brain-based abilities [3] used for knowledge acquisition, information manipulation, and reasoning [4]. Cognitive domains notably include perception, attention, memory, executive functions, praxia, gnosia, social cognition, awareness, learning, information processing speed, communication and visuospatial abilities.

Cognitive impairment represents a vital concern for patients when confronted with brain disease or cancer. It induces changes in brain functioning and has repercussions on personal, social, and quality of life [5]. Traumatic brain injury, stroke, encephalitis, anoxia, Alzheimer's disease, schizophrenia, cancer and cancer treatments are possible causes of cognitive impairment. Attention and executive function deficits, in particular, may heavily influence vocational activities [6]. For up to a third of concerned patients, continuing or returning to work becomes challenging even after recovery [7]. Global cognitive functioning is a significant predictor of return-to-work among stroke patients [8]. Other studies confirm these results among patients with schizophrenia [9] and traumatic brain injury [10].

As a scientific tool, Virtual Reality (VR) uses computer science and behavioral interfaces to simulate the behavior of 3D virtual entities inside a virtual world with real-time interactions. VR users are pseudo-naturally immersed in this virtual world that changes time, place and the type of interactions [11]. The concept of VR, as described by Sutherlands in 1965, implies that Virtual Environments (VE) should feel true and respond realistically to the users' actions [12]. Therefore, VR offers an innovative solution to enhance vocational rehabilitation, with the possibility to experience and interact with a controlled VE [13]. VR can simulate a realistic work activity to teach or train the users with a therapeutic perspective. VR is efficient for acquiring and retaining knowledge or training procedures [14]. Achieving the compelling sensation of being in a VE involves user interfaces. The interfaces depend on the available material [15] to provide different levels of immersion. Immersion is an objective measurement of the sensory fidelity induced by the VR system. Immersive VR or immersive interaction is the use of hardware and software to provide

Manuscript received 18 May 2023; revised 7 September 2023; accepted 9 October 2023. Date of publication 20 October 2023; date of current version 26 October 2023. *(Corresponding author: Emilie Hummel.)*

Emilie Hummel and Valérie Gouranton are with Univ Rennes, Inria, INSA Rennes, CNRS, IRISA, 35000 Rennes, France (e-mail: emilie.hummel@inria.fr; valerie.gouranton@irisa.fr).

Mélanie Cogné is with the Rehabilitation Medicine Unit, Rennes University Hospital, 35000 Rennes, France, and also with Univ Rennes, Inria, CNRS, IRISA, 35000 Rennes, France (e-mail: melanie.cogne@chu-rennes.fr).

Marie Lange is with the Clinical Research Department, Centre François Baclesse Caen, INSERM, ANTICIPE, Normandie University, UNICAEN, 14000 Caen, France (e-mail: m.lange@baclesse.unicancer.fr).

Anatole Lécuyer is with Univ Rennes, Inria, CNRS, IRISA, 35000 Rennes, France (e-mail: anatole.lecuyer@inria.fr).

Florence Joly is with the Clinical Research Department, Centre François Baclesse Caen, INSERM, ANTICIPE, Normandie University, UNICAEN, 14000 Caen, France, and also with the Medical Oncology Department, Caen University Hospital, 14000 Caen, France (e-mail: f.joly@baclesse.unicancer.fr).

Digital Object Identifier 10.1109/TNSRE.2023.3324131

complete multisensory interactions, including for body and head movement, leading to the sensation of being physically in a VE [16]. VR interfaces have undergone a great deal of evolution in recent decades, from monitor screens of various sizes and resolutions to nowadays head-mounted displays (HMD). VR apparatus can be divided into three categories, based on the immersion they can provide: non-immersive (e.g. desktop setup with keyboard, mouse, or joystick), semi-immersive (e.g. large screens, gesture recognition) and fully immersive (e.g. HMD or immersive room with human size screens, gesture recognition) [2].

VR has been used for various purposes in the medical field, such as motricity training [17], [18], pain distraction [19], [20] or cognitive rehabilitation [2], [21]. Patients are projected in a controlled VE for a passive or active experience and can successfully improve motor skills, mental well-being or cognitive domains. The use of semi or fully-immersive technology also increases the positive response and engagement of the users in video games [22], training [14] or clinical studies [23].

The ability to create a complex VE to simulate immersive workplaces and vocational situations is helpful for people aiming for training and return-to-work [24]. VR allows to adapt the scenario and interaction to target cognitive domains [25]. For these reasons, cognitive and vocational rehabilitation using VR has been investigated in the literature among patients with cognitive impairment [2]. While cognitive rehabilitation gathers many studies using VR, the return-to-work is a more specific aspect of patient rehabilitation. The studies focusing on vocational rehabilitation are even fewer. They use vocational VE as an intervention for patient rehabilitation. We are also interested in studies using ecological VE that are not related to vocational activity but still aim for the return of an active life for the patients.

This article provides thus an overview of vocational or ecological rehabilitation studies using VR in the context of cognitive rehabilitation. Our contribution is a comparison of these studies from a VR perspective and the analysis of VR use and implications in this context. In the remainder of this paper, we first present an overview of related topics, such as motor rehabilitation and vocational training. We then introduce our method for this survey and the collected corpus of sixteen studies on cognitive and vocational rehabilitation using VR. Finally, we discuss the presented articles and highlight the challenges and perspectives for future work in this domain.

II. RELATED TOPICS

We investigate two related topics that can provide references and inspiration for this article: rehabilitation and vocational training. First, rehabilitation is a wide medical domain that already uses VR for motor, cognitive or combined motor and cognitive rehabilitation. We divided this topic into two subparts: cognitive rehabilitation (see section II-A) and motor rehabilitation (see section II-B). Our findings on vocational training using VR is summarized in section II-C. The remainder of this article focuses on the combination between cognitive rehabilitation (or combined motor and cognitive rehabilitation) with the second related topic: vocational training. In addition, we consider the combination of cognitive rehabilitation and ecological training. The use of VR regarding these topics will be investigated in section IV.

A. Computerized Solutions for Cognitive Rehabilitation

Various computerized solutions to assess or improve cognitive domains for patients with cognitive impairment have been explored in the literature, e.g. for stroke [26] or for different neurocognitive disorders [2], [27]. These solutions can involve puzzle games or memory exercises that do not involve pseudo-natural interactions and a VE in which the participant can feel physically there. The authors of such solutions are mainly from a medical background and because VR is not their research domain, their computerized applications may wrongly be labeled as VR. In the following paragraph, we focus on cognitive rehabilitation, unrelated to vocational rehabilitation, using VR interfaces and environments. We include in non-immersive VR the computerized applications that feature a VE and pseudo-natural interactions.

When using VR for cognitive rehabilitation, various cognitive domains can be trained, e.g. memory for patients with Alzheimer's disease. Virtual interfaces are therefore different if their aim is to improve overall cognitive functioning or a subset of cognitive domains. Works focusing on memory, attention and executive functions tend to use video games with a list of tasks to achieve in an ecological context and come with potential distractors. Typical simulations are housework [28], [29], grocery shopping [30], [31], [32], [33], [34], [35], or submarine photography [36]. Simulations of a supermarket are commonly used, as they are efficient training for executive functioning [31], [32], [33], [35]. Visuospatial or communication functions require more specific training, with shapes manipulation and communication training [37], [38] that can be more difficult to challenge ecologically.

Cognitive rehabilitation using VR takes different shapes that change regarding the trained cognitive domain. The main approach is to give the patient a list of tasks to accomplish in the VE. This environment can vary but researchers tend to use ecological context to assist the rehabilitation.

B. Vocational Rehabilitation Using VR for Motor Functions Deficit

Motor rehabilitation is a domain in which VR is actively used, as VE are under full control and allow to monitor the user precisely [39]. Additionally, cognitive-motor interference allow to use motor tasks to target cognitive rehabilitation or as a mean to create a more challenging exercise, or vice versa [40]. VR allows the modulation of tasks, speed and effort according to the user's progress. Combined with a high sense of presence and realism, all these elements may help patients with their rehabilitation. VR applications for motor deficit combine different technological assets like exoskeletons, HMD, hand or motion tracking and haptic feedback to provide a multi-modal rehabilitation [39].

Upper limb rehabilitation usually requires hand tracking to give an insight of the finger or arms position. Some approaches increase the precision of the tracking using complementary devices [39]. For lower limb rehabilitation, various devices can be used to monitor the balance and posture of the user such as motion tracking suits, infrared cameras or platforms. Motor rehabilitation using VR offers promising results. It emphasizes the importance of having an adequate environment for rehabilitation, which can be done using VR [41]. The approaches for the VE are from realistic sports training (martial arts, gymnastics, yoga, football) to games of skills, or rhythm [42]. These environments immerse the user in a more pleasant context than the hospital rehabilitation room and have a powerful didactic potential.

VR has a strong potential to assist motor rehabilitation: the fine monitoring it provides is precious for therapists. Motor-cognitive interference allows to include motor rehabilitation to improve cognitive functioning. We classify them between motor or cognitive rehabilitation according to their primary study endpoint. The studies with cognitive domains as primary endpoint will be addressed in section IV.

C. VR for Vocational Training and Education

During their formation, trainees or students lack access to expensive professional tools and modern technologies that prepare them for their work environment [43]. VR in education offers an innovative approach to learning and collaborating while aiming to simplify access to education and enhance training methods [44]. VR can replicate expensive material in a 3D VE and allow their manipulation without any risk, improving the learning rate and enhancing education [43]. Moreover, such technology is appealing to young generations [24]. In both training and education, VE can ease the transfer of knowledge between learners and teachers because they provide credible interactions and feedback [45]. For vocational training in particular, VR is of great use when it comes to dangerous or precise tasks training. VR applications can simulate specific situations in a controlled environment, without any risk of hurting the trainee nor damaging the equipment [46], [47].

Kaminska et al. present a survey of VR applications in education or professional training [43]. They make a fundamental difference between the VR applications used for learning theoretical knowledge, practicing a task or solving a problem using the acquired knowledge. The complexity of the application and devices depends on the task and the educational goals, from a passive scene with a stereoscopic screen or HMD, to complex controllers with haptic feedback to reproduce the sensation of physical interaction. Vocational training tends to be on the more complex half. VR for vocational education is more common for medical training (including medicine, nursing, neuroscience, psychology, dentistry, etc), but has also been used for engineering, social sciences, mathematics, physics and astronomy [48]. When evaluated on this point, engineering as well as nursing students and trainees are better prepared to use complex machines when trained using VR applications. These results can also be achieved in more theoretical domains such as mathematics or physics [43]. Kaminska et al. warn about the need for a balance between pedagogy and the use of innovative technology for training and teaching. If VE does not replace a teacher-trainee interaction, it can enhance teaching by providing new tools for the teachers.

The state of the art shows various contributions for rehabilitation and training using VR. However, to our knowledge, no survey in the literature investigates the combination of cognitive and vocational rehabilitation. The remainder of this article introduces our findings on this topic.

III. METHOD

A. Study Selection

The corpus of this article was gathered using Google Scholar, ACM-DL (Association for Computing Machinery-Digital Library) and PubMed databases. The articles were collected and read between October 2021 and August 2023 and the keywords used were “(virtual (reality OR environment) OR oculus OR quest OR vive) AND (vocational OR occupational) AND (rehab OR training OR adaptation OR readaptation OR readaptative) AND (cognitive OR cognition)”. In addition, we considered adding one by one to the keywords either the targeted population or the cognitive domains. The population was selected among pathologies inducing neurodegenerative or acquired cognitive impairment and additional keywords were: “Alzheimer”, “acquired” or “traumatic brain injury”, “cancer”, “leukemia”, “encephalitis”, “dementia”, “schizophrenia”, “multiple sclerosis”, “stroke”,“head trauma”, “brain lesion”,“mild cognitive impairment”, “MCI”, “anoxia”, “hypoxia”, “post concussion”, “post concussive”. The specified cognitive domains were the functions impacting vocational rehabilitation and therefore targeted by our approach for this article: “attention”, “memory”, “mnesic”, “executive functions”, “executive”, “dysexecutive”, “dual task”, “visuospatial”, “communication”. To explore further the references of the preselected articles, we used ConnectedPaper tool (https://www.connectedpapers.com/). The inclusion criteria were the following:

1) VR intervention, i.e. an intervention that features VE and pseudo-natural interactions;
2) Fully-immersive, semi-immersive or non-immersive VR interface;
3) Presence of cognitive impairment;
4) Ecological or vocational virtual situation;
5) Cognitive rehabilitation as the primary study endpoint.

The exclusion criteria are the following:

1) Augmented reality or non-VR computer-assisted intervention;
2) Study assessing cognitive domain instead of rehabilitation intervention;
3) Motor rehabilitation as the primary study endpoint.

This selection process resulted in 452 screened articles among the databases, from which 290 were excluded when identified out of the scope of this article based on title and abstract. The remaining 162 articles were then reduced, according to our exclusion criteria, to 16 articles. The collected articles are the works of Jacoby et al. [31], Man et al. [49], Tsang et al. [50], Yip et al. [32], Canty et al. [33], Faria et al. [34], [51], Sohn et al. [9], Gamito et al. [52], Aubin et al. [53], Mrakic-Sposta et al. [35], Liao et al. [54], Park et al. [29], Giachero et al. [38] and Oliveira et al. [55], [56].

B. Data Analysis

In the collected studies, we extract the following information: 1) **VR apparatus** and 2) **tasks**, 3) level of **immersion**, 4) **targeted population**, 5) **results**, 6) **adaptivity** to the user and 7) **transferability** of acquired knowledge. Comparing the apparatus would only be possible on a global level, due to the lack of evaluation of the devices in studied articles. For the VR tasks, we analyze the inner proceedings of the tasks, the duration and frequency of sessions.

As defined in section I, the immersion contributes to the sensation of being physically in a VE and not every type of interaction needs a high level of immersion. The components of immersion can be summarized as the field of view (FOV), the field of regard (FOR), the display size, the display resolution, the stereoscopy, the head-based rendering, the realism of lighting, the frame rate and the refresh rate [57]. The level of presence, related to the immersion, is also a common assessment in VR studies. Presence is a subjective measurement of the user's perception regarding VR leading to the feeling of being physically in the VE. However, presence was not assessed in the collected studies and therefore cannot be one of our comparison criteria.

For our analysis, we focus on the FOR, the stereoscopy and head-based rendering as these criteria can be deduced from the protocol and setup description in the collected studies. To increase the readability in Table I when comparing the level of immersion applied to the participants, we give the studies a set of symbols according to the featured devices. The letter I if the user interacts with a VE, FOR if the VR device allows a large FOR in the VE, wider than the participant FOV (e.g. curved screens or HMD), S if it allows stereoscopy and follows head movement and G if the user not only interacts with a keyboard or a controller, but with gestures or their body. The symbols are summarized in Table I.

In most studies, results are expressed through cognitive domains scores, assessed with standard tests. A comparison between the results can be done when similar cognitive assessments are being used, otherwise, the degree of improvement is considered. When comparing each study's results, the pathology and its severity are taken into consideration.

The adaptivity of a vocational or ecological simulation is the extent to which the experience is personalized for each individual, based on their abilities and progress. The adaptivity of the studies is assessed by comparing the articles with the same procedure for every participant and the articles that adapt the content of their study based on participants' actions. It is assessed from an external perspective since most articles do not focus on adaptivity and do not evaluate it.

Transferability is the ability of the participants to transfer what they learned during the study, in the VE, to a real-life situation. VR has a noteworthy transferability for cognitive domains [58]. Transferability is important in vocational rehabilitation since it shows the efficiency of the procedure. It can be assessed by observing the participants in a real-life environment and evaluating their ability to use the techniques acquired during therapy for a challenging situation. Transferability of the studies is compared using the available results on employment or follow-up evaluations, when provided.

IV. RESULTS

The following sections describe the collected corpus with a VR spectrum along five sections: (i) the general approach regarding the experiment, (ii) the VR apparatus and task used in studies, (iii) the level of immersion, (iv) the adaptivity of the protocol and (v) the transferability of the contribution. These characteristics are summarized in Table I.

A. General Approach

The most common approach in the collected studies is to reproduce a vocational environment for the user to explore and perform a set of tasks. The designed work tasks are often inspired by the user's work domain and cognitively challenging [9], [49], [50], [54]. The other studies recreate ecological situations, without a specific professional angle, to train the user cognition in an everyday situation [29], [31], [32], [33], [34], [35], [38], [51], [52], [53], [55], [56]. Similarly to the vocational simulation studies, these studies offer to perform various cognitively challenging tasks, linked to the targeted ecological situation. Among the collected studies, executive functioning is trained by twelve of them, memory (including prospective and retrospective memory) by eleven of them, attention by ten of them and communication and visuospatial abilities by six of them. Concerning the variation of sessions' frequency and number, it varies between 6 and 36 sessions, of a duration between 20 and 120 minutes. The sessions are set between 4 and 24 weeks, with the exception of 1 session in one study [33], 2 sessions in a week in one study [53]. The average total number of sessions is 14.3 sessions.

B. VR Apparatus and Tasks

The apparatus used in the collected studies varies from a basic computer setup, large curved screens, motion tracking devices and HMD. The interface used to interact with the VE is a computer keyboard, a computer mouse, a joystick, the user's own hands or controllers. Examples of the used setup are displayed in Fig. 1. The majority of the collected studies use a basic computer setup, with a computer mouse, a keyboard [9], [33], [52], [53], [55], [56] or a joystick [32], [34], [49], [50], [51]. The screen size, when specified, is between 16" and 50". Motion tracking can be combined with a large screen, on which the participants see their body as a virtual reflection [31], or with a HMD with controllers [54] or without controllers [29]. Finally, one study uses a cycle-ergometer with a controller [35].

Among studies that feature vocational simulations, three simulate a store (clothing store, supermarket, or convenience store) with the participant acting as an employee [9], [50], [54]. The difficulties of the targeted jobs can be decomposed between social, technical and problem-solving skills: Tsang et al. confront the participants to three different difficulty levels through 10 sessions of 30 minutes each. Every session takes place in a clothes store and targets a different

TABLE I

Collected Articles. Population (Pop.); Randomized Controlled Trial (RCT); Acquired Brain Injury (ABI); Alzheimer (Alzh.); Schizophrenia (Schz.); Mild Cognitive Impairment Executive Functions (EF); Attention (Att.); Memory (Mem.); Prospective Memory (PM); Retrospective Memory (RM); Visuospatial Capacity (VC); Infrared (IR); Head-Mounted Display (HMD); Virtual Reality (VR); Artificial Intelligence (AI); Multi-Errands Tests - Short Version (MET-SV); Immersion Devices: I (Interactions With the VE), FOR (Device With a Big FOR), S (Stereoscopy); G (Gestures) as Described in III-B

References	Study type	Pop.	Cognitive domain	N	Control group	VR device	VR task	Number & frequency of sessions	Adaptivity	Transferability	Immersion	Results
Jacoby 2012 [31]	RCT	ABI	EF	12	Real environment training (N=6)	IR cameras and screen	Virtual mall: planification, organization, problem solving, multitasking or time management	10 sessions of 45min, between 4 and 5 times a week during 3 weeks	Difficulty levels based on performance (no more information)	Assessed with MET-SV (assessment in a real supermarket), good results	I ; G	Improvement. No significant difference between groups
Man 2013 [49]	RCT	ABI	EF	40	Real environment training (N=20)	Monitor, computer keyboard and mouse and joystick	Virtual office: identification of office utilities, managing inventory and emails,…	12 sessions of 20-25min	AI-powered adaptativity of the tasks	Self-efficacy questionnaire on work-related activities and on-site questionnaire	I	Improvement. No significant difference between groups
Tsang 2013 [50]	Single-blind RCT	Schz.	EF, Att., Mem.	75	Real environment therapist training (N=25) or conventional training (N=25)	38” monitor, joystick, computer mouse and keyboard	Virtual clothes store: handling customers and conflicts, sorting or checking clothes, solving problem	10 sessions of 30min over 5 weeks	None, the sessions get harder every time	Self-efficacy questionnaire assessing performance in sales-related activities	I	Significant improvement for work performance, EF, Mem. and Att.
Yip 2013 [32]	Pre-post test RCT	ABI	PM, RM, Comm., Att.	37	Real environment training (N=18)	32” monitor and joystick	Virtual supermarket: buying items from a list, remembering a list, noticing a specific detail	12 sessions of 30-45min	None	Self-efficacy questionnaire assessing prospective memory tasks	I	Significant improvement for PM, Comm., Att.
Canty 2014 [33]	-	ABI	PM	54	Healthy subjects (N=24)	Laptop computer	Virtual shopping: buying items from a list with various event during the task	1 session of 14min	None	Not assessed	I	Significant improvement for PM, Comm., Att.
Faria 2016 [34]	RCT	Stroke	Mem., Att., VC, EF, Comm.	18	Computer-assister training (N=9)	24” wide LCD monitor and joystick	Virtual city; navigation between common places, buying items, finding specific objects	12 sessions of 20min, during 4 to 6 weeks	None, the sessions get harder and visual cues are removed	Not assessed	I	Significant improvement on Att., Mem., VC, EF
Sohn 2016 [9]	Pre-post study	Schz.	EF, Mem.	10	NA	3 projectors and screens in an immersion room and computer mouse	Virtual supermarket and store: handling customers, handling payment, shelving	8 sessions of 35min once a week	None	Not assessed	I ; FOR	Significant improvement on Mem.
Gamito 2017 [52]	RCT	Stroke	Mem., Att., VC	20	No intervention (N=10)	Laptop with 16” screen	Virtual supermarket: buying items, navigating, finding a specific item, recognition of outdoor advertisements, digit retention	12 sessions of 60min, during 4-6 weeks	None	Not assessed	I	Significant improvement on Mem. and Att.
Aubin 2018 [53]	Exploratory study	Schz.	EF	5	NA	Screen, computer mouse and keyboard	Virtual supermarket: buying items from a list	2 sessions: one in the virtual environment, one in a real supermarket	None	Not assessed	I	Better results for real environment over virtual environment
Mrakic-Sposta 2018 [35]	Pilot RCT	MCI	EF, Mem., Att., VC, Comm.	10	No intervention (N=5)	Wide screen, cycle-ergometer and controller	Virtual park and supermarket: riding a bike, finding objects and buying items	18 sessions or 45min, during 6 weeks	None	Not assessed	I ; FOR ; G	Improvement. No significant difference within or between groups.
Liao 2019 [54]	Pre-post test RCT	MCI	EF, Att.	36	Real environment training (N=16)	Kinect, HMD and VR controllers	Public transportation simulation: buying a ticket and getting the right train ; virtual cooking: follow a recipe ; virtual store: find and check out for items ; motor rehabilitation	36 sessions of 60min sessions, during 12 weeks	None	Not assessed	I ; FOR ; S ; G	Significant improvement on Att.
Park 2019 [29]	Pilot RCT	MCI	EF, Att., Comm., Mem., VC	21	Computer-assisted training (N=11)	HMD and IR cameras for hand gesture tracking	Homelife with a child in a virtual house: social interactions (giving orders and training), checking, sorting or finding specific items	18 sessions of 30min, during 6 weeks	Difficulty levels based on performance on previous task	Not assessed	I ; FOR ; S ; G	Significant improvement on Att.
Faria 2020 [51]	RCT	Stroke	EF, Att., Mem., VC	32	Paper-and-pencil tasks on a computer (N=18)	24” wide LCD monitor and tracked handle	Virtual city simulation: buying items, navigating, getting a package, running errands	12 sessions	Difficulty based on individual tasks results	Not assessed	I ; G	Improvement. No significant difference within or between groups.
Giachero 2020 [38]	RCT	Stroke	Comm., VC	36	Conventional training (N=18)	50” curved screen	Dialogue or description in different ecological scenarios (train station, hotel, restaurant, supermarket, amusement park, cinema, travel)	48 sessions of 2h, during 24 weeks	None	Not assessed	FOR	Improvement. No significant difference within or between groups.

TABLE I

(Continued.) **COLLECTED ARTICLES.** POPULATION (POP.); RANDOMIZED CONTROLLED TRIAL (RCT); ACQUIRED BRAIN INJURY (ABI); ALZHEIMER (ALZH.); SCHIZOPHRENIA (SCHZ.); MILD COGNITIVE IMPAIRMENT EXECUTIVE FUNCTIONS (EF); ATTENTION (ATT.); MEMORY (MEM.); PROSPECTIVE MEMORY (PM); RETROSPECTIVE MEMORY (RM); VISUOSPATIAL CAPACITY (VC); INFRARED (IR); HEAD-MOUNTED DISPLAY (HMD); VIRTUAL REALITY (VR); ARTIFICIAL INTELLIGENCE (AI); MULTI-ERRANDS TESTS - SHORT VERSION (MET-SV); IMMERSION DEVICES: I (INTERACTIONS WITH THE VE), FOR (DEVICE WITH A BIG FOR), S (STEREOSCOPY); G (GESTURES) AS DESCRIBED IN III-B

Oliveira 2021 [55]	Pilot RCT	Alzh.	EF, Att., Mem.	17	Conventional training (N=7)	Laptop with 17" screen	Virtual city: hygiene and dressing task at home, cooking, grocery shopping, visiting an art gallery	12 sessions of 45min, during 6 weeks	Difficulty based on cognitive pre-test	None	I	Significant improvement. Not on specific cognitive domains
Oliveira 2022 [56]	Single arm pre-post study	Stroke	EF, Att., Mem.	30	NA	Laptop with 17" screen	Virtual city: hygiene and dressing task at home, cooking, grocery shopping, visiting an art gallery	7 sessions on average, of 30min	Difficulty determined by therapists	Not assessed	I	Significant improve-ment on EF, Att., Mem.

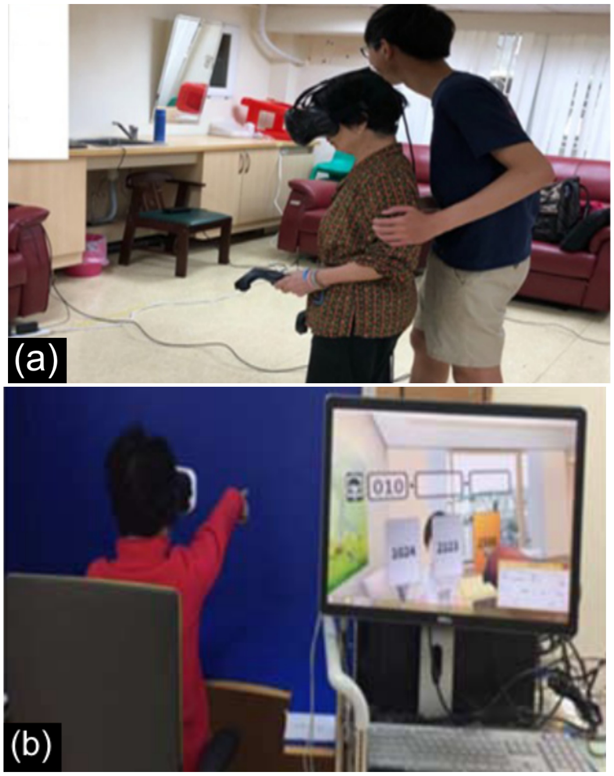

Fig. 1. Examples of VR apparatus: (a) HMD setup for cashier task [54], (b) HMD and hand tracking setup for the simulation of homelife [29]. The subjects have provided written informed consent allowing the publication of these images.

aspect of the job difficulty, like orientation, clothes sorting, problem-solving and customer handling [50]. Similarly, Sohn et al. make the participants repeat two scenarios for 8 weeks, one session per week and scenarios of 15 to 20 minutes. The two scenarios are in a convenience store or a supermarket, and train the participants in technical, social and problem-solving skills [9].

Liao et al. do not detail the tasks used for rehabilitation. Their study combines vocational simulations of supermarket employee or kitchen chef video games from Owlchemy Labs's "Job Simulator" software, with virtual rehabilitation activities like Tai Chi or football [54]. It involves 36 sessions of 1 hour with five different activities: taking public transportation, cooking as a kitchen chef, working in a convenience store, and training in Tai Chi or football.

This choice of vocational context is justified in the studies by store employee being a common job for the targeted population in these three studies. For one study, a virtual office was used [49]. With another approach, Man et al. provide an immersive office module, with tasks related to office work (identification of office items and utilities in the office, handling files and printers, sending and receiving emails, managing inventory, etc) [49]. Participants must make decisions according to a scenario through 12 sessions.

In all of the studies aiming for ecological simulations, the main approach is to simulate a virtual supermarket, with the participants as customers. The supermarket simulation can challenge the participants with time or resource management [31] or with memory or attention tasks [32], [52]. Jacoby et al.'s contribution is a virtual supermarket in which the participants must face planning, problem-solving and multitasking tasks during 10 sessions of 45 minutes [31]. The task could be shopping with a given budget or managing the time spent on the shopping. On the other hand, Yip et al. use a task of grocery shopping in a convenience store with 12 training sessions of 30-45 minutes of VR [32]. The virtual tasks consist of remembering the shopping list or noticing specific details in the environment. Canty et al. immerse the user in a virtual supermarket, with a list of items to purchase [33]. Multiple events are provided to challenge the prospective memory during one session of 14 minutes. The event could be to send a text message with a mobile phone at given times or to press a key on a specific trigger. Aubin et al. give their participants the task of filling the grocery cart based on a given list of items, and the payment at the checkout counter [53]. The simulation also includes social skills, with avatars of other customers and suggestions of dialogues to select or to read out loud.

The virtual supermarket can be placed in a virtual city, to provide more various and ecological interactions: the virtual city can feature streets and public transportation [52], various buildings to visit [34], [51] and sometimes a virtual home for everyday home activities [55], [56]. Faria et al. simulate a small city, featuring a supermarket, a post office, a bank, a pharmacy and an art gallery [34], [51]. The participants must navigate between those places to purchase items or to find specific objects. Participants are immersed in the virtual city for 12 sessions of 20 minutes, for 4 to 6 weeks in the first study [34] and for 12 sessions with no other indications in the second study [51]. Similarly, Gamito et al.'s virtual supermarket comes after an orientation task where the user needs to find their way to the supermarket, with the recognition of outdoor advertisements along the path [52]. The tasks in the supermarket consist of buying items, finding a virtual agent in a specific outfit color and digit retention. The participants of their study do between 2 and 3 sessions of 60 minutes, for between 4 and 6 weeks. Mrakic-Sposta et al. study's tasks consist of navigating a virtual park and supermarket, finding objects or events and buying items during 18 sessions or 45 minutes [35], during 6 weeks. The tasks feature distractors and similar items to differentiate before buying in order to challenge the participants. The two studies from Oliveira et al. feature tasks inside a virtual home, e.g. taking care of the morning hygiene, getting dressed up, cooking, remembering TV news, and outside, in a virtual city, e.g. grocery shopping, going to the pharmacy or an art gallery. In those two studies, the participants took part in 12 sessions of 45min, during 6 weeks [55], or in 7 sessions on average, of 30min each [56].

The last study of this corpus provides different ecological situations for the participants to describe or converse [38]. The situations take place in a train station, a hotel, a restaurant, a supermarket, an amusement park, a cinema or during travel. Three participants must describe the scene or give some information and can discuss the situation with the therapist or together, during 48 sessions of 2 hours in 24 weeks.

C. Level of Immersion

The identified components of immersion vary greatly depending on the device. The FOV and FOR are reduced with basic computer screens [33], [34], [49], [51], [52], [53], [55], [56] but are improved with the use of wide [32], [35] or 180° curved screens [9], [38]. The FOV and FOR are maximized when the user can see the VE all around them, with modern HMD [29], [54]. Stereoscopy and head-tracking are also enabled by the use of HMD, while no other study seems to include head-tracking devices. The addition of other senses or ways of interaction to the visual component improves the level of immersion [57] and users that need to use their whole body to interact with the VE are therefore more involved in the VR. The use of motion tracking increases the level of immersion [31], [35], [51], especially when combined with HMD [29], [54].

D. Adaptivity

Patients with cognitive impairment also have various preserved abilities and face different challenges that rehabilitation programs need to take into account. Each patient integrates the rehabilitation results at their own pace, and therapy is always personalized depending on the patient. In VE, such adaptivity is hard to achieve because the scenario and series of actions must be decided beforehand. In the presented studies, adaptivity is partially achieved with different difficulty levels based on the user's progress [29], [31]. When the task is easily performed (based on performance speed or success rate), the difficulty goes up, otherwise the participants might get more time or additional indications to finish the task. Two studies adapt the difficulty based on the participants' cognitive skills: related to the success of individual tasks [51], or based on pre-intervention tests [55]. Only one study focuses its contribution on adaptivity, with an artificial intelligence-powered algorithm that computes the difficulty of the next task from the correctness, time to finish, amount of assistance needed and accuracy of the previous task [49].

두유가 있을만한 구역의 표지판을 선택하세요.

Fig. 2. Example of VR applications: (a) Virtual clothes store as an employee [50], (b) Virtual convenience store as a customer [9] and (c) Virtual supermarket as a cashier [54].

The rest of the corpus does not incorporate adaptivity in their study. Their protocol gets more difficult after each session, at the same pace for every participant.

E. Transferability

VR training applications with strong similarity between the training and the real life situation can show high transferability for the users [59]. Among the corpus, four works assess the transferability [31], [32], [50], [53]. It can be assessed with the participants' feeling of self-efficacy for each task [32], [50], or by comparing results in a VE with results in the real environment [31], [53].

On one hand, among the studies using self-efficacy questionnaires, the results show significant improvement of self-efficacy after the intervention [32], [50]. On the other hand, two studies confront their VR intervention with a task in the real world. Jacoby et al. assess the transferability with Multiple Errands Test-Simplified Version (MET-SV) assessment, comparing their grocery shopping task in a virtual supermarket with the same task in a real supermarket [31]. Aubin et al. compare the task performance in a virtual supermarket with performance in a real supermarket [53]. Aubin et al.'s experiment assesses the ecological aspect of the simulations and while the transferability itself is not assessed, the transfer of motor and perceptual skills has been demonstrated in other fields with the use of ecological VE [60]. Their results show significant improvement of the score after the intervention [31] and better results for the real environment condition, suggesting a relationship between ecological situation and transferability [53].

V. DISCUSSION AND PERSPECTIVES

VR for vocational and cognitive rehabilitation is a domain that still needs further investigation, even though VR is commonly used in other medical specialties. Research in this area is not recent, with the first selected article being published in 2012, and appears to be continuing, with the latest articles published in 2022. Modern technology improvements provide better equipment that allows a better experience for novice users and is suitable for rehabilitation context.

Studies aiming for vocational rehabilitation can be patient-oriented, with patient education or counseling interventions, or can target work environments and supervisors. Research on return-to-work benefits from both aspects [61], but clinical studies usually focus on one aspect at a time. All of the studies gathered in this corpus are patient-oriented: their approach is to evaluate the use of virtual VR in a rehabilitation context, independently from the work environment.

Research in this domain has many leads to investigate, and this survey aims to analyze the current state of the art from a VR perspective.

A. VR Interactions and Immersion

The VR apparatuses described in the considered studies come with a wide variation. We differentiate fully-immersive, semi-immersive and non-immersive VR. For non-immersive devices, the borders of the screens are in the FOV of the participants, reminding the subjects of the real environment around them. Semi-immersive and fully-immersive setups allow a bigger or total FOR of VE around the participant. Participants are more inclined to feel present in the VE when they can move their head around without breaking the line of sight. Ecological tasks in cognitive rehabilitation context have navigation and visual search components, which need a large FOR and are enhanced by stereoscopy and head tracking. The used device has a strong impact on immersion for the participant. However, it can be necessary for the therapist to converse with the participants [38], bringing them back to the real world. Allowing collaboration in the VE, between therapist and patients, or between patients, would benefit the rehabilitation without breaking the immersion. Three of the collected studies use immersive interaction systems and devices. The immersion of the majority of studies is therefore limited by a part of the apparatus. With the exception of one study that uses a cycle-ergometer to mimic the ride of a bicycle [35], interaction with the VE in the corpus is done by either motion tracking or mechanical inputs. VR controllers and additional devices allow motion tracking while computer mice, keyboards and joysticks are less realistic of the interaction and therefore less immersing and engaging for the users [14], [22]. Moreover, since the state of the art on VR displays on presence and learning in a training scenario presented in Buttussi et al.'s article [14], HMD technology has improved. The device they considered the most innovative at the time is now representative of the literature. We can presume that the contribution of modern technology on the level of immersion, with the improvement of screens and resolution, is stronger than with older HMD. The contribution of immersion on cognitive rehabilitation is yet to be proved, with the evaluation of the feeling of presence for clinical studies, but the use of VR shows promising results concerning the improvement of cognitive functions, compared to traditional rehabilitation [2]. Immersion has, however, a significant impact on engagement and motivation, and current rehabilitation studies could strongly benefit from the use of innovative technology.

Additionally, all of the tasks using immersive devices in the corpus require a certain degree of manipulation, and the immersion is increased by the immersive device compared to traditional setups. Studies using a computer keyboard, a computer mouse or a joystick to interact with the VE allow a different set of actions that reminds the subject of the device they are using, thus limiting the immersion. The use of gesture and motion to interact with the VE, on the other end, immerses the user in VR. Tracking devices are commonly combined with HMD to achieve a more natural interaction [62], and multiple VR headsets have now built-in hand-tracking devices. The user can use gesture recognition instead of controllers. The use of multiple devices depending on the nature of the task is never put in practice, but is considered in vocational rehabilitation literature. For example, a HMD and controllers have been used for room-size manipulation and a tablet for money counting [1]. Vocational rehabilitation involves a wide variety of cognitive tasks and choosing the adapted apparatus should be discussed and based on the selected tasks more than the available technology.

B. Cognitive Tasks

Regarding the VR tasks represented in the corpus, the majority of the collected articles simulate a store, either a clothes store or a supermarket, with the participant as a client for ten of them or a worker for two of them. Grocery shopping is challenging in terms of executive functioning, while keeping an ecological context. Furthermore, orientation tasks of finding the way in a realistic VE enhance the virtual experience towards ecological validity. It extends the VE to a wider space than what traditional rehabilitation can otherwise provide and helps the participant to believe in the simulation.

Ecological validity is an important criterion when dealing with vocational rehabilitation. The remaining articles of the corpus find a task that suits the targeted population, with grandparents taking care of their grandchildren during a simulation of homelife with a child [29] or with specific tasks from a selection of common jobs among the population [54]. The variety of VR tasks in the sixteen collected studies shows that cognitive rehabilitation takes various shapes. Researchers are confronted with the difficulty of finding a vocational context that suits their population. Ecological tasks like grocery shopping or navigating a subway are common tasks with which every participant is familiar. Yet it is not representative of the population's work habits. Vocational tasks are important for vocational rehabilitation, but must consider that all participants come from a different background. VR allows more freedom in the task design, and rehabilitation tasks can be closer to a familiar situation. Patients with cognitive impairment can be confronted with a realistic work simulation or a more relaxing environment, while keeping an immersive and ecological experience.

Executive dysfunctions are involved in multitasking and have therefore a strong impact on return to work [3], leading to executive functions being a focus of nine studies. Attention and memory (prospective and retrospective) are also commonly trained. Finally, some studies train communication and visuospatial capacities. This gives us an insight of the important cognitive aspects involved in vocational rehabilitation and why supermarket simulations are popular for cognitive rehabilitation. Such ecological tasks that involve the use of various skills are recommended for rehabilitation [63]. The use of VR for attention deficit rehabilitation benefits from the distractions that can be applied to the participants in the VE, which can hardly be reproduced in traditional rehabilitation. VR also provides more possibilities for rehabilitation, with recent studies adding more complexity and diversity to the tasks in the VE [55], [56].

C. Adaptivity and Transferability

In the context of rehabilitation, VR allows monitoring the patient's actions to adapt the VE to their needs. Adaptivity in VR relies on scores and metrics, in order to automatically process the results. The scoring systems used in the collected articles are based on performance only, with records of the number of successes, errors, accuracy or time needed to finish a task. The use of artificial intelligence algorithms to adapt the simulation allows a more complex adaptation. These strategies of adaptation contribute to rehabilitation, by taking into account the variability of cognitive functioning among the users. When working with cognitive rehabilitation, patients can have a vast variety of cognitive abilities and difficulties, related to their cognitive impairment. In the literature, there is no proposition for now of adaptive models based on cognitive abilities [64]. Clinical studies aiming for cognitive rehabilitation could benefit from having better adaptivity. The drawback of having adaptive strategies is the difficulty of comparing the experimental conditions with every participant experiencing a different protocol. Comparing results requires more argumentation in order to demonstrate generalisability.

Transferability is a major concern of rehabilitation as it is related to the impact of rehabilitation on participants' life after therapy. Transferability has only been assessed in five studies out of sixteen. Among these articles, the transferability was often deduced from a subjective questionnaire. However, both objective and subjective outcomes show a significant improvement after the procedure. One study does not assess transferability but emphasizes the role of VR in the transfer of the intervention benefits to daily life [35]. VR has shown to be a strong tool for ecological validity and transferability, compared with traditional rehabilitation strategies [65]. Assessing the transferability is therefore important to confirm both the effectiveness and unity of the intervention and the VR contribution, especially for training tasks [59].

D. Perspectives

The assets brought by VR to vocational and cognitive rehabilitation is a topic of interest in the literature and several studies have been published in this domain. However, these studies show room for improvement regarding 1) immersion, 2) transferability, 3) adaptivity and 4) research approach.

Increased immersion has shown evidence of enhancing memory improvement [14] and patients with cognitive impairment with memory issues in particular could benefit from a higher immersion level. VR device is one of the factors influencing immersion and the other factors, e.g. presence could not be assessed. Studies are developed for day-to-day life adaptation and presence is important to enhance this ecological aspect, yet presence is never assessed in the studies considered in this paper. Research on cognitive rehabilitation using VR could benefit from presence assessment such as Witmer & Singer [66], Slater-Usoh-Steed [67] or Igroup presence [68] questionnaires. The evaluation and improvement of presence for the participants also improve the usability of VR attention tasks [69]. Regarding the use of immersive devices, literature shows that a high level of immersion enhances manipulation tasks [57]. However, when working with a naive population, participants can have difficulties getting familiar with the device and how to interact with it. They require more time to learn how to manipulate the device and can add a bias to the study if they fail to use it. Modern and innovative technology in particular can have a negative influence on a study because it is designed to strongly change the way the user interacts with the VE, for an immersive purpose [70]. The small number of studies using highly immersive interfaces can be explained as a trade-off for a more familiar device, keeping the participants in their comfort zone and dismissing the potential of immersive VR. In order to assess the effect of immersive VR on this topic, studies involving non-specialist participants and immersive technology should be cautious during the first sessions of the intervention. Designers of VR experiments should provide a dedicated time for the participants to get familiar with the apparatus, and an even longer time for patients with cognitive impairment. Their acceptability or reluctance regarding the interface can have an impact on the study, as highlighted in [53], and should be assessed before the conception of a VR solution. However, innovative and immersive technology, such as HMD or CAVE-like interface, is more and more known among the population, and VR interfaces have higher and higher performance. We can expect wireless HMD, lower latency and more powerful computing force to improve overall the patients' experience in clinical studies. Future research should take into consideration this evolution of innovative technology when designing studies. Future research should aim for a more usable and high-performance apparatus for rehabilitation studies, maximizing the comfort of the participants.

Along with a high level of immersion, VR can achieve a strong feeling of engagement in the therapy. As stated in section IV-E, immersion also facilitates the transferability of knowledge acquired during therapy. However, transferability is rarely assessed in current studies. When assessed, transferability is computed from a subjective questionnaire on self-efficacy, or with the MET-SV questionnaire [31]. These measures raise the question of the purpose of the assessment. The transferability is a measure that makes sense when assessed after a period of time. Assessing the transferability at the end of the intervention does not provide a good insight into the benefits of the intervention over a long period of time. However, this assessment is important to have a better understanding of cognitive and vocational rehabilitation. The lack of assessment for transferability and the lack of follow-up are issues that should be fixed in future research. The VR interventions for vocational or cognitive rehabilitation are various in the literature, with a tendency for supermarket or store simulations. Such tasks are challenging for executive functions, attention and memory and put the subject in an ecological context. In traditional rehabilitation, ecological situations are costly, time-consuming to implement, and difficult to control. Computerized solutions are a versatile solution to all of these drawbacks. However, it also has some limitations: ecological simulations do not always fit the vocational rehabilitation objectives and stay close to cognitive training exercises. Among computerized solutions, VR allows to immerse the patients in a fitting ecological situation, with full control over the environment. Assessment of transferability is important to evaluate the impact of immersing the participants in an ecological situation similar to the source of difficulties in real life. Moreover, in the collected studies, the used devices are often non-immersive devices. VR technologies are yet always innovating and provide experiences of better quality. The use of immersive technology could have an impact on transferability, by making the subjects face their difficulties, with full control of the simulation and with high fidelity. Assessing the impact of immersion on the transferability of cognitive and vocational rehabilitation would provide important information for therapists.

In the context of rehabilitation, VR allows the possibility to measure the patients' actions without intrusive devices. Moreover, the patient environment is in partial control during rehabilitation and even full control for full-immersive VR. However, current studies' adaptive strategies focus on performance scores such as success and error rate, time to finish a task or accuracy. Other metrics could be included to adapt the VE: gaze direction and head movements can give insights into the attention functions of the participant. Assessment of stress, through physiological measures (e.g. skin conductance, heart rate, breathing rate), or duration of inactivity could give insights into the user's difficulties.

Finally, while VR is more and more popular as an innovative tool for neurorehabilitation [71], the search for articles for this survey does not provide many recent results, with only four studies published in the past three years. Research in this subject requires expert skills in different areas of research, or a collaboration between two domains: medicine and computer science. This need for such expertise can be a reason for the lack of papers on this topic. For the majority of the collected studies, the authors have a medical background. Only six articles have at least one author from a computer science background [34], [35], [51], [53], [55], [56]. Multidisciplinary studies can be expensive in time and resources, if not out of reach. However, compared to a one-sided perspective, the collaboration of experts from different backgrounds has a major impact on the research work. Therapists bring their expertise on the medical context, identifying patients' needs, and can highlight the need for a simple interface for patients with cognitive impairment compared to healthy users. On the other hand, VR experts have all the necessary knowledge of innovative technologies and how they can be used. Research in VR explores different aspects of interaction, including multi-sensory interaction. The use of various modalities is important for both immersion and transferability, as real interactions have multiple components that contribute to the naturalness of the action. VR experts are also aware of the effect of embodiment on the participants. The sense of embodiment in VR refers to the sensations of being inside, having and controlling a virtual body [72]. The sense of embodiment can contribute to the immersion and the feeling of presence but is also beneficial for rehabilitation [73], [74] and engagement [75] in VR interventions. The combination of VR with vocational and cognitive rehabilitation is the union of two distinct domains and future research would benefit from the expertise of both fields.

VI. CONCLUSION

This article outlines cognitive rehabilitation studies using vocational or ecological VR for patients with cognitive impairment. From a VR perspective, it highlights the fundamental components of VR-based vocational rehabilitation. Following a strict selection process, sixteen studies were collected and analyzed. Their comparison criteria were their VR systems and their adaptivity, transferability, and immersion levels.

Our analysis shows that current systems tend to use non-immersive interfaces and have yet to demonstrate the potential of immersive VR. Adaptivity is a solid lead to improve vocational rehabilitation and requires strengthening in future research. While transferability has been rarely assessed, a virtual ecological environment and a high level of immersion could bring the participants to a deeper level of engagement than conventional therapy. Research in VR could also consider other aspects of virtual interactions in the context of rehabilitation, such as with multi-sensory feedback or virtual embodiment using avatars. Therefore, the use of VR in vocational and cognitive rehabilitation represents a promising multidisciplinary research topic that should heavily benefit from contributions coming from both medical and technological communities in the future.

References

[1] L. Bozgeyikli et al., "VR4VR: Vocational rehabilitation of individuals with disabilities in immersive virtual reality environments," in *Proc. ACM Int. Conf. Pervasive Technol. Rel. Assistive Environments*, 2015, pp. 1–4.

[2] G. Riva, V. Mancuso, S. Cavedoni, and C. Stramba-Badiale, "Virtual reality in neurorehabilitation: A review of its effects on multiple cognitive domains," *Exp. Rev. Med. Devices*, vol. 17, no. 10, pp. 1035–1061, Oct. 2020.

[3] N. Revheim et al., "Neurocognitive and symptom correlates of daily problem-solving skills in schizophrenia," *Schizophrenia Res.*, vol. 83, nos. 2–3, pp. 237–245, 2006.

[4] R. Gil, *Neuropsychologie*. London, U.K.: Elsevier Health Sciences, 2018.

[5] M. H. Selamat, S. Y. Loh, L. Mackenzie, and J. Vardy, "Chemobrain experienced by breast cancer survivors: A meta-ethnography study investigating research and care implications," *PLoS ONE*, vol. 9, no. 9, Sep. 2014, Art. no. e108002.

[6] C. A. Mateer and C. S. Sira, "Cognitive and emotional consequences of TBI: Intervention strategies for vocational rehabilitation," *NeuroRehabilitation*, vol. 21, no. 4, pp. 315–326, Feb. 2007.

[7] B. Bloom et al., "A systematic review and meta-analysis of return to work after mild traumatic brain injury," *Brain Injury*, vol. 32, nos. 13–14, pp. 1623–1636, Dec. 2018.

[8] J. van der Kemp, W. J. Kruithof, T. C. W. Nijboer, C. A. M. van Bennekom, C. van Heugten, and J. M. A. Visser-Meily, "Return to work after mild-to-moderate stroke: Work satisfaction and predictive factors," *Neuropsychological Rehabil.*, vol. 29, no. 4, pp. 638–653, Apr. 2019.

[9] B. K. Sohn et al., "Developing a virtual reality-based vocational rehabilitation training program for patients with schizophrenia," *Cyberpsychology, Behav., Social Netw.*, vol. 19, no. 11, pp. 686–691, Nov. 2016.

[10] E. Vikane et al., "Predictors for return to work in subjects with mild traumatic brain injury," *Behavioural Neurol.*, vol. 2016, pp. 11–20, Oct. 2016.

[11] P. Fuchs, G. Moreau, and P. Guitton, *Virtual Reality: Concepts and Technologies*. Boca Raton, FL, USA: CRC Press, 2011.

[12] I. E. Sutherland, "The ultimate display," in *Proc. IFIP Congr.*, 1965, pp. 506–508.

[13] C. J. Bohil, B. Alicea, and F. A. Biocca, "Virtual reality in neuroscience research and therapy," *Nature Rev. Neurosci.*, vol. 12, no. 12, pp. 752–762, Dec. 2011.

[14] F. Buttussi and L. Chittaro, "Effects of different types of virtual reality display on presence and learning in a safety training scenario," *IEEE Trans. Vis. Comput. Graphics*, vol. 24, no. 2, pp. 1063–1076, Feb. 2018.

[15] G. Riva, F. Davide, and W. A. Ijsselsteijn, "Being there: The experience of presence in mediated environments," in *Being there: Concepts, Effects and Measurement of User Presence in Synthetic Environments*, vol. 5. Amsterdam, The Netherlands: IOS Press, 2003, pp. 3–16.

[16] J. Waterworth and G. Riva, *Feeling Present in the Physical World and in Computer-Mediated Environments*. Cham, Switzerland: Springer, 2014.

[17] C. Camargo et al., "Virtual rehabilitation in women with post breast cancer—A case study," in *Proc. IEEE Int. Conf. Virtual Rehabil.*, Aug. 2013, pp. 188–189.

[18] G. House et al., "A feasibility study to determine the benefits of upper extremity virtual rehabilitation therapy for coping with chronic pain post-cancer surgery," *Brit. J. Pain*, vol. 10, no. 4, pp. 186–197, Nov. 2016.

[19] S. Nilsson, B. Finnström, E. Kokinsky, and K. Enskär, "The use of virtual reality for needle-related procedural pain and distress in children and adolescents in a paediatric oncology unit," *Eur. J. Oncol. Nursing*, vol. 13, no. 2, pp. 102–109, Apr. 2009.

[20] S. M. Schneider, C. K. Kisby, and E. P. Flint, "Effect of virtual reality on time perception in patients receiving chemotherapy," *Supportive Care Cancer*, vol. 19, no. 4, pp. 555–564, Apr. 2011.

[21] A. Chirico, F. Lucidi, M. De Laurentiis, C. Milanese, A. Napoli, and A. Giordano, "Virtual reality in health system: Beyond entertainment. A mini-review on the efficacy of VR during cancer treatment," *J. Cellular Physiol.*, vol. 231, no. 2, pp. 275–287, Feb. 2016.

[22] R. P. McMahan, D. A. Bowman, D. J. Zielinski, and R. B. Brady, "Evaluating display fidelity and interaction fidelity in a virtual reality game," *IEEE Trans. Vis. Comput. Graphics*, vol. 18, no. 4, pp. 626–633, Apr. 2012.

[23] G. Vailland et al., "VR based power wheelchair simulator: Usability evaluation through a clinically validated task with regular users," in *Proc. IEEE Virtual Reality 3D User Interfaces (VR)*, Mar. 2021, pp. 420–427.

[24] Z. Palkova, I. Hatzilygeroudis, Y. Zhang, and D. Cristol, "Virtual reality and its applications in vocational education and training," in *Handbook of Mobile Teaching and Learning*. Singapore: Springer, 2019, pp. 1245–1274.

[25] C. Picano, A. Quadrini, F. Pisano, and P. Marangolo, "Adjunctive approaches to aphasia rehabilitation: A review on efficacy and safety," *Brain Sci.*, vol. 11, no. 1, p. 41, Jan. 2021.

[26] M. G. Maggio et al., "Virtual reality and cognitive rehabilitation in people with stroke: An overview," *J. Neurosci. Nursing*, vol. 51, no. 2, pp. 101–105, 2019.

[27] A. Moreno, K. J. Wall, K. Thangavelu, L. Craven, E. Ward, and N. N. Dissanayaka, "A systematic review of the use of virtual reality and its effects on cognition in individuals with neurocognitive disorders," *Alzheimer's Dementia, Transl. Res. Clin. Interventions*, vol. 5, no. 1, pp. 834–850, Jan. 2019.

[28] S. Sweeney, D. Kersel, R. G. Morris, T. Manly, and J. J. Evans, "The sensitivity of a virtual reality task to planning and prospective memory impairments: Group differences and the efficacy of periodic alerts on performance," *Neuropsychological Rehabil.*, vol. 20, no. 2, pp. 239–263, Apr. 2010.

[29] E. Park et al., "Effects of a mixed reality-based cognitive training system compared to a conventional computer-assisted cognitive training system on mild cognitive impairment: A pilot study," *Cognit. Behav. Neurol.*, vol. 32, no. 3, pp. 172–178, 2019.

[30] P. Gamito et al., "Traumatic brain injury memory training: A virtual reality online solution," *Int. J. Disability Human Develop.*, vol. 10, no. 4, pp. 309–312, Jan. 2011.

[31] M. Jacoby, S. Averbuch, Y. Sacher, N. Katz, P. L. Weiss, and R. Kizony, "Effectiveness of executive functions training within a virtual supermarket for adults with traumatic brain injury: A pilot study," *IEEE Trans. Neural Syst. Rehabil. Eng.*, vol. 21, no. 2, pp. 182–190, Mar. 2012.

[32] B. C. B. Yip and D. W. K. Man, "Virtual reality-based prospective memory training program for people with acquired brain injury," *NeuroRehabilitation*, vol. 32, no. 1, pp. 103–115, Feb. 2013.

[33] A. L. Canty, J. Fleming, F. Patterson, H. J. Green, D. Man, and D. H. K. Shum, "Evaluation of a virtual reality prospective memory task for use with individuals with severe traumatic brain injury," *Neuropsychological Rehabil.*, vol. 24, no. 2, pp. 238–265, Mar. 2014.

[34] A. L. Faria, A. Andrade, L. Soares, and S. B. I. Badia, "Benefits of virtual reality based cognitive rehabilitation through simulated activities of daily living: A randomized controlled trial with stroke patients," *J. NeuroEngineering Rehabil.*, vol. 13, no. 1, pp. 1–12, Dec. 2016.

[35] S. Mrakic-Sposta et al., "Effects of combined physical and cognitive virtual reality-based training on cognitive impairment and oxidative stress in MCI patients: A pilot study," *Frontiers Aging Neurosci.*, vol. 10, pp. 282–292, Oct. 2018.

[36] A. Bellens, E. Roelant, B. Sabbe, M. Peeters, and P. A. Van Dam, "Evaluation of a new online cognitive assessment tool in breast cancer survivors with cognitive impairment: A prospective cohort study," *Supportive Care Cancer*, vol. 30, pp. 1–11, Aug. 2021.

[37] K. Grechuta et al., "Augmented dyadic therapy boosts recovery of language function in patients with nonfluent aphasia: A randomized controlled trial," *Stroke*, vol. 50, no. 5, pp. 1270–1274, May 2019.

[38] A. Giachero et al., "Conversational therapy through semi-immersive virtual reality environments for language recovery and psychological well-being in post stroke aphasia," *Behavioural Neurol.*, vol. 2020, pp. 1–15, Aug. 2020.

[39] R. A. Gougeh and T. H. Falk, "Head-mounted display-based virtual reality and physiological computing for stroke rehabilitation: A systematic review," *Frontiers Virtual Reality*, vol. 3, pp. 1–16, May 2022.

[40] C. Leone, P. Feys, L. Moumdjian, E. D'Amico, M. Zappia, and F. Patti, "Cognitive-motor dual-task interference: A systematic review of neural correlates," *Neurosci. Biobehavioral Rev.*, vol. 75, pp. 348–360, Apr. 2017.

[41] H. Sveistrup, "Motor rehabilitation using virtual reality," *J. Neuroeng. Rehabil.*, vol. 1, no. 1, pp. 1–8, 2004.

[42] S. A. Rahman and A. Shaheen, "Virtual reality use in motor rehabilitation of neurological disorders: A systematic review," *Middle-East J. Sci. Res.*, vol. 7, no. 1, pp. 63–70, 2011.

[43] D. Kamińska et al., "Virtual reality and its applications in education: Survey," *Information*, vol. 10, no. 10, pp. 318–337, 2019.

[44] Y. Jing, "VR, AR, and wearable technologies in education: An introduction," in *Handbook of Mobile Teaching and Learning*. Cham, Switzerland: Springer, 2019.

[45] J. Spilski et al., "Potential of VR in the vocational education and training of craftsmen," in *Proc. Int. Conf. Construct. Appl. Virtual Reality*, 2019, pp. 181–190.

[46] A.-S. Dris, F. Lehericey, V. Gouranton, and B. Arnaldi, "Risk-hunting training in interactive virtual environments," in *Proc. CIB W99 Conf.*, 2018, pp. 1–8.

[47] M.-S. Bracq et al., "Training situation awareness through error recognition in an immersive virtual operating room," in *Proc. Int. Conf. Multi-Area Simul.*, 2019, pp. 208–216.

[48] L. Freina and M. Ott, "A literature review on immersive virtual reality in education: State of the art and perspectives," in *Proc. eLearning Softw. Educ. Conf.*, no. 133, 2015, pp. 10–1007.

[49] D. W. K. Man, W. S. Poon, and C. Lam, "The effectiveness of artificial intelligent 3-D virtual reality vocational problem-solving training in enhancing employment opportunities for people with traumatic brain injury," *Brain Injury*, vol. 27, no. 9, pp. 1016–1025, Aug. 2013.

[50] M. M. Y. Tsang and D. W. K. Man, "A virtual reality-based vocational training system (VRVTS) for people with schizophrenia in vocational rehabilitation," *Schizophrenia Res.*, vol. 144, nos. 1–3, pp. 51–62, Mar. 2013.

[51] A. L. Faria, M. S. Pinho, and S. B. I. Badia, "A comparison of two personalization and adaptive cognitive rehabilitation approaches: A randomized controlled trial with chronic stroke patients," *J. NeuroEngineering Rehabil.*, vol. 17, no. 1, pp. 1–15, Dec. 2020.

[52] P. Gamito et al., "Cognitive training on stroke patients via virtual reality-based serious games," *Disability Rehabil.*, vol. 39, no. 4, pp. 385–388, Feb. 2017.

[53] G. Aubin, M.-F. Béliveau, and E. Klinger, "An exploration of the ecological validity of the virtual action planning–supermarket (VAP-S) with people with schizophrenia," *Neuropsychological Rehabil.*, vol. 28, no. 5, pp. 689–708, 2018.

[54] Y.-Y. Liao, I.-H. Chen, Y.-J. Lin, Y. Chen, and W.-C. Hsu, "Effects of virtual reality-based physical and cognitive training on executive function and dual-task gait performance in older adults with mild cognitive impairment: A randomized control trial," *Frontiers Aging Neurosci.*, vol. 11, pp. 162–171, Jul. 2019.

[55] J. Oliveira et al., "Virtual reality-based cognitive stimulation on people with mild to moderate dementia due to Alzheimer's disease: A pilot randomized controlled trial," *Int. J. Environ. Res. Public Health*, vol. 18, no. 10, pp. 1–13, 2021.

[56] J. Oliveira et al., "Computerized cognitive training using virtual reality on everyday life activities for patients recovering from stroke," *Disab. Rehabil., Assistive Technol.*, vol. 17, no. 3, pp. 298–303, Apr. 2022.

[57] D. A. Bowman and R. P. Mcmahan, "Virtual reality: How much immersion is enough?" *Computer*, vol. 40, no. 7, pp. 36–43, Jul. 2007.

[58] P. L. Weiss, R. Kizony, U. Feintuch, and N. Katz, "Virtual reality in neurorehabilitation," in *Textbook of Neural Repair and Rehabilitation*. New York, NY, USA: Cambridge Univ. Press, 2006, pp. 182–197.

[59] E. D. Ragan, "The effects of higher levels of immersion on procedure memorization performance and implications for educational virtual environments," *Presence*, vol. 19, no. 6, pp. 527–543, Dec. 2010.

[60] J. Tirp, C. Steingröver, N. Wattie, J. Baker, and J. Schorer, "Virtual realities as optimal learning environments in sport—A transfer study of virtual and real dart throwing," *Psychol. Test Assessment Model.*, vol. 57, no. 1, pp. 57–69, 2015.

[61] A. G. de Boer, T. K. Taskila, S. J. Tamminga, M. Feuerstein, M. H. Frings-Dresen, and J. H. Verbeek, "Interventions to enhance return-to-work for cancer patients," *Cochrane Database Systematic Rev.*, vol. 2017, no. 7, pp. 1–67, Sep. 2015.

[62] M. Sudha et al., "Approaches and applications of virtual reality and gesture recognition: A review," *Int. J. Ambient Comput. Intell.*, vol. 8, no. 4, pp. 1–18, 2017.

[63] P. W. Burgess et al., "The case for the development and use of 'ecologically valid' measures of executive function in experimental and clinical neuropsychology," *J. Int. Neuropsychological Soc.*, vol. 12, no. 2, pp. 194–209, 2006.

[64] T. Luong, A. Lecuyer, N. Martin, and F. Argelaguet, "A survey on affective and cognitive VR," *IEEE Trans. Vis. Comput. Graphics*, vol. 28, no. 12, pp. 5154–5171, Dec. 2022.

[65] A. G. Plaza, J. Delarue, and L. Saulais, "The pursuit of ecological validity through contextual methodologies," *Food Quality Preference*, vol. 73, pp. 226–247, Apr. 2019.

[66] B. G. Witmer and M. J. Singer, "Measuring presence in virtual environments: A presence questionnaire," *Presence*, vol. 7, no. 3, pp. 225–240, Jun. 1998.

[67] M. Usoh, E. Catena, S. Arman, and M. Slater, "Using presence questionnaires in reality," *Presence*, vol. 9, no. 5, pp. 497–503, Oct. 2000.

[68] T. W. Schubert, "The sense of presence in virtual environments: A three-component scale measuring spatial presence, involvement, and realness," *Zeitschrift für Medienpsychologie*, vol. 15, no. 2, pp. 69–71, 2003.

[69] A. Voinescu, K. Petrini, and D. S. Fraser, "Presence and simulator sickness predict the usability of a virtual reality attention task," *Virtual Reality*, vol. 27, pp. 1–17, Mar. 2023.

[70] A. Deblock-Bellamy, A. Lamontagne, B. J. McFadyen, M.-C. Ouellet, and A. K. Blanchette, "Dual-task abilities during activities representative of daily life in community-dwelling stroke survivors: A pilot study," *Frontiers Neurol.*, vol. 13, pp. 1–11, May 2022.

[71] T. Massetti et al., "The clinical utility of virtual reality in neurorehabilitation: A systematic review," *J. Central Nervous Syst. Disease*, vol. 10, pp. 1–18, Nov. 2018.

[72] K. Kilteni, R. Groten, and M. Slater, "The sense of embodiment in virtual reality," *Presence*, vol. 21, no. 4, pp. 373–387, Nov. 2012.

[73] P. Charbonneau et al., "Gaitzilla: Exploring the effect of embodying a giant monster on lower limb kinematics and time perception," in *Proc. IEEE Int. Conf. Virtual Rehabil.*, Jul. 2017, pp. 1–8.

[74] D. Banakou, S. Kishore, and M. Slater, "Virtually being Einstein results in an improvement in cognitive task performance and a decrease in age bias," *Frontiers Psychol.*, vol. 9, pp. 917–930, Jun. 2018.

[75] E. Kalina and M. C. Johnson-Glenberg, "Presence and platform: Effects of embodiment comparing a 2D computer and 3D VR game," in *Proc. IEEE Int. Conf. Immersive Learn. Res. Netw. (iLRN)*, Jun. 2020, pp. 31–37.