

Moving Beyond Single User, Local Virtual Environments for Rehabilitation

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Advanced Technologies in Rehabilitation: Empowering Cognitive, Physical, Social and Communicative Skills through Virtual Reality, Robots, Wearable Systems and Brain-Computer Interfaces

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Abstract. The rapid development of Virtual Reality-based technologies over the past decade is both an asset and a challenge for neuro-rehabilitation. The availability of novel technologies that provide interactive, functional simulations with multimodal feedback enable clinicians to achieve traditional therapeutic goals that would be difficult, if not impossible, to attain via conventional therapy. They also lead to the creation of completely new clinical paradigms which would have been hard to achieve in the past. In applications of rehabilitation for both motor and cognitive deficits the main focus of much of the early exploratory research has been to investigate the use of virtual reality as an assessment tool. To date such environments are primarily: (a) single user (i.e., designed for and used by one clinical client at a time) and (b) used locally within a clinical or educational setting. More recently, researchers have begun the development of new and more complex VR-based approaches according to two dimensions: the number of users and the distance between the users. Driven by a push-pull phenomenon, the original approach has now expanded to three additional avenues: multiple users in co-located settings; single users in remote locations; and multiple users in remote locations. After a presentation of examples that illustrate these various approaches, we will conclude in addressing questions and ethical considerations raised by this evolution in the use of virtual environments in rehabilitation.

Keywords. Virtual Reality, Rehabilitation, Tele-Rehabilitation

1. Introduction

The rapid development of Virtual Reality (VR)-based technologies over the past decade is both an asset and a challenge for neuro-rehabilitation. The availability of novel technologies that provide interactive, functional simulations with multimodal feedback (visual, auditory and, less frequently, haptic, vestibular, and olfactory channels) enable clinicians to achieve traditional therapeutic goals that would be difficult, if not impossible to attain via conventional therapy. For example, the practice of functional skills, such as street crossing or supermarket shopping, are inconvenient and sometimes dangerous for clients with brain damage when they take place in real settings. They also lead to the creation of novel clinical paradigms. For example, the

use of instrumented tangible cubes that control virtual building blocks, enables a clinician to assess the constructional ability of children with Developmental Coordination Disorder under dynamic conditions [1].

In applications of rehabilitation for both motor and cognitive deficits, the main focus of much of the early exploratory research has been to investigate the use of VR as

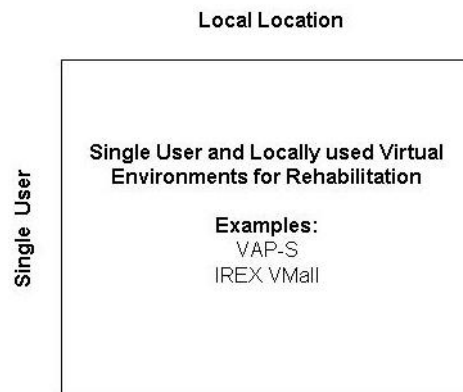


Figure 1. Single user and locally used virtual environments

an assessment tool [2, 3]. More recently researchers have been striving to develop and evaluate VR-based intervention strategies. Examples include the use of realistic functional simulations, tele-rehabilitation, and home-based therapy. For example, the IREX video capture VR system has been used to improve ankle movements in children with Cerebral Palsy [4] and a customized speech training program has been used to augment therapy for clients with stroke who have been discharged home [5].

In this chapter, we begin by providing a short overview of how virtual environments (VE) first began to be implemented for the purposes of cognitive or motor rehabilitation. To date such environments are primarily: (a) single user (i.e., designed for and used by one clinical client at a time) and (b) used locally within a clinical or educational setting (see **Figure 1**). The clinical attributes of such systems will be illustrated via two examples: the VAP-S [6] and the IREX VMall [7].

Researchers developed these technologies to enhance conventional assessment [8] and therapy [9, 10] with the aid of VEs; a single user in a particular location experiences a VR-based clinical session under the local supervision of a therapist. The potential of VR assets for rehabilitation are now well known [2, 10]. They include real-time interaction, objective outcome measures that are documented, and repeated delivery of virtual stimuli within simulated functional environments that are graded in difficulty and context. A variety of studies have begun to demonstrate the validity of VR use in neuropsychology and rehabilitation [11-13].

In recent years, we have observed a push-pull phenomenon which is leading to an increase in the application of VR technologies for rehabilitation. The “push” emanates from the continuous development of novel technologies, their more ready availability in clinical settings, and lowered costs. The “pull” stems from clients, clinicians and third party payers who recognize the need for treatment that goes beyond conventional therapy. As indicated above, VR-based therapy given to single users in local settings has been driven by the push-pull phenomenon. However, very recently, efforts are being made to expand to approaches designed to support multiple users and remote

locations. **Figure 2** presents a revised version of **Figure 1**, showing three additional avenues: multiple users in co-located settings (Arrow 1), single users in remote locations (Arrow 2) and multiple users in remote locations (Arrow 3). The latter two approaches are often referred to as tele-rehabilitation. This evolution in the use of VEs in rehabilitation raises research questions and ethical considerations that we will address below.

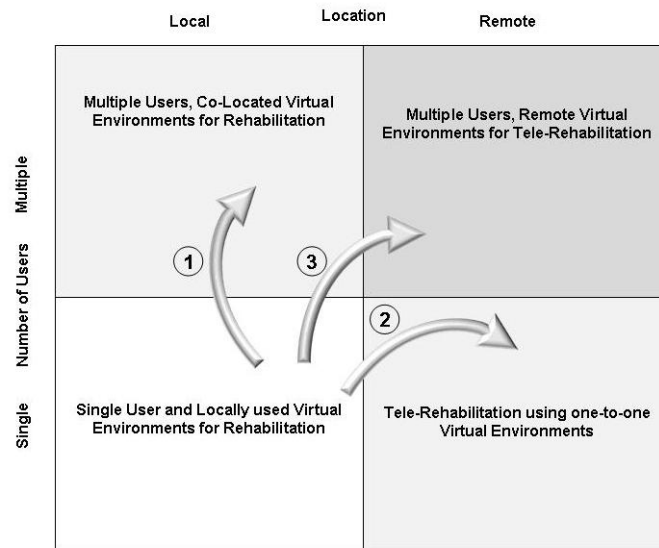


Figure 2. Moving beyond single user and local virtual environments for rehabilitation

2. Single User Approaches

Replicating the therapist-patient relationship in traditional therapy, the first VR-based applications were used with a single user (patient) who engaged in a particular VE in the presence of the therapist; this is what we refer to as the single user and locally used VE (**Figure 1** and lower, left quadrant in **Figure 2**). The clinical attributes of such systems are illustrated by two examples: the VAP-S [6] and the IREX VMall [7].

2.1. Virtual Action Planning Supermarket (VAP-S)

The Virtual Action Planning Supermarket (VAP-S) was designed to assess and train the ability to plan and execute the task of purchasing items on a shopping list [6, 14-16]. It was created with two main tools: 3D Studio Max from Autodesk (www.autodesk.com) and Virtools™ Life Platform from Dassault Systèmes (www.virttools.com). Operation of the VAP-S includes a series of actions, described as a task, and allows an analysis of the strategic choices made by clients and thus their capacity to plan, such as the “test of shopping list” [8]. The VAP-S simulates a fully textured, medium size supermarket with multiple aisles displaying most of the items that can be found in a real supermarket. There are also four cashier check-out counters; a reception point and a shopping cart, as illustrated in **Figure 3**. Some obstacles, like packs of bottles or cartons, may hinder the advance of the shopper along the aisles. In

addition, virtual humans are included in the supermarket such as a fishmonger, a butcher, check-out cashiers and some customers.

The test task is to purchase seven items from a clearly defined list of products, to then proceed to the cashier's desk and to pay for them. Twelve correct actions (e.g., selecting the correct product) are required to completely succeed in the task. Actions are considered as incorrect if the client: 1) chooses items that are not in the list or chooses the same item twice; 2) chooses a check-out counter without any cashier; 3) leaves the supermarket without purchasing anything or without paying; or 4) stays in the supermarket after the purchases. A training task which is similar, but not identical, to the test is also available to enable the user to get acquainted with the VE and the tools. The task-related instructions are, at first, written on the screen and the target items to purchase are displayed on the right side of the screen. As the client progresses with the purchases, the items appear in the cart and disappear from the screen. The cashier-related instructions are verbal and are given before the beginning of the session.

While sitting in front of a PC screen monitor, the client enters the supermarket behind the cart as if he is pushing it, and moves around freely by pressing the keyboard arrows. He is able to experience the environment from a *first person perspective* without any intermediating avatar. The client is able to select items by pressing the left mouse button. If the item selected is one of the items on the list it will transfer to the cart. At the cashier check-out counter, the client may place the items on the conveyor belt by pressing the left mouse button with the cursor pointing to the belt. He may also return an item placed on the conveyor belt to the cart. By clicking on the purse icon, the client may pay and proceed to the supermarket exit.



Figure 3. The Virtual Action Planning Supermarket (VAP-S)

The VAP-S records various outcome measures (position, times, actions) while the participant experiences the VE and executes the task. At least eight variables can be calculated from the recorded data: the total distance in meters traversed by the patient (referred to as the trajectory), the total task time in seconds, the number of items purchased, the number of correct actions, the number of incorrect actions, the number of pauses, the combined duration of pauses in seconds, and the time to pay (i.e., the time between when the cost is displayed on the screen and when the participant clicks on the purse icon). A review of the performance is available from a "Bird's eye view", i.e. from above the scene (see white traces in **Figure 4** and **Figure 5**).

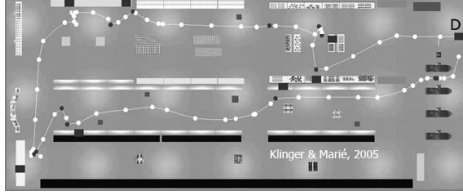


Figure 4. Trajectory while shopping for items by a user with no impairment.

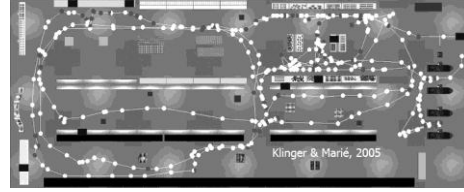


Figure 5. A typical trajectory of the same shopping task by a client with Parkinson's Disease.

The initial design of the VAP-S was carried out in the context of research on Parkinson's disease (PD) and the elderly. Its purpose was first to test the feasibility of the VAP-S for elderly people, and second to investigate the capacity of the VAP-S to discriminate between patients with PD and age-matched control subjects. Five patients with PD (two females, three males; age, 74.0 ± 5.4 years) and five age-matched healthy controls (four females, one male; age, 66.6 ± 7.7 years) were recruited, according to the inclusion criteria [6, 15]. A debriefing period allowed Klinger et al. to collect the participants' feedback: they well understood the task and VAP-S usage; thanks to the training session they easily became familiar with the VR interface. One limitation (related to the correct distance to apply from the shelves) was noted and revised in subsequent versions of the VAP-S. The performance results underlined a behavioral difference between patients with PD and controls: patients needed more time to execute the task and cover a longer distance. This difference was not related to motor difficulties since they navigated with keyboard keys at the same speed. It is rather related to their hesitations, numerous stops, and need to search for products not appropriate to the products' position in the VAP-S (see Figure 5). These data reveal the alteration of temporal and spatial organization of PD patients [17]. Moreover the review of the trajectory was appreciated by both the participants and the therapist.

The original VAP-S was then adapted by E. Klinger in 2005 for use by an Israeli population; the names of the aisles and grocery items, as well as all the elements of the task were translated to Hebrew [18, 19]. The purpose of the study was first to test the feasibility of the VAP-S for post-stroke patients, and second to examine the relationships between performance within the VAP-S and standard outcome measures of executive functions. Twenty-six post-stroke patients participated in the study [18]. In order to predict problems in everyday activities, they also were assessed with the six performance subtests of the Behavioral Assessment of Dysexecutive Syndrome (BADs) [20], which cover various aspects of the dysexecutive syndrome such as difficulty in planning and abstract thinking. Performance results showed the feasibility of the VAP-S for use by post-stroke patients. Analysis of the participants' performance showed a large variance of the scores within the VAP-S. The relationships between performance within the VAP-S and the key search subtest from the BADs that requires planning ability showed that the supermarket task requires planning ability which is one of the key executive functions.

The potential of the VAP-S as a predictive tool of executive function profiles is currently explored thanks to studies among various populations of patients with deficits in the central nervous system [19, 21].

2.2. IREX Video capture Virtual Mall (VMall)

Video capture VR uses a video camera and software to track movement in a single plane without the need to place markers on specific bodily locations. The user's image is thereby embedded within a simulated environment such that it is possible to interact with animated graphics in a completely natural manner. Users stand or sit in a demarcated area with a chroma key backdrop (used to subtract users from the real environment prior to inserting them into the virtual environment) and view a large video screen that displays simulated environments. A single camera films the user and displays his image within the VE. The user's movements are processed on the same plane as screen animation, text, graphics, and sound, which respond in real-time. Therefore the users see themselves in the VE and interact using their own natural movements [22]. Several virtual games which run on the same VR platform and have been adapted for rehabilitation (Birds & Balls, Soccer, Snowboard and Volleyball) were also used during the sessions (IREX™ Interactive Rehabilitation and Exercise System (www.gesturetekhealth.co) [23]. This system has been used in rehabilitation and has been shown to be suitable for use with patients suffering from motor and/or cognitive deficits [24-27].

The VMall is a virtual supermarket that runs on the IREX platform. It encourages planning, multitasking and problem solving while practicing an everyday task of shopping [28]. The products are virtually selected and placed in a shopping cart using upper extremity movements (see **Figure 6**). It has been shown to be a valid assessment tool which can differentiate between two groups of healthy people and between healthy people and those with stroke [7, 25], and which correlates with performance in a complex shopping task in a real mall [25].

The VMall was further validated by comparing a virtual version of the well-known test of executive functions, the Multiple Errands Test (MET), called the Virtual Multiple Errands Test (VMET) to the original MET [29]. The study population included three groups; post-stroke participants (N=9), healthy young participants (N=20) and healthy older participants (N=20). The VMET was able to differentiate between two age groups of healthy participants and between healthy and post-stroke participants thus demonstrating that it is sensitive to brain injury and aging and supports construct validity between known groups. In addition, significant correlations were found between the MET and the VMET for both the post-stroke participants and older healthy participants. These results provide initial support for the ecological validity of the VMET as an assessment tool of executive functions.

The potential of the VMall as an intervention tool for people with stroke who present difficulties in executive functions and multitasking [30] or in motor deficits [31] was also explored. The two companion studies of four and six participants with stroke, respectively, received ten 60-minute sessions in a 3 week period using the VMall. Intervention for the executive function deficits group focused on improving multitasking during a shopping task. A substantial percent improvement for most of the measures in the MET in an actual shopping mall and in the Virtual MET was found for all 4 participants. In addition, some improvement was found for a general IADL measure. Intervention for the motor deficits group focused on reaching movements by the affected upper extremity while the participant was engaged in a virtual shopping task. An improvement was found for all outcome measures during the intervention phase as compared to none or very little change during both baseline phases. The participants reported that the intervention helped them improve their weak upper

extremity and stated that they used it more in daily life than prior to the intervention. These data support the potential of the VMall as a motivating and effective intervention tool for the rehabilitation of people with stroke by presenting multitasking or upper extremity motor deficits.



Figure 6. The VMall, the left panel shows selection of a supermarket aisle, the middle panel shows a shopping cart with purchased food items, and the right panel shows selection of grocery products.

3. Co-located Multiple User Approaches

Researchers have foreseen the need to go beyond the design and implementation of single user and locally used VE, aiming to develop more complex VR-based approaches that advance along the two dimensions shown in **Figure 2**: the number of users and the distance between the users. With regard to the dimension of number of users (Figure 2, arrow 1), issues related to the role that additional users will play in a VE arise. They may be involved in an assistive role (e.g., a therapist may help the patient perform the activity or task), or in a positive or negative collaborative role (e.g., patients may be involved in a common activity to achieve a task). In order to illustrate these two aspects, we next describe the use of the IREX system in motor rehabilitation and the use of collaborative tables among children with autism.

3.1. Client to Therapist Interaction

As indicated above, users of IREX video capture VR see themselves in the VE and interact using their own natural movements [22]. Video-capture VR provides users with a mirror image view of themselves actively participating within the environment. This contrasts with other VR display technologies such as a Head Mounted Display (HMD) which provides users with a "first person" point of view, or many desktop platforms in which the user is represented by an avatar. The use of the user's own image has been suggested to add to the realism of the environment and to the sense of presence [32]. It also provides feedback about the user's body posture and quality of movement, comparable to the use of video feedback in conventional rehabilitation during the treatment of certain conditions such as unilateral spatial neglect [33].

Interaction and control is another attribute of video capture VR that has implications for therapy. This characteristic relates to how the user controls objects within the VE. Rather than relying on a pointing device or tracker, interaction within video-capture based environments is accomplished in a completely intuitive manner via natural motion of the head, trunk and limbs [22]. Not only is the control of movement more natural, but, in the case of the chroma key IREX, a "red glove" option (or any object with a distinct color) may be used to restrict system responses to one or more

body parts as deemed suitable for the attainment of specified therapeutic goals. For example, when it is appropriate to have the intervention directed in a more precise manner, a client may be required to repel projected balls via a specific body part (e.g., by the hand when wearing a red glove or by the head when wearing a red hat). Or, when the intervention is more global, the client will not use the red glove option and thus be able to respond with any part of the body. The ability to direct a client's motor response to be either specific or global makes it possible to train diverse motor abilities such as the range of motion of different limbs and whole body balance training.

Both attributes described above (see themselves in the VE and interact using their own natural movements) offer an intuitive interaction between a patient and the VE. A therapist can naturally enter the VE, replicating the conventional therapist-patient interaction while retaining VR's added assets.

3.2. Client to Client Interaction

Active Surfaces are an emerging class of devices and applications [34, 35]. They are shared co-located systems that represent a radical shift from the paradigm of one-user-one-computer. As such, they are subject to different design constraints than standard Graphical User Interface (GUI) applications. They are based on large interactive surfaces placed horizontally ('tabletop' devices) or vertically ('wall displays') on which a specifically designed interface is displayed or projected. These systems open up new possibilities for fostering collaboration and they can be used to increase the users' sense of teamwork and facilitate access control on large, shared displays. Zancanaro et al. [34] developed a tabletop device (StoryTable) that examined the interaction pattern in pairs of typically developed children when narrating a joint story using an interface that "enforced" joint actions (**Figure 7**). The objective was to foster the recognition of the contribution of the peer in dyadic interaction. In collaboration with that group, we used the StoryTable paradigm with high functioning Autistic Spectrum Disorder (HF-ASD) children to evaluate the effectiveness of a three-week intervention in which a computerized, co-located touch table interface combined with Cognitive Behavioral Therapy (CBT) intervention guidelines (e.g., self instruction, problem solving) [36-38]. Intervention focused on exposing three pairs of children, aged 8-10 years, with HF-ASD to an enforced collaboration paradigm while they narrated a story. Pre and post intervention tasks included a "low technology" version of the StoryTable and a non story-telling play situation using a free construction game, to examine generalization of the learned social behaviors. Results demonstrated progress in three major areas of social behaviors. First, the participants were more likely to initiate positive social interaction with peers after the intervention. Second, the level of shared play of the children increased from the pre-test to the post test and they all increased their level of collaboration following the intervention. Third, the children with ASD demonstrated lower frequencies of autistic behaviors while using the StoryTable in comparison to the free construction game activity. This preliminary study revealed the effectiveness of the integration of technology to enforce collaboration integrated with CBT framework.



Figure 7. The StoryTable. Left panel shows screen shot of one story telling background. Right panel shows two typically developed children engaged in a multi-touch activation.

4. Remote Location, Single User Approach

With regard to the dimension of location (local versus remote), several VEs have evolved that add distance between the patient and the therapist leading to what is called tele-rehabilitation (Figure 2, arrow 2). Their purpose was to improve access to care and to extend the reach of medical rehabilitation service delivery. In order to illustrate the clinical attributes of such systems, we will describe their use in the rehabilitation of upper extremity function in patients with stroke. Further information is provided by the Brennan et al. chapter within this book.

Due to changes in the health care delivery system in recent years, many patients can suffer reduced access to care even though they are returning at home with disabling deficits. Considering that fact, several groups of researchers developed VR-based tele-rehabilitation systems, focused either on clinic to clinic connections [39] or on clinic to home connections [40, 41]. Holden et al. proposed a tele-rehabilitation system that was an enhancement and expansion of their VR-based motor training system for the upper extremity, originally developed as a “single user and locally used VE” [40, 42]. The system provides real-time interactive training sessions at the patient’s home with a therapist who is located remotely at a clinic. Each partner (patient and therapist) disposes of two computers, one for the display of the VR program (VE display) and one for communication via video-conferencing. Both patient computers and therapist computers are connected via a high-speed Internet connection. Motion-capture equipment transmits information about patients arm movements to both VE displays (patient and therapist), and video cameras allow video-conferencing. The movements are done within the context of a virtual situation which requires that the patient imitate a pre-recorded movement. The therapist can direct and control the activity in real time, from a remote place. This system can be used to train a wide variety of arm movements in any place at the UE workspace.

A study, carried out with 11 subjects with stroke, demonstrated the feasibility of the system deployment in a home-based environment and the efficacy of this kind of training in the context of stroke [42]. Results showed significant improvement in upper extremity function following 30 VE treatment sessions (one-hour each, delivered 5 times per week) as measured with standard clinical tests. The changes were maintained, for the most part, at a four-month follow-up test.

Future applications of tele-rehabilitation systems, designed to further improve care after disabling events, should consider providing smart and easy to use systems for secure training of patients.

5. Remote Location, Multiple Users Approaches Approach

The obvious next step in the evolution of VEs for clinical use is to expand jointly in both dimensions (numbers of users and location) in Figure 2, arrow 3. Indeed, researchers have recently begun to develop and evaluate the use of “multiple users and remote VE” for tele-learning and tele-therapy. This phenomenon is supported by the continuous development of robust technologies such as faster, more secure Internet connections and the growing popularity of the social networks [43]. In order to illustrate this trend, we next describe some medical and health applications based on Second Life.

Second Life is an Internet-based virtual world launched in 2003 by Linden’s Lab (<http://lindenlab.com>). Thanks to the downloadable Second Life viewer, users, called “residents”, are able to inhabit and interact via their own graphical self representations, known as avatars. Second Life provides an advanced level of social interaction while allowing users to participate in individual and group activities, and to create and trade items and services. Second Life provides its own virtual currency, called the Linden dollar, which is exchangeable for real world currencies in a resident to resident market place facilitated by Linden Lab. By the end of March 2008, 13 million accounts were registered, although some residents have multiple accounts. About 38,000 residents are logged on to Second Life at any particular moment.

Second Life currently features a number of medical and health educational projects including Nutrition Game, Heart Murmur Sim, Second Life Virtual Hallucination Lab, Gene Pool, Occupational Therapy at the Virtual Neurological Education Centre (see [44, 45] for a review of these applications). All these initiatives focus primarily on the dissemination of medical information and the education of therapists and patients.

However a few Second Life VEs, called private islands, have been created for therapeutic purposes. For example, Brigadoon [46] was specifically designed for patients with Asperger’s syndrome. Brigadoon is a controlled environment where users are encouraged to feel comfortable and learn socialization skills at their own pace. This simulation is less fearful for people because it does not involve local interactions, yet, due to the representation of actual users via avatars, it retains the flavour of real social situations. Its ability to teach social skills that are effective in real world situations still needs to be evaluated.

6. Issues For Future Consideration

There are several key issues that need to be addressed as more and more VEs expand from being primarily supportive of single user, local location applications towards accommodating multiple users in local and remote locations.

- **User perspective** – Further research is necessary to determine the effectiveness of providing patients with first, third or bird's eye perspectives.

In the past such decisions were based primarily on the technology selected to render the VE. In the future, such decisions should be also driven by the therapeutic needs of patients with varying neurological conditions and the optimal presentation of therapeutic goals as designed by therapists.

- **Role of virtual presence** – It has generally been assumed that increasing the level of virtual presence helps to facilitate the achievement of therapeutic goals due to its impact on motivation and performance. This assumption should be more directly tested in single user, local location VEs. It is particularly important to establish the role of virtual presence in multi-user, remote location VEs due to the added difficulty in achieving in such settings.
- **Technology considerations** – Access to remote locations, especially in real-time, adds additional cost and technical complexity to the design and implementation of VEs. Considerations of increased band width and the use of sensors capable of transmitting high fidelity data must be taken into account.
- **Compliance** – Therapists are well aware that a key issue in the rehabilitation process is the motivation of a patient to be a willing partner in the process. Indeed, one of VRs major assets has been the use of game-like environments to increase motivation, participation and performance [10]. Whether and how much compliance may be lost due to changes in locality and number of users remains to be determined.
- **Ethical considerations** – The use of VEs in the traditional single user, local setting retained all elements of privacy that were guarded during conventional rehabilitation. The addition of other users and the transmission of data, images, and communication over the Internet clearly introduce ethical issues not previously considered.
- **Availability of software supporting functional VEs** – To date, most functional VEs have been customized by specific research groups, and often unavailable to other clinical researchers. Or, when available, not readily customizable for other applications (e.g., use in other languages or for different clinical populations). The recently publicized NeuroVR initiative (www.neurovr.org, see chapter in this book) provides a cost-free VE editor, which allows non-expert users to easily setup and tune VEs including a supermarket, apartment, park, office, high school, university and restaurant [47]. These VEs can then be run on the NeuroVR Player. Both are downloadable at no cost.

7. Conclusion

The rapid development of VR-based technologies over the past decade has been both an asset and a challenge for neuro-rehabilitation. The availability of novel technologies that provide interactive, functional simulations with multimodal feedback enables clinicians to achieve traditional therapeutic goals that would be difficult, if not impossible, to attain via conventional therapy. They also lead to the creation of

completely new clinical paradigms which would have been hard to achieve in the past. In applications of rehabilitation for both motor and cognitive deficits, the main focus of much of the early exploratory research has been to investigate the use of VR as an assessment tool. To date such environments are primarily: (a) single user (i.e., designed for and used by one clinical client at a time) and (b) used locally within a clinical or educational setting. More recently, researchers have begun the development of new and more complex VR-based approaches according to two dimensions: the number of users and the distance between the users. Driven by a push-pull phenomenon, the original approach has now expanded to three additional avenues: multiple users in co-located settings; single users in remote locations; and multiple users in remote locations. It is clear that the VR rehabilitation research community needs to address the new concerns that are associated with such novel VEs.

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