Designing informed game-based rehabilitation tasks leveraging advances in virtual reality. Disability and Rehabilitation, 34(22), pp. 1863-1870, 2012.

Disability & Rehabilitation, 2012; 34(22): 1863–1870

ISSN 0963-8288 print/ISSN 1464-5165 online
DOI: 10.3109/09638288.2012.670029

informa
healthcare

Designing informed game-based rehabilitation tasks leveraging advances in virtual reality

Belinda Lange, Sebastian Koenig, Chien-Yen Chang, Eric McConnell, Evan Suma, Mark Bolas & Albert Rizzo

University of Southern California, Institute for Creative Technologies, Los Angeles, California, USA

Purpose: This paper details a brief history and rationale for the use of virtual reality (VR) technology for clinical research and intervention, and then focuses on game-based VR applications in the area of rehabilitation. An analysis of the match between rehabilitation task requirements and the assets available with VR technology is presented. _Key messages and implications:_ Low-cost camera-based systems capable of tracking user behavior at sufficient levels for game-based virtual rehabilitation activities are currently available for in-home use. Authoring software is now being developed that aims to provide clinicians with a usable toolkit for leveraging this technology. This will facilitate informed professional input on software design, development and application to ensure safe and effective use in the rehabilitation context. _Conclusion:_ The field of rehabilitation generally stands to benefit from the continual advances in VR technology, concomitant system cost reductions and an expanding clinical research literature and knowledge base. Home-based activity within VR systems that are low-cost, easy to deploy and maintain, and meet the requirements for "good" interactive rehabilitation tasks could radically improve users' access to care, adherence to prescribed training and subsequently enhance functional activity in everyday life in clinical populations.

Keywords: Virtual reality, game-based rehabilitation, technology, history

Implications for Rehabilitation

- Virtual reality (VR) technology has an established track record of success in addressing the therapeutic needs of persons across a range of clinical health conditions.
- In-home systems for VR rehabilitation are now technologically and pragmatically feasible, but it will require informed professional input on software design, development and application to ensure safe and effective use.
- New tools are being created that will allow clinicians without programming expertise to build game-based VR tasks and this will serve to drive advances in rehabilitation interventions.

Introduction

Recent advances in VR technology have supported the creation, application and evaluation of sophisticated computer-based interactive rehabilitation tasks that can be delivered at a low cost. As a basis for guiding future research and development, this paper discusses the past and current state of this field and builds on the insights gained during evaluations of off-the-shelf computer games and low-cost user interaction technologies. Based on these insights, a software architecture is described for authoring and delivering interactive game-based rehabilitation tasks that leverage the assets that VR technology provides. The software is currently being designed around the functionality of low-cost commodity depth-sensing camera systems to enable the creation of game-based rehabilitation tasks that can be effectively delivered in the home. A primary aim of this work is to support "nonprogrammer" clinicians in their ability to develop rehabilitation activities that meet our suggested characteristics for informed rehabilitation tasks while leveraging well-matched VR assets. The construction of customized VR rehabilitation tasks that meet user needs should be no more complicated than the steps required to produce a *PowerPoint* slide presentation. Implications for clinical use of this architecture are discussed in the light of emerging VR game-based and user-tracking technologies.

Correspondence: Albert Rizzo, University of Southern California, Institute for Creative Technologies, Los Angeles, California, USA.
Tel: 213-610-4737. Fax: 310-574-5725. E-mail: rizzo@ict.usc.edu

The history and concept of clinical VR

History and context

A virtual revolution is ongoing in the use of simulation technology for clinical purposes. When discussion of the potential use of VR applications for human research and clinical intervention first emerged in the early-1990s, the technology needed to deliver on this "vision" was not in place. Consequently, during these early years, VR suffered from a somewhat imbalanced "expectation-to-delivery" ratio, as most users trying systems during that time will attest. The "real" thing never quite measured up to expectations generated by some of the initial media hype, as delivered in such 1990s films, *The Lawnmower Man* and *Disclosure*. Yet, the idea of producing simulated virtual environments (VEs) that allowed for the systematic delivery of ecologically relevant stimulus events and challenges was compelling and made intuitive sense. From this perspective, the capacity of VR technology to create controllable, interactive, multisensory three-dimensional (3D) stimulus environments, within which human behavior can be motivated and measured, offers clinical assessment and intervention options that would be challenging (if not impossible) to deliver using traditional approaches. Moreover, a long and rich history of encouraging findings from the aviation simulation literature lent support to the concept that clinical testing, training and treatment within highly proceduralized VR simulation environments would be a useful direction for psychology and rehabilitation to explore.

Over the last decade, the technology for creating VR systems has now caught up with this vision. Revolutionary advances in the underlying VR-enabling technologies (i.e. computation speed and power, graphics and image rendering software, display systems, interface devices, immersive audio, haptics tools, wireless tracking, voice recognition, intelligent agents and authoring software) have supported the creation of low-cost, yet sophisticated, VR systems capable of running on a commodity level personal computer. Such advances in technological "prowess" and accessibility have provided the hardware platforms needed for the conduct of scientific research and clinical intervention within more usable and useful VR scenarios. At the same time, the unique match between VR technology assets and the requirements of a variety of clinical application areas was being recognized by a determined and expanding cadre of researchers and clinicians. This growing recognition of what VR technology has to offer fueled the emergence of a significant research literature that has documented the many clinical and research targets, where VR has been shown to add value for assessment and intervention purposes [1–13]. To do this, VR scientists have constructed virtual airplanes, skyscrapers, spiders, battlefields, social settings, beaches, fantasy worlds and the mundane (but highly relevant) functional environments of the schoolroom, office, home, street and supermarket. Emerging R&D is also producing artificially intelligent virtual humans that both serve the role of standardized patients for training clinical skills to health professionals and as online health support agents [14]. As well, game-based elements can be integrated into such systems to promote user motivation and enhance subsequent adherence to intervention recommendations. This convergence of the exponential advances in underlying VR-enabling technologies with a growing body of clinical research and experience has served to drive the evolution of the discipline of *clinical VR*.

VR definitions

The concept and definition of VR has been subject to debate by scientists and clinicians over the years. VR has been very generally defined as "... a way for humans to visualize, manipulate, and interact with computers and extremely complex data [15]". From this baseline perspective, VR can be seen as an advanced form of human-computer interface [16] that allows the user to "interact" with computers and digital content in a more natural or sophisticated fashion relative to what is afforded by standard mouse and keyboard input devices. In some cases, with the aid of specialized VR display devices, users can become "immersed" *within* a computer-generated simulated environment that changes in a natural/intuitive way with user interaction.

VR sensory stimuli can be delivered by using various forms of visual display technology that can present real-time computer graphics and/or photographic images/video along with a variety of other sensory display devices that can present audio, "force-feedback" haptic/touch sensations and even olfactory content to the user. However, VR is not defined or limited by any one technological approach or hardware set up. The creation of an engaged VR *user experience* can be accomplished using combinations of a wide variety of interaction devices, sensory display systems and in the design of content presented in the VE.

For example, *immersive VR* can be produced by combining computers, head-mounted displays (HMDs), body tracking sensors, specialized interface devices and real-time graphics to immerse a participant in a computer-generated simulated world that changes in a natural way with head and body motion. Thus, an engaged immersive virtual experience can be supported by employing specialized tracking technology that senses the user's position and movement and uses that information to update the sensory stimuli presented to the user to create the illusion of being immersed "in" a virtual space within which they can interact. One common configuration employs a combination of a HMD and head tracking system that allows delivery of real-time computer-generated images and sounds of a simulated virtual scene rendered in relation to user movements that corresponds to what the individual would see and hear if the scene were real. Another method uses stereoscopic projection screens arrayed in various configurations, including six-walled rooms known as CAVES that allow users to interact in a less encumbered, wide field of view simulation environment. However, such CAVE systems are more costly and complex and are typically beyond the practical resources of a clinical service provider or basic researcher. In these immersive systems, one of the key aims is to perceptually replace the outside world with that of the simulated environment to create a specific user experience. Immersive HMD VR has been most commonly used in applications where a controlled stimulus environment is desirable for constraining a user's perceptual experience within a specific synthetic world. This format has been often used in clinical VR applications for anxiety disorder exposure therapy, analgesic distraction for patients undergoing acutely painful medical procedures and in the cognitive assessment of users with central nervous function dysfunction to measure performance under a range of systematically delivered task challenges and distractions.

By contrast, *nonimmersive VR* is commonly experienced using modern computer and console games systems (as well as in nongame research lab-generated systems). This format presents a 3D graphic environment on a flatscreen monitor, projection system or television (no real-world occlusion) within which the user can navigate and interact. Albeit delivered on a less immersive display, such graphic worlds are still essentially a VR *environment*. VEs presented on these widely available commodity display systems have the capacity to provide the user with significant options for interaction with dynamic digital content using traditional computer and game interface devices (e.g. keyboard, mouse, game pads, joysticks) in addition to more complex interaction devices that can track more natural user activity (e.g. data gloves, 3D mice, treadmills and some high-end "force feedback" exoskeleton devices). The use of such ubiquitous display and interface devices has promoted widespread access to this form of nonimmersive interactive media, primarily in the domain of entertainment. Moreover, researchers have investigated the value and usability of commercially available interaction devices and methods that can be used with flatscreen-delivered VEs that can allow users to interact with digital content using more naturalistic body actions beyond what is possible with traditional game interfaces (e.g. *Konami Dance Revolution, Sony Eyetoy, Nintendo Wii, Novint Falcon, Microsoft Kinect* [17–19]). Regardless of the hardware and display format, the capacity of VR technology to create controllable, multisensory, interactive 3D stimulus environments, within which human performance can be motivated, captured and measured, offers clinical and research options that are not possible using traditional methods.

The virtual rehabilitation connection

VR provides numerous assets that are well matched to the various requirements and standards for creating effective rehabilitation tasks [9,10]. One can appreciate this connection between VR assets and rehabilitation task requirements by first examining the general core characteristics for good rehabilitation tasks. These can be distilled into seven core elements.

The task must be

1. grounded in data-based assessment to specify the target activity to be precisely rehabilitated.
2. adjustable in terms of difficulty level from something that is possible for the user to perform, to a level representing the desired end-goal performance.
3. capable of repetitive and hierarchical administration to the user.
4. capable of providing the user with strategic feedback as to the outcome of performance.
5. quantifiable in order to measure performance and progress.
6. relevant to real world ecologically relevant functional activity.
7. capable of motivating user engagement and interaction with the task.

One of the cardinal assets provided by game-based VR simulation technology involves the capacity for systematic delivery and control of digital stimuli that can be interacted with by users. In this regard, an ideal match exists between the stimulus delivery assets of VR simulation approaches and the above-listed rehabilitation requirements. This "ultimate skinner box" asset can be seen to provide value across the spectrum of rehabilitation approaches, ranging from analysis and training at an analog level targeting component cognitive and physical processes (e.g. selective attention, grip strength), to the complex orchestration of more integrated functional behaviors (e.g. planning, initiating and physically performing the steps required to prepare a meal in a distracting setting). This stimulus control asset can also be seen to allow for the *repetitive* and *hierarchical* delivery of stimulus challenges across a range of difficulty levels. In this way, an individual's rehabilitation activity can be customized to begin at a stimulus challenge level attainable and comfortable for them, with gradual progression to higher difficulty levels based on their performance. VR also provides the capacity for the user to be given *strategic feedback* needed to shape and modulate performance toward a successful goal. Within such VEs, 3D user tracking technology required to link the interaction between user behavior and the target stimuli within the simulated activity can also be marshaled to *measure performance*. Thus, the experimental control required for rigorous scientific measurement, analysis and replication can still be maintained within simulated contexts that embody the *complex functional challenges* that exist in naturalistic settings. In this regard, VR offers rehabilitation, the ability to create simulated realistic environments in which repetitive and hierarchical performance can be tested and trained in a systematic fashion. By designing VEs that not only "look like" the real world but also actually incorporate challenges that require *real-world functional behaviors*, the ecological validity of rehabilitation methods could be enhanced. As a result, VR-derived behavioral data could have greater clinical relevance for enhancing prediction of user performance when facing the challenges in everyday life. Finally, by applying computer game development principles to the rehabilitation task development process [17,18], it is believed that user *motivation and engagement* will be enhanced. This could serve to promote better user adherence to rehabilitative activities and thereby increase the probability of achieving a successful outcome. The capacity to leverage these VR assets for the creation of innovative rehabilitation tasks provides the opportunity to create tools for a field that has long been mired in the methods of the past. When combining these assets within the context of functionally relevant, ecologically enhanced game-based VEs, a fundamental advancement could emerge in how human assessment and intervention can be addressed in rehabilitation.

Tracking the user: the primary challenge for virtual rehabilitation

For virtual rehabilitation to deliver on its potential, low-cost methods for tracking user movement and general activity are needed. Until recently, VR and computer game-based rehabilitation applications were hamstrung by the cost of equipment and the technological complexity involved in tracking the movement activity of users. Such applications required 3D user interface devices [20] that sensed and captured vigorous body activity as a usable input signal for meaningful interaction with virtual rehabilitation task content. Thus, complex and costly sensing systems capable of high sampling rates and with full six degree of freedom motion capture, such as magnetic or high-end optical tracking systems or mechanical robotic systems, were often used to capture the movement data needed to support rehabilitative interaction in VEs. To address this challenge, some researchers have created low-cost optical motion tracking systems that employ off-the-shelf cameras (e.g. *Logitech* webcams [21,22]). These types of cameras can track activity from the movement of light-emitting diodes or retroreflective markers (using infrared cameras) attached to strategic points of interest on the body or to relevant objects (e.g. hand-held jogging weights, plastic swords [23]). These systems have been found to be useful for rehabilitation purposes where the capture of a small number of constrained movement points is sufficient for the needs of upper/lower extremity and general balance focused applications. However, a low-cost system for capturing vigorous *full-body* activity for VE game-based interaction has always been the "bottleneck" in implementing virtual rehabilitation tasks in a widely accessible fashion. Thus, to promote better accessibility and widespread use by clinical users, *home-based* systems are needed that are *affordable* and *easy to deploy and maintain*, while still providing the movement-sensing fidelity required to drive engaging interaction within virtual rehabilitation game-based VEs.

Tracking the user with accessible off-the-shelf technology for virtual rehabilitation

Some researchers have tackled the "tracking challenge" by implementing an emerging class of off-the-shelf game console systems/interface devices to support more natural interaction with digital game content for rehabilitation. Early efforts have used the *Sony Eyetoy, Konami Dance Dance Revolution (DDR)* and the *Nintendo Wii* games [18,24] for this purpose. However, while low-cost and accessible, these early console game systems have significant limits regarding the type of movement activity that is possible to capture in support of the rehabilitation process. For example, the *Sony Eyetoy* is restricted to the capture of unnatural single-plane 2D activity. And while the *DDR* can certainly provide a fairly engaging activity interface, the existing game content is relatively fixed and not designed in a way that meets the requirements of a good rehabilitation task. On the surface, the functionality of the *Nintendo Wii* gaming console and the variety of sport and fitness game offerings seem to be closely aligned with rehabilitation needs. The interface for the *Wii* employs a camera-based and inertial tracking hybrid system that is inexpensive and can be used to interact with compelling and engaging game content. Unlike the *Sony Eyetoy*, user groups have now been able to adapt the *Wiimote* controller to interact with novel applications that can be created on a basic PC. This supports the potential for flexible development of activity-specific game content that may appeal to a variety of user interests for engaging participation beyond the standard *Nintendo* offerings. However, this system requires the user to hold onto a device and provides only single-point tracking. Thus, a full characterization of optimal full-body movement is impossible with the Wii. As well, "bad" movement can be encouraged using the Wii. Frequent users of some of the *Wii* games have learned various "cheats" for using the hand-held *Wiimote* controller, that while producing the desired game result, do so with much less actual naturalistic or rehabilitative movement. This issue, in addition to anecdotal reports of users being discouraged by comments of the avatar "coach" available on the *Wii Fit Sport* system, may make this system less regarded in the future for inspiring correct rehabilitation activity. This situation is in contrast to the *Nintendo Wii's* place in history as an innovative product that moved the epicenter of game interaction from the thumbs to the larger body as a whole.

Emerging off-the-shelf camera tracking and an architecture for rehabilitation task creation

One of the more exciting new developments in this area involves the *Xbox Kinect* system by *Microsoft,* which by its design could serve as a low-cost ($150) and accessible full-body tracking tool for virtual rehabilitation. This revolutionary game platform uses an infrared "depth-sensing" camera (developed by an Israeli company, *Primesense*) to capture users' full-body movement in 3D space for interaction within VEs and game content. The system does not require the user to hold an interface device or move on a pad as the source of interaction with digital content. Instead, the user's body is the game controller operating in 3D space and multiple users can be tracked in this fashion for both cooperative and competitive rehabilitation-focused activities. Another attractive feature is that the *Kinect* depth-sensing camera is USB compatible with a standard PC. This opens the door for developers to create specific rehabilitation tasks or adapt existing computer game content that can be interacted with using specified body action. Links to videos of users interacting with this technology are listed in Appendix A.

The Game-Based Rehabilitation Lab at the University of Southern California Institute for Creative Technologies has been testing this camera system and building software around its functionality to promote the creation of clinic- and home-based rehabilitation applications. The primary aim of this work is to create a software architecture that allows for the easy creation of informed rehabilitation game-based tasks that leverage the well-matched assets of VR technology by using the *Kinect* and similar camera-based tracking devices. An important piece of this software architecture is the flexible action and articlulated skeleton toolkit (FAAST). FAAST is designed as middleware to facilitate integration of full-body control with games and VR applications [25]. The FAAST toolkit is freely available online at: http://projects.ict.usc.edu/mxr/faast/. The toolkit relies upon software from OpenNI and PrimeSense to track the user's motion using the *PrimeSensor* or the *Microsoft Kinect* sensors. FAAST includes a custom VRPN server to stream the user's skeleton over a network, providing a user interface for VR applications based on markerless skeletal tracking through any VRPN client. Additionally, the toolkit can also emulate keyboard input triggered by body posture and specifically assigned gestures. This also allows the user to add custom body-based control to existing off-the-shelf computer games that do not provide official support for depth sensors.

The intent of the development of this flexible virtual rehabilitation software architecture is to motivate and support the creation of new rehabilitation content and strategies that can be widely disseminated at a low cost. The next aim in this development process is to expand the software into a valuable rehabilitation application that can be used by clinicians who have no programming experience. The intent is to provide built-in features/options with a user interface for creating game-based rehabilitation tasks that is as intuitively learnable/usable as the *PowerPoint* interface is for creating a slideshow! These features are currently under development and are guided by the core characteristics for rehabilitation tasks outlined earlier in this article while leveraging the VR assets that are well-matched to this process. This essentially produces the core elements of a toolkit consisting of modular content and design elements for developing game-based rehabilitation tasks that can be tailored to the needs of the individual user.

The feature sets currently being developed for this software includes:

Calibration to user baseline function

Users who have limited range of motion or who use wheelchairs might not be able to perform game tasks designed for users with full range of motion in the standing position. Our initial user testing of off-the-shelf video games in the clinic suggests that these games, while encouraging users to move, can be too complicated or difficult to play for people with limited range of motion or from the sitting position in a wheelchair. Calibration of the game tasks and stimuli to users' baseline function provides a tailored experience for the user that supports initial interaction appropriate to their entry-level of ability.

Library of game interaction templates

Features of existing off-the-shelf video games cannot be changed. Providing the clinician with options for different ways of interacting with game objects within a template format will allow a versatile, easy to use system that can be tailored to individual user needs and interests. Such templates include both static and dynamically moving stimuli that can be selected to foster appropriate game interaction.

A library of objects to "populate" templates

Within the clinical setting, tasks can be altered to encourage the same basic interaction while using different objects or user goals. Providing the clinician or user with options to populate the game interaction templates from a library of existing objects (or user-generated content) aims to provide individualized, engaging experiences for different users.

Stimulus delivery control (speed, size, quantity, rate, trajectory, etc.)

Our initial user testing of off-the-shelf video games in the clinic suggests that clinicians want control over the stimulus delivery properties within the game. The option to alter the speed of stimulus presentation and the quantity, placement and trajectory of stimuli within game-based rehabilitation tasks will allow clinicians to tailor tasks and stimuli to the user's level of ability and support the hierarchical delivery of challenge levels.

User representation options (1st vs. 3rd person, avatar visualization)

Our initial user testing of off-the-shelf games has indicated that some players preferred to interact within game-based environments using the 1st person view, whereas others preferred 3rd person [17]. Players also want the choice of having a basic avatar representation, tailoring an avatar to look like them or an abstract representation on the screen. Providing options to suit individual player preference has the potential to increase user motivation and engagement. Changing the visual representation of the avatar alters the way the user views, perceives and interacts with the environment, therefore, changing the level of task difficulty. For example, some users might have difficulty interacting with the VE if they cannot see an avatar represented on the screen. This visual feedback of what the body is doing in space provides the user with more information about their movement.

Display options (stereo TV, computer monitor, HMD)

Providing a choice of different displays, such as stereoscopic television, computer monitor or HMD, will provide users with options for delivery of the virtual rehabilitation tasks. Different delivery methods might be more appropriate for certain individuals and/or rehabilitation needs. A library of specific software drivers for these displays is included in the software.

Feedback options (stimulus physics & audio/haptics)

The integration of multisensory visual, auditory and haptic feedback will provide the user with both realistic and relevant feedback to support modulation of performance. Strategic feedback schedules can also be selected that illustrate performance to the user that will provide more than is possible with the final score in a purely game-based activity.

Quantification of performance

The use of low-cost tracking technologies, such as the *Microsoft Kinect*, allows the user's 3D movement to be quantified and saved for analysis and tracking of performance. Clinicians could benefit from the recording of performance data to analyze quality of movement and track patient progress within and across sessions. Users may benefit from being able to view visualizations of their activity from different spatial perspectives derived from this capture and quantification of movement.

Multiple users

The option to have multiple players interacting together within a game-based task offers the potential to enhance the rehabilitation process and motivate adherence to exercise protocols. Multiplayer games can provide social support for people who are isolated and improve in-game performance through collaboration and/or competition.

Artificial intelligence for support and challenge control

Once performance data is analyzed, the information will be integrated into the interaction to provide feedback and make adjustments to the level of challenge of the task. Automatic adjustment of challenge levels based on user performance could reduce the amount of clinician time required to make changes to the system. Artificial intelligence (AI)-driven feedback can also be provided in a number of different ways. For example, the use of an AI virtual human "coach-like" character, embedded in the software, to provide feedback and verbal support (based on real-time tracking and computational analysis of user interaction) could improve user engagement, guidance and adherence by presenting "distilled" feedback that is intuitively understandable by users beyond what is possible with the simple presentation of numeric performance results at the end of a session.

Network connection (synchronous and asynchronous)

For home-based use of these low-cost technologies, clinicians should have the option to work with patients online simultaneously or track patient progress on their own schedule. Working with one or multiple users online in real-time would allow clinicians to work and monitor patients in remote locations or save travel time and cost for patients that must use public transport or private taxi services to visit clinics. Asynchronous tracking of patient progress could allow clinicians the capability of monitoring patients following discharge or when time is available for providing updated changes to the system based on user performance.

Conclusions

This paper details work that aims to create a rehabilitation software toolkit designed to support and extends the skills of a well-trained clinician in the creation of informed VR rehabilitation tasks. The integration of this software architecture with low-cost game-based VR technologies will allow health care professionals to precisely create, deliver and control complex, dynamic, 3D stimulus environments for user interaction. For rehabilitation, such VR activities may be designed to more specifically target the sensorimotor impairments experienced by individual users with disabilities. As such, game-based VR rehabilitation tasks that are easily adapted to individual user needs will become a valuable adjunct to conventional therapy in inpatient, outpatient and home-based care settings.

While the vision for home-based rehabilitation is compelling for economic and accessibility reasons, professional and ethical issues will also need to be considered concomitantly as the technology to accomplish this evolves [26]. Thus, the appropriate development and use of the tasks created with this software must always be governed by evidenced-based practice guidelines. Indeed, Lewis and Rosie highlight this to also be important from user perspectives [27]. Although we are not at the point where software can replace the professional input and supervision that a clinician provides in the direct delivery of the rehabilitation process, automated AI systems are advancing at a rapid pace in other VR simulation domains (e.g. military training, industrial and manufacturing processes). A time will come in the future when advanced automation of the rehabilitation delivery process will be an available option. For example, it will soon be possible to create AI rehabilitation systems that will track user movement with *Kinect*-like sensors (and/or other equipment), while they interact with game-based tasks delivered on their internet-connected TV at home. User movement will then be analyzed in real time to automatically update rehab-game challenges that encourage optimal rehabilitative movement activity tailored to the users' needs while applying algorithms already in use by the game industry to maintain user engagement/flow [28]. As well, AI virtual human "therapists" will also be able to tap into this same computationally analyzed movement datastream and use it to initially characterize the user by instructing and guiding them through a set of baseline movement assessment activities. From that initial assessment, rehab task challenge levels will be automatically adjusted over time as the user interacts, progresses or fatigues, all while the virtual therapist is available to provide support and advice along the way. "Live" clinicians would still be able to check-in with users online and review numerically rendered performance data (or view intuitive visualizations of user movement in real time or offline) to monitor progress and perhaps "tweak" the automation parameters if needed. But regardless, the role of the live provider in this not-too-distant future scenario will either be transformed or vastly diminished.

These technological advances are not going to simply go away and will necessarily drive the evolution of new clinical models, which ensure that evidence-based practice standards are followed in the design and safe use of such automated interactive rehabilitation systems. Moreover, the role of a "human-in-the-loop" clinician will need to be reconceptualized and justified. Perhaps the clinician's role will morph into that of an ethical firewall to "supervise" a digital system to ensure that user outcomes are properly achieved and/or as a safety net for user protection. As well, a more predominant focus of live clinical attention may come in the form of promoting the smooth translation/transfer of a user's in-home rehabilitation gains to everyday functional and psychosocial life challenges where an automated system might have a more limited capacity. This will present significant challenges for a profession that currently places a high value on the human "touch" in the rehabilitation process and it is none too early to begin considering this possibility for a quantum shift in both professional roles and clinical care. This technology will continue to advance and the key challenge facing rehabilitation professionals will come in knowing where these tools can provide the most benefit to users, while also considering what role will best leverage the skills of a live clinician.

***Declaration of Interest*:** The authors report no declarations of interest.

References

1. Bohil CJ, Alicea B, and Biocca FA. Virtual reality in neuroscience research and therapy. Nature Rev Neurosci, 2011;12:752–762.
2. Glantz K, Rizzo AA, and Graap K. Virtual reality for psychotherapy: Current reality and future possibilities. Psychotherapy, 2003; 40: 55–67.
3. Holden MK. Virtual environments for motor rehabilitation: review. Cyberpsychol Behav 2005;8:187–211; discussion 212.
4. Merians AS, Fluet GG, Qiu Q, Saleh S, Lafond I, Adamovich SV. Integrated arm and hand training using adaptive robotics and virtual reality simulations. In: Sharkey PM, Sánchez J, editors. Proc. 8th Intl. Conf. on Disability, Virtual Reality and Assoc. Technologies. pp 131–138, Viña del Mar/Valparaíso, Chile, 31 August–2 September 2010.
5. Parsons TD, Rizzo AA. Affective outcomes of virtual reality exposure therapy for anxiety and specific phobias: a meta-analysis. J Behav Ther Exp Psychiatry 2008;39:250–261.
6. Parsons TD, Rizzo AA, Rogers S, and York P. Virtual reality in paediatric rehabilitation: A review. Developmental Neurorehabilitation, 2009. 12: 224–238.
7. Powers MB, Emmelkamp PM. Virtual reality exposure therapy for anxiety disorders: A meta-analysis. J Anxiety Disord 2008;22:561–569.
8. Riva G. The key to unlocking the virtual body: virtual reality in the treatment of obesity and eating disorders. J Diabetes Sci Technol 2011;5:283–292.
9. Rizzo AA. Virtual Reality applications for the cognitive rehabilitation of persons with traumatic head injuries. In Murphy, HJ (ed.), Proceedings of the 2nd International Conference on Virtual Reality and Persons With Disabilities, 1994. CSUN: Northridge.
10. Rizzo AA, Schultheis MT, Kerns K and Mateer C. Analysis of Assets for Virtual Reality Applications in Neuropsychology. Neuropsychol Rehabil, 2004;14: p. 207–239.
11. Rizzo AA and Kim G. A SWOT analysis of the field of Virtual Rehabilitation and Therapy. Presence: Teleoperators and Virtual Environments, 2005;14, 1–28.
12. Rizzo A, Parsons TD, Lange B, Kenny P, Buckwalter JG, Rothbaum B, Difede J, et al. Virtual reality goes to war: a brief review of the future of military behavioral healthcare. J Clin Psychol Med Settings 2011;18:176–187.
13. Rose FD, Brooks BM, Rizzo AA. Virtual reality in brain damage rehabilitation: review. Cyberpsychol Behav 2005;8:241–62; discussion 263.
14. Rizzo AA, Kenny P, Parsons T. Intelligent Virtual Humans for Clinical Training. Int J Virt Reality & Broadcast, 2011. 8: Available at: http://www.jvrb.org/8.2011/
15. Aukstakalnis S. and Blatner D. Silicon mirage: The art and science of virtual reality, 1992. Berkeley, CA: Peachpit Press.
16. Rizzo AA, Buckwalter JG, and Neumann U. Virtual reality and cognitive rehabilitation: A brief review of the future. The J Head Trauma Rehabil, 1997. 12: p. 1–15.
17. Lange B, Flynn B, Rizzo AA. Initial usability assessment of off-the-shelf video game consoles for clinical game-based motor rehabilitation. Phys Ther Rev, 2009. 14: p. 355–363.
18. Lange B, Flynn S, Proffitt R, Chang CY, Rizzo AS. Development of an interactive game-based rehabilitation tool for dynamic balance training. Top Stroke Rehabil 2010;17:345–352.
19. Lange B, Suma EA, Newman B, Phan T, Chang C, Rizzo A, Bolas MT. Leveraging Unencumbered Full Body Control of Animated Virtual Characters for Game-Based Rehabilitation. Proceedings of the 2011 International HCI Convention, 2011. 14: p. 243–252.
20. Bowman DA, Kruijff E, LaViola JJ, Poupyrev I. 3D User Interfaces: Theory and Practice, 2005. Boston: Pearson Education.
21. Yeh SC, Wang C, Sawchuk A, Rizzo AA. An interactive 3D user interface for home-based tele-rehabilitation: autostereo display, LED tracking system and wireless passive haptics device. The Proc. IEEE Interfaces Mixed Reality Workshop, 2007.
22. Shefer-Eini D, Ratzon N, Rizzo AA, Yeh S, Lange BS, Yafa B, Dietz A. et al. Simple camera tracking virtual reality system for evaluation of wrist range of motion. Proceedings of the 2010 International Conference on Disability, Virtual Reality and Associated Technology, 2010. p. 123–130.
23. Yeh SC, Lange B, Chang CY, Wang C, Sawchuck AA, Rizzo AA. Effects of stereoscopic displays and interaction devices on human motor behavior. The Engineering Reality of Virtual Reality. Edited by McDowall, Ian E.; Dolinsky, Margaret. Proceedings of the SPIE, 2008. 6804: p. 5–10.
24. Deutsch JE, Borbely M, Filler J, Huhn K, Guarrera-Bowlby P. Use of a low-cost, commercially available gaming console (Wii) for rehabilitation of an adolescent with cerebral palsy. Phys Ther 2008;88: 1196–1207.
25. Suma EA, Lange B, Rizzo A, Krum DM, Bolas MT. FAAST: The Flexible Action and Articulated Skeleton Toolkit. The Proceedings of the 2011 IEEE Virtual Reality Conference, 2011. 247–248.
26. Rizzo AA, Schultheis MT, Rothbaum BO. Ethical issues for the use of virtual reality in the psychological sciences. In Bush S. and Drexler M. (Eds.), Ethical issues in clinical neuropsychology, 2002. Lisse, NL: Swets and Zeitlinger Publishers. p. 243–280.
27. Lewis GN, Rosie JA. Virtual reality games for movement rehabilitation in neurological conditions: How do we meet the needs and expectations of the users?
28. Cowley, B, Charles D, Black M, Hickey R. Toward an understanding of flow in video games. ACM Computers in Entertainment, 2008. 6: Article 20 p. 1–27.

Appendix A – Links to videos of users interacting with camera-base tracking technology

A brief introduction to how the Primesense/Kinect cameras will revolutionize virtual rehabilitation

http://www.youtube.com/watch?v=geyIvG4uKxY

Primesense Kinect camera application for upper extremity virtual rehabilitation

http://www.youtube.com/watch?v=9bv1TDanH4E&feature=related

Wheelchair user comments on Primesense camera and motor rehab

http://www.youtube.com/watch?v=CtJijspdQuc

Primesense Kinect space invaders body/arm interaction

http://www.youtube.com/user/AlbertSkipRizzo#p/u/7/xjFUI7xtr2Q

Primesense Kinect space invaders arm only interaction http://www.youtube.com/watch?v=tYZvC0Ka5CI

Balance rehabilitation game using Primesense Kinect camera

http://www.youtube.com/watch?v=2AMRnAWEzzI

Kinect used to play world of warcraft

http://www.youtube.com/watch?v=WeVb6cSXGpU

Dr. Carolee Winstein (OPTT RERC Co-Director) discusses the Primesense camera for rehabilitation

http://www.youtube.com/watch?v=lnFt3KSlInc