NIDRR Perspectives on VR Applications for Addressing the Needs of those Aging with and into Disability

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Abstract. As persons with disabilities age, progressive declines in health and medical status can challenge the adaptive resources required to maintain functional independence and quality of life [1]. These challenges are further compounded by economic factors, medication side effects, loss of a spouse or caregiver, and psychosocial disorders [1-2]. The gradual loss of functional independence and increased reliance on others for transportation, access to general medical and rehabilitation care can be jeopardized [2]. The combination of these factors when seen in the context of the average increase in lifespan in industrialized societies has lead to a growing crisis that is truly global in proportion. While research indicates that functional motor capacity can be improved, maintained, or recovered via consistent participation in a motor exercise and rehabilitation regimen [3], independent adherence to such preventative and/or rehabilitative programming outside the clinic setting is notoriously low [1]. This state of affairs has produced a compelling and ethical motivation to address the needs of individuals who are aging with disabilities by promoting home-based access to low-cost, interactive virtual reality (VR) systems designed to engage and motivate individuals to participate with “game”-driven physical activities and rehabilitation programming. The creation of such systems could serve to enhance, maintain and rehabilitate the sensorimotor processes that are needed to maximize independence and quality of life. This is the theme of the workshop to be presented at the MMVR conference.

Keywords. Virtual Reality, Aging, Disability, Technology

Introduction

This MMVR workshop will bring together NIDRR supported researchers, users and industry partners to present and discuss the issues relevant to advancing the science and practice for using VR applications with those aging with and into disability. The session will commence with a user panel that will discuss the challenges that are experienced by aging adults with disabilities, followed by NIDRR Researchers presenting state of the art work using VR and associated technologies to address these challenges. Access to such systems by users will be the theme of the closing panel that will be made up of industry leaders, users and researchers. The objectives of this session include: 1. Promote awareness of the unique challenges and needs of adults

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with disability for maintaining and enhancing functional independence at this point in the lifespan; 2. Educate the public and professionals about the current NIDRR-supported efforts to address these challenges using VR and associated technologies; 3. Clarify the issues involved in promoting equal access to VR and game-based applications for older adults with disability.

1. Virtual Reality Rehabilitation

Over the last 15 years, a virtual revolution has taken place in the use of Virtual Reality (VR) simulation technology for clinical purposes. Technological advances in the areas of computation speed and power, graphics and image rendering, display systems, body tracking, interface technology, haptic devices, authoring software and artificial intelligence have supported the creation of low-cost and usable VR systems capable of running on a commodity level personal computer. At the same time, a determined and expanding cadre of researchers and clinicians have not only recognized the potential impact of VR technology, but have now generated a significant research literature that documents the many clinical targets where VR can add value over traditional assessment and intervention approaches [4-8]. To do this, scientists have constructed virtual airplanes, skyscrapers, spiders, battlefields, social events populated with virtual humans, fantasy worlds and the mundane (but highly relevant) functional environments of the schoolroom, office, home, street and supermarket. This state of affairs now stands to transform the vision of future clinical practice and research in the disciplines of psychology, medicine, neuroscience, physical and occupational therapy, and in the many allied health fields that address the therapeutic needs of children and adults with disabilities. This convergence of the exponential advances in underlying VR enabling technologies with a growing body of clinical research and experience has fueled the evolution of the discipline of Clinical Virtual Reality. This is expected to have significant impact on promoting access to VR technology for addressing the needs of persons aging with disabilities.

2. VR Applications for Successful Aging with Disabilities

In 2008, the National Institute on Disability and Rehabilitation Research (NIDRR) made a 5-year award to the University of Southern California (USC) and Rancho Los Amigos National Rehabilitation Center (RLANRC) to establish a unique Rehabilitation Engineering Research Center (RERC)—"Optimizing Participation through Technology" (OPTT). The overall purpose of OPTT RERC is focused on those aging with and into disability. Over the first two years, we built a strong interdisciplinary infrastructure engaged in a set of research and development activities at the nexus of biomedical engineering and technology, sensorimotor systems rehabilitation, and gerontology and aging (see http://www.isi.edu/research/rerc/). Central to our research and development activities is the creation and delivery of VR simulation technologies for enhancing targeted skills (e.g., dexterity, balance) and exercise in those who are aging into and with disability.

One of the biggest challenges we face with the research and development of VR applications is in maintaining a proper balance between usability, inherent flexibility to allow adaptation to the user's needs, and cost, all while assuring the most efficient and

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appropriate means toward important rehabilitation goals and one that is compatible with an ever-changing technology. There is no doubt that many of the so called off the shelf 'rehab' games are enjoyable, engaging and can even foster social interaction among family and friends—all important for supporting healthy minds and bodies, but it is less clear (and one of our major concerns) if important rehabilitation goals that are tailored to the special needs of those aging with a disability are being achieved. To this end, we have attempted to create a theoretically defensible, evidence-based, conceptual model as a means to guide the development of VR simulation technologies for rehabilitation in the context of OPTT-RERC. Our model contains three overlapping elements: Skill Acquisition, Capacity Building, and Motivational Enhancements. VR game-based rehabilitation provides the glue for achieving the aims of the model.

A pathway from impairment reduction (i.e. physiological loss) to functional capability (e.g., instrumental activities of daily living, self-care, mobility) to more general function in real-world contexts (e.g., independent living, social participation) is more often implicit but less frequently operationalized in VR games-based therapeutic intervention protocols. Task-specific practice is considered to be the most important element of any behavioral training program, particularly when improved functional skills are sought (e.g., cognitive and physical). In fact, the effects of practice are often underestimated and all too often, programs fail to be effective because either ample practice time was not prescribed or compliance was poor. Recently, our work has shown that in addition to time-on-task practice, the practice structure (e.g., variable or constant) is important for optimizing consolidation and motor learning [9]. The scientific rationale and evidence for impairment mitigation (capacity) comes from a growing body of work showing the importance of fundamental impairments including strength and control for restoration of function (e.g., individuals post-stroke, elderly at-risk for falls) [10]. Similarly, the scientific rationale and evidence for motivational enhancements (intrinsic drive) as well as the pursuit of meaningful goals for sustainable behavioral change (e.g., cognitive behavioral intervention such as 'Matter of Balance', comes from a growing body of work showing the importance of self-regulation, self-management, and self-efficacy for behavioral change that supports beneficial outcomes [11-14]. In most cases, the motivational enhancements strengthen self-confidence and support participant control or autonomy (intrinsic motivation). Providing choice in the context of effective intervention programs engages the learner and supports adherence.

The active ingredients of an effective task-oriented VR game likely consists of interactions that are: 1) Challenging enough to require new learning and active attentional engagement to solve a motor problem; 2) Progressive and optimally adjustable, such that over practice, the task demand is optimally adapted to the user's capability and the environmental context. Extending the environment outside the laboratory or clinic is an important aspect of an optimally adapted, consumer-centered program. 3) Interesting enough to promote active participation to engage a 'particular type of repetition' that Bernstein referred to as 'problem-solving'. For more details, we elaborate and provide examples of intervention programs based on this conceptual model in the context of stroke rehabilitation in two recent publications [15-16].

Once the particular task or set of tasks to-be-trained has been chosen, the VR simulation game can be embedded into the fully-defined, task-oriented training program. VR simulation technology affords certain key design features that map nicely onto the active ingredients for an effective program. These include: 1) Focus on a specific skill and involve data-based and task-specific training (skill/practice); 2) Have

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adjustable difficulty levels from something simple for the user to accomplish, to a level representing normal or skilled performance (capacity building); 3) Be quantifiable in order to assess progress (assessment, motivation); 4) Be administered repetitively and hierarchically to allow enough practice with the right amount of challenge (motivation, skill acquisition/practice); 5) Provide the user with feedback as to the outcome of performance (builds confidence); 6) Have some relevance to real world function (meaningful, skill/task-based, motivating); 7) Motivate and engage the user (enhances compliance). With this brief overview of our theoretical and practical model, the following sections will describe some of the VR research and development from the MMVR workshop presenters that is relevant to aging with a disability.

3. VR Simulations for Recovery of Upper Extremity Function (Merians et al.)

Sensorimotor impairments and participation restrictions remain a pervasive problem for patients post stroke, with recovery of upper extremity function particularly recalcitrant to intervention. 80% to 95% of persons demonstrate residual upper extremity impairments lasting beyond six months after their strokes (17). One of the issues that may contribute to less than satisfactory outcomes for the upper extremity is the complexity of sensory processing and motor output involved in normal hand function. There is a vital need to develop rehabilitative training strategies that will improve functional abilities and real-world use of the arm and hand in order to increase independence [18-19]. To address this need, we have developed an exercise system that integrates robotic-assisted arm training with complex VR gaming simulations [20].

We are using this system in several innovative ways. First, the system allows us to utilize current neurophysiological findings regarding the importance of repetitive, frequent and intensive practice for skill development and motor recovery to train the hemiparetic upper extremity of people post stroke [21-22]. After a two-week period of training, the participants were able to more effectively control the upper limb during reaching and hand interaction with the target as demonstrated by improved proximal stability, smoothness and efficiency of the movement path. This improved control was in concert with improvement in the distal kinematic measures of fractionation (ability to move fingers one at a time) and improved speed. These changes in robotic measures were notably accompanied by robust changes in the clinical outcome measures.

Because of the systematized, objective nature of this system, it allows us to test hypotheses regarding the most efficacious therapeutic interventions. It is controversial whether training the upper extremity as an integrated unit leads to better outcomes than training the proximal and distal components separately. During recovery from a lesion, the hand and arm are thought to compete with each other for neural territory. Therefore, training them together may actually have deleterious effects on the neuroplasticity and functional recovery of the hand. However, neural control mechanisms of arm transport and hand-object interaction are interdependent. Therefore, complex multi-segmental motor training is thought to be more beneficial for skill retention. We are investigating these competing theories to determine if and how competition among body parts for neural representations stifles functional gains from different types of training regimens.

Lastly, we are also exploring how this promising therapeutic strategy may actually change neural connections in the brain as a patient's motor functions improve. Animal and human research suggests that functional recovery is dependent on neural reorganization. We have developed an innovative MRI-compatible VR system that

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tracks bilateral hand movement and uses these measurements to drive motion of virtual hand models during an fMRI experiment. Our preliminary data suggest that, indeed, robot-assisted training in VR may be beneficial for functional recovery after chronic stroke. Further, our data suggest that this functional recovery may be attributed to increased functional connectivity in bilateral sensorimotor cortex.

4. VR Simulation for Recovery of Cognitive Function (Patton et al.)

A key aspect of rehabilitation recovery is deliberate, repetitive practice that resembles functional activity in some way. This can involve tool use, and can be accomplished via interactive VEs that incorporate robotics that can render haptic feedback. Our recent work has evaluated several clinically promising uses of these haptic/graphic environments (HGE) in stroke recovery, which often involves exploiting the features of HGE by distorting the visual and mechanical fields in which users operate. Our MMVR talk will present this work as an extension of our neurorehabilitation research [23-24] with moderate-severely impaired inpatients with TBI, in which a key deficit is attention. Our approach is believed to be distinctive in that we use the HGE in an *extremely minimal environment* -- a cursor and target in the dark with no other distractions. This concept emerged from our observations that patients in the earliest stages of recovery exhibit severe impairment of both focused and sustained attention. It was hypothesized that since VR allows for complete control of the task environment and difficulty level, it might lead to short-term gains that in turn might lead to longer-term benefits in these users.

Our initial study provided an assessment of the tolerance of a VR intervention for attention remediation in persons with severe TBI [25]. A small sample of patients with severe TBI receiving acute inpatient rehabilitation in the early stages of recovery were exposed to a minimalistic interactive VR reaching task. Six TBI patients and three healthy controls were tested while reaching for successive visual targets. Initial results showed the system to be well-tolerated and engaging, and users focused on the task without being distracted by environmental stimuli while showing gains in proficiency (increased target acquisitions). Encouraged by this preliminary work, our next study tested a more comprehensive 2-day treatment protocol to evaluate how haptic cues might be beneficial [26]. Users visited the laboratory for two successive days, and on each day they executed 6 blocks of training that included three haptic feedback conditions: 1) no haptic forces, 2) resistive haptic forces (giving subjects a "break-through" sensation as they acquired the target) and 3) facilitative forces (giving subjects a 250 ms “nudge” toward the target whenever a 1 second period of near-zero speed was detected). We hypothesized that haptic feedback would refocus the patient's attention as well as increase time-on-task for subsequent movements. Overall, 19 of 22 patients were able to tolerate the task and target acquisition time on a 3D cancellation task showed improved performance across trials. The haptic nudge condition resulted in superior performance compared to the breakthrough condition. Subjects with posttraumatic amnesia demonstrated improved performance across trials, with carry-over between day 1 and day 2 indicating improved procedural memory despite the fact that subjects lacked the capacity for declarative learning. We are now developing a prolonged 2-week clinical intervention while moving to transfer this technology to a viable system on a smaller and more affordable scale to promote better patient access. This study will include incremental task difficulty adjustment features so that as

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subjects improve, the task challenges will engage patients in both the earliest stages of recovery and in those whose progress requires more demanding exercises.

5. VR Simulation Architecture for Remote Exercise (Banerjee et al.)

The application of VR in rehabilitation engineering can be broadly categorized into two main areas: motor rehabilitation and cardiovascular exercise. Fortunately, both motor rehabilitation and cardiovascular exercise share almost the same technologies and devices. The primary difference being that cardiovascular exercise requires a larger range of movement, higher frequency and larger intensity. The challenge is to harness the technology optimally for efficient utilization for these differing aims. To address this challenge, we have created a new software architecture, known as REGAL (Remote Exercise and Game Architecture Language) to design virtual exercise environments for people with lower body disabilities. The software also facilitates the development of new virtual exercises by other developers who are interested in creating fitness and rehabilitation applications. The new exercises can be uploaded to the architecture and be played by users similar to the pre-loaded exercises we developed, and the REGAL architecture also supports 3D PC games that are developed using other SDKs and game engines.

The first version of the architecture and a "throwing" demo received feedback via questionnaire from 26 participants [27]. Users reported that they were easily able to experience a 3D perspective in the virtual environment (VE); were satisfied with the consistent and responsive natural VE interaction (but expected more); and users with lower body disabilities showed higher satisfaction with all aspects of the VE than users without disabilities. In the current version of the architecture, with which we are designing two rowing demonstrations: the first is based on *PhysX* and *Coin3D* with a very simple 3D scene, while the second is based on a *FarCry* demo (http://farcry.us.ubi.com/) to show how to reuse currently available VR games [28]. In the *FarCry* demonstration, the acceleration data from a *Wii* remote was used to successfully drive the navigation and avatar movement. More standard motions need to be recognized and defined for other rowing styles and other exercise equipment. Moreover, the users might want to define their own gestures for particular exercise equipment and the architecture should be able to let the user record their gestures and to recognize those user specific motions later in the application.

6. Conclusions

In this special session, we will present the challenges faced in the creation and delivery of VR simulation technologies for addressing barriers faced by individuals aging with and into disability. The NIDRR funded projects outlined, use a range of interaction devices, programming engines, and emerging approaches for addressing the sensorimotor and cognitive challenges that adults with disabilities face throughout the lifespan. We will present research that supports the development of a range of VR applications focused on improving upper/lower extremity functions, on remediating cognitive impairments, and on providing technology to promote access to home-based exercise for persons aging with and into disability. And, novel strategies for promoting user access to VR rehabilitation will be discussed with both users and developers.

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