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Erratum: The last issue of the Journal of Physical Therapy Education (Volume 24, Number 3, Fall 2010) contained an error in the title on page 44. Endangered Roles in Physical Therapist Education: A Feminist Vision for Scholarship in Clinical Education, by Carla Sabus, PT, PhD, should have read Engendered Roles in Physical Therapist Education: A Feminist Vision for Scholarship in Clinical Education.
2010
The Texas Consortium for Physical Therapy Clinical Education, Inc.
is proud to announce the inaugural 2010 recipient of its newly created
Exemplary Site for Physical Therapy Clinical Education Experiences
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Quentin Mease Community Hospital
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Houston, Texas
As clinicians we often argue that our effectiveness is enhanced by the interpersonal interactions and the direct contact that we have with clients and students. However, changes in the world economy and the social climate are placing stresses on health care and education, which require new approaches for delivery of service. Increasing numbers of elderly and infirm individuals have insufficient direct access to rehabilitation facilities or clinicians. In addition, there is a lack of funding for training new clinicians at universities, and it remains difficult to find faculty committed to teaching aspiring clinicians. All these factors impede public access to rehabilitation services.

Despite the current limitations in funding and recruitment, current and future generations of students are increasingly comfortable in developing personal relationships through technology-supported social interactions. It is likely that this approach to interpersonal communication will transfer into the health care domain.

The past decade has witnessed numerous exciting developments in technology that can be applied to rehabilitation in both clinical practice and teaching. A number of different therapeutic technologies are already available for use in clinics and classrooms, but the value of these programs is not always well defined. One of the main concerns is whether there is any value added by having these technological services conveyed from a distance. Clinicians and educators use a combination of verbal, visual, and physical interactions to deliver their content. Delivering equivalent interactions via technology presents significant obstacles; however, it also presents numerous opportunities to enhance the quality, consistency, and documentation of delivery. New rehabilitation technologies may provide more responsive treatment tools or augment the educational process; however, the scarcity of education about technological advancements and apprehensions by clinicians related to the role of technology in the treatment delivery process puts us at risk of losing the benefit of an essential partnering between clinicians and technology developers. The rapid rise of technology is pushing the market place, and it is essential that rehabilitation specialists oversee the quality and validity of these new applications before they reach the consumer.

In order to determine the importance and best applications of technology, we need to thoughtfully consider whether it is best that the technology replicate the actions of a therapist/teacher, or whether technology should be used to assist or augment these actions. In our own area of interest, that of applying virtual reality to rehabilitation, we are often faced with having to justify our technological approach to research and treatment. Concerning the application of virtual reality, the question most often asked is why we do not just employ the same techniques in the physical world. The answer to this question is that technology offers great potential for enhancing and perpetuating our treatment outcomes. For example, virtual reality permits the user to interact with a multidimensional and multisensory environment in real time. It provides an opportunity for patients/clients to engage in challenging but safe, ecologically valid environments while maintaining the clinician’s control over stimulus delivery and measurement. Virtual reality offers the opportunity to provide both standardized and individualized interventions while monitoring the resulting behaviors. Finally, by using virtual reality, interventions can be provided within a functional, purposeful, and motivating context that can be readily graded and documented. Although we might be able to provide some of these features with various traditional approaches to treatment and education, we argue that employing the new technology provides access to all of these attributes in a more efficient and effective fashion.

In this special issue of the Journal of Physical Therapy Education, we spotlight some of the new technologies that have specific applications to rehabilitation and teaching. Each article will focus on the design of the technology and empirical data that demonstrates how the technology can or will be used. Huhn and Deutsch, along with Kliger and Pfeiffer, present new methods for bringing technology into the classroom to promote didactic learning. Lotan et al and Grynzspan et al discuss how technology can be used to support therapeutic interventions with people that have intellectual or cognitive impairments. Experiments in which virtual technology is currently being used for upper-extremity and locomotion training in patients with stroke are presented in articles by Burdea et al and Perez and Fung. Lange et al and Mawson and Mountain present computerized exercise programs that are currently being tested for home use, and Tucker provides current advances in computerized technology to monitor and record general activity levels for assessment and research purposes. Finally, Laufer and Weiss detail a systematic review to explore a measure of current validity for the use of virtual reality technology in the rehabilitation of children with sensorimotor deficits.

We anticipate that these articles will serve as an entrée into the technological advances in teaching and intervention and entice you to explore and access new technologies that are already having a major impact in the field of rehabilitation.
REFERENCES


Development and Assessment of a Web-Based Patient Simulation Program
Karen Huhn, PT, MS, and Judith E. Deutsch, PT, PhD

Background and Purpose. The development of clinical-reasoning skills is dependent on substantial exposure to realistic patient experiences. Academic programs are constrained by several factors, including the amount of time they can expose students to real patient cases. Typically, text cases and standardized patient experiences are used to increase student exposure; however, both of these methods have limitations. Computer-simulated patients may be an alternative or supplemental pedagogy that can be used to expose students to realistic patient cases with greater frequency.

Method/Model Description and Evaluation. Existing computer-simulated cases used to teach clinical reasoning to medical students were modified to include the Guide to Physical Therapist Practice to add examination and interventions used by physical therapists. First, 5 faculty and second-year students performed a usability analysis. Second, they conducted a feasibility study to determine if the software could be integrated into a specific class.

Third, a pilot study was conducted that compared the effectiveness and efficiency of the a Web-based simulation compared to a traditional small-group discussion. Outcomes for the pilot study included the health science reasoning test (HSRT) and implementation costs.

Outcomes. The outcome of this project was the design and testing of a computerized patient simulation program that can be used to teach clinical reasoning to physical therapy students.

Discussion and Conclusion. Existing clinical-reasoning software was modified for use by physical therapist students. Incorporating software into a physicial therapy class was proved to be feasible. When compared to a traditional teaching group, the Web-based simulated group had significant improvements in some aspects of clinical reasoning and cost less to implement. However, the software requires further changes for greater congruency with physical therapist clinical reasoning. Additionally, questions of dosing and integration into a physical therapist education curriculum rather than a discrete class need to be addressed.

Key Words: Clinical reasoning, computerized simulation.

BACKGROUND AND PURPOSE

Clinical reasoning has been defined as “the intellectual activity which synthesizes information obtained from the clinical situation, integrates it with previous knowledge and experience and uses it for making diagnostic and management decisions.” It is an integral skill that allows the proficient diagnosis and management of patients. Research has identified 3 stages in the development of clinical-reasoning skills. Stage 1 is the reliance on basic science knowledge, the second is organization of knowledge, and the last is exemplars from practice or clinical experience.

Substantial practice with realistic patient cases builds expertise in problem-solving through organization of knowledge. Organization of knowledge is the structuring and restructuring of information to speed cognitive processing and problem-solving. This organization of knowledge is acquired through direct experience in the context in which it is to be used.

Most medical education programs and physical therapist education programs require a clinical setting experience that allows students to practice interviewing and evaluation skills. Time, safety issues, and patient availability often constrain the amount of hours students spend in the clinical setting. In order to increase students’ exposure to real patient experiences in a safe environment, health professional programs have initiated the use of computer-simulated patients to teach history taking, examination, and diagnosis skills. Several authors have reported that computerized patient simulation programs were at least as effective as traditional methods to improve knowledge and had a high rate of student satisfaction.

Currently, the primary approach to teaching clinical reasoning to physical therapist students is to use case-method strategies, which include a variety of problem-based learning (PBL) techniques and standardized patient encounters. Although both techniques are effective and provide a method to integrate didactic and clinical knowledge in a patient-centered manner, both are limited in the frequency with which they can be applied. Difficulties with implementing a substantial amount of PBL cases include the time and labor required to train facilitators and deliver the cases. PBL cases also include a lack of realism as the case is discussed rather than experienced. The student also is subject to the influence of the faculty facilitator through the injection of personal bias and clinical experience.

Simulated or standardized patients (SPs) are lay people trained to act as patients and portray aspects of a real patient case. The benefits of using SPs to deliver cases include the ability to control the learning environ-
ment, adjust the difficulty of the case, expose students to a clinic-like environment without risk to patient safety, and enhance instructor–student interaction to maximize the educational benefit.\textsuperscript{16} However, the cost and time to train standardized patients, as well as the number of raters required for scoring the experience, limit the number of SP experiences allotted in the curriculum. In addition, researchers report that SPs are best used for an initial diagnostic work-up and for practice and evaluation of physical examination skills, but are less effective for patient intervention skills.\textsuperscript{17,18}

Use of computerized patient simulation programs in physical therapist education appears to be quite limited. Web-based computerized patient simulations may serve as a complement to PBL and SP cases to teach clinical reasoning to students. Potential benefits of computerized simulations for the development of clinical reasoning include the capability to learn in any location at any time and the capacity to repeatedly access the same problem until mastery is achieved. Typically and necessarily, text and SP cases are used to expose students to frequently seen clinical scenarios. The capacity for students to complete Web-based simulated cases on their own time enables instructors to expose students to less frequently seen patient cases and clinical settings, such as a patient case set in a neonatal intensive care unit. The simulation program provides immediate, individualized feedback based on predetermined criteria, even in the absence of a clinical instructor. In addition, Web-based cases allow errors in judgment so that the student can learn from the consequences of their judgments and actions.\textsuperscript{19} Education researchers report that learning from errors can promote the development of expertise and improve future interactions.\textsuperscript{20} Another benefit of computerized simulations is that the outcome is based on the learner's responses rather than ratings by trained observers, as with standardized patients, thereby eliminating a source of bias from the examiner.

Computerized simulations allow educators to address several common problems in physical therapist education, including the lack of patient availability, assessing professional competence, patient safety, and the role of deliberate practice in which one practices an activity with the primary goal of improving some aspect of performance.\textsuperscript{21} Potential limitations to the use of computerized simulations include the time and cost to develop the simulation and the difficulty in incorporating narrative reasoning into the simulated experience.

The development of new technology is an iterative, multiple-step process. These steps include identifying a need, establishing a framework on which to base the design, design, testing and modification, and establishing validity. The purpose of this paper is to describe the development and assessment of a computerized patient simulation program to teach clinical-reasoning skills to physical therapist students. The first step, identification of need, was discussed in the beginning of this paper. The remainder of the paper will describe the initial modification of an existing program, identification of limitations leading to a substantial redesign, and subsequent testing and validation of the simulation program.

**METHOD/MODEL DESCRIPTION AND EVALUATION**

**Modification of Existing Software**

The authors chose to use existing clinical-reasoning software rather than design a new program. DxR Clinician,\textsuperscript{22} a Web-based patient simulation program designed to teach clinical reasoning to medical students, was chosen. Used in more than 300 medical programs worldwide, this program tracks the users' thought processes as they complete a patient history, examine the patient, order tests (X-ray, MRI, etc), and diagnose. Students are required to repeatedly state the patient problem, generate hypotheses, and interpret information. They are free to follow their own path of inquiry, choosing from a database of history and exam items to gather the information they need. Scoring is based on predetermined criteria established by the case author. Immediate feedback is provided upon completion of the case, and the instructor can provide additional individualized feedback upon review of the student's record.

Initially, the software required 2 substantial modifications to meet the needs of physical therapist students. One was the addition of examination tools used by physical therapists, such as range of motion, strength, palpation, and functional mobility tools. The second was the incorporation of interventions used by physical therapists. The *Guide to Physical Therapist Practice*\textsuperscript{23} was used to select both the examination and intervention tools.

**Initial Testing**

To identify problems with design, layout, ease of use, and technical issues, the authors performed a usability analysis on the revised software. To procure faculty members' and students' thoughts regarding the potential use of the program in the curriculum, we asked 5 faculty members involved in teaching clinical reasoning and 5 second-year physical therapist students to complete a patient case using the software. Participants met in an on-campus computer lab and listened to a brief instructional session on the purpose of the software, the purpose of the session, and how to navigate within the software. The participants then completed a case using the software and took part in an informal discussion in regards to the intended outcomes.

Both students and faculty reported that they felt the program was useful. Students reported that they would like to see more cases and have more time to "play" with it. Faculty felt that there was a place for it in the curriculum; however, they suggested that additional modifications would be useful. Faculty were concerned that the primary outcome of the case was diagnosis rather than management, and they felt this was not the primary goal of examination for the physical therapist student. Technical issues, primarily in the area of the interventions encountered during the session, were reported to the development company for correction.

**OUTCOMES**

**Feasibility study.** Both students and faculty agreed that there was value in the program; therefore, the authors proceeded to a feasibility study. Its purpose was to evaluate the feasibility of incorporating the software into an existing course. A class of 45 students completed a case using the software as part of a course titled Clinical Inquiry I. This course was chosen because it is the course in which students are introduced to the clinical-reasoning process. Prior to completing the simulation case, students participated in an instructional session that provided an overview of the software program and instructions to navigate through a case. Two weeks after the instructional session, the students met as a class in a computer lab and completed a single simulation case using the DxR software. The students completed a satisfaction questionnaire designed to assess their preference for using computers to learn and obtain their feedback on interfacing with the program, the ease of use of the program, and the desire to use more Web-based simulations. All 45 students were able to complete the case simultaneously, indicating sufficient server compatibility and capacity. A remaining technical issue with the intervention section prevented students from choosing certain interventions, which lead to frustration on their part. Despite the technical issue, student satisfaction with the program was high, with several requesting additional cases and the majority reporting that they enjoyed learning with computers. Based on the results...
of the feasibility study, we decided to proceed with a pilot study.

**Pilot study.** The purpose of the pilot was to study the effectiveness and efficiency of teaching clinical reasoning using Web-based patient simulations as compared to traditional small-group discussion. This study took place in a Therapeutic Exercise course where, traditionally, students complete a series of facilitator-led, text-based cases in small groups of 7 to 9 students. For the purposes of this study, the class was randomly divided into 2 groups; 1 completed 3 cases using the traditional text-based cases, and the other completed 3 Web-based simulation cases. The content of the cases was consistent; only the delivery method varied. To assess clinical-reasoning skills, students completed a preintervention and postintervention Health Science Reasoning Test (HSRT). The HSRT provides an overall quantitative score of clinical reasoning skills and 5 subscale scores for analysis, evaluation, inference, and inductive and deductive reasoning. The authors chose the HSRT as an outcome test because it was specifically designed to test critical-thinking skills of allied health students. To assess transfer of knowledge, students' performance was evaluated using a practical exam. To evaluate efficiency of learning, time spent on case completion was quantitatively measured by faculty in the text-based cases and by the software in the simulation group. Time spent on case completion was used as an outcome because the literature on computerized simulations indicates that computerized learning may be a more efficient method of learning than traditional methods.

The authors analyzed data for 36 students, 19 in the experimental group and 17 in the control group. Data from the HSRT were analyzed using a 2 factor (group and time) ANOVA with repeated measures to determine both between-group and within-group differences. Preintervention HSRT scores were not significantly different between groups. Analysis of variance revealed no significant effect for group or instructional method for the total HSRT score. Post-hoc analysis of the within-group subscale scores of the HSRT using paired t tests revealed a significant finding in the Web-based simulation group for the evaluation subscale ($t = 3.105, P = .007$) and approached significance for the analysis and inductive subscores. Within-group analysis of the small-group discussion participants failed to reveal significant findings for any of the subscale scores. An independent t test for practical exam scores approached significance ($t = 4.2, P = .06$), with the simulation group scoring slightly higher. The text-based group averaged 60 minutes per case while the simulation group averaged 48.6 minutes per case, suggesting that the simulation group was more efficient, requiring less time spent on tasks for similar outcomes.

**DISCUSSION**

Preliminary work with the simulation program suggested that using computerized simulation is feasible and that students may benefit from increased exposure to patient cases and a more objective method to measure clinical-reasoning skills. However, the clinical-reasoning process inherent in the program proved limited in its congruency with that of physical therapists. The primary conclusion of the studies was that, in order to truly realize the potential of the computerized simulation, the simulation program should incorporate a clinical-reasoning process representative of physical therapists.

![Figure 1. Schematic of Software Process](image)
The process of making additional modifications began with a needs analysis, which helps to realize the gap between what is and what should be. The analysis for this project identified what was lacking in the program and what was missing. The primary area that was lacking was the clinical-reasoning process, as stated above. A comparison of the accepted models of clinical reasoning in physical therapy with the framework currently in the program revealed a specific missing aspect: the identification of patient-identified and physical therapist–identified problems and a method to use these problems to guide patient management. Hypothesis development was already in the program, but the hypotheses were diagnostic, rather than hypotheses related to the identified problems. The program also lacked a method of linking a problem to a hypothesis and a hypothesis to an investigation in order to reinforce the process. For example, once students identified a patient problem, the program could require students to list at least 1 hypothesis for that problem. Students would then link the hypothesis to the examination item chosen. Once students moved to the intervention part of the program, it would require them to choose an intervention and indicate which problem from the problem list that intervention would address. This process of linking components of the examination would make the student's clinical-reasoning process more visible to the faculty.

Since we made substantial changes to the process in the program, corresponding changes to the scoring also were necessary. The software program could still match the user’s performance to predetermined criteria set by the case author; however, scoring also would include the student’s linking of items in the examination and management phases of the program, students’ goals, and their goals linked to the identified problems. Figure 1 (see previous page) presents a schematic of the final version of the software program after all of the aforementioned changes were made.

Validation Process
A simulation can be validated only in the context in which it is used. This involves assessing how closely the simulation aligns with the construct on which it is based. In order to establish content validity and process validity, the authors asked 6 experts in the field who are knowledgeable in the field of clinical reasoning to examine the process incorporated into the software. The authors asked experts to indicate if they thought the clinical-reasoning process incorporated into the program was expressed in a manner consistent with the original construct of accepted models of clinical reasoning and with their conceptualization of clinical reasoning (Table 1).

Once all the programming changes were completed and validity of the simulation was established, the software was retested. The same students who had completed cases in the pilot study completed a case as a group with the program author highlighting the changes made to the program. Students then completed a case and a survey independently. Twenty-two students completed the case and a survey designed to gather their opinions regarding the functionality and usefulness of the program (Table 2).

Results of the pilot test revealed that students need to experience at least 3 cases to fully understand the program and to be able to find items. The fact that students completed only 1 case as a group and 1 independently may account for their feedback that the program was not user friendly. Despite the lack of user friendliness and students’ relative neutrality, the majority of respondents still wanted the opportunity to complete additional cases.

The purpose of this paper was to describe the iterative development and assessment of a computerized patient simulation program. The steps taken in the process included determining a need, initially modifying an existing program, testing, redesigning, and establishing validity. The process occurred over a time frame of 3 years at an expense of $50,000 for programming and substantial faculty hours in design and testing.

Modifying existing software had both benefits and drawbacks. The primary benefit was that the majority of the software was already written, saving development time and costs. The project also benefited from the original design team’s experience and knowledge with computerized simulations to teach clinical reasoning. The authors have developed a collaborative working relationship with the software company and are currently discussing future projects. The collaboration on the simulation software has led to a commercial product that could be used by clinicians. The drawback of working with an existing program was the amount of modifications needed in order to create a program suited to physical therapist students.

Technology can be used to enhance education and address educational conundrums; however, as with any other instructional tool, it should be driven by sound pedagogy and evaluated to see if it achieves the intended goals. Educational technology is “the study and ethical practice of facilitating learning and improving performance by creating, using, and managing appropriate technological processes and resources.” Technology should not be used or developed solely because it is unique or different. Instead, technology should be driven by a belief that it will enhance or improve upon current educational methodology or fill a pedagogical void. The literature regarding the development of clinical reasoning skills is clear on the need for substantial practice with realistic patient cases. Current educational settings and techniques do not allow for substantial exposure to realistic cases until clinical education experiences, which most often occur at the end of the students’ education. This pedagogical void made pursuing the use of technology appropriate in this case.

Cost-benefit analysis is another factor that should be considered before a transition to technology. Often, developing new

<table>
<thead>
<tr>
<th>Question</th>
<th>Strongly Agree</th>
<th>Agree</th>
<th>Neutral</th>
</tr>
</thead>
<tbody>
<tr>
<td>Do you feel the framework is representative of the clinical reasoning process of physical therapists?</td>
<td>3</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>Is the framework consistent with established frameworks?</td>
<td>4</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>Are all of the necessary elements of clinical reasoning represented?</td>
<td>1</td>
<td>4</td>
<td>1</td>
</tr>
<tr>
<td>Is the framework organized in a manner consistent with the reasoning process?</td>
<td>2</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>Do you feel the information gained from this framework would provide you with insight into a student’s clinical reasoning skill level?</td>
<td>1</td>
<td>4</td>
<td>1</td>
</tr>
</tbody>
</table>

Table 1. Content Validity
Table 2. Student Feedback

<table>
<thead>
<tr>
<th>Question</th>
<th>Strongly Agree</th>
<th>Agree</th>
<th>Neutral</th>
<th>Disagree</th>
<th>Strongly Disagree</th>
</tr>
</thead>
<tbody>
<tr>
<td>Do you feel the program helped organize your thinking?</td>
<td>0</td>
<td>6</td>
<td>8</td>
<td>6</td>
<td>2</td>
</tr>
<tr>
<td>Do you feel the requirement to “link” hypothesis to investigations helped to focus your investigations?</td>
<td>0</td>
<td>4</td>
<td>10</td>
<td>6</td>
<td>2</td>
</tr>
<tr>
<td>Do you feel the requirement to “link” interventions to problems helped to focus your management of the patient?</td>
<td>0</td>
<td>7</td>
<td>8</td>
<td>6</td>
<td>1</td>
</tr>
<tr>
<td>After reviewing the feedback provided by the program, would you do anything differently if presented with a similar case?</td>
<td>1</td>
<td>14</td>
<td>4</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>Was the program user friendly?</td>
<td>1</td>
<td>3</td>
<td>6</td>
<td>9</td>
<td>3</td>
</tr>
<tr>
<td>Would you like the opportunity to complete additional cases?</td>
<td>2</td>
<td>10</td>
<td>2</td>
<td>5</td>
<td>3</td>
</tr>
</tbody>
</table>

technology requires a substantial financial and time commitment. Without an educational benefit worth the cost or a decrease in the current costs necessary to teach the task, new technology may not be worthwhile. The educational benefit of increased exposure to cases without the need to sacrifice class time brought the added benefits of individualized immediate and delayed feedback and an objective method of measuring clinical reasoning skills. For this project, the cost-benefit analysis indicated that the development of the technology was worthwhile.

Further Research
Several unanswered questions remain regarding the software developed. The most substantial question is whether the simulation is more effective than traditional methods of teaching clinical reasoning. To investigate this question, we currently are conducting a randomized trial that is an extension of the pilot study. To address the issue of dosing, each group is completing 6 cases rather than 3. The timing of how to incorporate the simulation into a curriculum also needs to be studied. In a survey completed as part of the pilot study, 51% of the class reported that they would like the simulations in their first year and 27% in the first semester of their second year. Dosing also can be studied. The software’s capability to accommodate learning in any location, at any time, may enable educators to expose students to substantially more cases. However, the questions remain as to how many cases are necessary to affect a change in clinical reasoning score and when students reach cognitive overload. It is the authors’ belief that technology cannot and should not replace traditional education methods; rather, it should supplement and enhance them. Studies assessing how to best incorporate the simulations with current educational methods also are needed.

This paper has described the iterative process of designing educational technology. It is the authors’ hope that our experiences can increase the dialogue among physical therapist educators regarding the need for and the appropriate use of educational technology and encourage others to pursue design opportunities.

REFERENCES
Engaging Students in Blended Courses Through Increased Technology
Dominique Kliger, PhD, and Elizabeth Pfeiffer, PhD, OTR/L, BCP

BACKGROUND AND PURPOSE
Blended learning combines the use of multiple delivery media with various event-based activities.\(^1\) Blended learning is most often associated with the use of electronic media in combination with more traditional classroom settings,\(^2\) although by the nature of its definition, it is not limited to set contexts or types of media. The amount of time spent in a traditional classroom setting versus engagement in other media-based learning varies significantly. A course could require regular in-class weekly meetings with the use of multimedia to supplement the course learning content or could require only a few classroom meetings with the majority of the learning experiences through multimedia methods.

Emerging technology over the past 15 years has resulted in a surge of blended-learning opportunities. In the health professions, blended learning has not only had an impact on methods of learning in traditional professional (entry-level) and postprofessional programs, but has also expanded access to continuing education. Blended learning incorporates both traditional face-to-face classroom and online learning experiences. Online course offerings have increased rapidly in higher education over the recent years.\(^3\) Allen, Seaman, and Garrett\(^4\) report that a course is considered blended learning if 30% to 79% of the content is offered online. The 2 primary facets that characterize the blended-learning experience are the types of media and the various event-based activities used in the learning process.

CASE DESCRIPTION
Singh\(^1\) discussed the concept of event-based activities in blended learning. These include, but are not limited to: face-to-face classroom meetings; self-paced learning experiences such as discussion forums; and live, online-learning experiences, such as chat rooms. These event-based experiences include both synchronous and asynchronous learning methods. Synchronous experiences require the learner and instructor to communicate in real time, while asynchronous learning experiences occur without real-time presence (ie, any time, any place). The use of multiple delivery media supports the various event-based learning. Media such as Web-based course platform systems, social networking sites, and virtual collaboration software are only a few of the many tools used in blended learning.

Although blended learning is not a new concept, the expansion of technology over the past 15 years has changed how we deliver content and information in higher education, and has significantly increased opportunities for learning.\(^5\) Blended learning is based on the concept that each learner is unique with different learning needs, and that learning is a continuous process. As with any approach to teaching and learning, there are pros and cons. Some of the cons of blended learning include the complexity of scheduling due to the various event-based activities, and acquiring the technological needs and resources of the multiple media that are used. The use of technology can be unreliable at times and training is often necessary for students to learn new media or to alleviate their apprehensions about the use of technology. There continues to be limitations in technology that influences the successful use of media in blended learning. For example, narrow bandwidths prevent the easy use of dual media when communicating to students (eg, showing a video online while speaking to students). Students are still required to attend face-to-face classroom activities that require travel and, at times, other expenses. There is also a lack of willingness for some teachers to learn new technology and utilize media in their teaching strategies due to the time necessary and the lack of compensation provided for the extra work required. The most apparent pro of blended learning is the ability to extend educational programs and experiences to those who are not able to participate consistently at fixed locations and set times. It can resolve issues of classroom space, which is a struggle for many universities and may provide cost-reduction benefits for students.
who do not have to travel as often.

Blended learning combines the benefits of both face-to-face and distance education approaches. Along with this, blended learning fosters continuous learning experiences and is "particularly effective in its ability to facilitate a community of inquiry.” A sense of community fosters key aspects of learning in higher education, including open communication and the dialogue necessary in developing critical-thinking skills. In order to promote the best teaching practices, it is essential to understand the effectiveness of blended learning and multiple media delivery strategies that promote student engagement necessary for effective learning. This article introduces preliminary evidence on the effectiveness of blended learning and strategies to promote student engagement through the use of multiple delivery options.

OUTCOMES
There is a significant amount of emerging literature focused on the effectiveness of blended-learning strategies. In the past, concerns were reported regarding whether the teaching and learning processes of blended learning were as effective as the teaching and learning processes of the traditional, face-to-face classes. Recent literature supports that blended learning is as or more effective than traditional face-to-face courses in students’ academic outcomes. In a study specific to the health professions, Strickland completed a retrospective study using course evaluations, grade point averages, and course grades of 2 groups of bachelor students in a respiratory therapy program. One group completed a pediatric respiratory therapy course in a traditional face-to-face classroom setting, and the other group used a blended-learning approach. There was no specific information provided on the type of course content. Blended learning was identified in the study as “courses that utilized electronic media to supplement, but not replace, the traditional classroom.” Results showed that there was no significant differences in course grades or grade point averages in the program when comparing the cohorts. There were also no statistical differences in the course evaluations between the 2 classes. The author discussed the benefits of using a blended-learning approach, including accessibility to course material, flexibility, and an ability to increase class size. An earlier study by Rivera and Rice found similar results to this study when comparing a Web-based versus face-to-face course delivery method. This study identified no significant differences between the 2 courses in grades or in reports of student satisfaction.

A more recent comprehensive meta-analysis including 23 studies, not inclusive of the Strickland or Rivera and Rice studies, identified that students participating in blended-learning classes actually performed better than those in more traditional face-to-face classes. It was suggested that the blended-learning experiences offered additional learning time and instructional components when compared to face-to-face classroom experiences. One study in the meta-analysis by Shilling and Polenem identified that students who completed a blended course on evidence-based medicine significantly outperformed their peers who received the information in a traditional face-to-face format during clerkship. Other studies have identified that blendedand distance-learning approaches promote an increased ability for critical thinking (an essential skill in practice for professional and postprofessional therapists) when compared to more traditional methods of course delivery. Preliminary evidence for the use of blended learning provides positive support for this type of course delivery method, although there continues to be a need for research that includes higher levels of evidence and relates findings to outcomes in clinical practice.

DISCUSSION
As with any teaching strategy, various factors that are not associated with event-based activity or media are used that can facilitate or impede learning, such as teacher skills and philosophy, and, appropriate supports and resources. Garrison and Kanuka identified “front end” issues that need to be considered when using blended learning, including policy, resources, and support. There needs to be policies at the university level that support blended learning along with the necessary resources, both in personnel and media, that support the teaching and technology needs associated with this course delivery method. According to Garrison and Kanuka, one of the most important aspects of facilitating a successful experience in blended learning is “technological resources that are dependable and transparent.” Transparency promotes student engagement in the learning process, as well as influences student satisfaction with the course.

Student Engagement in Virtual Environments
As in face-to-face classroom settings, there are educational benefits in online classes that encourage active student engagement. According to Mandernach, one way to achieve student engagement is for educators to promote an active-learning environment and develop strategies to create personal connections with students while interacting with them in virtual classroom settings. By giving special attention to student cognitive engagement, educators can enhance student interest.

While new communication and information technology alone does not determine student success, students enrolled in a blended program are presented with supplementary opportunities to express their ideas. When reliable technology, appropriate training, and proper instructional design are in place, students tend to ask more questions when they are online. When technology performs well, it becomes transparent during online classroom interactions and affects the students’ sense of social presence (interpersonal awareness of others). According to Dow, students struggle to establish person-to-person awareness in online-learning environments, where social context is not available. Students can create social cues in the online classroom by using digital Web cameras when they interact remotely with other students, so they can be seen when speaking. Or, student photos can be uploaded to the online classroom so that classmates can recognize who is speaking.

Virtual Classroom Settings
Virtual classroom environments vary in form, interaction mode, and meeting time. Some virtual spaces promote students to engage in both synchronous and asynchronous activities. Since 1984, when Daft and Lengel introduced the concept of “information richness,” online courses have been compared to face-to-face meetings, which are considered to be the richest because they incorporate the ability to provide instant feedback and offer multiple cues. According to Shaw et al., an important attribute of information richness is related to the medium’s capacity to convey instant feedback. They posit that by promoting social presence cues, instructors create a greater sense of immediacy and warmth in the virtual communication, and therefore promote a better learning environment.

The interactive virtual space described below addresses issues related to social presence and information richness, when students and faculty virtually interact via desktop videoconferencing systems such as Wimba, WebEx or Adobe Connect. When students interact in class, they are able to see other students’ facial expressions and hear their voices. When interacting online, if any of these non-verbal cues are not available, students express a feeling of disconnect. According to Kliger, desktop videoconferencing interactions have the potential...
to reduce students’ perception of being distant from instructors and classmates, create more personal interactions, and change students’ learning practices. According to Johnson and Huff, a rich interaction medium can minimize the isolation reported by online students who do not utilize these interactive tools.

The figure above displays a faculty member conducting an online presentation to other faculty members (via Wimba Classroom). This presentation was archived and inserted on an online faculty newsletter. This type of meeting platform, provided by Wimba, Adobe Connect, WebEx, and other providers, enable faculty to: (1) conduct live lectures, (2) conduct virtual office hours, (3) sponsor guest speaker presentations from the speaker’s current location, (4) conduct research collaboration meetings from remote locations, (5) record presentations for future viewings, (6) promote virtual student presentations, and (7) promote remote classroom interpreting (remote classroom interpreting allows hearing-impaired students to utilize virtual classroom platforms such as WIMBA to interact with their interpreters remotely).

As students have the ability to see their classmates when they participate and present in class, they no longer feel a distance barrier. Students’ perception and motivation levels are also affected by the format of the virtual interaction. According to an online student interviewed, students do not want to portray that “they do not know what they are talking about when they are interacting online.” Students report that being seen by others reduces the sense of anonymity (even when their names are displayed next to the messages posted) they felt when interacting only via text messages.

The ability to see other classmates promotes the feeling of “being there” and allows students to maintain the sense of cohort that exists when they interact in classrooms hosted on campus. According to Nowak and Biocca, virtual spaces promote the feeling of “being there” as: (1) a “telepresence” (being in a virtual space), (2) “co-presence” (being there with others), or (3) “social presence,” which extends the concept of co-presence to emphasize the experience of being there with someone else “whose presence creates the opportunity for meaningful interaction and related social processes.”

Blended courses provide students with the opportunity to extend to their virtual interactions, the personal impressions established during the on-campus classroom interactions so that they experience “social presence” when interacting in virtual spaces that use video and audio media.

This article is not intended to address the virtual spaces in which students have the ability to select how they portray their identity, such as when they attend class in Second Life, a virtual-world environment in which students present themselves through an avatar of their design. Nevertheless, when con-
sidering meeting in those virtual settings, it is important to also consider the effect that the extended and transformed identities (that students create prior to joining the class) may have on pedagogies and on learners. 

CONCLUSION
There are several issues to consider when creating blended-course materials. Strategic decisions, among others, involve the consideration of a variety of students’ needs and the format of the materials to be presented online. According to Shawa et al., online course materials can be diverse and be designed to raise the learning interests of students based on their needs for high information richness media. Nowadays, desktop videoconferencing interaction systems are capable of offering rich media and content. When used as part of a blended course, these systems can promote social presence and opportunities for instant feedback, and as a result, present a valuable array of learning opportunities for students. Recent research has already identified that students participating in blended learning perform better than students in more traditional face-to-face classrooms. The addition of rich and transparent media provides opportunities to further enhance learning in blended-learning courses as well as enhance engagement and social presence, resulting in increased student satisfaction.

REFERENCES
Training Caregivers to Provide Virtual Reality Intervention for Adults With Severe Intellectual and Developmental Disability

Meir Lotan, PT, PHD, Shira Yalon-Chamovitz, OT, PhD, and Patrice L. (Tamar) Weiss, OT, PhD

Background. Individuals with intellectual and developmental disabilities (IDD) are in need of effective physical fitness training programs, leisure time opportunities, and strategies to improve their participation in daily life activities.1

Purpose. This study sought to present an educational program that enabled the implementation of a virtual reality (VR) program operated by in-house caregivers for adults at a severe level of IDD.

Methods. During the initial stages of this series of studies, 2 groups of participants underwent a video-capture, VR-based, game-like, exercise program. The first study group (N = 33; mean age = 28.1 ± 5.3 years; moderate IDD) was trained by an experienced occupational therapist, and the second study group (N = 30; mean age = 52.3 ± 5.8 years; moderate IDD) was trained by occupational therapy students. Changes in physical fitness were monitored for all participants in comparison to matched control groups. A third study group (N = 20; mean age = 48.1 ± 8.6 years; severe IDD) was trained by in-house caregiver staff. An educational program including gathering appropriate caregivers, presenting theoretical background for the program, as well as providing on-going technical support was implemented.

Results. The strategy used to enable the implementation of a VR program by in-house caregivers was shown to be feasible. The VR intervention program promoted activity and was motivating to and enjoyable by all participants with mild to moderate IDD and to most individuals with severe IDD. Significant (P < .05) improvements in physical fitness were demonstrated for all research groups in comparison to the matched control groups, supporting the effectiveness of this educational program.

Conclusion. VR technology was found as fully effective tool to engage adults with mild to moderate IDD, and some with severe levels of IDD, in a variety of activities by caregivers from different educational backgrounds and professions. Key Words: Intellectual disability, Developmental disability, Virtual reality, Physical fitness, Best practices.

BACKGROUND AND PURPOSE

The fact that many individuals with intellectual and developmental disability (IDD) maintain a sedentary life style, experience poorer health and have less access to health care than the general population,1 suggest that these individuals are at risk for a multitude of secondary health problems. However, the physical condition of this population may improve with appropriate intervention.2 Previous studies reveal that provision of additional leisure opportunities and participation in leisure activities by individuals with cognitive limitations contributes to improvement in self-confidence and self-concept, improvement in social and motor skills, increased communication abilities, greater physical fitness and weight reduction.3-5

Although participation in vigorous leisure activities has been shown to improve participants’ physical fitness, coping skills, level of stress, and adjustment to a life with disabilities, the majority of leisure pastimes available for people with severe cognitive and physical limitations is often extremely limited, tending to involve sedentary activities.6,7 A review of the literature on leisure activities for people with disabilities highlights the need for increased exposure to augmented leisure opportunities and documents a positive relationship between satisfaction with leisure and self-esteem, companionship, enjoyment and relaxation.8 At the same time, the pervasive lack of opportunities for a wide choice of independent leisure activities may contribute to the development of dependent behavioral patterns, learned helplessness and depression.9-11 For individuals with IDD, some limitations initially must be overcome to take part in demanding physical activities. These limitations include:

• Physical environment: Adults living in nursing homes were less likely to exercise than the non-nursing home residents12; therefore, in order to enhance participation, activity programs must be made available for this population.

• Participation in exercise programs set by personal characteristics: Ruuskanen and Parkattis1 study reported poor health status by 60% of the women and 38% of the men as the main reason for not participating in exercise. Moreover, decreased motivation to participate in activity programs is common to many with IDD. In order to enhance participation levels and reduce the influence of physical limitations, a program must be appealing and motivating to the special
appears to provide an answer to the challenge present users with opportunities to engage with computer hardware and software to the use of interactive simulations created. The results of 2 of these studies have tested. Half of the participants experienced a 6-week VR intervention program (3 times per week) using the Sony PlayStation® 2 EyeToy® video capture system. The program was operated by occupational therapy students who were supervised by a physical therapist with expertise in physical fitness and an occupational therapist with expertise in technology; 30 participants were in the control group.

The limitation of the first 2 studies was that VR service delivery was made available only by research-funded personnel. As mentioned above, the crucial elements to participation in exercise programs are: environmental availability, involvement of on-site support personnel, and a highly motivating yet feasible activity. Therefore, identifying a way to embed the VR activity within the daily routine of a residential setting with involvement of in-house staff was necessary. The objective of the third study, reported in this paper, was thus twofold. First, the study sought to determine whether effects similar to those shown in the first 2 studies could be repeated by training in-house caregiving staff to independently implement a VR game-based exercise program. Second, the study intended to test the effectiveness of VR technology in motivating individuals at a severe level of IDD to participate in a physical activity program.

METHODS

Participants

The participants included 44 men and women with severe IDD and varying ability to ambulate. Criteria for selecting residents to participate in the VR program included individuals with a severe level of IDD, aged 21 to 60 years, and with the ability to actively move at least the head and one of the arms. They were excluded if they had an uncorrected visual impairment that prevented them from accurately viewing a large TV monitor, if they were unable to answer questions with a distinctive yes or no response, and if they had behavioral problems that would disrupt their participation in this program.

The participants were randomly divided into research (N = 20, age range = 37-58 years, mean ± SD age = 48.1 ± 8.6 years) and control (N = 24, age range = 25-58 years, mean age = 49.1: ± 5.4 years) groups. They were matched for age, IDD level, and functional abilities. The research protocols were approved by the Institutional Review Board at the University of Haifa and by the Israeli Ministry of Social Affairs and Services, Division of Services for Individuals with IDD. The intervention and test procedures were described to each person on the list and they were informed of their right to withdraw from the study at any time without penalty. Participants gave their verbal consent to participate.

Focus group participants included all of the residential caregiver staff who were recommended as suitable by the residence manager (based on their availability, interest in new programs, prior knowledge in computers, and familiarity with the residents) and who agreed to implement the VR intervention. Six to eight caregivers took part in each of the 3 focus groups; all had at least 5 years experience working with people with IDD (Table).

Instruments

GestureTek IREX® video capture VR system. The participants sat in a demarcated area viewing themselves on a large video screen that displayed 1 of 7 simulated games: "Birds and Balls, "Soccer, "Drums, "Car racing," "Juggler," "Ocean" and "Parachute." These games were chosen based on the range of levels of difficulty that would make them suitable to users who were severely limited in their cognitive and motor skills. The specific games played during each session were selected by the caregivers who operated the program, in accordance with the choices conveyed by each participant (usually by gestures or facial expressions indicating preference for one game over another). The participants moved their hand and upper body to control the interaction with virtual objects within the virtual environments. Since the VR system is operated via a single camera facing the user, all actions took place in the coronal plane only.

Resting heart rate. Physical fitness measurements were made with the Polar® F11 Fitness Heart Rate Monitor. The height, weight, and age of each participant were inserted into the pulse meter before measurement initiation. The placement of the transmitter belt was visually demonstrated and then placed on the body of the participant. The pulse readings of each participant were collected every 15 seconds at rest.

VR training program. Caregivers within the residential facility were informed about the planned VR game-based intervention program at an oral group presentation that described the importance of physical activity and the use of VR in different educational and rehabilitation programs, presented the results of past interventions with VR for individuals with IDD, and gave guidelines for the implementation of the present program. Each caregiver was given an opportunity to join the program but also was free to decline to participate. An occupational therapist with ex-
pertise in VR technology and familiarity with the GestureTek IREX® VR system performed a group demonstration on the operation of the system and was then "on call" to provide technical and individual professional support whenever the caregivers had difficulty in operating the system. After several weeks, it appeared that the caregivers hesitated to contact the technical support person, so the OT began to make weekly visits to ensure a smooth operation of the system and respond to any difficulties that arose.

**Procedure**

The research group was enrolled in an 8-week intervention program consisting of individual 30-minute sessions 2 to 3 times per week. The matching of participants and caregivers was determined according to the acquaintance of each caregiver with a participant and that caregiver’s availability to run the intervention throughout the entire 8 weeks. Each caregiver was responsible for 2 participants in each study cycle; one caregiver replaced another occasionally due to changes in the work roster.

The heart-rate-at-rest measurements for each participant were performed 1 week prior to initiation of the study and the post-intervention tests were completed within 1 week of the program’s conclusion. The outcome measurements took about 30 minutes to complete for each participant and included a 10-minute rest period after the participant reached the testing room. All tests were performed by physiotherapy students blinded to the participant’s group allocation. The participants in the control groups received regularly programmed activities (eg, recreational or work type activities) during the time spent by the research group in the VR activity.

The sessions were conducted in a specially designated room at the participants’ residential dormitory and operated by resident caregivers who were trained to use the VR system. During the first and second sessions, all games were introduced to the participants; from the third session onward, the caregiver encouraged participants to select their preferred games.

Open-ended focus groups were conducted with the caregivers who were implementing the VR intervention. The focus groups took place at the beginning of the intervention, at mid intervention and after the termination of the intervention. All 3 focus groups were held in the same room, in which all VR moderators and the researchers sat around a large meeting table together. All meetings were professionally recorded and transcribed. Each meeting was accompanied by a managerial level person from the facility. The goal of the focus groups was to gather data concerning the characteristics of the caregivers implementing the VR program, the training and support program for the caregiver staff, technical issues, and appropriateness of VR intervention program for this population.

**RESULTS AND DISCUSSION**

**Physical Fitness Outcome**

A significant (P < .05) reduction in pulse at rest measurements was found for the research group but not for the control group, suggesting improvement in cardiovascular fitness. These findings were reported elsewhere and are consistent with the results reported in the authors’ previous studies.

**Focus Group Results**

The analysis of the focus group transcripts revealed that the overall involvement in the VR program was beneficial for staff members and participants alike. However, some challenges and barriers that require further improvement were identified, both with regard to the program’s appropriateness for people with IDD and with regard to its implementation by caregivers.

**Characteristics of the caregivers implementing the VR program.** As described above, the caregivers participating in the current study were selected from among the staff at a particular residential setting. Certain characteristics, such as their role at the facility, knowledge of computers, and an understanding of technology, appeared to influence the suitability of the caregiver for their participation in the VR program. The caregivers themselves suggested that the most significant characteristics for successfully taking part in such a program were the following:

- Motivation to participate in the study
- High personal level of ability (ie, responsible, reliable, and with a positive outlook towards the VR activity)
- Ability to work with a variety of residents
- Interest in technology and ability to operate computer-based activities

Indeed, the facility manager attested that: "We took people who had the abilities, who had the desire . . . a staff member was selected because we were sure that he [or she] would enjoy it and give the best result possible . . . .”

**Training and support program for the caregiver staff.** The VR program was operated by caregivers who were trained by professionals proficient in VR prior to the start of the activity and were supported throughout the entire period of its implementation. The effectiveness of the training and support were examined as part of the focus group discussion in terms of the feasibility of in-house staff operating a VR intervention program as a routine activity in residential facilities for people with IDD. Due to the novelty of the program, some difficulties arose when trying to implement it. These included:

- Initiating the program. This proved difficult due to the large number of participants (N = 20) in a single training cycle as was originally planned, other responsibilities of caregivers, and the lack

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**Table. Demographic Data of Caregivers**

<table>
<thead>
<tr>
<th>Code</th>
<th>Age (Years)</th>
<th>Sex</th>
<th>Position</th>
<th>Years Worked</th>
<th>Education</th>
</tr>
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<tbody>
<tr>
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<td>Male</td>
<td>Caregiver</td>
<td>22</td>
<td>Certified caregiver</td>
</tr>
<tr>
<td>2</td>
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<td>Male</td>
<td>Caregiver</td>
<td>13</td>
<td>Certified caregiver</td>
</tr>
<tr>
<td>3</td>
<td>43</td>
<td>Male</td>
<td>Care manager</td>
<td>24</td>
<td>Bachelor’s degree</td>
</tr>
<tr>
<td>4</td>
<td>43</td>
<td>Male</td>
<td>Caregiver</td>
<td>20</td>
<td>Certified caregiver</td>
</tr>
<tr>
<td>5</td>
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<td>Caregiver</td>
<td>35</td>
<td>Certified caregiver</td>
</tr>
<tr>
<td>6</td>
<td>53</td>
<td>Female</td>
<td>Care manager</td>
<td>32</td>
<td>Bachelor’s degree</td>
</tr>
<tr>
<td></td>
<td>Mean ± (S.D)</td>
<td>47.3± (6.2)</td>
<td>-----</td>
<td>24.3± (8.1)</td>
<td>----</td>
</tr>
</tbody>
</table>

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of a coordinator who oversaw the program. Dividing the participants into two groups (N = 10), and designing a more structured VR activity curriculum for all caregivers and participants was reported to be beneficial.

- A need for technical support. Due to restricted knowledge and experience of the caregivers in handling the equipment, the need for additional technical support was identified. Therefore, an occupational therapist that was highly trained in operating the VR equipment was assigned to make weekly visits to the facility. She provided more substantial technical and professional support than the initially planned telephone support with and physical support only "on demand."

The focus group participants agreed that initial training followed by technical and professional support is necessary for implementing any strategy that relies on caregiver intervention. One of the clearest messages was with respect to the importance of the instruction: "... without the instruction we could not have gotten far . . . ."

The participants agreed that, under these conditions, the VR intervention should become part of the regular residential routine.

The caregivers emphasized the importance of both technical and administrative support, such as purchasing the appropriate equipment, allocating a room for the intervention, integrating the intervention into the work roster, and, of course, training.

**Technical aspects.** The technical difficulties noted by the caregivers focused on various levels of the VR system setup and operation. Caregivers reported technical problems with the operation of the games, some of which occurred only once, and other problems that recurred in certain games. The ability of the caregiver to deal with the problem depended on the complexity of the problem, the technical skill of the caregiver, and the immediacy of guidance from the support person. The provision of immediate guidance (eg, how to solve specific problems), whether by phone or in person during the weekly visits, greatly improved the caregivers' ability to deal with the various problems. Another difficulty arose from the lack of a simple setup to select and run games. Several suggestions were made to improve the VR system's usability (eg, shortening the time between selection and onset of each VR game). Finally, the VR system requires a specific environment: a room large enough to accommodate the computer, large monitor, camera, participant (often in a wheelchair), and caregiver operator. The room also must have sufficient light to operate the video capture equipment.

**Appropriateness of VR intervention program for this population.** A question arose as to whether the effect of the VR intervention was due, in part, to the fact that the participating residents had more opportunities to leave their dormitories and get individual attention, a phenomenon that was not typical of the regular daily routine which involved mostly group activities. For example, in response to the question with respect to the influence of the use of the VR intervention program, 2 caregivers remarked: "... just the fact that they were taken out of the unit for something else, this change is also good for them . . . ." and "... just the fact that we take him, and he isn't in a group, just the fact that you move him. Today the caregivers can't (since they work with 6-12 residents minimum) give personal attention . . . ."

However, the unique effect of the VR activity was further elaborated upon in response to the question that compared the benefits of the VR intervention to other activities such as going out for a walk or working in the garden. A caregiver commented:

... If I work with the resident, if he isn't active in the dormitory . . . nothing . . . apathetic, and I take him there (to the VR room) and he stands opposite the camera and does those motions, moves himself and sees himself move on the television, that's a sign that it means something for him . . . that it's more that the individual part of the personal attention . . . or of something new. But something in the system itself that causes him to make some response . . . that it attracts him and caused him to make the movements that he is making for the first time.

**CONCLUSIONS**

The purpose of this study was to evaluate the feasibility of a VR exercise intervention for adults with severe IDD implemented by in-house staff. According to reports by caregivers, participation in the selected virtual games with their associated physical and cognitive demands was found to be motivating for many but not all participants. Participation in energetic leisure activities by people with severe intellectual and physical disabilities tends to be extremely limited, and they are often found to be involved in more sedentary activities such as watching television and modified arts and crafts. Our findings suggest that, when provided with accessible and appropriate leisure opportunities, such as the VR game environments as adapted for the current study, participants with severe intellectual and physical disabilities are able to become more active through physically demanding leisure activities. Our findings provide support for Gignac and Temple's recommendations that a key element in involving individuals with IDD in exercise programs is the use of activities that attract them, that they find reinforcing, and that are of value for them. In the current study, VR served as a medium that appears to meet all of these requirements. The ability of VR to enhance motivation to take part in an enjoyable physical activity plays an important role in achieving greater participation in physical fitness programs by individuals with IDD.

As demonstrated by the results of the current study, despite certain technical problems, the in-house caregiver staff was able to help residents with IDD participate in and enjoy physically challenging activity. This technology thus widens the spectrum of accessible leisure activities for individuals at a severe level of IDD. Integrating a VR program as part of the routine schedule of a residential facility was found to be feasible and beneficial to participants and staff members alike.

**ACKNOWLEDGMENTS**

The authors thank the staff and residents of the all residential settings taking part in the series of experiments. We also thank those in the administrative level of all these settings for their assistance in designing, supporting, and running the intervention programs. We gratefully acknowledge the support of the Israeli Ministry of Social Affairs and Services, Division of Services for Individuals with IDD. The authors thank the Shalem Foundation for their financial support.

**REFERENCES**


Motor Retraining in Virtual Reality:
A Feasibility Study for Upper-Extremity Rehabilitation in Individuals With Chronic Stroke
Grigore Burdea, PhD, Daniel Cioi, PhD, Joseph Martin, Bryan Rabin, Angad Kale, and Phillip DiSanto

BACKGROUND AND PURPOSE
Individuals with stroke can improve upper-extremity function in the chronic phase, providing rehabilitation is intensive, attended, and of sufficient duration. Virtual reality has been used in motor retraining; however, off-the-shelf game consoles may not be appropriate for those with marked motor impairment and high finger or arm spasticity. The objective of this study was to investigate the feasibility and effects of training in individuals with chronic stroke who are either high-functioning or low-functioning, and also spastic.

Case Descriptions. Four volunteers, 3 men and 1 woman, were recruited from a local aphasia support group. All individuals were chronic post stroke with right-side hemiplegia. Training took place at the Tele-Rehabilitation Institute at Rutgers University. The intervention was performed on the Rutgers Arm II, a prototype training table that senses supported arm movement and grasp strength and tilts to resist or assist reach. Participants played games that adapted automatically to each individual’s motor abilities. The games were practiced over 6 weeks, 3 sessions every week, with sessions lasting up to 1 hour. The 4 participants were evaluated by a senior physical therapist before, immediately following, and 6 weeks after the intervention. No occupational or physical therapist was present during the training sessions.

Outcomes. The primary outcomes were changes in the affected upper-extremity subset of the Fugl-Meyer test and self-reported changes in the participants' activities of daily living. Improvements in active range of motion and grasp strength were secondary outcomes. All individuals improved in Fugl-Meyer scores and retained these gains (participant 1, 45 to 50; participant 2, 16 to 22; participant 3, 12 to 20; participant 4, 42 to 51). Participants 2 and 3, who presented with severe motor impairment, began using their affected arms in daily activities subsequent to training. All participants improved in their shoulder, elbow, and finger flexion active range of motion. Remarkably, participants 2 and 3, who were unable to exert force in grasping or pinching pre-training, could now do so and retained these gains at 6 weeks following the intervention. Well-being and mood seemed to improve in all participants.

Discussion and Conclusion. Results show that motor retraining in virtual reality is feasible, well-tolerated by participants, and benefitting them. The Rutgers Arm II system was able to train participants, who varied greatly in their degree of motor impairment, but without a clinician being present. The present study contributes to the body of knowledge on novel virtual rehabilitation interventions for the upper extremity.

Key Words: Upper extremity, Virtual reality, Sustained grasp, Rutgers Arm, Stroke.

BACKGROUND AND PURPOSE
The direct and indirect costs associated with head injuries from stroke or trauma approach $200 billion a year in the United States alone.1,2 At the completion of standard-of-care motor retraining (6 to 9 months post stroke), individuals present with varying levels of upper-extremity (UE) functional recovery. Their recovery depends not only on the type and severity of the initial injury to the central nervous system, but also on the intensity and length of rehabilitation subsequently provided. Diminished upper-extremity function in the chronic phase post stroke negatively affects the individual’s degree of independence in activities of daily living (ADLs), mental health, and social life.

The person’s motivation to improve and the important role knowledge of results feedback plays in motor relearning3 both point to the need to investigate virtual reality as an element of therapy. Virtual worlds4 have been shown to provide rich knowledge of results and to increase motivation if tailored to the individual’s abilities.5,6 Virtual reality previously has been investigated as a way to conduct motor rehabilitation following a stroke. Merians and colleagues7 used a combination of real and virtual object manipulation tasks to train 3 individuals who were in the chronic...
phase following stroke. During 2 weeks of daily exercises (10 sessions), the participants trained their range, speed, and fractionation in the affected fingers and thumb, as well as grasping force. All 3 participants improved in grasping strength (as measured by a dynamometer), and in finger/thumb range of motion. This translated to better performance on the Jableen test of hand function for 2 of the individuals. Holden and colleagues found that it was possible to train participants at a distance, when the physical therapist interacted with the individual in a shared virtual reality. In that study, 11 participants who were in the chronic phase following stroke participated in thirty 1-hour training sessions in virtual reality, resulting in significant improvement in UE function as measured by standard clinical tests (Fugl-Meyer test of motor recovery, Wolf motor test, and shoulder strength). Rand and colleagues investigated the use of a virtual mall (or "VMall") together with a video capture system as an intervention tool to train the weak UE of individuals post stroke. Participants received ten 1-hour treatment sessions in their homes, over a period of 3 weeks, which resulted in improved clinical measures as well as increased use of the weak arm in ADLs. A controlled study of subacute individuals (fewer than 12 months post stroke) showed that the addition of 30 minutes per day of PlayStation-based videogame intervention to the conventional therapy received by the experimental group produced more functional independence, compared to participants in a control group who only watched the games in healthy players. It follows that individuals with disabilities who play the Wii unsupervised and intensely may be at increased risk of complications.

In order to successfully provide motor retraining on a game system that can accommodate individuals with either low or high levels of UE function, without the risk of tendonitis, and without requiring dexterity or weight-bearing ability in the affected arm, we have developed the Rutgers Arm II. The prototype system uses infrared tracking of arm movement; gravity modulation; combined strengthening of shoulder, arm, and hand; and custom virtual reality games that have attributes for motor rehabilitation. This article reports on 4 participants who are in the chronic phase post stroke: 2 who are very low-functioning and 2 with moderate-to-severe dexterity challenges in using his affected UE in daily activities. The objectives of this study were to: (1) examine changes in UE function following training on the Rutgers Arm II and the retention of these gains; (2) determine if UE motor gains in virtual reality map to changes in ADLs and improved patient morale; and (3) determine if training on this computerized system is possible without the physical therapist being present during training (either locally or remotely). We hypothesized that computerized virtual reality-based systems and training methods such as the one described here, if proven successful, may be one way to alleviate the burden on society, by training individuals who are in the chronic phase following stroke regardless of their level of function. However, implementing dedicated VR motor rehabilitation systems may require additional training and credentialing for physical and occupational therapists. This may be accompanied by a change from the current "hands-on" approach in therapy to a computer-mediated one.

### CASE DESCRIPTIONS

#### Participants

Four individuals, 3 men and 1 woman, participated in the intervention (Table 1). All had had a left hemisphere stroke that had occurred between 12 months and 35 months prior to the study. The participants were recruited from the aphasia support group at Kean University. They were receiving speech therapy (and were allowed to continue it during this study), but none were receiving occupational or physical therapy at the time. Since our VR system prototype did not use voice input, speech therapy overlapping the study was not considered a confounding factor. The 4 participants received medical clearance from their attending physicians and subsequently signed a consent/assent form approved by Rutgers University Institutional Review Board. The individuals were evaluated and trained at the Tele-Rehabilitation Institute at Rutgers University in fall 2009.

Participant 1, a 57-year-old man, had experienced a left hemisphere ischemic stroke 35 months prior to the study. After the stroke he underwent 38 days of inpatient physical and occupational therapy, followed by 9 months of outpatient physical and occupational therapy and a longer period of speech therapy. This participant had major loss of touch and loss of proprioception. He was taking antidepressant and antiseizure medication at the time of the study and was walking with a cane. At the start of the study his affected handgrip strength was 123 N, pulp-to-pulp pinch strength (thumb-index) was 21 N, key pinch (thumb-index) was 55 N and 3-tip pinch (thumb-index-middle) was 30 N. He reported having moderate-to-severe difficulty in using his affected UE in daily activities.

Participant 2, a 46-year-old woman, underwent a hemorrhagic stroke 14 months prior to the study. She received 3 weeks of inpatient physical and occupational therapy, followed by 8 months of outpatient physical and occupational therapy. She was taking anti-depressant and antiseizure medication and did not practice physical exercise prior to the study. Her affected arm presented with high spasticity of the elbow and fingers and had low blood circulation; the arm felt cold to the touch and looked bluish in color. She could walk independently, but was unable to grasp or pinch with her affected hand. She was also unable to use her arm in any daily activities.
Participant 3 was a 62-year-old man who had sustained a left-side ischemic stroke 12 months prior to the study. He was in intensive care for 32 days, followed by 6 weeks of inpatient physical, occupational, and speech therapy. After discharge from the hospital, this participant received 8 months of outpatient physical and occupational therapy. He was taking antidepressant and memory improvement medication. The man was able to walk with a quad cane for a short distance, but chose to be pushed in a wheelchair. As with participant 2, he was unable to grasp or pinch with his affected hand. He kept his affected arm in a sling, and his spouse reported that he was not using his affected arm at all. As a result, he had low blood circulation and weakness in the affected UE.

Participant 4 was a 70-year-old man who had experienced a left-side ischemic stroke 14 months prior to the study. He was in intensive care for 6 weeks, followed by 2 months of inpatient physical, occupational, and speech therapy. After discharge from the hospital, this participant received 30 days of outpatient physical and occupational therapy. The man had sustained a heart attack approximately 10 years prior to the study and had a stent implanted. At the time of the study he was taking medications to lower his blood pressure and prevent blood clots. He was ambulating independently but had severe aphasia and spoke no English. His affected handgrip strength at the start of study was 49 N, and his pulp-to-pulp, key, and 3-tip pinch strengths were 9 N, 12 N, and 6 N, respectively.

### Data Collection Instruments and Methods of Collection

Data were collected at evaluation sessions before, immediately following, and 6 weeks after the intervention and transparently during each training session. Evaluation sessions primarily involved collection of clinical motor and functional UE measures and were performed by a senior PT. While she was not present during the training sessions, she was aware of the purpose of the study and the therapy methodology, which is a limitation of this study. Another limitation is the lack of data on the participants’ central vision system abilities. Because visual feedback plays a crucial role in VR-based training protocols, the researchers should have accounted for possible visual cut, visual neglect, other degradations to the participants’ visual acuity, or their possible visuomotor associative impairments. Instead the researchers relied on participants’ reporting no visual channel or visuomotor associative impairments before the study, which is a limitation.

The primary standardized measures used in this study were the UE subset of the Fugl-Meyer (FM) test of hand function, and the changes in activities of daily living (ADLs) self-reported on a standardized questionnaire. The secondary measures were the affected UE active range of motion, measured with mechanical goniometers, and the affected hand grasp strength and finger pinch strength measured with a mechanical Jamar dynamometer and a mechanical pinch meter, respectively. A limitation of these measurements is the static nature of the collected data versus the dynamic changes in forces needed in skilled ADLs. Similarly, goniometer readings are static, measuring joint values (range), but not the time taken (velocities or accelerations) to actively achieve those joint values.

### Intervention

**Computerized system.** Participants sat against a custom low-friction square table with 1 corner cut out, facing a large display and resting their affected forearms on a low-friction sensing support. The support had embedded electronics to detect grasp strength, as well as a micro-switch to detect when the elbow was lifted off the table. A combination of an overhead infrared camera, light-emitting diode (LED) markers at the corners of the table and on the forearm support, and image analysis software allowed a personal computer (PC) to detect arm movement in the plane of the table. A separate LED attached to the contralateral shoulder was used to detect unwanted trunk rotation. The table could tilt to resist or assist movement. The PC rendered a number of custom video games designed specifically for upper-extremity rehabilitation. The participant controlled a hand avatar, which responded in real time to supported arm movement, and which closed its virtual fingers in response to the grasping of the rubber bar on the forearm support. At the start of each training session the participant was asked to baseline the arm reach area and maximum grasp (Figure 1). The arm reach and hand grasp baselines were used to adapt the games to each participant, allowing even those with very small arm movement to be trained. Games required either momentary grasp of 25% of maximum grasp or sustained grasp at 10% of maximum. These thresholds were chosen to prevent the fatigue and discomfort observed in earlier trials.

Four Java 3D™ games were custom-designed to support the clinical function, allowing better control on levels of difficulty and better adaptability to each participant com-

<table>
<thead>
<tr>
<th>Table 1. Case Characteristics Pre-traininga</th>
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<tbody>
<tr>
<td><strong>Case</strong></td>
</tr>
<tr>
<td><strong>Age (years)</strong></td>
</tr>
<tr>
<td><strong>Gender</strong></td>
</tr>
<tr>
<td><strong>Type of stroke</strong></td>
</tr>
<tr>
<td><strong>Time since stroke (months)</strong></td>
</tr>
<tr>
<td><strong>Motor impairment level</strong></td>
</tr>
<tr>
<td><strong>Initial Fugl-Meyer UE score subset (66 score max)</strong></td>
</tr>
<tr>
<td><strong>Co-morbidities</strong></td>
</tr>
<tr>
<td></td>
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<tr>
<td></td>
</tr>
<tr>
<td><strong>Ambulation</strong></td>
</tr>
<tr>
<td><strong>Language</strong></td>
</tr>
</tbody>
</table>

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pared to off-the-shelf games. The Breakout 3D game (Figure 2) required participants to destroy an array of cubes by bouncing a ball off a paddle avatar controlled by the affected arm. Faster balls and smaller paddles increased game difficulty, as did the table tilt and the requirement to grasp as a condition of bounce. The Pick-and-Place game (Figure 3) trained UE motor control, shoulder and grasp strength, and coordination. The participant was asked to closely follow a prescribed path, which varied depending on the placement of a virtual ball and a target square on the screen. Each pick-and-place iteration produced a trace of the actual movement overlaid on the prescribed path. Summative knowledge of results (KR) was provided at the end of a number of pick-and-place repetitions, in the form of a bundle of traces and numerically by the path error representing the closeness of the actual path to the prescribed one. The Treasure Hunt game (Figure 4) depicted an island on which a number of treasures were buried within an area delineated by a wall of boulders. The participant controlled a shovel avatar by grasping above a specific threshold and dug out as many treasures as possible in the allowed amount of time. Depending on setting, sand storms covered some of the already dug-up treasures, requiring more arm movement to dig them up again. The Card Island game was aimed at training short-term memory, visual memory, grasp coordination, shoulder strength, and arm endurance. The game presented the same island, but this time showed an array of playing cards arranged face down. The participant was required to overlap a given card with the hand avatar and then squeeze to turn it face up. If the individual selected 2 matching cards, the pair of cards disappeared from the island. To motivate participants, the game was customized with cards that had images of pets, relatives, or other scenes of interest to each individual. The game’s difficulty increased when more cards were presented. Further details on the computerized system setup can be found in Burdea et al.
Table 2. Changes in Upper-Extremity Fugl-Meyer Test Scores and in Activities of Daily Living Over the 6 Weeks of Training and at 6-week Follow-up

<table>
<thead>
<tr>
<th>Case 1</th>
<th>Case 2</th>
<th>Case 3</th>
<th>Case 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>PR</td>
<td>PO</td>
<td>FU</td>
<td>PR</td>
</tr>
<tr>
<td>Fugl-Meyer (max score 66)</td>
<td>45</td>
<td>48</td>
<td>50</td>
</tr>
<tr>
<td>Activities of Daily Livinga</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Any of your usual work, household activities</td>
<td>2</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>Your usual hobbies, recreational or sporting activities</td>
<td>1</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>Lifting a bag of groceries to waist level</td>
<td>2</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>Lifting a bag of groceries above your head</td>
<td>1</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>Grooming your hair</td>
<td>3</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>Pushing up on your hands (eg, from bathtub or chair)</td>
<td>3</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>Preparing food (eg, peeling, cutting)</td>
<td>1</td>
<td>1</td>
<td>3</td>
</tr>
<tr>
<td>Driving</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Vacuuming, sweeping, or raking</td>
<td>3</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>Dressing</td>
<td>4</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>Buttoning clothes</td>
<td>2</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>Using tools or appliances</td>
<td>1</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>Opening doors</td>
<td>3</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>Cleaning</td>
<td>3</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>Tying or lacing shoes</td>
<td>1</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>Sleeping</td>
<td>5</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>Laundering clothes (eg, washing, ironing, folding)</td>
<td>3</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>Opening a jar</td>
<td>2</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>Throwing a ball</td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>Carrying a small suitcase (with affected limb)</td>
<td>1</td>
<td>5</td>
<td>5</td>
</tr>
</tbody>
</table>

Abbreviations: PR, pre-study; PO, post-study; FU, follow-up.

*Rated on a scale from 1 to 5: 1 = extreme difficulty or unable to perform; 2 = quite a bit of difficulty; 3 = moderate difficulty; 4 = a little bit of difficulty; 5 = no difficulty.

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Experimental protocol. The therapy on the Rutgers Arm II system consisted of 18 training sessions over 6 weeks (3 sessions per week), with a duration that increased from 40 minutes of actual play (week 1) to 50 minutes (week 2) to 1 hour (weeks 3 to 6). The intensity of training was also increased from training on a horizontal table (weeks 1 and 2), to training on a table tilted up at 10° (week 3) and at 20° (weeks 4 to 6). Each session consisted of a baseline exercise followed by a sequence of exercises (Pick-and-Place, then Breakout 3D, followed by Treasure Hunt and Card Island) and the sequence repeated as needed to produce the prescribed session duration. The level of exercise difficulty was increased from easier games in week 1 (no grasp required) to momentary grasp being required in weeks 2 to 4 and sustained grasp in weeks 5 and 6. Difficulty was increased further by making the balls in the Breakout 3D game travel progressively faster, by making the targets smaller in the Pick-and-Place game, and by introducing progressively more frequent sand storms in the Treasure Hunt game.

At the end of training sessions in weeks 5 and 6, participants were asked to briefly practice functional tasks, such as carrying a small suitcase, put on and zip their jackets prior to exiting the lab, help their caregivers put on jackets, and to open the laboratory door with the affected arm.

OUTCOMES

Participant 1
Upper-extremity Fugl-Meyer score prior to training was 45 points, representing moderate motor impairment. The participant did not need assistance during training and instead practiced against a 25° table tilt in week 6. He was able to do so without a problem for the prescribed 1 hour of therapy per session. Post training, the participant’s Fugl-Meyer score increased to 48 (7% improvement) (Table 2). His independence in ADLs, as reported on the standardized questionnaire, increased in 14 activities at the end of the intervention. This participant now was able to hold a spoon, as his grip geometry resembled that which he used when grasping the rubber pear of the forearm support. Subsequently he began feeding himself with a spoon using his affected arm (Figure 5). The individual now could hold his wife’s jacket, something that, according to her, was the first time he had done in the 3 years following his stroke.

Post training, the participant had statistically significant increases in affected UE active range of motion in shoulder flexion (9%), shoulder abduction (25%), elbow pronation (18%), elbow supination (50%), and pinkie proximal-metacarpal-phalanx (PMP) joint flexion (11%). His affected hand pinch strength, measured with a mechanical pinch meter, had increased 57% for pulp-to-pulp (thumb-index) pinch and 36% for 3-tip pinch (thumb-index-middle). At follow-up, the participant’s UE Fugl-Meyer score had increased further to 50, 11% higher than before therapy. He was even more independent than he was before training, performing 18 of the 20 ADLs in the set. The individual spontaneously had begun to use the affected arm in shoveling snow (Figure 6), an activity he had not performed with the affected arm since his neural accident 3 years prior. At follow-up, he maintained some of the gains in active range of motion: shoulder abduction had increased by 37%, elbow pronation by 27%, and elbow supination by 53%. His index and pinkie could flex 21% and 11% more, respectively, than before training. He now had normal PMP extension in middle and ring fingers. Gains in pinch strength were also maintained, with pulp-to-pulp pinch being 48% stronger and 3-tip pinch 53% stronger than before training.

Participant 2
Participant 2 was very low-functioning, with marked motor impairment and a pre-training UE Fugl-Meyer score of 16. For her the table was tilted down 15° weeks 2 to 5 to facilitate movement away from the trunk, and it was horizontal in weeks 1 and 6. Since she had difficulty with shoulder abduction and elbow extension due to spasticity, she was assisted and constantly encouraged by the laboratory technical staff. Participant 2 was also constantly reminded to relax, something that helped her extend the elbow further. The speed of the balls in Breakout 3D was kept at the slowest setting, allowing this participant to play and enjoy that game. There was however no grasp requirement in the games for this participant, due to her high finger spasticity. Her post-therapy Fugl-Meyer score was 18, an increase of 12%. Before training, the participant was unable to perform any of the ADLs in the set, except for sleeping. She had extreme spasticity in her shoulder and fingers, was unable to extend the fingers of her affected hand, and had no strength in either gripping or pinching. After training, she was able to open doors (Figure 7), although with significant difficulty. She had statistically significant increases in active range of motion of her affected shoulder and finger exten-
sion. Her shoulder extension range increased 100%, from 10° to 20°, her shoulder internal rotation range was 21% greater, her elbow flexion improved by 14%, her elbow extension was increased by 23%, and her elbow pronation improved by 40%. Her PMP flexion ranges improved for all fingers (thumb, 27%; index finger, 35%; middle finger, 29%; ring finger, 26%; pinkie finger, 50%). Remarkably, after the intervention participant 2 was able to apply force with her affected hand (grip = 18 N; pulp-to-pulp pinch = 16 N; key grip pinch = 10 N), but still was unable to perform a 3-tip pinch. At follow-up, the individual’s Fugl-Meyer score had increased further to 22 (37% more than before training). Her independence in ADLs continued to grow: She was now able to lift a bag, dress, launder clothes, and open a jar, having quite a bit of difficulty in all these activities. Participant 2 experienced a marked decrease in her elbow spasticity, which diminished further at follow-up. Due to performing more activities using her affected arm, her blood circulation (based on skin color and temperature) had visibly improved. The individual reported having only moderate difficulty in opening doors. At follow-up she continued to improve in active range of motion of her affected arm and fingers. Compared to before training, her active range of motion had increased 150% in shoulder extension, her shoulder abduction had improved from 0° to 24°, elbow extension had increased 40%, and elbow pronation improved 106% (from 35° to 72°). Although she was still unable to extend her fingers, flexion improved further. Compared to pre-training, values of her PMP joint flexion were better by 66% for thumb, 67% for index finger, 40% for middle finger, 40% for ring finger, and 109% for pinkie finger. She continued to be able to exert force in grip (15N) and pulp-to-pulp pinch (12N), while her key pinch grew by 110% compared to post-training measurements (from 10 N to 21 N).

**Participant 3**

Participant 3 was low functioning, with marked motor impairment and a pre-training Fugl-Meyer score of 12. Prior to the study, he did not use his affected arm in any activities of daily living (Table 2). His elbow and fingers were spastic, so he was unable to extend his fingers or to exert any force in either grip or pinch. Due to his marked motor impairment, participant 3 was unable to train at 20° of table tilt, so his training in weeks 4 to 6 was conducted at 15° of table tilt, 1 hour per session. This participant had difficulty with shoulder abduction and elbow extension and was assisted and constantly encouraged by the laboratory technical staff. Post training, his Fugl-Meyer score had increased 5 points (42% better). Participant 3 had stopped holding his arm in a sling and instead (with encouragement) had begun using his affected UE in ADLs. He had only moderate difficulty lifting a bag, opening a door (Figure 8), or carrying a small suitcase. Overall, the individual now could perform 8 activities of the standardized set reported in Table 2. Due to an increase ADLs post training, participant 3 had improved blood circulation in his affected arm (based on skin color and temperature). He had a remarkable increase in active range of motion. Compared to pretraining measurements, he was able to extend his shoulder 40% further, and shoulder abduction had increased 33%. The participant was now able to extend his elbow fully (from 58° before training to 0° post training). While still unable to extend fingers, his finger PMP joint ranges in flexion had improved 62% for thumb, 20% for index finger, 12% for middle finger, and 8% for ring finger. Post training, participant 3 was able to exert force in all measured grasping configurations (grip = 16 N; pulp-to-pulp pinch = 19 N; key pinch = 27 N; and 3-tip pinch = 19 N, with thumb, index, and middle fingers). At the 6-week follow-up evaluation, participant 3’s Fugl-Meyer score had increased to 20, a 67% improvement over his pre-training score. The individual had lost a bit of independence in daily use of his affected arm, but was still able to perform 6 of the 20 ADLs in the standardized set. Due possibly to psychological causes, this participant had returned to the intermittent use of a wheelchair; something he had stopped doing during training. He maintained gains in active range of motion and being able to exert force with his affected hand. Compared to pre-training measurements, at follow-up his shoulder flexion range was 22% greater, shoulder extension increased 37%, and shoulder abduction had improved 33%. He maintained gains in elbow active extension, which was now 5°, compared to 58° before training. The participant’s elbow pronation range was 16% greater, and supination had increased from 0° before training to 49° at follow-up. While still unable to extend fingers in his affected hand, he maintained gains in finger PMP joint flexion range compared to pre-training measurements (40% greater for thumb, 11% for index finger, and 14% for middle finger). The participant’s ability to ex-
The participant's thumb active flexion range of motion had improved substantially post training. Participant 4's joint active range of motion had improved 38% for shoulder extension, 18% for elbow pronation, and 13% for elbow supination. The participant's thumb active flexion range had improved 11% for the PMP joint and extension went from 13° to 0° (normal). His range of overextension had increased from 2° to 45° for the index PMP joint, from 10° to 18° for the middle finger, and from 19° to 32° for the ring finger. The individual's force exertion capacity in the affected hand had improved substantially post training (63% for grip strength; 50% for key pinch; and 266% for 3-tip pinch). At follow-up, participant 4 had maintained gains in UE Fugl-Meyer score, which was now 51 (9 points higher than at pre-training, a 21% improvement). He reported being able to perform 15 of the 20 ADLs in the set. However, in 6 tasks he reported having more difficulty than at the completion of training. According to the participant's spouse, despite the research team's advice to keep using his arm more at home, he was not doing so. Compared to his pre-training active range of motion, he had maintained statistically significant gains in shoulder extension (28%) and elbow pronation (21%). The individual also had maintained gains in thumb and middle-finger PMP joint flexion (20% and 18%, respectively). He still was overextending the index to 15° and ring finger to 45°. The participant had maintained his gains in force exertion, which, compared to pre-training measurements, had increased 43% for grip strength, 77% for pulp-to-pulp, 175% for key pinch and 216% for 3-tip pinch.

**DISCUSSION AND CONCLUSION**

**Training Results**

Even though all 4 participants began with different degrees of impairment, after the intervention functional outcomes had improved for each individual with respect to his or her initial level of activity. All were able to play the games with the affected UE, we believe due to the capability of the experimental system to customize the intervention to each participant's functional level at each training session. We assumed that participants with the greater levels of impairment most likely would not have been able to use off-the-shelf gaming systems for therapy, and our study results showed that it was feasible, and indeed beneficial, for them to train on the Rutgers Arm II system. At follow-up, 6 weeks after the end of therapy, all cases had continued to improve their Fugl-Meyer scores by as much as 5 to 9 points. This positive outcome exceeds results from other studies using virtual reality-based training and gravity unloading. At follow-up, participant 1 had continued to improve in his degree of independence performing daily tasks (Table 2). Except for driving and sleeping, he had improved in all standardized tasks. Participant 2 had made further gains in the use of her affected arm, while participant 3 had lost some gains, but still was using his affected arm in 5 tasks, as compared to none before training. All participants had maintained gains in active range of motion in their affected UE joints. All participants improved in finger flexion, a movement that was practiced in the games. Naturally, enthusiasm is tempered by the small number of participants in this study, and further controlled trials are needed to determine the most effective training methods or systems. Furthermore, in some cases there were deviations from the protocol due to individual limitations, or better-than-expected abilities. The impact of these protocol changes on the results will need to be examined further.

Grasp training results were also very good: Participants 2 and 3, who were unable to grasp or pinch prior to training, were now able to do so. All participants improved in pinch strength (something trained during the games) and participant 3 improved in grasp strength, with gains maintained at follow-up. These results were much better than those obtained in our prior study where grasp strength improvements were mixed. We attribute the better results in the present study to longer training (6 weeks versus 4 weeks in the prior study) and to the requirement of sustained grasp at higher game difficulty levels. Maintaining grasp and pinch strength improvements at follow-up in the absence of training may also have been due to an increased use of the affected UE at home, which the participants were encouraged to do.

**Changes in Activities of Daily Living**

The self-reports in the standardized questionnaire in Table 2 show that the 6 weeks of training on the Rutgers Arm II prototype were associated with improvements in ADLs for all participants. These included the ability to use tools and lift a bag of groceries or a suitcase (participants 1, 3, and 4). Participant 2, who had a greater degree of impairment, at follow-up was able to lift a bag, dress, open a jar, and open a door with difficulty, while she had been unable to do any of these activities before training.

The 4 participants were in the chronic phase post stroke and were not undergoing other physical or occupational therapy during the study. We argue that the clear gains after training can be attributed both to the intensive use of the Rutgers Arm II system during training and increased use of the affected arm in ADLs. We assume that the participants gained confidence to perform such tasks when they first practiced them under supervision at the completion of training sessions in weeks 5 and 6. It may be possible that some of the requested ADLs were tasks the participants did not know that they could do. However, the connection with our training and encouragement and the resulting improvement in arm use cannot be ignored. While this is a small study, and each participant had individual characteristics and family environment, our findings nonetheless point to the continuum that has to exist between clinic and home. The best results were obtained by the participant who had an encouraging caregiver (based on team observations during training sessions), while home conflicts clearly did not help. These findings are in line with studies showing that strong social support improves outcomes, especially in patients with severe physical or cognitive deficits.

**Participants’ Acceptance of the Technology**

All participants were compliant with the protocol. They either attended the therapy and evaluation sessions on time or made up the training sessions they missed. They were engaged in the training, as attested to by the length of training which they completed (up to 1 hour of actual exercise per session). No participants complained about the intensity or length of training. Participant 3 volunteered that he wanted to train again on the system if given the chance. These findings are in line with other studies which describe...
good engagement with and acceptance of VR-mediated UE training post stroke. Importantly, unlike our earlier study, the participants trained without a physical or occupational therapist being present. Nevertheless, we did not observe any diminished interest or diminished attention to games, nor a diminished intensity of training in the absence of a therapist in the room.

Changes in Participants’ Well-Being and Morale

No standardized evaluation was done to quantify the participants’ improvement in cognition, well-being, and morale. Nonetheless, certain changes were apparent to the research team. Prior to training, 3 of the participants exhibited negative behavior, including a lack of smiling and cursing their caregivers. As training progressed, their spirits improved: They started smiling, being nicer to their caregivers, wearing more colorful clothes, and attempting to do new tasks with their affected arm. These changes need not be attributed to the technology or therapy they received. They could be associated with more self-confidence (in winning the games or doing tasks with their affected arm) and to the increased attention they received. To clarify these findings, we plan to add depression and cognitive evaluations in future studies.

The present study contributes to the body of knowledge that indicates that long durations of motor retraining on a VR system are feasible for low-functioning as well as higher-functioning patients who are in the chronic phase post stroke. Furthermore, the training in the present study was done without a physical or occupational therapist present, which has implications for cost and therapist availability as limitations to conventional therapy. Longer durations of training may be possible, once the computer can be relied upon to assist with repetitive task training.

While a PT or OT was not involved in the motor retraining in this study, the 4 participants occasionally needed the assistance of another person. Although this assistance and monitoring was performed by the technical staff in this research, it is a role that in the future may be covered by a physical therapist or occupational therapist assistant. Our experience was that the system was easily understood by the clinician, due to its interactive graphical user interface. If enough care is paid in the design of new virtual rehabilitation systems to ensure clear instructions, we can envision a new type of therapist emerging. This “virtual therapist,” will be a skilled clinician that administers VR interventions for several patients with various impairments and functional levels, either locally or remotely.

ACKNOWLEDGMENTS

The research reported here was made possible by a grant from the Coulter Foundation and the generosity of Cristian and Andreea Frăncu. Moustafa AbdellBaky provided technical support. Maeve Holenski, PT, performed all the clinical evaluations of the participants. Mary Jo Santo Pietro, PhD, and Wendy Greenspan, MA, of the Institute for Adults Living with Communication Disabilities at Kean University were instrumental in patient recruiting.

REFERENCES

Background and Purpose. Breathing often becomes impaired or difficult after surgeries or in the presence of disease or injury. Breathing exercises are imperative to ensure the health of lungs. Despite this, patient adherence with breathing exercise regimes is not commonly assessed. There is a need for breathing exercise programs that will motivate patients to perform breathing exercises and provide individualized challenge levels and quantitative measurement of progress and adherence. An incentive spirometer apparatus measures the volume of air inspired and expired, and provides visual feedback while performing breathing exercises. The development of a game-based incentive spirometry system aims to overcome the typical exercise inertia to motivate patients to perform breathing exercises and to provide individualized challenge levels and quantitative measurement of progress and adherence.

Method/Model Description and Evaluation. This research involves an interdisciplinary team of physical therapists, game designers, engineers, and computer scientists. The iterative game-design process was used to develop 6 prototype games. The games underwent a series of user tests. Two game prototypes underwent further refinement and user testing with a sample of physical therapists and people with disabilities. Game usability was assessed and feedback was provided on the incentive spirometry device, game play, system goals, and potential improvements.

Outcomes. Initial assessment of the prototype system indicated that both physical therapists and potential users enjoyed the incentive spirometry game and encouraged further development. The potential end users indicated their excitement about the concept of using games for breathing exercises and look forward to the completed game.

Discussion and Conclusions. Following further refinement and development, the game-based breathing system will be assessed for effectiveness in improving patient adherence and reducing pulmonary complications, compared to standard treatment techniques. The integration of medical devices with video game technologies offers great potential to improve assessment and treatment tools and patient adherence with physical therapy.

Key Words: Virtual reality, Breathing exercises, Exercise adherence, Respiratory, Game-based rehabilitation.

BACKGROUND AND PURPOSE
Breathing exercises are used extensively within a range of patient populations for prophylactic care and treatment of respiratory complications. Incentive spirometry (IS) offers visual feedback for patients while performing breathing exercises. Incentive spirometry is a widely used, accepted technique for the prevention and treatment of respiratory complications in a range of patient populations, including postoperative, spinal cord injury, chronic obstructive pulmonary disease, and cystic fibrosis. However, several publications have questioned the effectiveness of IS and its use is a topic of much debate in the clinical setting and in the literature. Evidence supporting the use of breathing exercises and IS is controversial due to varied methodologies and treatment protocols. One major difficulty with assessing the efficiency of this type of exercise program is patient adherence. Specific levels of adherence with IS exercise programs have not been reported; however, poor patient adherence with exercise programs and home-based tasks is a widely accepted issue in physical therapy. In their review of studies using IS, Overend et al. and Guimaraes et al discussed the potential confounding outcomes that could result from the lack of measurement of patient adherence. The lack of consistent findings within IS outcome studies could be the result of poor patient adherence, lack of treatment consistency, poor patient performance, or the reliance on subjective recordings of treatment sessions.

Video games are becoming widely used across the general population. More than 65% of all households play computer or video games. The use of computer and video games for health education, assessment, and treatment has rapidly become a focus within the academic and clinical areas of psychology and physical and occupational therapy. Video and computer games can allow for consistent delivery of treatment procedures that can also be modulated in a specific rule-based...
fashion dependent on the dynamic changes that occur in the patient’s performance in real time as well as across treatment sessions. This form of consistent, yet adaptive task delivery can target rehabilitation within relevant and engaging contexts. Video games allow for the creation of computer-generated 2D or 3D simulations, in which hierarchical task-relevant challenges can be delivered and titrated across a range of difficulty levels.19 In this way, a patient’s plan of care can be customized to begin at a challenge level that is attainable and comfortable for them, and then proceed with a gradual progression of challenge that is determined by the patient’s performance in real time. Furthermore, game-based environments allow for the presentation of more interesting and motivating stimuli. By designing video game environments that stimulate interest and focus attention on a task, patients might be more likely to perform exercises in situations where pain and/or boredom may inhibit treatment adherence. Video game technology also supports precise and detailed capture and analysis of user responses for tracking progress and improvement within and between sessions, a valuable feature for patients and therapists.

The use of a video game for breathing exercises has a number of potential benefits. Video games can provide therapists and patients with an individualized and easily altered level of challenge. Patients might be unlikely to perform breathing exercises if they are too difficult or alternatively, if they are not challenging enough. Patients may be more likely to perform exercises if the level of challenge was accommodated to their individual needs. Video games have the potential to motivate patients to perform and maintain adherence with exercise programs. Patients might be unlikely to perform breathing exercises due to pain, lack of motivation, or poor understanding of the task. A video game could help focus the patient’s attention on the game-related task, rather than the “chore” of performing the breathing exercises. Furthermore, patients and therapists can monitor progress and adherence through the quantitative data gathered and stored during game play. The time, date, session length, and performance metrics can be recorded and saved to track progress and adherence, allowing patients and therapists to monitor the exercise program and visualize changes. This provides researchers and therapists with the tools to measure adherence, reducing the unknown variable of patient adherence as a potential confounder in treatment outcomes. Access to session data can be used to set therapy goals, demonstrate improvement over time, and provide patient education regarding respiratory exercise and care.

**METHOD DESCRIPTION AND EVALUATION**

**Stakeholder Needs**

Informal interviews were performed with physical therapists, occupational therapists, researchers, and key patient populations to explore the need for, and determine key development features of, a computer-based game for breathing exercises. All stakeholder groups supported the concept and provided specific needs and requirements, including the option to change the level of air inspiration or expiration for different patients, the ability to record data from the interaction, and a motivating and fun game that encourages the accurate execution of a range of different breathing patterns. A focus group was undertaken with a sample of 10 participants with spinal cord injury. The group was asked to discuss their experiences with breathing exercises. The majority of participants described breathing exercises as boring and many described maintaining a regular exercise regime as difficult because they could not motivate themselves to do the exercises unless they were experiencing respiratory complications. The game concept was then described and the group provided input on the use of a game as part of a breathing exercise regime and gave specific input on the game ideas themselves. The group agreed that the use of a game where they could collect points and save scores would be more interesting than existing breathing exercise tasks. The group agreed on the following requirements for a successful computer-based breathing exercise program: an easy installation process, the ability to save software on individuals’ personal computer, only basic computer knowledge needed to install or use the program, and the game would be fun to use. The group agreed that they did not need the games to be realistic, provided they were not condescending or attempting to hide or reduce the focus on the breathing mechanic. Scoring, leader boards, and the ability to track progress were important system features.

**Hardware**

The development of an interface that would allow breathing as a method of controlling a video game was the first crucial step in the process of developing a game to motivate breathing exercises. A spirometer is an apparatus for measuring the volume of air inspired and expired by the lungs. The spirometer records the amount of air and the rate of air that is breathed in and out over a specified time. Incentive spirometry is designed to mimic natural sighing or yawning by encouraging the patient to take long, slow, deep breaths.20 The IS device (Figure 1) provides patients with visual feedback when they inhale at a predetermined flow rate or volume and sustain the inflation for a predetermined period. The objectives of this procedure are to increase transpulmonary pressure and inspiratory volumes, improve inspiratory muscle performance, and re-establish or simulate the normal pattern of pulmonary hyperinflation.21-23 A number of electronic spirometry devices were explored for use prior to the decision upon the current input device. The

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**Figure 1. Incentive Spirometry Device<sup>a</sup> With Airflow Attachments**

<sup>a</sup>Vernier Software and Technology.

This spirometer attaches to the computer via USB.
current input device uses airflow measured from a spirometer and the Vernier LabPro® system to interact with the computer-based video game environment. The spirometer records the amount of air and the rate of air that is breathed in and out over a specified time. When attached to the spirometer, the LabPro system can be used to measure the airflow from the spirometer and present the data in graphical format on a computer screen. The prototype interaction device developed for this project was programmed to use the airflow measured from a spirometer via a LabPro system as an input device to interact with games developed using Microsoft’s XNA Game Studio in C# programming language. Using the spirometer as the input device eliminates the need for a keyboard or joystick; instead, the user breathes through the spirometer device in order to control tasks within the game environment.

Iterative Design Process

The iterative game design process was used to develop the game content. Iterative design is a process-based design research methodology24,25 in which designers create and test games in various basic forms prior to completing a full prototype. The designers become participants in order to critique their designs and the game play mechanics. Within these procedures of investigation and experimentation, a special form of research takes place: “The process of iteration, of design through play, is a way of discovering the answers to questions you didn’t even know were there. And that makes it a powerful and important form of design research.”24(p19)

The first step in the process is brainstorming. Brainstorming for game development involves defining the problem.25 Once the initial brainstorming is completed, the next session involves critically discussing and refining the ideas.25 The process is repeated (brainstorming, expanding, and refining) until the team agrees upon the most appropriate idea. This is the idea that can be prototyped and further explored.

Rapid prototyping of game mechanics and core game play concepts can be performed in 2 ways: using physical props or using software.25 Regardless of the format, rapid prototyping provides the designers and the player with the ability to play the game in a simplified format in order to determine: (1) if the rules make sense and hold up during play, (2) if the game mechanics work, (3) how scoring works, and (4) if the game will be enjoyable to play.

Fullerton et al.25 suggest a range of levels of playtest participants. Designers should perform the initial playtests to determine if the first prototype works the way they anticipated. Following the initial playtest and redesign stage, peers are suggested as the second level of playtest participants. Once the game is playable with a clearly defined set of rules and refined game play mechanics, the game should be playtested by participants from the target audience for the game.

During the playtests, the researchers follow a script in order to allow the playtester to play without receiving too much information about the game.25 Playtesters are encouraged to talk aloud as they play. Following completion of the playtest, the playtesters are asked to complete a series of questionnaires, and the researchers ask a series of open-ended questions about specific aspects of the game. Both quantitative and qualitative measures are recorded during the playtests. Overall, the iterative design process involves cycles of design, prototyping, and playtesting to develop and evaluate the key components of play prior to beginning the actual software development. Once playtesting and prototyping cycles are completed, the game can be developed in the intended format and evaluated in a larger trial to determine: (1) if the game is fun, (2) if the graphics are appropriate and entertaining, (3) if the game mechanics work, and perhaps most importantly, (4) if the game performs the required therapy goals. The game development has followed this process, and is currently being playtested by users from the intended audience.

Software

To date, 6 basic game prototypes have been developed for initial playtesting and user feedback. A method was developed to provide the therapist with control over the settings of the game in order to individualize treatment goals and level of challenge. Once the spirometer device is connected to the computer, the therapist or user can open a program that allows for individual calibration and storage of individualized data for use within the game. The user interface is simple and easy to use. Once opened, the screen displays a white background with a red line visualizing inspiration and expiration using the device. The user is instructed to perform the appropriate breathing pattern (e.g., 1 deep breath, followed by 3 relaxed breaths; or 2 quick breaths in, followed by a hold and a breath out). Once completed, the breathing pattern is labeled and the user is prompted to confirm and save the output (Figure 2). When starting the game, the user is prompted to select the appropriate breath file (labeled with a unique patient number identifier). The game uses the selected data file as the threshold level for game play. The time, date, session length, and game performance metrics can be recorded and saved at the end of each session. The performance data from the spirometer is saved during each session; however, reliability testing of this data is still required before it can be used to compare lung function between sessions. However, within-session performance is tracked and saved in a file.
The 6 game prototypes were developed by graduate students of electrical engineering and computer science as part of a semester-long research class. The students were involved in expanding the game concept, designing the interaction, programming the games, and integrating the hardware interface.

**Frog Jump.** The game requires the user to control a frog with their breath. By breathing in, the user can control the length of the frog’s jump. If the user’s inspiration is performed at the correct rate and depth, the frog will gradually increase in size and change color. The change in color provides a visual cue to the user to breathe out. Upon expiration, the frog will jump forward. If the user does not perform a deep enough breath in, or if the breath is taken too slowly, the frog will not increase in size and will not change color. If the user takes a breath that is too fast or too deep, based on individual user settings, the frog will change color to red and do a small vertical jump in the air without moving forward.

**Bird’s Journey.** The game requires the user to control a flying bird using their breath. The bird must be maneuvered to follow a series of targets. When the user breathes in, the bird will fly higher. When the user breathes out, the bird will fly lower, enabling the user to collect items. The targets were placed along a curve to provide a clear visual indication of the pace and depth of the breathing. The pace of the game is set to music.

**Tank Targets.** The game requires the user to control a plane using their breath. The plane must be maneuvered over a landscape. When the user breathes in, the plane flies higher, enabling the user to collect tokens. When the user breathes out, the plane flies lower, and attacks tanks traveling along a road.

**Fish Feeding.** The game requires the user to control the release of fish food with their breath. Fish are arranged in a fish tank, moving around the tank at various speeds and patterns. Fish food moves across the top of the tank on a conveyor belt. The user can control the release of fish food using their breath. Upon inspiration, the conveyor belt stops. Upon expiration, the food will drop into the tank.

**River Crossing.** The game requires the user to control the character, a camel, with their breath. The goal of this game is to help the camel cross the river. Logs float across the river, between the 2 riverbanks (Figure 3). When the user breathes in, the camel jumps onto a log. If the user’s breath is too deep, the camel will overshoot the log. If the user’s breath is too shallow, the camel will not reach the log. When the camel does not reach the log, it splashes into the water and the game returns the camel back to the riverbank. This game was developed to encourage breath stacking, therefore, the breathing pattern is 2 inspirations followed by expiration, or 3 consecutive inspirations followed by expiration. The number of logs in the river can be set before starting the game to reflect the required breathing pattern.

**Magic Carpet.** The game requires the user to control a magic carpet with their breath. The user must breathe in to fly over buildings and breathe out to fly under bridges (Figures 4 and 5). If the user’s breath is too shallow, the magic carpet will hover in front of the building.

**OUTCOMES**

The game prototypes have undergone a series of iterative playtesting and refinement cycles. Initial iterative playtesting series with a sample of 19 healthy participants indicated that the game play and interaction were intuitive and players found the spirometry device easy to use. Users liked the feel and responsiveness of the controller. The controller was intuitive and fun to use, and game play was satisfying. Some initial issues identified by playtesters were the use of ambiguous ins-
structions and directions. The development of clearer instructions or visual demonstrations was suggested. The addition of a more goal-oriented task was suggested, along with clearer instruction as to the pattern of breathing required. Seven users suggested the use of music to provide a beat or tempo to guide the pace of breathing. Nine users suggested the use of different collectable targets and more feedback on correct and incorrect breathing patterns. Revisions were made to the game play based on the feedback from the playtesting session.

The most recent round of playtesting was performed on the River Crossing and Magic Carpet games. Six therapists and 6 patients with prior experience in using IS playtested the games. All participants played the River Crossing game. Three therapists and 2 patients also played the Magic Carpet game. Participants were asked open-ended questions about look and feel of the game and the potential use of the game to perform breathing exercises. Therapists and patients agreed that the games were fun to play, visually interesting, and provided useful visual and auditory feedback of results. The use of individualized files for game play difficulty was described as a unique asset of the games, allowing the user to work at their own level of challenge. Two therapists suggested other breathing exercises that would be useful for their patients. These exercises, along with suggestions from the participants about visual assets, feedback, and game play, will be incorporated into the next version of the games.

**DISCUSSION**

Maintaining adherence with breathing exercises can be a matter of life and death. The proper use of IS can have an impact on lung function following disease or surgery, however, the impact is directly related to adherence. Measuring adherence is difficult and often not reported directly in the literature. Since IS is low cost and it is often performed without the supervision of a practicing clinician, having a clinician supervise all IS activity to ensure adherence would be cost prohibitive. The development of a motivating, cost-saving, objective-reporting, and adherence-regulating IS device will help to ensure objective health outcomes after disease or surgery affecting lung function.

The individuals surveyed for this preliminary study indicate that they would enjoy using such a device, and the clinicians indicate that they can see the potential clinical benefit from such a device. The device and breathing program that we intend to develop further includes the spirometry device, which can be purchased for $295.00, and $3.00 for an attachable bacterial filter. We foresee that each patient using their own device while in the hospital, and depending on the objective data delivered from the device, a unit could be rented for home use. However, if the device indicates low adherence or typical lung function, a device for home would be unnecessary. Other devices and techniques to incorporate respiratory muscle strengthening are currently being explored. Furthermore, we intend to design more breathing games to ensure interest over time. Games will be developed in which the clinician will have more complete control over game parameters. Once refined, the device will be assessed for effectiveness in improving patient adherence and reducing pulmonary complications compared to standard treatment techniques for a range of patient populations (eg, postoperative, spinal cord injury, chronic obstructive pulmonary disease, cystic fibrosis). The first 2 studies will focus on postoperative-in-patients following surgery and patients with spinal cord injury as part of a home-based exercise routine.

**CONCLUSION**

The integration of medical devices with video game technologies offers great potential to improve assessment, and to collect objective data regarding patient adherence and lung function. The implementation of existing game-design models and user-centered iterative design offers a platform for the development of game-based rehabilitation tools.

**ACKNOWLEDGMENTS**

The authors would like to thank individuals with spinal cord injury for their generosity of time and feedback; clinicians at Precision Rehabilitation in Long Beach, CA, for their important feedback regarding clinical use; and graduate students Chao Wang, Qijun (Sophia) Guo, Ajit Singh Sirohi, Wenli Huang, Jingming Huang, Jasmeet Singh and Hao Tan for their hard work in the prototype development. This research was partially funded from a Gaming and Computer Science Grant from Microsoft Research.

**REFERENCES**


Background and Purpose. We have developed a novel cane device to be used in conjunction with a treadmill-based virtual reality (VR) locomotor system. This proof-of-principle paper reports the rationale, instrumentation, feasibility, and clinical implications of the cane device, as well as preliminary results from persons with stroke and healthy older adults using the device.

Subjects. Five persons with stroke and 5 healthy older adults participated.

Methods. Average walking speeds with and without use of the cane are compared between the overground physical environment (PE) and a self-paced, treadmill-based virtual environment (VE). Additional gait parameters examined while walking with and without the cane in the VE are: (1) gait variability quantified as the coefficient of variation (% CV) for stride duration, and (2) step width. We also reported and discussed the vertical loading forces transmitted through the cane during self-paced treadmill walking in the VE.

Results. Results reveal that walking with the instrumented cane on a treadmill is feasible for use in both healthy and stroke populations. It is evident that people who normally walk unaided.

Discussion and Conclusion. This work represents the first instrumented cane for use with a treadmill-based locomotor system. The use of this assistive device would add to the ecological validity of such gait rehabilitation systems. It is expected that gait training with the instrumented cane can be carried over to overground walking, although further studies are warranted.

Key Words: Walking aid, Virtual environment, Stroke, Locomotor rehabilitation.

BACKGROUND AND PURPOSE

Walking aids, specifically canes, are frequently used in gait rehabilitation and are often prescribed as a long-term mobility aid for people with a wide range of musculoskeletal, neurological, and balance conditions. In both stroke and elderly populations, the frequency of cane use in everyday life is very high, either for all walking activities or solely for community (out-of-home) mobility. In a frail elderly population, canes were rated as the second most important assistive device overall, after eye glasses.1 There are 2 main substantiated reasons why many people depend on this simple aid for mobility. First, using a cane is known to improve confidence and reduce the anxiety associated with “fear of falling,” which is a very important consideration for both the elderly and stroke populations.2 Often, many elderly people, and even high-functioning ambulators poststroke, do not venture outdoors without a cane; they feel that the cane provides increased security and safety. This dependency may be more pronounced in areas where weather conditions (ie, high winds, snow, ice, etc) can promote even greater fear when ambulating outdoors. Second, ample evidence now exists to clearly establish the role that cane use can play in improving balance control and postural stability during stance and gait.3-14 Rehabilitation specialists—physical therapists more than any other professionals—are in the position to offer these patients appropriate recommendations and training with walking aids. Furthermore, it is the responsibility of physical therapists to assure that the theoretical knowledge upon which they base their clinical decisions is based on current information and up-to-date evidence.

Literature Review

One of the main goals of rehabilitation in stroke and other populations is the restoration of independent gait, with or without the use of an assistive device. Evidence has shown that task-oriented interventions and intense task practice15 promote the reacquisition of motor skills, including gait. Although evidence-based stroke practice recommendations strongly support the use of treadmills for gait training16,17 due to the intense repetition of gait cycles that can be performed, many clinicians believe that gait practice overground is nevertheless necessary to assure the transition from treadmill walking to “real world” walking (with or without a cane).

The ability to generalize learning and transfer gait adaptations gained from treadmill training to overground walking has improved with the emergence of virtual reality (VR) technology. The increased visual (optic flow) and other sensory inputs now available can better simulate natural, true-to-life walking conditions. However, even with these advances, there remains an important dissimilarity between treadmill and overground gait training. In our clinical experience, the fixed bars on treadmills (either in front or to the side of the treadmill’s walking surface) provide stabilizing support very similar to the parallel bars used in many physical therapy departments. Parallel bars are often used for preparation of gait training and a variety of balance and gait exercises. However, many physical therapists will restrict gait training conducted in parallel bars and promote early overground training (with a walking aid and assistance as needed) with the rationale that the rigid bars provide too much balance support that does not challenge the postural control required to eventually walk.
Regardless of treatment approach, clinicians recognize that cane use is necessary at times and can improve a patient's level of independence, safety, and confidence, particularly in community ambulation. In the stroke population, as noted above, evidence is mounting in favor of using standard, single-point canes over multi-legged versions (such as quad canes or walkers) in both acute and chronic phases, and that beneficial gains for the patient far outweigh any potential disadvantages. Therefore, evidence has shifted the clinical question of whether or not to use a cane for stroke rehabilitation to when to introduce the cane into the rehabilitation process.

Although primarily known for providing mechanical support and for reducing weight bearing through a weaker limb, a cane also assists in the propulsion and braking portions of gait as well as augmenting somatosensory information. There is growing evidence to support that this latter function of canes, providing additional sensory and proprioceptive feedback, may play a particularly vital role in stabilizing gait in populations with general balance problems, including older adults and people with stroke. The sensory feedback related to body position may serve to compensate for sensorimotor impairments affecting balance control and help cane users reduce fall risk and achieve independent ambulation. Studies examining the forces exerted on canes in people with poststroke gait dysfunctions have demonstrated generally lower-peak vertical forces, as compared to people with musculoskeletal or orthopedic conditions where the reduction in limb loading is of primary concern. It is possible that people with balance problems (including elderly and stroke populations) use canes more for this attribute of facilitating postural control through increased somatosensory information, rather than as a means of physical support. Preliminary results from a current study on the effects of enhanced somatosensory input (from both haptic cues and cane use) on level and incline walking in people poststroke are pointing toward beneficial effects, including increased gait rhythmicity (decreased stride time variability) and gait speed, decreased step width, and improved center-of-mass (COM) control. 

Over the past 2 decades, researchers and clinicians have explored the effect of using technology for stroke gait rehabilitation. An advanced system that combines the use of virtual environments (VEs) with a self-paced treadmill mounted on a 6-degree-of-motion platform has been developed and used for gait evaluation and retraining in people poststroke. The use of VE typically presents the user with opportunities to engage in environments which appear and feel similar to real-world situations and events. The use of VR technology to study and train both upper- and lower-extremity motor skills in people with stroke has been well documented and established. Virtual reality systems also are now more accessible in hospital and rehabilitation settings, making them more available for everyday clinical use. Despite the important and widespread use of canes, canes have not yet been incorporated into these new methods of gait training. The concept of creating a cane for use with a self-paced treadmill, although simple, adds to the ecological validity of a VR system and thus enhances the simulation of true-to-life walking activities. It is suggested that transfer of learning to overground walking with a cane may also be facilitated. The purpose of this paper is to present the development of this novel cane device and provide results from a pilot study investigating the cane's feasibility.

SUBJECTS

Five people with stroke (age 65.2±5 years) and 5 healthy controls (67.6±6 years) participated in this study. The participants were part of the larger study examining the extent to which additional sources of sensory information affect gait performance during incline walking in people poststroke, as mentioned earlier. The additional sensory input was provided through contact cues at the fingertip (haptic cues) or through the palm of the hand with use of a specifically designed instrumented cane presented in this paper.

METHODS

Instrumentation and Measures

An advanced locomotor system which combines the use of VR with a self-based treadmill and a motion platform, as previously documented, was used. This system is coupled with a 3D scene rear projected onto a large screen in front of the treadmill creating a VE. The Computer-Assisted Rehabilitation Environment (CAREN) software manufactured by Motek Medical BV controlled and synchronized the instantaneous treadmill speed with the VE scene progression and the platform movement.

The VE scenario designed for this project was that of a clearly delineated, 40-meters long outdoor walking path set amidst grass and trees. Kinematic data, sampled at 120 Hz, was gathered using a 6-camera Vicon MX motion analysis system manufactured by Oxford Metrics Group. Subjects wore reflective markers positioned on body landmarks according to Vicon’s Plug-in-Gait model. Prior to walking, the Activities-specific Balance Confidence (ABC) questionnaire was completed with subjects in an interview format. The ABC rates balance self-efficacy, reflecting the subject’s own perspective on his or her walking abilities, and is valid in a stroke population.

Three walking trials within the VE were analyzed; the first trial, or baseline trial, without cane use (NC1); the cane trial (which was randomly inserted within other walking conditions for another study); and the third, or last trial, without cane use (NC2). For 2 subjects, only the baseline trial was used (due to a technical problem in S3 and fatigue in S5). The gait parameters under study were speed, variability (coefficient of variation for stride duration [% CV]) and step width. The overground gait speed was measured with the 10-meter walk test, whereas gait speed.

within the VE was calculated using the instantaneous speed output from the treadmill motor through the middle 20 meters of "steady-state" walking. Values were averaged over the 2 10-meter lengths for comparison with the overground measures. To calculate stride-to-stride variability and step width, the kinematic data was processed with a customized computer script in Matlab software, developed by MathWorks,²⁷ to determine the gait events of initial foot contact and foot-off for each limb, based on the sagittal plane foot trajectory. Measures of gait variability have been found to be more sensitive than direct gait measures such as gait speed, and therefore provide more precise indices of walking performance.²⁸ Less variability in a gait parameter such as stride duration would indicate a more rhythmic and stable gait pattern. It is suggested that measures of variability may also reflect qualitative aspects of gait otherwise overlooked by measuring gait speed alone. Stride duration was defined as the time taken between 2 consecutive initial foot contacts of the same limb (1 gait cycle). The % CV for stride duration, measured as the percent standard deviation over the mean, was compared between conditions (cane versus no cane) and between groups (stroke versus controls). Step width was defined as the distance (cm) between the left and right limb heel as measured by heel marker distance when in the double support phase of gait. Step width is often related to dynamic gait stability such that decreases in width represent better balance and improved postural control. The gait cycles occurring in the middle 20 meters of walking were retained for analysis.

Visual analog scales (VAS) were used to evaluate individual differences and were completed immediately following the experiment. Two parameters of interest were quantified: (1) the degree of ease (0/10) or difficulty (10/10) in using the cane; (2) the attention directed towards walking (0/10) or cane use (10/10).

Treadmill cane device. A typical single-point, adjustable aluminum cane with an offset foam handle was refurbished for use with the treadmill. The lower section of the cane was affixed with a ball joint with its center mounted onto the center of a tri-axial force transducer, produced by AMTI (series MC2.5-500).²⁹ The ball joint permits the cane to be moved in all 3 degrees-of-freedom, but constrained to a standard deviation of 30 degrees in both the sagittal and frontal planes. The combined cane tip-ball joint force transducer unit was then mounted onto a metal plate that was screwed on to either the left or right side of the treadmill, as needed (Figure 1). The upper-cane part with the handle could then be slipped over the lower unit and adjusted for cane height. Three additional holes were drilled into the upper-cane tube to accommodate the extra height of the force transducer (approximately 3 inches). The analog force data were sampled at 1200 Hz. The vertical force data were processed using a customized Matlab program. The values were expressed as a proportion of the body mass of the individual and then normalized to the gait cycle.

Protocol
All participants signed an informed consent form approved by the Montreal Centre for Interdisciplinary Research in Rehabilitation (CRIR) institutional ethics review board. The single experimental session began with an interview and clinical measures, including the 10-meter walk test with a cane (for those who used the aid in their everyday lives) and/or without the cane.

The reflective markers were attached and a safety harness was positioned on all subjects, which was then secured to a ceiling track during walking trials. Participants walked on a self-paced treadmill while viewing the VE scene projected in front as they walked a 40-meter level path. For added safety, a physical therapist stood nearby and supervised the subjects with stroke, as needed.

As noted, the participants were in control of their own walking speeds on the treadmill since they were tethered onto an electromotor with the digital output and its first-derivative servo-controlling the treadmill motor. They were instructed to walk at a comfortable pace. Each subject underwent a period of habituation that included walking on the self-paced treadmill on level, up, and down slope surfaces (5° slope change) with and without cane use, as well as adapting to the VE. The experimental protocol involved 3 walking surface conditions, including level, up slope, and down slope, along with 3 touch conditions, including no cane (NC), cane (C), and use of light touch (haptics). The presentation order of the walking conditions was randomized between 2 baseline trials (NC-level walking). The baselines were used in order to examine the effect of learning and adaptation to the system as well as to evaluate fatigue. Rests were provided as necessary during both the habituation and the experimental phases. For the purpose of this paper, only the experimental trials of level walking with and without the cane were analyzed.

Results
Participant characteristics and their overground gait speeds are described in the Table. The average chronicity of stroke was 5.1±2.1 years. Scores from the ABC questionnaire are also provided. For all subjects with stroke, the instrumented cane was held in the non-affected hand during treadmill walking.
whereas the controls were asked to choose their preferred hand for cane use (likely corresponding to their dominant hand).

As expected, gait speeds were generally lower in people with stroke, as compared to healthy older adults, regardless of environment (VE or physical environment [PE]). All subjects walked with a lower gait speed on the self-paced treadmill within the VE, as compared to overground walking within in the PE. The mean reduction in gait speeds in the VE was greater for the subjects with stroke, as compared to controls. For both groups, the speed in the VE cane conditions was closer to the overground speed. The mean speed changes from overground walking in the PE to treadmill walking in the VE walking without the cane was a reduction of only 2% with the cane, as compared to 27% without. For controls, the reduction in speed ranged between 6% with the cane and 10% without the cane. The second baseline condition without cane use (NC2), when available, tended to be higher than the first (NC1). The mean gait speeds with and without cane use for both groups are provided in Figure 2. A mean increase of 20% in speed occurred when the subjects with stroke used the cane, while healthy controls demonstrated a mean change of 3%.

Figure 3 shows the gait speeds from 3 representative individuals; 2 subjects with stroke and 1 healthy control subject. The 2 subjects with stroke contrast between higher and lower functioning, based on their overground walking speeds. The stroke subjects, when using the instrumented cane, were able to closely match their PE walking speed when using the cane in the VE. The control subject appears to show greater difficulty in using the cane as reflected by the corresponding lower gait speed in the VE cane condition.

Table. Subject Characteristics

<table>
<thead>
<tr>
<th>Stroke Subjects</th>
<th>Age (years)</th>
<th>Gender</th>
<th>Lesion side</th>
<th>Cane Use</th>
<th>OG Speed (m/s)</th>
<th>Treadmill Cane side</th>
<th>ABC Score (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>61</td>
<td>M</td>
<td>L</td>
<td>Yes</td>
<td>0.62</td>
<td>0.80</td>
<td>1.01</td>
</tr>
<tr>
<td>2</td>
<td>72</td>
<td>M</td>
<td>L</td>
<td>No</td>
<td>0.30</td>
<td>0.80</td>
<td>97.8</td>
</tr>
<tr>
<td>3</td>
<td>63</td>
<td>M</td>
<td>R</td>
<td>Yes</td>
<td>0.83</td>
<td>0.30</td>
<td>65.6</td>
</tr>
<tr>
<td>4</td>
<td>69</td>
<td>F</td>
<td>L</td>
<td>Yes</td>
<td>0.30</td>
<td>0.83</td>
<td>66.0</td>
</tr>
<tr>
<td>5</td>
<td>61</td>
<td>F</td>
<td>N/A</td>
<td>No</td>
<td>65.2 (± 5.0)</td>
<td>3M 2F 1L 3R 1Y 1N 1O 1L 1R</td>
<td>71.3 (± 17.8)</td>
</tr>
</tbody>
</table>

Healthy Controls

<table>
<thead>
<tr>
<th>Healthy Controls</th>
<th>Age (years)</th>
<th>Gender</th>
<th>Cane Use</th>
<th>OG Speed (m/s)</th>
<th>Treadmill Cane side</th>
<th>ABC Score (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>68</td>
<td>M</td>
<td>No</td>
<td>1.30</td>
<td>0.71 (± 0.27)</td>
<td>96.8</td>
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<tr>
<td>2</td>
<td>77</td>
<td>F</td>
<td>No</td>
<td>1.27</td>
<td>1.26 (± 0.03)</td>
<td>89.1</td>
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<tr>
<td>3</td>
<td>61</td>
<td>F</td>
<td>No</td>
<td>1.22</td>
<td>1.25 (± 0.03)</td>
<td>99.4</td>
</tr>
<tr>
<td>4</td>
<td>64</td>
<td>M</td>
<td>No</td>
<td>1.25</td>
<td>1.25 (± 0.03)</td>
<td>92.4</td>
</tr>
<tr>
<td>5</td>
<td>68</td>
<td>M</td>
<td>No</td>
<td>67.6 (± 6.0)</td>
<td>1.26 (± 0.03)</td>
<td>98.5</td>
</tr>
</tbody>
</table>

Abbreviation: m/s, meter per second.

Figure 3. Individual Differences in Gait Speeds With and Without Cane Use

Mean gait variability for the stroke and control group is shown in Figure 4. As expected, gait variability quantified as % CVs of stride duration was higher in the stroke group regardless of walking condition. All subjects in the stroke or control groups show a significant decrease in stride duration variability in both limbs when using the instrumented cane. The reduction in variability ranged between 16% to 18% for the subjects with stroke, and 5% to 15% for the healthy controls.

Step width for the stroke group was reduced by a mean of 9.9% when using the instrumented treadmill cane, as compared to the no-cane condition (Figure 5), with all subjects demonstrating decreased step width. In controls, although an overall mean reduc-
The purpose of this paper was to introduce a novel cane device specifically developed and designed for use with an existing treadmill-based immersive VE locomotor system. The overall concept was to add to the realism of the VE by making the walking activity more natural and similar to overground walking with a cane. The cane device, together with the motion platform, self-paced treadmill, and VE, created a more ecologically valid locomotion system that can be used as a tool for both clinical and research purposes.

Training gait with the cane device on a self-paced treadmill and immersed in a VE would allow patients to safely practice a variety of real-life walking skills (ie, crossing streets, maneuvering inclined surfaces, negotiating and avoiding obstacles, walking and shopping, etc.). It would also allow therapists to have precise control over condition complexity and difficulty, which would be impossible overground with conventional therapy. The patients can walk with an aid similar to that which they would eventually use overground, such as a cane, and therefore training would specifically target skill acquisition. The balance control required for cane use as well as the motor control necessary to stabilize the cane would be promoted and practiced with greater repetition. Additionally, the sensorimotor integration involved in coordinating cane use with the gait cycle (ie, timing and loading patterns) could be developed more intrinsically during the intense training possible with treadmill walking. The instrumentation of the cane provides valuable information to the therapist concerning the amount of support a patient uses while walking. Based on this knowledge, clinicians could evaluate and train cane use more accurately. Precise recommendations with respect to the amount of force to apply on the cane could be made through real-time (immediate) feedback as the patient walks on the self-paced treadmill. This augmented feedback may facilitate more effective overground cane use. Patients may learn that only light support through the cane is required in order to improve gait performance and safety as well as enhance self-efficacy.

The improvements in gait (higher gait speeds, lower gait variability, and reduced step width) observed when the individuals with stroke walked with the instrumented cane on a treadmill as compared to walking without a cane, are consistent with gait changes seen during overground walking with a cane. Moreover, as expected, it appears that lower-functioning ambulators with stroke (or anyone who normally uses a cane) may benefit more from the instrumented cane than higher functioning individuals who do not need a cane. The timing of the peak vertical forces, coinciding with the stance phase for the affected limb, is consistent with other studies examining cane forces used in people with stroke. This further demonstrates the similarity in function between the instrumented cane on a self-paced treadmill and a regular cane for walking overground.

Using the instrumented cane was perceived to be easy for both stroke and control subjects. It is important to note that no explicit instructions for using the cane were provided to the subjects, and therefore the use was intuitive and the gait changes occurred naturally. An interesting observation is that the control subjects rated a relatively higher level of attention shifted to the cane as compared to the subjects.
with stroke. This might be due to the fact that cane walking was a novel task for the healthy controls, and as such, increased attention was necessary for skill acquisition, especially in what could be considered a dual-task activity.

CONCLUSION

This study demonstrates the successful development and feasibility of an instrumented cane to be used on a self-paced treadmill. To our knowledge, this is the first instrumented cane to be used in conjunction with a VR and treadmill-based locomotor system. It is suggested that treadmill gait training with the instrumented cane could transfer to overground walking with a cane. Further studies are required to explore this possibility and address clinical intervention issues related to using the instrumented treadmill cane.

ACKNOWLEDGMENTS

The authors would like to thank all study participants. We acknowledge the technical assistance of C. Beaudoin and Y. Bahat in the creation and programming of the virtual scenes, as well as G. Lepky for cane instrumentation. We also gratefully acknowledge the expert assistance of V. Goussev, L. Hughey, R. Kizony, and A. Oates for their contributions to the study. This study was funded in part by a Canadian Institute of Health Research (CIHR) team grant in Multidisciplinary Locomotor Rehabilitation. C. Perez is a recipient of a studentship award from the Fonds de la recherche en santé de Québec (FRSQ).

REFERENCES

A New Virtual Environment Paradigm for High-Functioning Autism Intended to Help Attentional Disengagement in a Social Context

Ouriel Grynszpan, PhD, Jacqueline Nadel, PhD, Jacques Constant, MD, Florence Le Barillier, Noëlle Carbonell, PhD, Jérôme Simonin, PhD, Jean-Claude Martin, PhD, and Matthieu Courgeon

Background and Purpose. This article presents a review of the question regarding the link between social communication difficulties and altered executive functions (i.e., cognitive functions involved in the control of behavior, such as planning, inhibition, working memory, etc) in high-functioning autism spectrum disorders (HFASD).

Model Description and Evaluation. We first analyze the difficulties experienced by individuals with HFASD in processing contextual cues during social conversations. We extend this approach to include verbal and nonverbal communication. We then focus on alterations in the ability to process facial expressions during an ongoing conversation. This ability involves attentional resources that are discussed in light of the executive dysfunction attributed to autism spectrum disorders. On this basis, we hypothesize that the difficulties in appreciating the synergy between facial expressions and speech could be linked to impairments in shifting attention from one to the other.

Outcomes. A new experimental paradigm designed for testing this hypothesis is presented. It relies on a virtual environment system based on eye-tracking technology that enables users to control the visual display via their gaze. The intent behind this apparatus is to compensate for the deficits in shifting attention attributed to autism spectrum disorders.

Discussion and Conclusion. We describe the procedure devised for testing this new virtual environment paradigm and discuss the technological choices taken in order to comply with the issues addressed in HFASD. We conclude with preliminary observational data supporting the potential therapeutic use of this virtual environment system.

Key Words: Pragmatics, Relevance theory, Executive dysfunction, Attentional disengagement, Emotion, Facial expression, Virtual environment, Eye-tracking, Gaze-contingency.

BACKGROUND AND PURPOSE

Autism is defined as a pervasive developmental disorder. A triad of criteria comprise the diagnosis: qualitative alterations in social interaction; qualitative impairments in verbal and nonverbal communication; and restricted, repetitive, and stereotyped patterns of behavior, interests, and activities. Autism displays a high inter-individual variability and is usually referred to as a spectrum. Although autism frequently is paired with intellectual retardation, there are no limitations to the Intellectual Quotient (IQ) of people with autism spectrum disorders (ASD). High-functioning autism refers to the autistic spectrum subgroup that has an average or above-average IQ. Despite preserved intellectual abilities and often well-developed vocabulary, individuals with high-functioning autism spectrum disorders (HFASD) exhibit profound communicative and social difficulties.

ASD is considered to involve a primary deficit in pragmatics, which refers to the ability to use language to communicate effectively in social contexts. People with HFASD often fail to form appropriate pragmatic inferences necessary for understanding irony, lies, jokes, metaphors, and deception. They have a tendency to interpret speech literally, rather than in reference to a context. For instance, an experiment on contextual disambiguation of homographs (words with the same spelling but different meanings) required determining the meaning of a homograph according to the context of a short text. Compared to typically developing controls, participants with HFASD selected the literal interpretation more often, thus displaying a tendency to omit context.

The goal of this research is to develop effective computer-assisted training methods for people with HFASD through investigations of the multiple factors underlying cognitive and socio-emotional deficits. The present paper explains the rationale for a system designed to train individuals with HFASD to decipher social conversations. This system uses eye-tracking technologies to assist with understanding a socially expressive virtual character. We concentrate on issues pertaining to social communication comprehension in HFASD in the framework of relevance theory, which derives from the field of linguistics.

We then concentrate on reported failures to adequately process facial expressions in the...
context of a social intercourse. Failures in contextual processing of facial expressions are interpreted in light of the executive dysfunction attributed to ASD and, in particular, the attentional shifting impairment. Finally, we present an experimental virtual environment system designed to test our hypothesis about cognitive dysfunction involved in dialog understanding deficiencies.

**MODEL DESCRIPTION AND EVALUATION**

**Relevance Theory Framework**

Pragmatic processing during verbal interactions in ASD has been analyzed in the framework of relevance theory, which originates from the field of linguistics. Relevance theory adopts an inferential model in which the listener infers what the speaker means on the basis of the evidence provided by the speaker which includes, but is not restricted to, verbal language. This theory states that “human cognition tends to be geared to the maximization of relevance,” that is, what produces a “worthwhile difference to the individual’s representation of the world,” for instance a “true conclusion.” The search for relevance guides the listener’s inferences and the speaker conveys information accordingly. Furthermore, maximizing relevance also implies minimizing the listener’s cognitive efforts in searching for relevance. The multiple stimuli available to a listener may vary in salience and accessibility, thus requiring different degrees of processing effort. The relevance of an input decreases when the processing effort increases, as illustrated by Wilson and Sperber in an imaginary scenario where someone who is allergic to chicken is told either “We are serving chicken” or “Either we are serving chicken or (7^2 – 3) is not 46.” Both propositions provide the same logical information, but the former is more relevant.

In relevance theory, communication relies on manifest stimuli, referred to as ostensive stimuli, which are purposely intended to attract the listener’s attention and induce expectation of relevance. Ostensive stimuli convey information about the speaker’s intention to express meaning. Relevance theory places the ability to understand the mental states of others as a central requisite for communication. This has drawn the attention of researchers in the field of ASD, given the impairments attributed to ASD in acquiring a “theory of mind,” that is, the ability to understand one’s own mental state and that of others. For instance, Happé conducted an experiment showing that comprehension of irony and metaphors in children with ASD correlated with performances in theory of mind. She suggested that communicative deficits in ASD could be linked to an inability to distinguish ostensive from non-ostensive behavior, due to the lack of recognition of the intention to inform. Denis and colleagues provide evidence that participants with ASD perform similarly to typical controls in tasks requiring semantic disambiguation, but that differences arise when elements from the context are needed to understand the intention behind the utterance. Loukusa and colleagues found differences between participants with HFASD and typical participants in tasks requiring combining speech with world knowledge and prior context. In contrast, understanding feelings did not yield significant differences. Moreover, participants with HFASD had greater difficulties in explaining their correct answers, suggesting that they experienced difficulties with complex contextual connections even when they were able to comprehend intentions and emotions.

**Integration of Nonverbal Contextual Stimuli**

Real-life social interactions rely on verbal exchange as well as nonverbal social and emotional stimuli. Expressive nonverbal behaviors build the surrounding context and shape the meaning of speech. Early acquisition of pragmatic competences relies on the integration of linguistic and extralinguistic sources of information, including gesture, facial expression, and intonation. By characterizing the emotions displayed by an individual, facial expressions provide a powerful channel for communicating about mental states and intentions. An utterance can be completely diverted from its literal meaning by the adjunction of a simultaneous facial expression, as, for instance, when one wants to express irony or sarcasm. Missing out on these crucial cues may preclude non-literal interpretations of speech.

Few studies on HFASD have been devoted to dysfunction in the processing of facial expressions during an ongoing conversation. Klin and colleagues proposed a novel paradigm based on eye-tracking technology for studying the spontaneous viewing patterns of people with ASD when they watch social scenes on a video display. The experiment compared a male adult with HFASD and a male adult without autism who were watching a film displaying intense social interactions involving the integration of speech, facial expressions, and gestures. The visual traces showed the atypical attempts of the participant with HFASD to retrieve socially meaningful cues in the faces of the actors. The participant with HFASD would stay focused preferentially on the mouth region while the participant without autism would gather additional relevant information from the eye region. When one actor spoke to another, the participant with HFASD would not pay as much attention to the listener’s facial expressions. The altered ability to attend to nonverbal stimuli appeared to account for the misunderstanding of several social scenes by the participant with HFASD. Klin and colleagues carried on the investigation in another study in which participants with HFASD were compared to participants not diagnosed with autism, when watching selected extracts of the previously mentioned film. Data showed that participants with HFASD focused less on the eyes and more on the mouth, body, and objects than did the control group participants. Though individuals with HFASD are believed to hold average performance in recognizing basic emotional facial expressions, they are considered impaired at recognizing mental states from the eye region alone. Brain imaging studies suggest that individuals with HFASD may employ deviant strategies for deriving emotions from facial expressions.

The virtual environment system presented in this article conforms to the paradigm proposed by Klin and colleagues that calls for the use of eye-tracking technology for examining the use of facial expressions by people with HFASD.

**Multimedia Applications for Social Training**

Previous attempts have been made to use computer-assisted methods for teaching social skills to people with ASD. Bernard-Optitz, Sriram, and Nakhoda-Sapuan showed that children with HFASD improved their performances after training on a software application that required finding solutions to problematic social conflicts. Tartaro and Cassell designed a virtual character resembling a child for training children with ASD in collaborative storytelling. Mitchell, Parsons, and Leonard revealed that some teenagers with HFASD exhibited improvement in reasoning about social skills after an intervention based on a virtual environment representing a socially challenging situation (a café). Several studies focused on the ability to process facial expressions during social interactions. Moore and colleagues showed some evidence that children and adolescents with HFASD could associate an emotionally connoted social situation with the appropriate facial expression of a virtual character. Using eye-tracking, Trepagnier and colleagues developed a virtual system that provides reinforcements to participants when they direct their gazes at the face of an individual appearing on a video display. Golan and Baron-Cohen designed
a multimedia software application dedicated to training recognition of complex emotions, such as embarrassment or intimacy. Although participants with HFASD improved in recognizing facial expressions, they did not show any gain on holistic tasks involving the integration of facial expressions, voice intonations, and contextual cues. The problems experienced by people with HFASD in constructing the context of a social situation may derive from difficulties in connecting relevant stimuli scattered in the surrounding environment. As pointed out by Loveland, individuals with ASD face difficulties not only with the recognition of emotional stimuli but also with the ability to associate those stimuli with an ever-moving context.

The authors of the present article first addressed this issue in a preliminary study that developed a computer-assisted method targeting the pragmatic disorder attributed to HFASD. The study was conducted with 10 adolescents with HFASD and 10 children without HFASD, all matched on developmental age and academic level. The application displayed a series of written dialogues, each containing a particular utterance that had to be interpreted non-literally (e.g., irony or metaphor). Participants could click on any utterance to see the facial expression of the character speaking (Figure 1). Results suggested that participants with HFASD did not use the facial expressions appropriately to infer the correct non-literal interpretations of the dialogues, in contrast with the participants without HFASD. Participants with HFASD acted as if they were not aware of the relevant quality of facial expressions in a social conversational context.

**Attentional Shifting Impairment**

On the basis of our preliminary experiment and the analyses of viewing patterns in the studies of Klin and colleagues, we hypothesize that failure to recognize ostensive behavior could partly derive from difficulties in merging information from the multiple verbal and nonverbal modes of communication. In the framework of relevance theory, the relevance of a stimulus decreases when the processing effort increases. Merging multiple verbal and nonverbal stimuli requires swift attention abilities for capturing transient social stimuli. Given the attentional shifting dysfunction attributed to ASD, the relevance of facial expressions could be diminished due to the processing effort involved in attending to both facial expressions and speech simultaneously.

A number of studies have documented an executive dysfunction in people with ASD. The term executive functions refers to a set of cognitive functions that encompasses planning, working memory, inhibitory control, inhibition, shifting mental sets, and the initiation and monitoring of action. Hughes and colleagues define executive functions as "an umbrella term for the mental operations which enable an individual to disengage from the immediate context in order to guide behavior by reference to mental models or future goals." Landry and Bryson examined the abilities of people with ASD to disengage and transfer attention in a task in which they first gazed at a stimulus in front of them before another stimulus would appear either on the left or on the right. In some trials, the central stimulus remained on, even after the peripheral stimulus had appeared, so as to examine attentional disengagement. In other trials, the central stimulus disappeared once the peripheral stimulus appeared, so as to examine the transfer of attention. Results showed that children with ASD had marked difficulties in disengaging attention and subtler problems in attentional transfer.

Hughes and colleagues investigated the attentional shifting component of executive functions during a problem-solving task in which participants aged 7-18 were presented with 4 boxes on a computer screen. Patterns of pink abstract shapes and superimposed white lines appeared in 2 of these boxes with their position varying from trial to trial. Participants had to deduce whether or not the patterns were correctly positioned based on "correct/incorrect" feedback provided by the computer. The underlying rule guiding pattern positioning changed after a given number of trials, according to 9 stages. The pink shapes were the guiding feature for the first 7 stages. The last 2 stages required shifting attention to the white lines, thus assessing the ability to shift attention from one stimulus dimension (pink shape) to another dimension (white lines) during a problem-solving activity. Participants with ASD were significantly impaired on this attentional shifting task compared to control group participants.

Difficulties in shifting attention could hamper the ability to disengage from the current focus of the individual's attention during a conversation. Accordingly, an individual paying attention to the mouth of a speaker would tend to stay focused on the mouth even if the speaker's eyes held an ostensive expression, as observed by Klin and colleagues. As highlighted by Hughes and colleagues, the
impaired ability to shift attention from one stimulus dimension, for instance, the voice of the speaker, to another stimulus dimension, such as the face of the speaker, could hinder the ability to capture transient social stimuli such as facial expressions when they are needed for resolving pragmatic ambiguities. From a relevance theory standpoint, attentional shifting disorders could increase the processing effort required to consider facial expressions when they are not in the current focus of attention, thus decreasing their relevance for people with HFASD. This point is in line with the findings from our preliminary study.23

OUTCOMES

New Experimental Paradigm

Our hypothesis considers attentional shifting skills as a key component of the ability to extract and process relevant facial expressions in the context of a social interaction. Hence, if the attentional shifting dysfunction is compensated for, the pragmatic disambiguation power of facial expressions should improve. To test this hypothesis, we designed an experimental protocol based on a novel virtual environment paradigm. We conceived a task in which a virtual character addresses the participant. While doing so, the character utters a sentence that can be interpreted in 2 distinct ways. The character’s facial expressions enable disambiguation of this key sentence. For example, the virtual character might say, “I’m so lucky,” while displaying a sad facial expression. Participants must then answer a question about the feeling of the virtual character (eg, “How does John feel?”) and a second question about what causes that feeling (eg, “How do you know that?”). Participants must select 1 of 3 displayed assertions for each question. One assertion is correct, one is the incorrect literal interpretation of the key sentence, and the last one is a false non-literal interpretation. The literal interpretation tests the participant’s tendency to disregard facial expressions. The false non-literal interpretation assesses whether participants comply with the task.

Our paradigm uses the above-mentioned task to evaluate the performances of participants in 2 different conditions, one of which was designed to alleviate attentional shifting efforts. The first condition serves as a control condition in which participants explore the animated scene freely, without any specific help. The second condition is the experimental condition that encompasses an apparatus aimed at guiding the visual exploration of participants. This apparatus relies on 2 components: instruction and a gaze-contingent visual display that relies on eye-tracking technology. The instruction explicitly encourages the participant to look at the facial expressions (eg, “Look at the character’s face to understand what he/she feels.”). The gaze-contingency of the display refers to the fact that the graphic display changes as a function of where the user directs his or her gaze.28 The entire graphical interface is blurred, except for an area centered on the point gazed at by the participant. The guided visual exploration apparatus has been conceived consistently with the assumption that attentional shifting impairment in ASD can be decomposed into 2 components: (1) disengagement and (2) transfer of attention. The gaze-contingent display was designed to compensate for the first component; as soon as the participant begins shifting away from a given cue, this cue is blurred and its attractiveness should therefore be attenuated. The instruction given to participants is intended to help with the second component; it encourages them to transfer attention to the facial expressions. Hughes and colleagues25 suggest that the attentional shifting impairment in ASD could induce a behavioral pattern “triggered directly by environmental features (leading to distractibility and a loss of behavioral control).”26(489) The gaze-contingent display is believed to favor a reduced distractibility by blurring distracting stimulus outside of the focus of attention. In other words, the participants can only see what they look at. Finally, the gaze-contingent display is thought to stimulate the participants’ awareness of their own eye movements, giving them an enhanced sense of agency that favors the control of their attentional resources.

We created 60 different scenarios of virtual characters reporting an experience. Each scenario follows 1 of 2 patterns that are counterbalanced. In the first pattern, the speech of the virtual character provides enough contextual information for answering the subsequent questions; the facial expressions are not essential, although they may offer useful redundancy. In the second pattern, part of the context is given exclusively by the facial expressions, which are therefore essential for comprehension. We hypothesize that, for individuals with HFASD, the second pattern would be more difficult than the first. We also expect their performances to be higher in the experimental condition (guided visual exploration) than in the control condition (free visual exploration); scores on the questions and fixations on the face are expected to increase in the experimental condition. As well, we expect differences between the first and second patterns of trial to be smaller in the experimental condition compared to the control condition.

Figure 2. Examples of Animated Scenarios With a Virtual Character Speaking to the Participant and Displaying Emotional Facial Expressions

The animated virtual character is designed with Poser Pro.29
DISCUSSION AND CONCLUSION

Description of the Virtual Environment System

The virtual characters were designed with the Poser Pro software application. To avoid bias due to the fact that the movements in the virtual character’s face would cause the participants’ gaze to be attracted to it, we embedded the virtual character in videos of real environments that include different moving objects and people. These environments provide a context that makes the task seem closer to real life situations (Fig. 2). Since the protocol focuses on evaluating the ability to use facial expressions, other sources of possible relevant contextual information need to be concealed. In particular, the virtual character’s voice needed to hold minimal intonation so as to avoid an experimental bias. For this purpose, we relied on text-to-speech synthesis performed with Virtual Speaker. The lips synchronization was performed with the Poser Pro software.

A remote infrared camera (model D6-HS Remote from Applied Science Laboratories) placed under the screen tracks the eye of the participant. The display is controlled by a robust gaze-contingent prototype that computes the focal position of the gaze on the screen and then processes the graphic display in real time so that the entire visual display is blurred, except for an area centered on the point gazed at by the participant. This gaze-contingency system can be seen as simulating a gaze-controlled lens (Figure 3). The size of this lens has been fixed so that it enables the individual to see clearly either the eye region or the mouth region, but not both at the same time.

The application presents the animated scenes in 3 successive stages, encompassing the same number of scenes. In the first stage, the gaze-contingent display is deactivated; participants do not benefit from the visual exploration guidance modality (control condition). However, the eye-tracker still functions in order to collect the gaze fixations used as experimental measures. In the second stage, participants receive the aforementioned instruction that encourages looking at the face, and the gaze-contingent visual display is activated (experimental condition). According to our hypothesis, scores and number of fixations on faces should be higher than during the first stage. In the third and final stage, the gaze-contingent visual display is deactivated again (control condition). The purpose of this final stage is to estimate whether skills that could have been acquired during the experimental condition (second stage) would transfer to the control condition, which is closer to natural settings. Indeed, it should be noted that the virtual characters possess human-like features and are embedded in real settings. An effort was made to create a virtual environment that would resemble real-life situations as much as it was technologically possible with the tools employed.

Preliminary Observations and Conclusion

Technical tests were conducted to evaluate the performance of the virtual environment system. Several features are especially demanding in terms of computing load and can potentially slow down the system. Indeed, the system logs the gaze coordinates synchronously with snapshots of the visual display so that the experimenters can later replay the viewing patterns of the participants. The system also blurs the visual display in real time when gaze-contingency is activated. The technical tests when gaze-contingency was activated showed that the visual display would function at a speed of 20–22 frames per second. This was enough for an adequate viewing of the animations. We evaluated to approximately 100 milliseconds the upper bound of the time delay between movements of the participant’s gaze and the gaze-controlled lens. The spatial accuracy of the gaze-controlled lens depends on the calibration of the eye-tracker that is specific to each participant. The calibration is carried out by experienced users of the eye-tracker.

The protocol devised to test the virtual environment is currently being carried out with participants who have HFASD and participants who do not. Thus, as yet, only preliminary observations are available. The protocol was reviewed and approved by the regional ethics committee. Informed consent was obtained for each participant. To date, 15 adults without HFASD and 14 adolescents and adults with HFASD have completed the experiment. None of the participants dropped out of the experiment, although the experiment contains 60 animated scenarios and usually lasts at least 1 hour. At the end of the procedure, participants were asked to comment about their experience. They were especially questioned on whether they had felt discomfort when gaze-contingency was activated. Seven participants without HFASD and 4 participants with HFASD answered in the affirmative, although they specified that the discomfort was not critical. Only one participant with HFASD reported that the experiment was too long, whereas 3 expressed satisfaction about their experience. Five participants without HFASD mentioned that they had perceived a spatial drift between their gaze and the gaze-controlled lens, and 2 participants who do not have HFASD declared perceiving a temporal delay. None of the participants with HFASD made similar comments. Four participants without HFASD and only 1 participant with HFASD mentioned that they had noticed a contrast between the speech of the virtual characters and their facial expressions.

We are currently recruiting additional participants. Preliminary observations are encouraging, and we expect that the final
outcome measures will enable us to refine the system. The second stage of our research will be to conduct a longitudinal study aimed at assessing a training program based on this virtual environment, with the ultimate goal to use this program for therapy.

ACKNOWLEDGMENTS

This research project is supported by the following foundations: La Fondation de France and La Fondation Adrienne et Pierre Sommer (Project #2007 005874). We are particularly thankful of Noëlle Carbonell who was highly involved in the project, being one of its initiators, and who passed away during the course of the project. We are very thankful to the staff and students of La Maison pour les personnes autistes du département d’Eure et Loir in Chartes, France, for their participation in the program. We also thank Daniel Gepner for his help in conducting the experimental trials.

REFERENCES

The SMART Rehabilitation System for Stroke Self-management: Issues and Challenges for Evidence-based Health Technology Research
Sue J. Mawson, PhD, MCSP, and Gail M. Mountain, PhD, MPhil, DipCOT

Background and Purpose. Stroke is one of the major causes of disability in the UK with over 100,000 cases of first stroke and 3,000 cases of further stroke every year. In the USA, it is the third leading cause of death and serious long-term disability. The benefit of telehealth technologies is now recognized and a range of telehealth systems have already been successfully developed to assist people to self-manage the medical aspects of long-term conditions. This paper presents the rationale for the use of technology for the remote rehabilitation of stroke survivors and describes the research findings used to inform the design, development and deployment of the SMART device for upper limb self-managed rehabilitation.

Case Description. Case studies involving 4 stroke survivors with a mean age of 61.5 (SD27.5), 2 male and 2 female, were used in the final stages of prototype deployment for the SMART system. Changes in functional activity were analyzed through predeployment and postdeployment measurement. Descriptive statistics were used to calculate where there was an observed improvement, maintenance, or deterioration in the TELER indicators, the Timed Up and Go (TUG) values and the Motor Assessment Scale (MAS).

Outcomes. Functional improvements were observed in 50% of items measured with 40% unchanged and 10% deterioration.

Discussion. The Randomized Controlled Trial may not be the most appropriate research method to be used in the early design, development and prototype deployment of telerehabilitation systems because of the complexity of the development process, the interaction processes, the clinical requirement, and the individual needs of the stroke survivor. An evaluation framework is suggested that can provide observations and information essential in the development of health technologies.

Key Words: Stroke, Self management, Rehabilitation.

BACKGROUND AND PURPOSE
Stroke is one of the major causes of disability in the UK, with over 100,000 cases of first stroke and a further 3,000 cases of further stroke every year. The direct annual costs in the UK is £2.8 billion, with £530 million spent on inpatient care annually. In the USA, stroke is the third leading cause of death and serious long-term disability. One year after having experienced a stroke, 35% of those who survive are significantly disabled, with upper-limb impairments being particularly prevalent. At 4 years post stroke, 65% of stroke patients are dissatisfied with upper-limb function.

Rehabilitation in the form of intensive, repetitive, task-specific exercise is essential if functional abilities and independence are to be regained following stroke. Strong evidence exists to confirm that organized, specialized stroke care improves outcomes. However, organizational issues and resource limitations mean that many patients do not receive adequate rehabilitation post discharge from hospital. Additionally, to date, only limited attention has been given to how self-management might be instrumental in the longer-term management of stroke. Given that most patients do not receive the extent of rehabilitation recommended in UK National Guidelines, the costs of optimal treatment and rehabilitation are much higher than those indicated by current cited expenditure.

The benefit of telehealth technologies is now recognized. Telehealth is "the remote exchange of physiological data between a patient at home and medical staff at a hospital to assist in diagnosis and monitoring." A range of telehealth systems already have been introduced successfully to assist people to self-manage the medical aspects of long-term conditions. One example is the technology used to measure blood sugar levels in diabetes, providing immediate feedback to the user. However, the potential of technology for telerehabilitation is yet to be realized.

Rehabilitation is traditionally provided through face-to-face contact with a therapist, with the therapist being an agent of intervention. This resource-intensive mode of delivery greatly contributes to the previously cited high costs of stroke care and rehabilitation. Telerehabilitation can enable the delivery of rehabilitation to individuals in their own homes, at a distance from the therapist. Recipients also are able to make decisions about when they participate in rehabilitation; thus, shifting the locus of control from the therapist to the end user and facilitating self-management skills. However, telerehabilitation devices also are socio-technical systems in that they include both human components (the end users and health practitioners) and technological components, with the system being...
contextualized within the environment where the technology will be used. Consequently, the development, testing, and mainstreaming of telerehabilitation devices provide significant challenges for research. For example, in order for the technology to be clinically effective and acceptable to both therapists and end users, it must meet a number of requirements. These include ensuring that the telerehabilitation system is able to deliver prescribed rehabilitation interventions that are tailored to meet individual needs. The technology also must be sufficiently robust, comprehensible, and acceptable for confident and independent use by individuals in their own homes, while maintaining secure data exchange between user and therapist. Finally, if telerehabilitation systems are to be successfully embedded within health care delivery, they must demonstrate clinical efficacy. This paper describes the work undertaken to determine the preliminary clinical utility and clinical effectiveness of a prototype telerehabilitation system for upper-limb stroke rehabilitation to illustrate the complexity of issues that must be taken into account and to discuss the methodological challenges that face health technology researchers.

CASE DESCRIPTION

The SMART Rehabilitation System

The SMART rehabilitation system uses motion sensor technology to track functional movement of the impaired upper limb. Once the sensors have been attached in the correct locations on the arm and chest and the equipment assembled, users wait for confirmation that the system is ready and then undertake an exercise from a library of prescribed interventions (eg, reach out and stretch the arm and then return). Users undertake a series of repetitions before receiving feedback on quality and range of movement from a decision support interface developed specifically for the prototype. Several forms of feedback about exercise performance are possible. The SMART manikin displays, on a computer screen, a rendered model of the user's upper-limb movement so that comparison can be made between the user movement and the target. Exercise graphs also are available to illustrate the extent to which the user movement matches the target exercise. If there is a perfect match, the user receives a score of 100 for that exercise. In addition, for each of the movement variables (eg, shoulder flexion/extension, wrist pronation/supination), the therapist can set thresholds of permissible mismatch. In this way, large mismatches between the user’s movement and the target movement will be permitted in the early stages of rehabilitation. As the user makes progress, the therapist can reduce the permissible mismatch to make the task more challenging. For future prototypes, remote access to the data stored on the system by therapists will be accessed through a Web-based interface using secure Internet protocol.

Ensuring Clinical Utility

If telerehabilitation technology such as the SMART system is to be adopted by practice, it must be acceptable to physical therapists, occupational therapists, and others involved in the delivery of rehabilitation. This means that the technology has to be capable of facilitating the undertaking of prescribed interventions, use acceptable terminology, and provide appropriate feedback about user progress to therapists. Initial phases of this research program consisted of consultation activities with clinicians on the multidisciplinary team, as previously reported. This article highlights further findings from the authors’ research that relate to the issue of clinical utility and describes case studies used during the initial deployment of first prototype.

Creating a Library of Interventions

The initial SMART prototype incorporated “reach forward” as the sole target exercise, to be achieved by placing an object (a cone) at a determined distance (full passive range of reach) from the seated user. Subsequent feedback from users and professionals highlighted the limitations of this single movement choice. A library of prescribed interventions was deemed necessary to enable therapists and users to select the most appropriate intervention for the individual, as they would when devising a traditionally delivered rehabilitation program. For the SMART prototype, identifying the most relevant interventions therefore required consultation with therapists who specialize in neurological rehabilitation. Clinical researchers devised a questionnaire that listed the physiological and functional components of 10 commonly applied upper-limb interventions for distribution at the 2007 UK Annual Conference of Physiotherapists with a Special Interest in Neurology. Respondents were asked to select the 5 interventions from the list that they used most, and rank in order of frequency used (1 being most frequent). Twenty-eight questionnaires were completed and returned from respondents whose experience in neurology ranged from 2 to 26 years. Analysis found that the following 7 interventions were most frequently chosen and highest scoring: reach arm forwards; take a drink; take hand to mouth; reach sideways away from body; put arm in a sleeve; reach to the floor; reach arm sideways across body. This library was incorporated into the next SMART prototype.

Figure 1. The SMART Telerehabilitation System’s First Prototype
Identifying the Adequacy of Feedback

Researchers also consulted clinical therapists regarding the information about the progress of individual users that they would like to have available through the decision support interface screen. A small focus group of specialist neurological occupational and physical therapists was convened. Participants were shown the manikin display results for 1 person with stroke who had used the first prototype (this used 2 sensors only; one on the upper arm and a second on the wrist). They were asked what they could interpret from the screen without being provided with any other information. One commented, “I think this gives a lot of information on timing and number of repetitions, and it gives a definite insight into the quality of the movement within the upper limb itself.”

All noted the restricted range of movement at the elbow and correctly interpreted the internal rotation of the limb during the reach movement. They also could interpret clearly the degree of fluency, extent of precision, and the jerkiness of movement of the impaired limb. The same group was then shown a video of the same user undertaking the same exercise and asked how the information conveyed through the video compared with that given on the decision support interface. They all noted the excessive trunk activity on the videorecording that had not been shown by the screen manikin due to the absence of a sensor on the user’s trunk. Also, even though they could deduce from the screen feedback that the user had touched the target object, the video showed the user’s hand in a nonfunctional position, which had not been conveyed through the screen because of a lack of a hand sensor. A further observation was that the screen manikin did not show the stabilizing activity of the other arm on the table. However, they also stated that the SMART system axis views gave them higher-quality information about movement from different angles. This feedback was used to support decisions about the optimum number of sensors for the second prototype. The need for clinical utility had to be reconciled with simplicity and functionality. Therefore, the second prototype added a trunk sensor but not a hand sensor due to the increased complexity this would have created.

Incorporating Movement Measurement

According to the focus group clinicians, the range of movement of the impaired limb (ie, extension, flexion, pronation, supination) was the most important outcome for physical stroke rehabilitation. However, methods of measurement created some discussion before consensus was reached. Precision of movement was identified as being the second most-important outcome, in particular, movement trajectory and directionality as well as how many times a movement changes direction as an indication of fatigue. The physical therapists agreed that being able to view measures for individual movements within a set of repetitions to see how quickly fatigue makes an impact would be useful within a system. Records of the time of day that exercises are carried out also may help to understand reasons for fatigue. Movement sequencing (eg, which joint initiated the movement and the ordering of joint movement) also was identified as being clinically valuable. This would enable physical therapists to set a goal of improving the normality of movement. One therapist suggested that an area of the limb on the decision support interface could light up to identify where movement started, with added the capability of switching this feature on or off depending on patient needs. For example, if a patient started a movement with the shoulder rather than the arm, a red light could activate. The therapists assumed that the system would measure speed of movement and thought that this would be beneficial information, particularly when linked to measures of quality of movement and fatigue levels.

Terminology

The therapists who were consulted had difficulty accepting the incorporation of terminology different from that in which they had been educated and socialized. For example, “cycle time” was not as acceptable as “time taken” or “speed of movement.” Tasks, repetitions, and sets were considered to be the most appropriate terms and preferred to the word “exercise.” Several “tasks” completed consecutively would be considered “repetitions;” a number of these repetitions would be considered “sets” of repetitions. This raised interesting questions regarding what could be a disjunction between therapist and end-user preferences regarding the terminology used by telerehabilitation systems.

Feedback Provided Through the Decision Support Interface

The authors sought opinions about a variety of graphs and charts on the decision support interface and invited new ideas. The bar charts showing information about daily/weekly tasks, repetitions, and sets were considered to be simple to read for both users and professionals. Scattergrams and box plots were considered to be useful for collating data over a longer period (eg, comparing weeks and months). To provide users with feedback about reaching the target, a simple thermometer-style representation, with a line showing how far the person had reached (and an indication that they had managed to achieve the target), was suggested. The focus group participants also were enthusiastic about a speedometer-style indicator showing how far the user had gone towards reaching the target.

The calendar function was considered the easiest way to access the graphical information on the SMART system. By accessing the calendar, the participating therapists quickly appreciated that it was possible to see how many times the equipment had been used and at what time of day. Clicking on each recorded task or activity could then provide an adequate amount of detailed data for each of the repetitions and sets on a per-session and daily basis. To look at changes over time, they could click a button displaying a week of information, with similar functions to view data on a monthly or quarterly basis. Although these facilities were appreciated, the therapists pointed out that recorded data might have to be deleted; for example, if other family members wanted to try the system, data from the first user would skew the resulting outcome.

Determining Clinical Effectiveness and Developing an Evidence Base for Rehabilitation Technologies

The next research challenge following the initial system prototyping with clinicians was to investigate the feasibility and clinical utility of using this innovative rehabilitation system within the homes of stroke survivors and, subsequently, to establish the feasibility of an experimental research design and data collection methodology.

Considerable debate has taken place over the last decade about the small proportion of medical treatments and health technologies that are based on sound scientific evidence and about the wisdom of basing clinical decisions and practice solely on the findings of quantitative research. According to Sackett, “External clinical evidence can inform, but can never replace, individual clinical expertise, and it is this expertise that decides whether the external (formal) evidence applies to the individual patient at all and, if so, how it should be integrated into a clinical decision.” Similarly Mant suggests, “The paradox of the clinical trial is that it is the best way to assess whether an intervention works, but arguably the worst way to assess who will benefit from it.”

It is interesting that Sackett uses the term “individual patient” while many clinical guidelines are based on the hierarchy of
evidence where the gold standard is the randomized controlled trial (RCT), a research methodology that does not provide any information about the individual patient in the trial. This research method does not allow the researcher to investigate the interactions between multiple variables that may exist during the development of telerehabilitation technologies such as the SMART system.

Considering the history of the RCT can aid in understanding some of the problems associated with this hierarchy. The RCT experimental design was first used within the agricultural industry where researchers were developing and testing new products such as fertilizers to establish which produced the best results. All factors could be controlled—the nutrients, sunlight, and hydration—ensuring that the resulting difference in growth could be attributed, with high levels of confidence, to the chemicals applied.

Herein lies the inherent problem. Health interventions, behavior, social networks, and the environment cannot be controlled in the same way, and the interaction between such variables and body systems are fundamental to the intervention and, indeed, the outcome. Furthermore, in complex health technology interventions, it always will be difficult to identify the “active ingredient” of the intervention as defined by the Medical Research Council.21 Wade22 supports this issue of interactive processes: “It is probably impossible to isolate the effects of one profession within the team. More importantly, it is also probably both scientifically invalid and politically inappropriate.”22,23

However, different methods exist to collect and present information about an individual patient, methods that are more appropriate for health technology research, providing information about the feasibility and clinical utility of the technology prior to pilot studies to determine effects sizes for full RCTs. These include the case study, the case report, the single case experimental design (SCED), and the pluralistic realistic evaluation.22-28 Each research method collects multiple observations of the attributes to be measured, the social and environmental factors that may have an impact on usage with combinations of both qualitative, and quantitative data collection. Although none of these methods can provide evidence of attribution, they do provide knowledge of associations and relationships and support theoretical assumptions identified prior to the observations.

For the purpose of evaluating the feasibility and clinical utility of the SMART system in the subjects’ homes, the authors chose to use a case study design with a mixed-method data collection.

Table 1. Description of Subjects

<table>
<thead>
<tr>
<th>Time since stroke:</th>
<th>7 months to 4 years</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean age:</td>
<td>61.5 (SD = 27.5)</td>
</tr>
<tr>
<td>Sex:</td>
<td>2 male/2 female</td>
</tr>
</tbody>
</table>

SMART Case Study Research Questions

- Does using the SMART system alter activity (function) following a stroke?
- Does repetitive, task-oriented activity change motor behavior?
- How do users and caregivers perceive the SMART system?
- Can users interpret visual feedback of upper limb movements?

Case Study Aims

- To examine changes in activity following use of the SMART system in the home environment.
- To ascertain the patients’ and caregivers’ views of the usability and feasibility of the SMART system when used in a home environment.
- To establish how use of the SMART device influences motor behavior during post-stroke exercise.

Case Study Protocol

At the time of this study, the SMART system was comprised of 2 Xsens orientation sensors, sensor attachments, and a small media PC and touch screen. The Xsens orientation sensor is a small box, measuring 39 x 54 x 28 millimeters and weighing 35 grams. Each sensor is connected by a wire to a device (100 x 150 x 40 millimeters, 278 grams) worn at the waist. The device communicated wirelessly (Bluetooth) with a small media PC. The user interface to the PC was via a touch-screen. The sensor attachments were made of soft, elastic neoprene-type material. During the case studies, the SMART system was installed in the patients’ home. Users and their caregivers received training in how the SMART prototype is clinically important to the stroke individual. TELER indicators were chosen from the TELER stroke library by the patient and the therapists to reflect the desired outcomes to be achieved.

Motor function also was measured at the beginning and end of the 2-week period using standardized tools, the upper-limb section of the Motor Assessment Score,32,33,34 and the Timed Up and Go test.35 All posttest measurements were undertaken by a second researcher blinded to the initial scores.

Pre and Posttest Deployment

TELER29 is a measurement system based on clinically significant change over time. It is a method of clinical note making that incorporates three 6-point ordinal scales within the analysis (TELER Indicators). These scales were previously validated indicators30,31 or were individually constructed for each patient functional needs, ensuring that the impact of the SMART prototype is clinically important to the stroke individual. TELER indicators were chosen from the TELER stroke library by the patient and the therapists to reflect the desired outcomes to be achieved.

Motor function also was measured at the beginning and end of the 2-week period using standardized tools, the upper-limb section of the Motor Assessment Score,32,33,34 and the Timed Up and Go test.35 All posttest measurements were undertaken by a second researcher blinded to the initial scores.

Qualitative Interviews

At the end of the 2-week period, researchers conducted (and recorded) semi-structured interviews with the patients and caregivers to gather feedback about their perceptions of the usability of the SMART system and how they used the system to alter their own rehabilitation program.17

Inclusion Criteria

- Upper-limb impairment following stroke
- Age 60 or over at stroke onset
- Familiar with IT/computer word processing
- Exclusion Criteria
- Con-committant disease involving the upper limb
- Severe communication disorder
- Severe perceptual disorder (including visual field deficit)
- Cognitive impairment or inability to provide written consent

Subjects

Participants for the clinical case studies were 4 volunteers from a local private physical therapy clinic. Ethics approval was obtained from the Sheffield Hallam University Ethics Committee and informed written consent was obtained from all participants. The target exercises were those that would constitute part of the patients’ normal rehabilitation regime. The 4 subjects used the SMART system daily (or at intervals they deemed appropriate by themselves), with the sensors recording the performance of exercises selected from the library of exercises previously developed (Table 1).
OUTCOMES

Case Study Analysis
Changes in functional activity were analyzed through predemotion and postdeployment. Descriptive statistics were used to calculate where there was an observed improvement, maintenance, or deterioration in the TELER indicators, the Timed Up and Go (TUG) values and the Motor Assessment Scale (MAS) (Tables 2 and 3).

DISCUSSION

Conclusions Regarding an Appropriate Evaluation Framework
Upper-limb problems continue to be present 3 to 6 months after stroke onset in 55% to 75% of patients, of which an estimated 10% will be appropriate for motor telerehabilitation, taking into account the exclusion of those with severe cognitive impairment and motor problems. This research has demonstrated that the SMART rehabilitation system could be used to support early discharge, shifting spending from inpatient to outpatient care and potentially reducing the overall cost of care for the National Health Service. This radical new way of delivering and monitoring rehabilitation requires a significant paradigm shift—away from a traditional therapy delivery model to a more patient-based, self-management paradigm. In addition to being more cost effective, the SMART rehabilitation system may also be a more effective intervention, in that it enables the therapist to determine the extent of adherence to exercise programs.

This shift in delivery of care proposed by the SMART rehabilitation system matches several of the goals articulated within the NHS Plan, namely, the reduction of health inequalities, the redesigning of services to meet patient needs, using information technologies as a means of achieving patient-centred services, and empowering people to manage their own health care needs. Moving away from a face-to-face delivery model of rehabilitation to a concept of self-management has been further developed since the publication of the NHS Plan, with a greater emphasis upon helping individuals take direct control of their own health and well-being. Within the telehealth field, no international guidelines exist for consistent assessment of the impact of telehealth, although the European Commission is anticipated to provide advice by 2011.

Internationally, evidence (supported only by small-scale UK studies) indicates that the use of remote health technologies with the focus on enabling people to help themselves

Table 2. Examples of TELER Indicators Used in the Case Study

<table>
<thead>
<tr>
<th>UPPER-LIMB TASKS</th>
<th>LOWER-LIMB TASKS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Components:</td>
<td></td>
</tr>
<tr>
<td>Move hand towards object</td>
<td>0: Unable to achieve any component</td>
</tr>
<tr>
<td>Touch/grasp</td>
<td>1: Able to achieve 1 of the components</td>
</tr>
<tr>
<td>Lift object</td>
<td>2: Able to achieve 2 of the components</td>
</tr>
<tr>
<td>Place and release object</td>
<td>3: Able to achieve 3 of the components</td>
</tr>
<tr>
<td>Gesture</td>
<td>4: Able to achieve 4 of the components</td>
</tr>
<tr>
<td></td>
<td>5: Able to achieve all 5 components</td>
</tr>
<tr>
<td>HAND GRASP</td>
<td></td>
</tr>
<tr>
<td>Components:</td>
<td></td>
</tr>
<tr>
<td>Pick up a paper clip</td>
<td>0: Unable to achieve any component</td>
</tr>
<tr>
<td>Hold a pen</td>
<td>1: Able to achieve 1</td>
</tr>
<tr>
<td>Pick up an empty soft drinks can</td>
<td>2: Able to achieve 2</td>
</tr>
<tr>
<td>Hold a post card/envelope in supination</td>
<td>3: Able to achieve 3</td>
</tr>
<tr>
<td>Hold a key</td>
<td>4: Able to achieve 4</td>
</tr>
<tr>
<td></td>
<td>5: Able to achieve all</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td>HAND GRASP</td>
<td></td>
</tr>
<tr>
<td>Components:</td>
<td></td>
</tr>
<tr>
<td>0: Able to grasp large beaker</td>
<td>0: Unable to achieve any component</td>
</tr>
<tr>
<td>1: Able to grasp medium beaker</td>
<td>1: Able to achieve 1</td>
</tr>
<tr>
<td>2: Able to grasp small beaker</td>
<td>2: Able to achieve 2</td>
</tr>
<tr>
<td>3: Able to grasp small peg</td>
<td>3: Able to achieve 3</td>
</tr>
<tr>
<td>4: Able to grasp button but not manipulate it</td>
<td>4: Able to achieve 4</td>
</tr>
<tr>
<td>5: Able to grasp and manipulate button</td>
<td>5: Able to achieve all</td>
</tr>
</tbody>
</table>

Table 3. Functional Changes Observed Pre and Post Deployment of SMART System

<table>
<thead>
<tr>
<th>Type of Change</th>
<th>Number of Items</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Deterioration</td>
<td>2</td>
<td>10%</td>
</tr>
<tr>
<td>No Change</td>
<td>8</td>
<td>40%</td>
</tr>
<tr>
<td>Improvement</td>
<td>10</td>
<td>50%</td>
</tr>
<tr>
<td>Total</td>
<td>20</td>
<td></td>
</tr>
</tbody>
</table>

Table 4. Changes in All Measures Pre and Post Deployment of SMART System for Individual Subjects

<table>
<thead>
<tr>
<th>Subject</th>
<th>Motor Assessment Scale</th>
<th>TELER</th>
<th>TELER</th>
<th>TELER</th>
<th>Timed Up and Go (seconds)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>14-16</td>
<td>3-3</td>
<td>3-3</td>
<td>3-3</td>
<td>24-18</td>
</tr>
<tr>
<td>2</td>
<td>4-9</td>
<td>2-5</td>
<td>1-3</td>
<td>2-5</td>
<td>41-67</td>
</tr>
<tr>
<td>3</td>
<td>5-8</td>
<td>2-2</td>
<td>4-4</td>
<td>0-0</td>
<td>35-36</td>
</tr>
<tr>
<td>4</td>
<td>9-10</td>
<td>3-1</td>
<td>0-1</td>
<td>2-2</td>
<td>12-9</td>
</tr>
</tbody>
</table>
can demonstrate not only a significant improvement in health outcomes and patient satisfaction, but also a substantial reduction in hospital use. The UK Department of Health has challenged researchers to demonstrate this shift from hospital care on a wider scale, suggesting that more people with long-term conditions can be supported to retain independence in the community through the use of innovations in health technologies.

The 2006 European Commission report also suggests a “new healthcare delivery model based on preventative and person-centred health systems. This new model can only be achieved through proper use of ICT, in combination with appropriate organisational changes and skills.”

This article describes some of the research work undertaken in developing the SMART rehabilitation system, suggesting an evaluation framework that can provide observations and information essential in the development of health technologies. The authors suggest that the RCT may not be the most appropriate research method to be used in this early design, development, and prototype deployment of telerehabilitation systems because of the complexity of the development process, the interaction processes, the clinical requirement, and the individual needs of the stroke patient.

REFERENCES

Computer Adaptive Testing for Patient-Reported Outcomes: Resources for Clinical Research

Carole A. Tucker, PT, PhD, PCS

Background and Purpose. The physical therapy profession actively continues to develop systems of standardized outcomes to provide evidence of treatment efficacy and to improve rehabilitation practices. The emergence of patient-reported outcomes (PROs) of perceived health outcomes and health-related quality of life has gained increased importance in clinical research and practice. The objective of this report is to provide an introduction to the development of PROs using item response theory and computer adaptive testing, and to provide an overview of the National Institutes of Health’s Patient-Reported Outcome Measurement Information System (PROMIS). PROs are increasingly relying on computer adaptive testing (CAT), a promising technology that helps resolve the classic conflict between practicality and precision faced by traditional outcome measures. CATs require a set of items developed using Item Response Theory in combination with CAT software.

Method/Model Description and Evaluation. Item Response Theory (IRT) methods for instrument development in combination with computer adaptive testing approaches for administration are advancing PROs in health care.

Outcomes. PROMIS is a system of PROs based on IRT/CAT that are available to clinical researchers for adoption.

Discussion. CATs can be integrated seamlessly with electronic data capture systems and electronic health records to provide a means to implement standardized systems of PROs across multiple sites.

Conclusion. Health care research and practice systems are using these emerging technologies for developing and administering standardized health outcomes, and physical therapists’ professional education should begin to include the necessary knowledge to enable them to become competent users and developers of PROs using CATs.

Key Words: Computer adaptive test, Patient-reported outcomes, Standardized assessment.

BACKGROUND AND PURPOSE

The physical therapy profession has a critical need for standardization of measures as it continues to build evidence to support best practice. Standardization of health and rehabilitation outcomes in this profession is an active focus of efforts by the American Physical Therapy Association (APTA). From a clinical service perspective, processes to monitor interventions for individual patients have become seriously fragmented as different hospitals, clinics, and programs select outcome instruments that cannot easily be compared across systems. Using an assortment of instruments also complicates credentialing and training for a large clinical staff. In many instances, clinicians simply lack the time for administration of the “best” instrument due to time constraints or length of the instrument. Enhanced monitoring supported by standardized outcomes should result in better program decisions and improved service delivery for patients and help in the identification of evidence-based clinical pathways. From a clinical research perspective, a uniform approach to health outcomes measurement could enhance the comparability of measures across clinical research sites and projects and improve the generalizability of study results. Although efforts are under way to develop clinically meaningful outcomes with low administration burden, few instruments or batteries of instruments have been accepted or adopted by the physical therapy profession for clinical practice or research.

Evaluations of the effectiveness of medical care have conventionally focused on clinical end-points, including laboratory tests, imaging, and clinical exams measuring changes at the body structure and function level. However, many outcomes associated with the use of medical and surgical devices, medications, or interventions are known only to the patient. Patient reported outcomes (PROs) enhance clinicians’ understanding of the impact of illness, health, and interventions from the patient’s perspective. For example, symptoms (eg, pain, fatigue), activity behaviors and participation, perceived health, and health-related quality of life are all experienced by the individual, and these patient perceptions are often best determined using PROs. Simply put, well-designed PROs can provide a level of precision and validity in the measurement of these patient-perspective outcomes that cannot be achieved using traditional clinical performance or morbidity indicators. Standardized, accessible PRO instruments with low administration and scoring burden would enable clinicians to monitor the impact of medical, surgical, and rehabilitation interventions on an ongoing basis across severity levels and facilities.

The lack of a standard set of PROs is in part due to traditional approaches to instrument development and delivery. Traditional instruments have difficulty meeting precision standards across all levels of the functional continuum because of the restriction of the number of items the respondent can reasonably answer. The development of standardized measures that can precisely yet comprehensively measure health status and capture the fine granularity of change at individual and group levels to support clinical decision-making presents a daunting task using traditional measurement development methods. However, PROs developed using item response theory (IRT) methods and implemented as computer adaptive tests (CATs) are emerging as the preferred approach for developing outcome measures in
health care research and practice. A CAT is a contemporary measurement technology that relies on item banks, large sets of items reflecting an underlying construct of interest (eg, physical function, pain, depression), that are statistically calibrated using Item Response Theory (IRT). CAT software is then used to administer a logical subset of these items based on the patient’s real-time responses to provide the most efficient and precise outcome score. Hence, CAT technology offers a promising method to resolve the classic conflict between practicality and precision faced by traditional functional instruments.

The growing need for standardized assessment of patient outcomes in the health care system in combination with the emerging availability of advances in information technology and modern measurement approaches, such as CAT-PROs, provide opportunities for physical therapists to become active contributors and consumers of CAT-PROs in clinical research and practice. The objectives of this report are to provide an introduction to computer adaptive testing (CAT) technology for PROs and an overview of the National Institutes of Health’s (NIH) Patient-Reported Outcome Measurement Information System (PROMIS) Assessment Center, a publically available, Web-based system for clinical research using PROs.

**METHOD/MODEL DESCRIPTION AND EVALUATION**

Successful development and implementation of CAT-PROs requires many of the same methodologies as used in traditional outcome measurement development. Both require identification of the purpose of the measure; definition of the construct of interest; development of items; consideration of the population and sampling design; and assessment of reliability, validity, and responsiveness to change. Although these processes are of crucial importance in the development of CAT-PROs, this report will focus on basic IRT and CAT methods for PRO development and modern measurement approaches that are often less familiar to physical therapists.

**Item Response Theory**

*Item Response Theory* (IRT) is a family of statistical modeling techniques that permits an analysis of response characteristics to individual items and how they relate to other items in a particular cohesive domain of interest. IRT relates characteristics of items (item parameters) and characteristics of individuals (latent traits) to the probability of the respondent choosing a given response for an item. In simpler terms, IRT can be used to quantify the relative difficulty of items in a test—how each item fits within the set of items—and estimate the person’s score on this same measurement scale. Traditional approaches to outcome measure development based on classical test theory rely on population-based statistics for individual scores (eg, mean, range, standard deviations of how a group did determines each individual’s relative score or grade). Unlike classical test theory, IRT describes the association between where a respondent falls on a given concept or trait (θ) and the probability of a particular response to an item. IRT provides a way to organize the information so that a precise score can be obtained from just a few items, providing higher precision of measurement with fewer items and decreasing administration burden. Hence, IRT provides a means to design instruments with the flexibility of using all items or any subset of items to estimate the performance of individuals along a functional scale.

IRT is useful for examining item-level properties of a set of items or “item bank” as well as information provided by individual items. In IRT, item characteristic curves are derived, indicating the probability that a person with a given ability level will choose each possible response. This links the relative difficulty of each item with the specific level of ability of the person (Figure 1). Item information functions also are derived for each item and show how much information an item contributes across the possible score range (Figure 2). The set of individual item information curves for all items in a model form the test information function. The test information function indicates how well the underlying construct is captured by the entire set of items (Figure 3). Once calibrated, each item’s “difficulty” and person ability estimate are scaled on the same metric. Potential ceiling effects, floor effects, and content gaps in the item bank can be determined. The presence of differential item functioning (DIF), indicating that variables other than the latent variable affect the test score, can be determined as well.

**Figure 1. Example of 2-Item Characteristic Curves**

![Figure 1](image1)

Each curve of an ICC corresponds to one of the 5 responses for the item (unable to perform, with much difficulty, with some difficulty, with little difficulty, without any difficulty). The horizontal axis is the range of the construct in terms of relative skill expressed in logits, with lower skill levels to the left and higher skill levels to the right. The vertical axis is the probability distribution of each response over the construct.

**Figure 2. Information Function Curves**

![Figure 2](image2)

The 2-item information function curves in this figure correspond to the set of item characteristics in Figure 1. The horizontal axis is the range of the construct in terms of relative skill expressed in logits, with lower skills to the left and higher skills to the right. The vertical axis is the probability distribution of each response over the construct. This items demonstrate a peak in the information function around the region of difficulty where the answers best discriminate amongst the response choices (ie, less overlap).
The test information curve is derived from the sum of the individual items’ information curves and indicates the total test information. In this set of items, the total test information for each test or scale score value is indicated on the left axis, while the standard error for each test score is indicated on the right axis. The test performs quite well in the middle region, with less information at the extremes where there are fewer items. Ideally, test information curves range from -3 to +3 logits. This test information curve exhibits a ceiling effect as noted by the higher error (dotted curve) and the lower probability of the test information curve at the high end of the construct.

In summary, IRT analyses enable reliable and precise outcome measurement. Since fewer items are needed for an equal level of precision, IRT-based assessments can be shorter than similar tests based on classical test theory. Greater precision in the test score can be obtained by including additional items, thereby, reducing measurement error. With more precise measures, a smaller sample size may be adequate to power clinical research studies. IRT depends on the assumption that the construct being measured can be expressed as a range of ability on a definable continuum characterized by a number of items that can be ordered from low to high, or easy to difficult. IRT does require that the construct underlying the measure is a cohesive factor (or fairly uni-dimensional) and that there is a hierarchy (high to low, easy to difficult) among the items. Not all constructs are suitable for IRT analyses and subsequent use in CATs. In these cases, traditional test methods or qualitative techniques may be better suited for instrument development of such constructs. Finally, the application of IRT methods in initial item bank development requires a large number of subjects, often over 500, for the calibration phase. This can be difficult for a single site to recruit, but is achievable in multi-site data collection or for large health care systems.

Computer Adaptive Tests

The basic notion of an adapted test is to mimic what an experienced clinician would do. A clinician learns most when he or she directs questions at the patient’s approximate level of proficiency. Administering items that are either too easy or too hard provides little information to the test score and adds to the administrative burden. For example, a question about community ambulation is unnecessary if the patient is just taking steps in the parallel bars, whereas a question about the ability to negotiate 3 to 5 steps is pointless if the patient is currently walking up and down 3 flights of stairs. CATs use a simple form of artificial intelligence that select questions tailored to the test-taker, shorten or lengthen the test to achieve the desired precision, score everyone on a standard metric so that results can be compared, and display results instantly.

CATs generally begin with administration of 1 item that is selected a priori on the basis of the range it covers—typically an item with information in the middle of the construct range. All respondents answer the same first question, which is an advantage for purposes of standardization. On the basis of the response to the first item, the respondent’s test score and confidence interval are estimated. The next item presented to the respondent is the item that adds the most information to the previous item(s) or best fine-tunes the current estimated score. This next item is administered, the respondent answers, the estimated score and confidence interval are once again updated, and the process continues until the test ends based on a pre-specified stopping rule.

In addition to the calibrated item bank, CATs require software to implement the logic needed for test administration that specifies rules guiding starting, stopping, and scoring procedures chosen to meet the tester’s needs. The CAT can be specified to stop once the score achieves a certain level of precision, after a maximum number of items have been answered, after a set time, or even after a certain number of specific content-related questions have been asked. If the CAT-PRO will be used to monitor an individual’s change, higher precision in the score is necessary and additional items could be provided until the specified precision is achieved, rather than stopping after a predetermined number of items. The choice of items also can be modified to include subsets of “necessary” items that may not be used solely based on the CAT logic of “most IRT information.” For example, for a CAT-PRO of physical activity, one might want to make sure that the items include activities of daily living, occupation, recreation, and transportation.

The long-term advantages of CATs are important to consider in the context of the current evolution of existing standardized instruments. Once a traditional, fixed-format outcome instrument has created an accumulation of reliability and validity studies, test developers and users tend to be reluctant to make any changes to the instrument. In contrast, the CAT platform can become a dynamic instrument, in which changes and improvements can take place incrementally. Pilot items can be introduced into the CAT (remaining unscored during an assessment period), but banked for future analyses. If such pilot items are shown to improve the precision or breadth of the scale, then the items can be integrated into the item bank and made available for future CAT assessments. In a high-volume clinical system, pilot items could be tested quickly and made part of the item bank on a regular basis. Since the new items are integrated within the same measurement model based on the item characteristics and the defined construct, the validity of the instrument essentially remains the same.

A further advantage of this approach is that the new CAT instrument can be “backward compatible,” that is, scores on existing instruments can be derived from the new CAT. This is possible through IRT equating and linking of the new CAT scale to each of the original instrument scales by cross-calibrating the known test characteristic curves. By standardizing and calibrating all items measuring the same concept, even those from different instruments, results can be meaningfully compared and interpreted.

Even when IRT and CATs are used to construct PROs, clear definition of the purpose of the measure is still required. Subsequent assessment of the instrument’s validity, reliability, and responsiveness to change also must be completed prior to acceptance of...
the measure as providing appropriate standardized outcomes. The NIH's PROMIS® approach to development of IRT-based CATs and PROs provides guidance and standards for test construction, including qualitative approaches such as cognitive interviewing and focus groups, as well as IRT and CAT quantitative psychometric guidelines.

OUTCOMES

PROMIS: Patient-Reported Outcomes Measurement Information System

The growing importance of CAT assessment methodology in medical research is signified by its inclusion within the National Institutes of Health (NIH) Roadmap.13 As part of its roadmap initiative, the NIH formed the Patient-Reported Outcomes Measurement Information System (PROMIS) network to develop methods for efficiently and validly examining health outcomes from patients’ perspectives.2,4 The first phase of PROMIS produced psychometrically robust item banks that support assessments of PROs using both fixed-length and computerized adaptive tests.2 PROMIS provides the tools researchers need to integrate the thousands of independent patient-reported measures into an efficient, standardized system. As a result of the first phase of PROMIS, a repository of psychometrically robust survey items and computerized adaptive tests that measure several latent traits within the physical, mental, and emotional health dimensions of PROs is available for the clinical researcher. Ongoing efforts in the second phase of PROMIS focus on clinical validation of the instruments, expansion of the Assessment Center capabilities, and development of additional item banks for pediatrics and other health outcomes of interest. The currently supported health domains and availability of instruments can be viewed at the PROMIS Web site.8 Two other NIH efforts of interest to the rehabilitation field also support IRT-based CAT-PROs: Quality of Life Outcomes in Neurological Disorders (Neuro-QOL)15 and the NIH Toolbox.16

In addition to the existing PROMIS instruments, the PROMIS Assessment Center provides a means to deploy PROs through Web-based or computer interfaces.8 Researchers can log on to the Assessment Center and search for items and instruments that target specific research questions of interest. They can use the existing measures in PROMIS or enter personal surveys, including institutional review board (IRB) required documents for human subjects, study-specific information and descriptions, and demographic questions. The Assessment Center supports both cross-sectional and longitudinal study designs, and the researcher can specify the timing window (eg, 6 weeks after baseline measure +/- 3 days) for measurement. Clinical researchers can then direct their patients to a secure, study-specific Web site generated by the Assessment Center to take the study survey.

The availability of a variety of differently focused health status measures delivered through a single system allows the user to measure multiple dimensions efficiently. Hence, clinical researchers are able to develop a more comprehensive understanding of their patients’ health status that better supports evidence-based practice in physical therapy. The availability of CAT-PROs allows integration of outcome results using electronic data capture, resulting in point-of-care access to the information from the outcomes assessment. The data from Assessment Center can be exported into spreadsheets and statistical programs by the researcher. Standardized clinical reports are under development.

DISCUSSION

Future Directions

As rehabilitation delivery systems become more integrated, outcomes management systems within and across settings will play an increasingly important role in determining how services are evaluated. Accordingly, more contemporary models of data collection, such as CAT technology, are urgently needed to monitor outcomes across care settings. For example, at check-in for a clinic visit, patients could quickly answer CAT-PROs and the results could be placed in the hands of the clinical team at the point of care. Web-based PROs can be used to monitor a patient's status with responses scored and forwarded to the medical care team via updates to the electronic health record. If the patient's status changes per his or her Web-based PRO, a clinic appointment or phone contact could be made, providing a more efficient method of determining the need for care. Patients' answers to PROs in advance of visits could help periodic outreach clinics better determine staffing needs. For example, a clinic might staff more physical therapists if, on a Web-based CAT-PRO they accessed from home a week before clinic, a high percentage of patients reported that they were less physically active and had more difficulty moving around.

The use of PROs delivered by Web-based electronic data capture systems, or by phone (using audio surveys with touch tone or text responses) in combination with data gained from objective monitoring technologies (eg, step monitors, global positioning system devices, accelerometers) can provide a comprehensive picture of how patients function within their real-world environment. The PROs add contextual and affective information (eg, What specifically are you doing? How are you feeling?) to the data obtained from objective monitoring (eg, movement, heart rate, global position). The use of mobile phone technology and electronic diaries, prompting the user to answer short surveys or CAT-PROs at any moment, add the real-time aspect to such combined data collection methods.

CONCLUSION

In conclusion, CAT-PROs for clinical practice and research are emerging as important outcome measures that support standardization tools for physical therapists. Clinicians can gather a more comprehensive picture of patient status using CATs and enhance the evidence supporting best practice. PROs based on computer adaptive testing are available for public use in the PROMIS Assessment Center, or in combination with other publically available electronic data collections systems. Physical therapy education should include the topics of test construction using IRT and delivery of CATs so that the profession can be fully involved in this emerging technology for standardization of health outcomes. Physical therapists interested in learning more about CAT-PROs are encouraged to visit the NIH PROMIS Web site8 and take advantage of the publically available resources. The Assessment Center workgroup offers periodic, low-cost workshops on CATs/IRT that are designed for clinical researchers who want to gain practical experience using the Assessment Center.

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Background and Purpose. Virtual reality (VR) is emerging as a valid tool for the rehabilitation of individuals with a variety of disabilities. The objective of this study was to systematically review studies pertaining to the use of VR technology in the rehabilitation of children with sensorimotor deficits.

Methods and Materials. A literature search of PubMed, CINAHL, Cochrane, Pedro, Hooked on Evidence and Google Scholar was undertaken. Included were research reports published in peer-reviewed journals that utilized VR in the assessment and/or treatment of children ages 2 to 18 with sensorimotor disorders. No restrictions were made as to study methodology, outcome measures, or type of VR technology employed. The research methodology and strength of evidence of each study was evaluated by 2 independent reviewers.

Summary of the Literature. The search identified 26 studies; 5 examined primarily the degree to which VR induces playfulness, volitional behavior, pleasure and/or motivation; 4 used VR to assess spatial abilities; 17 examined the effects of VR interventions for a variety of treatment objectives. Only 3 studies were randomized control trials, and 8 employed single-case designs. Evidence strength and quality of methodology of the majority of studies was fair to poor. Most studies presented positive outcomes.

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Received March 1, 2010, and accepted July 30, 2010.

Discussion and Conclusion. VR-based rehabilitation in children with a variety of sensorimotor deficits is feasible and safe, and has potential as an effective assessment and treatment modality. However, higher quality research is necessary before the value of VR in pediatric rehabilitation truly can be ascertained.

Key Words: Virtual reality, Sensorimotor impairment, Children, Systematic review.

BACKGROUND AND PURPOSE

Children with sensorimotor deficits, whether the result of non-progressive insults to the nervous system (eg, cerebral palsy (CP), spina bifida, and traumatic brain injury), or as a result of progressive neurological conditions (eg, muscular dystrophy) present with a wide range of impairments affecting their functional abilities, their participation in daily activities relevant to their age, and, ultimately, their quality of life. Virtual reality (VR) computer-based technology provides the user with opportunities to interact with virtual objects and events that appear, sound and, in some cases, feel similar to those of the real world.1-3 Over the past decade, VR has emerged as a rehabilitation tool for both adults and children with a variety of physical disabilities.1-11

The expected benefits of VR-based rehabilitation stem from various characteristics of this technology that include the opportunity for experiential active learning that is fun, motivating, and challenging, yet safe and ecologically valid.8 VR attributes may be particularly suited to the achievement of effective motor learning (see reviews by Holden1 and Sveistrup11). The old adage “practice makes perfect” is supported by a growing body of research indicating that changes in motor behavior and in neural plasticity are dependent on the intensity of training and the number of task specific repetitions.12-14 Additional factors important for motor learning include the type, amount, and timing of feedback of movement performance and results.15,16 By offering an engaging activity, VR technology can encourage repetitive, task-specific behavior that is graded to the competence level of the user, while providing the feedback necessary for effective motor learning. At the same time, the automated nature of stimulus delivery within the virtual environments (VEs) enables the physical therapist to focus on users’ performance and guide them to the use of effective strategies. Furthermore, online interaction with VEs demands careful monitoring of the user’s response, thus VR also provides the ability to objectively monitor and measure changes in performance and behavior.8

The integration of VR technology for rehabilitation purposes is particularly appealing in pediatric rehabilitation because children frequently are not compliant in following conventional therapeutic programs that they may not find very meaningful or interesting.17 In contrast, play is a fundamental and enjoyable occupation of children by which they develop their sensorimotor, cognitive, and social/psychological skills.18 Children with sensory or motor disabilities, which affect voluntary movement or mobility, often experience limited opportunities to engage in play.19 Thus, using VR-based play activities for pediatric rehabilitation may be particularly beneficial as they provide children with opportunities to playfully explore their environment while diminishing the impact of their disability and enhancing their compliance with repetitive practice necessary for skill acquisition.20

The field of VR in rehabilitation has grown immensely since first introduced in the 1990s, with studies addressing a wide spectrum of treatment objectives.8 Earlier review papers summarizing this emerging body of work adopted primarily a descriptive approach, presenting the characteristics and possible advantages of VR-based rehabilitation and the results of interventions applying a range of VR technologies to different patient populations.1,3,4,9,11 A recent review of VR applications in pediatric rehabilitation adopted a
similar approach. However, with the matura-
tion of the field, systematic and critical review
the effectiveness of VR as an assessment and
intervention tool becomes necessary. Several
such reviews have been published in recent
years regarding the use of VR in adult rehabi-
ilitation, evaluating, for example, the effective-
ness of VR interventions for upper extremity
motor recovery of patients following a stroke
or with acquired brain injury and the use-
fulness of VR training for adult patients with
mobility problems. Generally, these reviews
indicate that, while VR is a potentially useful
rehabilitation tool, research evidence is still
in its early stages. A recent systematic review
reached similar conclusions in examining the
effectiveness of interactive computer games
as therapeutic tools for children with sensori-
motor disorders. This review also included a
few studies employing VR technologies.

The objective of the present systematic re-
view is to critically evaluate the studies per-
taining to the application of VR technology
to the assessment and treatment of children
with sensorimotor deficits. VR technology
is applied for a wide variety of assessment and
treatment objectives; therefore, the studies
are discussed in light of the health dimen-
sions addressed by the International Classi-
cation of Functioning Disability and Health
(ICF).

METHODS AND MATERIALS

Inclusion Criteria
The present review included studies that uti-
liized VR technology for the assessment and/or
treatment of children (2 to 18 years) who
experienced physical disabilities resulting
from sensorimotor disorders. It also included
studies that assessed the degree to which the
claimed attributes of this technology (eg, be-
ing enjoyable and motivating) are manifested
when VR is used in the pediatric population.
Studies with children who are typically devel-
oped were included only when they served as
a control group. No restrictions were made as
to study methodology, outcome measures, or
the type of VR technology employed. Review
articles or articles that only described a VR
system or a VR rehabilitation program with-
out results from accompanying VR training
or VR-based assessments were excluded. Only
articles published in peer-reviewed journals in the English language were con-

Literature Search Methods
The authors searched the following elec-
tronic databases in July 2009: PubMed, CI-
NAHL, Cochrane Library, Pedro, Hooked
on Evidence, and Google Scholar. Key words
used for the initial search were: VR, virtual
environment, or augmented reality. Articles
with titles and/or abstracts including any of
the following terms were retrieved: physical
disability, function, motor, mobility, sensory,
sensorimotor, spatial, navigation, play, moti-
vation, traumatic brain injury, cerebral palsy,
spina bifida, and developmental coordination
disorder. The reference lists from relevant re-
view and research articles were used to iden-
tify additional articles and authors. Articles
citing the relevant articles (as determined
by Google Scholar) were also searched. The
text full of articles identified by the title and/or
abstract as possibly relevant to the present
review were read, and a final decision on in-
clusion was made by both researchers on the
basis of the full article.

Assessment of Methodological
Quality of Included Studies
Two researchers independently graded the
methodological quality of the included studies
using the classification of study designs de-
scribed by Jovell and Navarro-Rubio (Table
1). This classification was designed only for
the evaluation of studies using quantitative
rather than qualitative methods. Neverthe-
less, due to the possible importance of some
of the latter studies, qualitative articles were
included and were designated as descriptiv-
estudies at evidence level VIII or IX. To
provide more in-depth information regard-
ing the conduct of the studies, the authors
adapted the conduct questions proposed by
the American Academy for Cerebral Palsy
and Developmental Medicine and applied
them to studies with evidence levels ranging
between I and VII (Table 3).

SUMMARY OF THE LITERATURE

Retrieved Studies
The preliminary search in PubMed using the
intervention terms (VR, virtual environment,
or augmented reality) and limited to the 0-18
years age group and the English language
yielded 253 titles. Only 13 of these were iden-
tified as relevant to the present review. Ex-
cluded titles were related to: other subjects
(11), surgical and medical diagnostic and
intervention procedures (54), non-impaired
children (66), review articles and commentar-
tories (14), pain treatment (21), learning
and attention disorders (20), autism (10),
and other non related conditions (eg, con-
cussion, epilepsy, eating disorders, etc) (35).
Similarly, the search in CINAHL yielded 73
titles, 11 of which were relevant. The others
were excluded as they related to: autism (7),
pain treatment (16), reviews and commentar-
tories (7), typical children or adults (2), learn-
ing disabled (1), various other conditions, or
abstracts in conferences (26). No systematic
reviews were reported by the Cochrane Li-
brary. The Pedro database presented 5 review
articles and 8 studies related to VR, none of
which pertained to children. The Hooked on
Evidence database included 18 titles related
to VR, only 2 of which concerned children.
Some of the retrieved articles were the same
in the different searches, thus the above data-
bases presented the authors with 17 relevant
articles (18 studies). An additional 7 articles
were identified by searching the reference
lists of the various articles and by searching
cited articles in Google Scholar. In 3 of the 24
relevant articles, 2 studies were described.
However, since one of the studies involved
typical children, the total number of studies
reviewed here is 26.
Characteristics of Studies

Summaries of the retrieved studies, presented in chronological order, are provided in Table 2. Information regarding author, date of publication, evidence level, research design, VR technology, overall objective, population characteristics, statistical analysis, ICF category and outcome measures, and results is included.

VR attributes. Five studies using video capture VR technology (4 using Gesture Xtreme (GX) and 1 PlayStation II EyeToy) examined primarily the degree to which playfulness, volitional behavior, joy and/or motivation is exhibited by children during VR. One of these studies also reported the effect of VR interaction on fatigue. A total of 63 children diagnosed with CP participated in these studies with 3-19 children per study. The studies were descriptive in nature (evidence level VIII and IX) with only 1 employing a more rigorous qualitative analysis.

Additionally, 5 studies whose primary objective was to assess the effect of VR intervention (described in the next section) also reported the degree of pleasure/fun, interest and motivation experienced by the children. Four of these studies utilized video capture technology, and 1 used gloves with haptic feedback. While the evidence level of these studies was somewhat higher than the previous group (ranging between VI and VIII), the analysis of the effect of VR attributes was primarily descriptive with only 1 study employing a more rigorous qualitative analysis. These studies evaluated VR attributes in a total of 28 children, with 2 of the studies reporting the effects on 11 children with diagnoses other than CP or with unspecified diagnosis, and 1 comparing the responses to VR between 10 children with and 6 children without disabilities. While none of these 10 studies had a control group receiving a different intervention, they all consistently reported that the VR experiences were generally very enjoyable and motivating, promoting positive effects on measures such as playfulness, creativity, self-competence, self-efficacy, and social participation. Furthermore, no adverse responses such as fatigue or frustration were reported.

VR as an assessment tool. All 4 studies in which the primary objective was assessment examined different aspects of spatial ability including perception, memory, and navigation. In accordance with the ICF, 3 of the studies focused on the body function domain, and 1 examined activity restrictions. All studies compared children with various physical disabilities with typically developed children (cohort design, evidence level VI), using desktop VR technology. The studies involved groups with 12 to 36 children in the experimental groups (children with disabilities) and 18 to 24 children in the control groups. In total, 84 children with disabilities participated in these studies presenting with the multiple diagnoses (eg. cerebral palsy, muscular dystrophy, spinal atrophy) with the largest group being spinal bifida. All the studies used a cohort design with methodological quality varying between studies. Results were analyzed using parametric statistics (ANOVA and t-test) in 2 of the studies, and non-parametric statistics in the other 2 studies. In general, all but one study demonstrated significantly poorer spatial performance in children with physical disabilities in comparison to typically developed children.

Intervention studies. The 17 intervention studies addressed a variety of treatment objectives, with many addressing more than one objective. The 2 primary treatment objectives in the reviewed studies were upper extremity (UE) performance and visual perceptual skills.

Upper-extremity performance. The effect of VR treatment on UE performance was addressed in 6 studies. A total of 55 children were treated in these studies, 50 of whom were diagnosed with CP. Two of the studies were randomized controlled trials with small (5) to medium (19) numbers of children per group. However, due to the small group size, only one of them employed inferential statistics. The remaining studies employed single case controlled designs with pretreatment and post-treatment assessments and descriptive statistics. The number of subjects per study ranged from 1 to 5. Multiple baseline and follow-up assessments were performed only in 1 of these studies. Three of the studies examined treatment effect on body function limitations, 3,43 and 3 studies included activity restrictions in addition to body function limitation. One study examined activity and participation restrictions. The studies examined the effect of the intervention on different activity restrictions using a variety of outcome measures including: Quality of Upper Extremity Skills Test, 3,43 Bruininks-Oseretsky Test of Motor Proficiency, 3,43 Pediatric Motor Activity Log, 3,43 Canadian Occupational Performance Measure, 42 Fine Motor Domain of the Peabody Developmental Motor Scale, 41 Melbourne Assessment, 29,36 Box and Block Test, 29 and Nine Hole Peg Test. Two of the studies also examined UE body function impairments using Fugl-Meyer Assessment 43 and kinematics of reaching.

Three of the studies used the GestureTek IREX or GX video capture system, 33,34,43 2 used the PlayStation II EyeToy, 29,41 1 used a sensor glove, 41 and 1 used a haptic glove. The treatment protocols also varied to a great extent between the studies: session durations ranged from 45 to 90 minutes, number of sessions per week ranged from 1 to 5, and number of treatment weeks ranged from 3 to 8. The most intensive treatment was provided by You et al 43 with a total of 1200 VR hours, and least intensive by Jannink et al 29 with a total of 360 hours. All the studies, with the exception of the randomized controlled study by Reid et al, demonstrated some improvement in UE function following treatment. Thus, for example, intensive treatment enhanced reaching, self feeding and dressing, which was accompanied by changes in cortical reorganization.

Visual perceptual skills. The effect of VR training on spatial performance was assessed in 5 studies (presented in 4 articles), with a total of 77 children with CP and 13 children with other disabilities. In 2 of the studies, performance of children with disability following training was compared to performance of children with typical development who were not exposed to the training condition. Two of the studies were nonrandomized, controlled prospective trials with group sizes ranging from 9 to 27 children; one was a cohort of studies with relatively small group sizes ranging from 7 to 10 children, and one was a single case control study. Results were analyzed using inferential analysis (ANOVA and t-test) in 4 of the studies.

Two types of outcome measures were used in these studies: spatial performance (orientation, navigation and/or object identification) in the real world following training in a made-to-scale virtual environment, and standardized computer and paper tests of visual perceptual performance. Body function limitations were addressed in 2 studies, and activity restrictions were addressed in 3 studies. Four studies used desktop displays, and a single study used the Nintendo Wii system. The treatment protocols varied between studies with the total number of treatment sessions ranging from 1 to 12. Two studies did not provide information regarding treatment time, and session times for the others ranged from 30 to 90 minutes. The most intensive treatment was provided by Deutsch et al. The results of these 5 studies indicated that training in a virtual environment can transfer to improved
<table>
<thead>
<tr>
<th>Article</th>
<th>Level &amp; Design</th>
<th>VR System</th>
<th>Overall Objective</th>
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<tr>
<td>Wilson et al45</td>
<td>Level VI; Cohort study, 2-group posttest design</td>
<td>3D Construction Kit; desktop display</td>
<td>Intervention</td>
<td>ExpG: severely disabled WC use; ContG: able bodied.</td>
<td>ExpG-10 ContG-8</td>
</tr>
<tr>
<td>Hasdai et al47</td>
<td>Level VI; Cohort study; 2-group post test design</td>
<td>Computer maze</td>
<td>Intervention</td>
<td>CP (14); muscular dystrophy(8); ExpG inexperienced powered WC drivers; ContG experienced drivers</td>
<td>ExpG-11 ContG-11</td>
</tr>
<tr>
<td>Reid46</td>
<td>Level III; Small group RCT; 2 group pre/post design</td>
<td>Video capture; GE</td>
<td>Intervention</td>
<td>CP; GMFCS Level I-V</td>
<td>ExpG-3 ContG-3</td>
</tr>
<tr>
<td>Reid34</td>
<td>Level VII; single case pre/post series</td>
<td>Video capture; GE</td>
<td>Intervention &amp; VR attribute</td>
<td>CP; GMFCS Level III (n = 1) &amp; IV( n = 2)</td>
<td>3</td>
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<tr>
<td>Reid33</td>
<td>Level VII; single case pre/post series</td>
<td>Video capture; GE</td>
<td>Intervention &amp; VR attribute</td>
<td>CP; GMFCS Level III (n = 1), Level IV (n = 3)</td>
<td>4</td>
</tr>
<tr>
<td>Reid31</td>
<td>Level IX; Case report</td>
<td>Video capture; GE</td>
<td>VR attribute</td>
<td>CP; GMFCS Level III &amp; IV</td>
<td>3</td>
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<tr>
<td>Stanton et al40</td>
<td>Level VI; Cohort study; 3-group comparison</td>
<td>Super Scape; desktop display</td>
<td>Assessment</td>
<td>ExpG: CP, Spina bifida, muscular dystrophy, &amp; other; subdivided into: more mobile (11), less mobile (23) at young age; ContG: able bodied</td>
<td>ExpG-34 ContG-24</td>
</tr>
<tr>
<td>Miller &amp; Reid19</td>
<td>Level VIII; Descriptive; qualitative analysis</td>
<td>Video capture; GE</td>
<td>VR attribute</td>
<td>CP; mean GMFCS Level -2.7</td>
<td>19</td>
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<tr>
<td>Steele et al48</td>
<td>Level VII; Within subject controlled case study</td>
<td>Kaiser Electro-Optics Pro-View Head Mounted Display</td>
<td>Intervention</td>
<td>CP; 16-year-old following multi-level surgery</td>
<td>1</td>
</tr>
<tr>
<td>Mean Age (Years)</td>
<td>Procedure</td>
<td>ICF Level Outcome Measures</td>
<td>Analysis</td>
<td>Results</td>
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<tr>
<td>ExpG-9.1</td>
<td>ExpG: explored computer simulation of a real building via a game; ConG not exposed to the VE or to real environment</td>
<td><em>ICF Activity</em> Identifying of invisible objects’ locations in real environment; navigation in real world</td>
<td><em>t</em> test; <em>P</em> &lt; .05</td>
<td>The estimates of ExpG and route finding were superior to the ConG</td>
<td></td>
</tr>
<tr>
<td>13.6</td>
<td>Inexperienced WC drivers trained moving through a virtual maze, 30-45 min twice a week for up to 12 weeks</td>
<td><em>ICF Activity</em> Functional evaluation scale of driving skills; simulation test</td>
<td>Non-parametric tests; <em>P</em> &lt; .05</td>
<td>Training in VR significantly improved driving of children w/out previous experience; skills of ExpG following training still less than ConG</td>
<td></td>
</tr>
<tr>
<td>Range 10-12</td>
<td>ExpG 90-min VR intervention, 2 x a week for 4 weeks &amp; standard care; ContG standard care only</td>
<td><em>ICF Activity</em> Sitting Assessment for Children with Neuromotor Dysfunction</td>
<td>Descriptive (change scores)</td>
<td>Changes in all 4 domains of postural control were observed only in the group following VR</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>2 90-min sessions a week for 4 weeks, each using 6 applications requiring arm movement and postural control</td>
<td><em>ICF Activity/participation</em> Canadian Occupational Performance Measure; Interview to assess pleasure and motivation</td>
<td>Descriptive; change in group means</td>
<td>Mean change indicating improvement in performance, self-efficacy, motivation, interest, and pleasure</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>8 weekly 90-min sessions VR intervention</td>
<td><em>ICF Body Function/Activity</em> Quality of UE Test; items 5 &amp; 6 of Bruininks-Oseretsky Test of Motor Proficiency; non-structured interview</td>
<td>Average percent change, visually inspected</td>
<td>Clinically significant changes in Quality of UE Test in 2 children; some changes in other UE measures in all subjects; positive comments regarding motivation, interest, &amp; pleasure</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>Single VR play interaction (duration not mentioned); unstructured interviews</td>
<td><em>ICF N/A</em> Impression of person-environment relationship</td>
<td>N/A</td>
<td>Children generally immersed in VR, able to participate in unfamiliar play activities</td>
<td></td>
</tr>
<tr>
<td>ExpG-14.1</td>
<td>Single session (no time constraint); VE maze exploration</td>
<td><em>ICF Body Function</em> Ability to determine optimal path</td>
<td>Chi-square analysis, <em>P</em> = .05</td>
<td>ExpG significantly less able to choose correct path; within this group—those who were more mobile during developing years performed better</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>Single VR play interaction (duration not mentioned); 30-45 min, structured in-depth interview</td>
<td><em>ICF N/A</em> themes emerging from interviews</td>
<td>Coded in software; analyzed by 2 authors &amp; reviewed by 3 others</td>
<td>Children relatively limited in play experience, VR play is perceived as safe, enjoyable; positive effect on self competence, self-efficacy, &amp; social acceptance</td>
<td></td>
</tr>
<tr>
<td>16</td>
<td>During days 2-6 post surgery, half the physical therapy sessions with VR &amp; half w/out; treatment order randomized</td>
<td><em>ICF Body Function</em> Pain self report with Faces Scale; knee ROM; parent’s &amp; therapist’s report of child’s anxiety level</td>
<td>Descriptive (percentage)</td>
<td>Overall VR reduced pain by 41.2%; no difference in ROM; parent and therapist reported less anxiety</td>
<td></td>
</tr>
</tbody>
</table>
### Table 2. Characteristics of Studies continued

<table>
<thead>
<tr>
<th>Article</th>
<th>Level &amp; Design</th>
<th>VR System</th>
<th>Overall Objective</th>
<th>Population Characteristics</th>
<th>Number</th>
</tr>
</thead>
</table>
| Akhutina et al\(^27\)   | Study I: Level IV; 2 group, pre/post design  
Study II: Same | Study I: Super Scape; desktop display  
Study II: Same | Study I: Intervention  
Study II: Intervention | Study I: CP; groups not matched by severity  
Study II: CP; 1 dropped from ExpG, 5 from ContG; severity pair matched |         |
|                         |                |                    |                   | Study I: ExpG-12  
Study II: ExpG-24  
ContG-9  
ContG-27 |         |
| Foreman et al\(^28\)    | Level VI; Cohort; 2 group posttest design | Super Scape; desktop display | Intervention | ExpG – CP (4); other motor impairment (3); ContG – able bodied | ExpG-7  
ContG-7 |
| Wilson et al\(^39\)     | Level VI; Cohort study; 2-group comparison | Super Scape; desktop display | Assessment | ExpG – CP & other physical disabilities; 8 using WCs, 4 walking aids; ContG – able bodied | ExpG-12  
ContG-19 |
| Reid\(^20\)             | Level VIII; Case study descriptive series | Video capture; GE | VR attribute | CP; WC use (7) & ambulatory (6) | 13       |
| Harris & Reid\(^30\)    | Level VIII; Case study series | Video capture; GE | VR attribute | CP; GMFCS I-V | 16       |
| You et al\(^43\)        | Level VII; single case control; pre/post design | Video capture; IREX | Intervention | CP; hemiparesis | 1        |
| Wiedenbauer et al\(^38\) | Level VI; Cohort study; 2-group comparison | 3D Game-Studio; desktop display | Assessment | ExpG – Spina Bifida  
ContG – able bodied; verbal IQ matched | ExpG-18  
ContG-18 |
| Bryanton et al\(^32\)   | Level VI; Cohort study, ABBA design | Video capture IREX | Intervention & VR attribute | ExpG – CP; GMFCS Level I-II; ContG – able bodied | ExpG -10;  
ContG -6 |
| Reid & Campbell\(^42\)  | Level III; RCT; 2 group pre & post design | Video capture; GE | Intervention | ExpG – CP; GMFCS Level I-V  
ContG – CP; GMFCS Level I-V | ExpG – 19  
ContG – 12 |
<table>
<thead>
<tr>
<th>Mean Age (Years)</th>
<th>Procedure</th>
<th>ICF Level Outcome Measures</th>
<th>Analysis</th>
<th>Results</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Study I:</strong> Range 7-14</td>
<td>Study I: ExpG - standard care &amp; VR spatial training (6-8 sessions of 30-60 min) ContG - standard care</td>
<td><strong>ICF Body Function</strong> Study I: 2 computer spatial assessment tasks and 2 non-computer tasks</td>
<td>ANOVA; ( P = .05 )</td>
<td>Study I: Significant training effect, no group difference; the less severely disabled benefited more from VR</td>
</tr>
<tr>
<td><strong>Study II:</strong> Range 7-14</td>
<td>Study II: Same as above, with 5 30-min sessions of cognitive training prior to VR to ExpG</td>
<td><strong>ICF Body Function</strong> Two computer spatial assessment tasks and 3 non-computer tasks</td>
<td>ANOVA; ( P = .05 )</td>
<td>Study II: VR group improved more</td>
</tr>
<tr>
<td>ExpG-12.3 ContG-25.6</td>
<td>ExpG – 5 training sessions in the VE model of the real school. ContG – no training</td>
<td><strong>ICF Activity</strong> Orientation test in the real school environment</td>
<td>NOVA; ( P &lt; .01 )</td>
<td>ExpG (children with disabilities) more accurate</td>
</tr>
<tr>
<td>ExpG-8.2 ContG-9.4</td>
<td>Familiarization with VE followed by spatial memory test</td>
<td><strong>ICF Body Function</strong> Latency and error scores</td>
<td>Mann-Whitney test; ( P &lt; .05 )</td>
<td>No differences between groups; similar directions bias between groups</td>
</tr>
<tr>
<td>10.4</td>
<td>8 60-min. sessions that were videotaped, 3 of which were later scored</td>
<td><strong>ICF N/A</strong> Test of Playfulness</td>
<td>Descriptive results: mean &amp; SD; qualitative analysis</td>
<td>Different VEs produced varying levels of playfulness, creativity, pleasure, persistence, &amp; control; frustrating &amp; unpredictable VEs less effective</td>
</tr>
<tr>
<td>Range 8-12</td>
<td>8 60-min VR sessions with 5-10 environments were video recorded; a randomized sample was evaluated by a single researcher</td>
<td><strong>ICF N/A</strong> Pediatric Volitional Questionnaire</td>
<td>Descriptive results: Median &amp; mode</td>
<td>Different VEs produced varying levels of volitional behaviors; features promoting volition include challenge, variability and competition</td>
</tr>
<tr>
<td>8</td>
<td>60-minute sessions, 5 times a week for 4 weeks using 2 games and 88-131 repetitions per game</td>
<td><strong>ICF Body Function</strong> IActivity Bruininks-Oseretsky Test of Motor Proficiency; Modified Pediatric Motor Activity Log; UE subtest of Fygl-Meyer; Functional MRI</td>
<td>Descriptive (score, % change)</td>
<td>Measurable neuroplastic changes at the sensorimotor cortex; clinically significant improvements in use &amp; quality of UE movement</td>
</tr>
<tr>
<td>ExpG-11.3 ContG-11.7</td>
<td>1 30-min VR session; different phases involving route &amp; landmark knowledge</td>
<td><strong>ICF Body Function</strong> Training required for route &amp; landmark knowledge</td>
<td>ANOVA and correlation analysis; ( P = .05 )</td>
<td>ExpG showed impaired route knowledge but not impaired landmark knowledge.</td>
</tr>
<tr>
<td>Range ExpG-10-17 ContG-7-16</td>
<td>Single 90-min session; ankle dorsiflexion exercises in chair-sitting and long-sitting; 10-min blocks of conventional and VR exercises</td>
<td><strong>ICF Body Function</strong> Child’s report on interest &amp; fun (with VAS); same by parent; ankle ROM; hold time at end range; completion time, number of repetitions</td>
<td>t tests; ( P = .05 )</td>
<td>Both groups – VR more fun and interesting; more repetitions in conventional exercise; longer hold time and greater ROM in VR exercise</td>
</tr>
<tr>
<td>ExpG-9.7 ContG-9.7</td>
<td>ExpG – 8 weekly 90-min sessions VR intervention, 6-7 applications/session. ContG – “standard of care” in OT and/or PT focusing on UE, average once a week</td>
<td><strong>ICF Activity &amp; Participation</strong> Canadian Occupational Performance Measure; Quality of UE Test; Harter Self perception Profile for Children</td>
<td>t tests ( P ) value not disclosed</td>
<td>No significant difference between groups, except for the Harter’s social acceptance subscale where ExpG higher score</td>
</tr>
</tbody>
</table>
Table 2. Characteristics of Studies continued

<table>
<thead>
<tr>
<th>Article</th>
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<th>VR System</th>
<th>Overall Objective</th>
<th>Population Characteristics</th>
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<tbody>
<tr>
<td>Chen et al41</td>
<td>Level VII; Single case pre/post series with multiple assessments</td>
<td>VR-based 5 Digital Data Glove; EyeToy-Play System</td>
<td>Intervention</td>
<td>CP; could follow instructions &amp; reach forward &gt; half arm length; no surgery &amp; no recent Botox shots to UE</td>
<td>4</td>
</tr>
<tr>
<td>Tam et al35</td>
<td>Level VIII; qualitative analysis</td>
<td>Video capture; Movement to Music System</td>
<td>Intervention &amp; VR attribute</td>
<td>CP, Spina Bifida or muscular atrophy; ability to hear &amp; respond to music</td>
<td>6</td>
</tr>
<tr>
<td>Jansen-Osmann et al37</td>
<td>Level VI; Cohort study; 2-group comparison</td>
<td>VE Maze; desktop display</td>
<td>Assessment</td>
<td>ExpG – Spina bifida; ContG – able bodies; matched by age, gender, and verbal IQ</td>
<td>ExpG-20 ContG-29</td>
</tr>
<tr>
<td>Jannink et al29</td>
<td>Study I: Level VIII; Non controlled clinical series</td>
<td>Study I: EyeToy-Play System</td>
<td>Study I: VR attribute</td>
<td>Study I: CP; normal IQ, ability to flex extend affected shoulder elbow</td>
<td>Study I: 12</td>
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<tr>
<td></td>
<td>Study II: Level III; RCT; 2 group pre/post design</td>
<td>Study II: Same</td>
<td>Study II: Intervention</td>
<td>Study II: CP same criteria as Study I; GMFCS Level I-IV</td>
<td>Study II: ExpG-5 ContG-5</td>
</tr>
<tr>
<td>Deutsch et al44</td>
<td>Level VII; Single subject pre/post design with follow-up</td>
<td>Nintendo Wii</td>
<td>Intervention</td>
<td>CP; seizure disorder; asthma; IQ 79</td>
<td>1</td>
</tr>
<tr>
<td>Wille et al36</td>
<td>Level VII; single case pre/post series</td>
<td>Customized gloves with haptic feedback and 3 VR games</td>
<td>Intervention and VR attribute</td>
<td>Upper-extremity deficits with different etiologies</td>
<td>5</td>
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<tr>
<td>Mean Age (Years)</td>
<td>Procedure</td>
<td>ICF Level Outcome Measures</td>
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<tr>
<td>Range 5.3-8.5</td>
<td>45 min with the digital glove and 75 min with EyeToy per week for 4 weeks; treatment goals and program individualized; 3 baseline, 4 during invention, and 2 follow-up assessments</td>
<td><em>ICF Body Function/Activity</em> Kinematic parameters during reaching in VR to 3 directions; Fine Motor Domain of Peabody Developmental Motor Scale (PDMS)</td>
<td>Visual inspection &amp; 2-SD band analysis</td>
<td>3 children improved in some kinematic measures during reaching; 2 improved in the visual-motor integration subtest of the PDMS</td>
<td></td>
</tr>
<tr>
<td>Range 2.6-7</td>
<td>6-8 weekly sessions of 30 min in clinic combined with home use including structured &amp; free play</td>
<td><em>ICF Activity &amp; Participation</em> Environmental determinants of health; participate in play; psychosocials skills; body function; music knowledge</td>
<td>Qualitative analysis of in-depth interviews with mothers and children</td>
<td>VR treatment expanded horizons; positive impact on environmental determinants of health</td>
<td></td>
</tr>
<tr>
<td>ExpG-11.4</td>
<td>Exploration of VR maze with and without landmarks</td>
<td><em>ICF Body Function &amp; Activity</em> No. of learning trials &amp; recalled landmarks. Pen &amp; paper tests of visuospatial abilities</td>
<td>ANOVA and correlation analysis; ( P = .05 )</td>
<td>ExpG showed significantly poorer performance in most measures</td>
<td></td>
</tr>
<tr>
<td>ContG-11.8</td>
<td>Study I: Range 7-16</td>
<td>Study I: <em>ICF N/A</em> User satisfaction questionnaire</td>
<td>Study I: Descriptive (frequency)</td>
<td>Study I: General satisfaction, motivating, understandable, and not overly fatiguing</td>
<td></td>
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<tr>
<td></td>
<td>Study II: ExpG – 30-min sessions, twice a week for 6 weeks; standard care both groups with total treatment intensity equal</td>
<td>Study II: <em>ICF Activity</em> The Melbourne Assessment of Unilateral Upper Limb Function</td>
<td>Study II: Descriptive (%)</td>
<td>Study II: ExpG improve by 9-13%; ContG improve by 1-2%</td>
<td></td>
</tr>
<tr>
<td>ExpG-11.8</td>
<td>13</td>
<td><em>ICF Body Function/Activity</em> Test of Visual Perceptual Skills; postural control by Posture Scale Analyzer; functional mobility</td>
<td>Descriptive (change scores)</td>
<td>Visual-perceptual skills improved in all domains except visual memory; increased lower extremity loading; decreased postural sway; increased walking distance post training; further improvement in 3 month follow-up</td>
<td></td>
</tr>
<tr>
<td>ContG-12.3</td>
<td>13.9</td>
<td><em>ICF Activity</em> Melbourne Assessment; Box &amp; Block Test; 9-Hole Peg Test; fun evaluation on 10-point scale</td>
<td>Wilcoxon signed rank test ( P = .05 )</td>
<td>Significant improvement Melbourne Assessment &amp; Nine Hole Peg Test in 4 of subjects; and in all subjects in Box and Block; mean motivation high</td>
<td></td>
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</table>
The majority of studies provided detailed descriptions of the study population (16/20) and of the intervention procedures (19/20), and used appropriate outcome measures (19/20) and statistical evaluations (20/20). However, due to the small number of participants in each study, inferential statistics were possible in only 13 of these studies and a power calculation was provided only in 1 study. A control exposure (non VR treatment) was included only in 1 single-case design study, but was well described in the majority of the studies that included a 2-group design (11/13). In contrast, the majority of studies did not describe the exclusion criteria (18/20); did not ensure that the person conducting the study was blind to group allocation or, in the case of cohort studies, to the objectives of the study (15/20); nor did they report the number of subjects dropped or lost to follow-up (16/20).

**DISCUSSION**

The review identified 26 studies that investigated the use of VR in the rehabilitation of children with sensorimotor disabilities. Five of these studies focused solely on the quality of VR-child interaction, examining such factors as pleasure, motivation, and/or playfulness provided by this medium. These studies generally suggest that children find the VR intervention to be a positive experience, which can induce children to perform repetitive tasks while experiencing feelings of well-being without adverse side effects. An additional 4 studies utilized VR primarily as an assessment tool of perceptual abilities.

With the exception of 1 study, these studies showed that VR technology is able to identify perceptual limitations in children with disabilities in comparison to children who are typically developed. In the majority of the studies (17/26), VR technology was used primarily as an intervention tool, focusing on the examination of its effectiveness in meeting a variety of rehabilitation objectives. Overall, these studies demonstrated a positive effect of VR rehabilitation on at least 1 of the outcome measures. However, due to the low methodological quality of these studies, they do not provide the necessary scientific evidence to either support or reject the use of VR in the rehabilitation of children with sensorimotor disabilities.

Only 3 of the studies were RCTs. Two of them examined no more than 5 children per treatment arm. Thus, their evidence strength is only fair. In the one RCT with larger group sizes (19 and 12 for the group receiving VR and conventional treatment, respectively) a statistically significant greater improvement in the group receiving VR intervention was observed only in 1 out of 8 outcome measures; the rest showed no difference between groups. However, as stated by the authors, the relatively high attrition rate observed only in the control group as well as the variability in the participant's functional level (GMFCS Level I-V) likely affected the ability of the chosen outcome measures to detect significant differences.

Four assessment studies and 3 intervention studies used VR primarily as an intervention tool. Employment of varied VR technologies, research procedures and outcome measures is not surprising. Although the majority of these studies lacked methodological rigor and only 3 of the 9 studies used inferential statistics, all the studies indicated a positive outcome in at least one of the measured outcomes.

**Assessment Studies’ Conduct**

Results of the assessment of the conduct of 20 studies are presented in Table 3. Excluded from this analysis are the studies that examined VR attributes (evidence level VIII and IX), and 1 intervention study that employed only a qualitative analysis (evidence level VIII). Only 3 studies were RCTs with small (3) to medium (19) size groups per treatment arm. Due to the small group sizes, inferential statistics were used only in 1 of them. All included assessment studies and 3 of the treatment studies employed a cohort design comparing performance of children with and without disabilities. One of these cohort studies also employed an AB-BA design in which both groups, with and without disabilities, alternatively received conventional and VR treatment. In one nonrandomized controlled prospective study, severity of disability was partially matched between groups.

Six studies were single-case control series with a pretreatment and post-treatment design, and one was a single case control design in which VR and no treatment were provided in random order. However, only 1 of these single case control studies had multiple baseline and follow-up assessments and only 1 study included a follow-up assessment.

The majority of the remaining studies (those that did not examine perceptual skills) did not include a control group at all. Thus, the effects of VR as an intervention modality involved either case studies or a single case pre/post series design with the number of children per study ranging from 1 to 6. Only 1 study exposed the subject to both a VR and a control intervention. Only 1 used multiple base line assessments, and 2 included follow-up assessments. Although all of these studies reported encouraging positive effects, they must be classified primarily as feasibility studies since they all examined small-num-
### Table 3. Factors Determining Study Conduct

<table>
<thead>
<tr>
<th>Article</th>
<th>Design/Question Number</th>
<th>Total Positive Items</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wilson et al&lt;sup&gt;45&lt;/sup&gt;</td>
<td>Cohort Posttest only</td>
<td>3/10</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
<td>No</td>
<td>N/A</td>
<td>Yes</td>
<td>No</td>
<td>Yes</td>
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<tr>
<td>Hasdai et al&lt;sup&gt;47&lt;/sup&gt;</td>
<td>Cohort Posttest only</td>
<td>6/10</td>
<td>Yes</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
<td>N/A</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
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<tr>
<td>Reid&lt;sup&gt;46&lt;/sup&gt;</td>
<td>RCT 2-group pre/post design</td>
<td>7/10</td>
<td>Yes</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
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<tr>
<td>Reid&lt;sup&gt;34&lt;/sup&gt;</td>
<td>Single-case pre/post series</td>
<td>4/10</td>
<td>Yes</td>
<td>No</td>
<td>Yes</td>
<td>No</td>
<td>Yes</td>
<td>No</td>
<td>Yes</td>
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<td>Reid&lt;sup&gt;33&lt;/sup&gt;</td>
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<td>3/10</td>
<td>Yes</td>
<td>No</td>
<td>Yes</td>
<td>No</td>
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<td>Stanton et al&lt;sup&gt;40&lt;/sup&gt;</td>
<td>Cohort</td>
<td>4/10</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
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<td>Steel et al&lt;sup&gt;48&lt;/sup&gt;</td>
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<td>6/10</td>
<td>Yes</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
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<td>Yes</td>
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<td>Akhutina et al&lt;sup&gt;27&lt;/sup&gt;</td>
<td>Study I 2-group pre/post design</td>
<td>6/10</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
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<td>Yes</td>
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<tr>
<td>Akhutina et al&lt;sup&gt;27&lt;/sup&gt;</td>
<td>Study II 2-group pre/post design</td>
<td>7/10</td>
<td>Yes</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
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<td>Foreman et al&lt;sup&gt;28&lt;/sup&gt;</td>
<td>Cohort Posttest only</td>
<td>5/10</td>
<td>Yes</td>
<td>No</td>
<td>Yes</td>
<td>No</td>
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<td>Wilson et al&lt;sup&gt;39&lt;/sup&gt;</td>
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<td>5/10</td>
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<td>You et al&lt;sup&gt;43&lt;/sup&gt;</td>
<td>Single-case pre/post design</td>
<td>4/10</td>
<td>Yes</td>
<td>No</td>
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<td>No</td>
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<td>Wiedenbauer et al&lt;sup&gt;38&lt;/sup&gt;</td>
<td>Cohort</td>
<td>4/10</td>
<td>Yes</td>
<td>No</td>
<td>Yes</td>
<td>No</td>
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<td>Bryanton et al&lt;sup&gt;32&lt;/sup&gt;</td>
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<td>5/10</td>
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<td>Reid &amp; Campbell&lt;sup&gt;42&lt;/sup&gt;</td>
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<td>10/10</td>
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<td>Yes</td>
<td>Yes</td>
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<td>Yes</td>
<td>Yes&lt;sup&gt;a&lt;/sup&gt;</td>
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<tr>
<td>Chen et al&lt;sup&gt;41&lt;/sup&gt;</td>
<td>Single-case pre/post design &amp; follow-up</td>
<td>5/10</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
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<td>Jansen-Osmann et al&lt;sup&gt;37&lt;/sup&gt;</td>
<td>Cohort</td>
<td>5/10</td>
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<td>No</td>
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<td>Yes</td>
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<td>Jannink et al&lt;sup&gt;29&lt;/sup&gt;</td>
<td>Study II RCT 2-group pre/post design</td>
<td>7/10</td>
<td>Yes</td>
<td>Yes</td>
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<td>Deutsch et al&lt;sup&gt;44&lt;/sup&gt;</td>
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<td>4/10</td>
<td>Yes</td>
<td>No</td>
<td>Yes</td>
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<td>Wille et al&lt;sup&gt;36&lt;/sup&gt;</td>
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</table>

<sup>a</sup>Dropout rate reported, but was not balanced between groups.

### Conduct questions

1. Were the characteristics of the study population well described?
2. Were exclusion criteria of the study population well described and followed?
3. Was the intervention well described?
4. Was there a control exposure and, if yes, was it well described? (both parts of question were true for a yes response)
5. Was group allocation randomized? For single-case controlled design, was treatment order allocation randomized? (not applicable for cohort design)
6. Were the measures used clearly described, valid, reliable, and sensitive for measuring the outcomes of interest?
7. For 2-group design, was the outcome assessor unaware of the intervention status of the participants? For cohort design and for a single group design, was the assessor unaware of study objectives?
8. Did the authors conduct and report appropriate statistical evaluation?
9. Did the authors include power calculations?
10. Were dropout/loss to follow-up reported?
bers of children without appropriate control measures. Thus, they do not offer a solid scientific base for the implementation of VR technology in the rehabilitation of children.

VR involves creating environments which simulate real life situations, thus using this technology seems natural for interventions that are related to a child's functional activities and reintegration into society. Analysis of the outcome measures in terms of the ICF revealed that 10 studies focused on a range of body function impairments, and 14 on activity restrictions. Yet, only 3 studies examined the effect on participation restrictions; that is, the carry-over effect into the daily life of the children. Within these categories, the diversity of outcome measures used was such that no one measure was employed more than twice, and some of the measures used were developed solely for the studied VR intervention and therefore lacked evidence as to their reliability and validity. In terms of treatment intensity, the studies ranged from a single treatment session (eg, Foreman) to 5 sessions per week leading to a total of 1,200 hours of training. The absence of consistency of these factors makes it difficult to compare and integrate the results even with regard to perceptual and upper extremity deficits that were addressed by the highest number of studies (9 and 6, respectively).

Recent systematic reviews on the efficacy of VR rehabilitation in the treatments of adults with neurological disorders repeatedly reached similar conclusions indicating that, while VR-based rehabilitation generally results in positive outcomes with no adverse effects, its evidence base is too limited in terms of research quality to permit a definitive assessment of its value. Some have argued that the lack of sufficient evidence as to the efficacy of VR-based rehabilitation reflects the relative immaturity of this research discipline. Although early publications regarding VR-based rehabilitation in the mid-1990s focused on the development of the technology and its novel applications, emphasis of research in the 21st century has shifted to the acquisition, retention, and transfer of speech skills in acquired apraxia of speech. J Speech Lang Hear Res. 2008;51:1088-1113.

CONCLUSION

This review identified a wide range of VR applications used to assist in the rehabilitation of children with sensorimotor deficits. The results suggest that VR interventions are safe and feasible for children with a variety of disabilities and, in particular, for children with CP. They indicate that VR is potentially an exciting rehabilitation technique, which is particularly attractive for children with disabilities since it engages them in play that motivates them to explore and practice repetitive activities necessary for skill acquisition. However, an improvement in the methodological quality of the research is necessary before the effects of VR intervention can be truly assessed. Indeed, the ability to draw definitive conclusions as to the effectiveness of VR-based rehabilitation is hindered not only by poor research design and methodology, but also by the diversity of research objectives, outcome measures, and treatment intensity presented in the different studies. Future well-controlled studies that compare the effectiveness of VR-based rehabilitation relative to more traditional approaches are necessary. Using appropriate, reliable, and valid outcome measures, these studies should examine the effect of VR-based rehabilitation at all levels of the ICF, and particularly at the activity and participation levels. Future research is also necessary to provide clinicians with guidelines as to the optimum treatment intensity necessary to achieve various treatment goals via VR.

REFERENCES


Audience response systems (ARSs) have become widely popular instructional tools among health professional educators and are aimed at the current generation of students, a generation that strongly values technology and quick assessments of learning. An ARS enables educators to display questions electronically to the audience in multiple-choice or true-false format and embed them into a discussion or lecture presentation. Audience members can then individually and anonymously respond using an ARS keypad. Turning Point Software¹ allows for real-time display of responses providing the audience with immediate formative feedback of their comprehension of the material tested. In addition, immediate summative feedback of class performance is available to the instructor allowing for further clarification of key principles as required. Description of the usefulness of ARS technology in the classroom is scarce in research literature.

The authors of this study integrated ARS technology into a course titled, Anatomy for Physical Therapists, a 6-credit course completed by first-year students enrolled in the Doctor of Physical Therapy (DPT) program at Mayo School of Health Sciences. In addition to the traditional didactic lecture and laboratory dissection sessions, peer-teaching sessions were incorporated into the 16-week course to augment student learning. The peer sessions were lead by second-year DPT students. The purpose of this article was to survey perceptions regarding the effectiveness of ARS technology among first-year DPT students enrolled in human gross anatomy. The authors also sought to describe the benefits and challenges of incorporating ARS technology into the peer-teaching sessions as perceived by the second-year DPT student peer teachers. Thirteen peer-teaching sessions were scheduled throughout the anatomy course. Attendance at each session was voluntary. At the onset of each session, students in attendance completed a 12-15 question nongraded quiz utilizing ARS technology. During the quiz, peer teachers had the opportunity to clarify and provide further instruction as prompted by the predominance of incorrect responses. Following the completion of 13 peer-teaching sessions, the students and peer teachers were surveyed on the benefits and usefulness of ARS technology. Twenty-five students (89%) and 6 peer instructors (100%) completed separate surveys.

The majority (96%) of first-year students indicated that they “agreed” or “strongly agreed” that incorporating ARS technology into peer-teaching sessions enhanced their confidence to actively participate in the review session. Furthermore, the authors found that many students (68%) believed that they were better prepared for graded weekly anatomy examinations after participating in the ARS review session as opposed to simply picking up a study packet for independent review. Seventy-two percent of the student respondents surveyed indicated that the ARS technology allowed them to gauge their level of mastery of laboratory dissection material, and 100% said the same of lecture material. Of the students, 92% concluded that the review sessions utilizing ARS technology served as an effective use of their study time. One limitation of the ARS format identified by the students was the occurrence of unnecessary and distracting communication, which occurred during the time interval allotted for answering the question. Of the students, 56% indicated that the chatter potentially impeded their learning. Nevertheless, a large majority of the students (92%) recommended the continued use of ARS technology during future peer-teaching sessions.

The authors also reported a highly positive perception of the usefulness of ARS technology among the peer teachers. All 6 peer teachers perceived the use of ARS technology to have aided in rapid assessment of student knowledge and to have encouraged discussion in review sessions. A limitation noted was that 50% of the tutors reported difficulty in formulating questions in ARS format. The authors noted that the peer teachers were not provided with any resources to assist in question writing. In the future, the authors proposed to implement a learning module for the peer teachers aimed at writing effective multiple-choice test questions.

This study supports the use of ARS technology in discussion-based, peer-teaching sessions. As in this study, ARS technology may assist peer teachers and faculty alike in the rapid assessment of student knowledge, facilitation of discussion, and clarification of knowledge deficits, thereby enhancing teaching methods.

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REFERENCES

The term “blended learning” describes combining traditional face-to-face classroom activities with online learning activities. This text, *Blended Learning in Higher Education: Framework, Principles, and Guidelines*, is divided into 2 parts, with an extensive appendix section. Part 1 consists of 4 chapters. In the introductory chapter, the authors present the development of interest in and scope of online and other technology instructional tools relative to the evolving challenges and expectations of higher education. The remaining 3 chapters provide guidelines and principles that provide faculty with the knowledge necessary to implement blended design into their courses. In Chapter 2, the conceptual foundation and essential elements of blended learning are discussed. In Chapter 3, the authors use numerous examples from the literature to illustrate how the principles of blended learning can be implemented. Chapter 4 goes on to discuss the need for and issues surrounding institutional support of faculty. Multiple examples of current practice of effective professional development are described.

Part 2 of the text presents practical application of the principles previously described into course design and instructional activities. In Chapter 5, the authors provide several examples of best practice in blended design instruction. Chapter 6 gives examples of how to implement blended-learning course design and instructional activities congruently with goals of contemporary higher education. In Chapter 7, the focus shifts to practical information about techniques and tools to most effectively engage students in collaborative and reflective blended-learning activities. Chapter 8 then concludes this section with a look forward to the potential for the evolution of technology into higher education.

The appendices contain numerous forms and templates that faculty can apply to their own courses. Sample templates include a Project Proposal Form, a Blended Learning Course Outline, and an Assessment Rubric for an e-Portfolio Assignment. There also are several questionnaires included that can be used to collect feedback on the learning experience and learning outcomes from the students and faculty perspectives. Finally, data summarizing the student’s experience in an exemplar blended-learning course is reported.

This text serves as a useful resource to faculty novice to the use of technology in the classroom. The examples provided are numerous and not specific to any particular discipline, which makes application of the principles presented across disciplines relatively easy. The text strikes an appropriate balance between presentation of the theoretical frameworks that guide the pedagogy with practical application of blended learning. And finally, the materials in the appendices are extremely useful as they can be used by an individual to develop blended-learning activities or introduced at an institutional level.

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**Book Reviews**


The term “blended learning” describes combining traditional face-to-face classroom activities with online learning activities. This text, *Blended Learning in Higher Education: Framework, Principles, and Guidelines*, is divided into 2 parts, with an extensive appendix section. Part 1 consists of 4 chapters. In the introductory chapter, the authors present the development of interest in and scope of online and other technology instructional tools relative to the evolving challenges and expectations of higher education. The remaining 3 chapters provide guidelines and principles that provide faculty with the knowledge necessary to implement blended design into their courses. In Chapter 2, the conceptual foundation and essential elements of blended learning are discussed. In Chapter 3, the authors use numerous examples from the literature to illustrate how the principles of blended learning can be implemented. Chapter 4 goes on to discuss the need for and issues surrounding institutional support of faculty. Multiple examples of current practice of effective professional development are described.

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The author of this text, *Hybrid Learning: The Perils and Promise of Blending Online and Face-to-Face Instruction in Higher Education*, challenges us as readers (and fellow educators) to question the role of technology in our higher education classrooms. In the self-titled Chapter 1, Early Resistant Adopter of Technology, Snart suggests that we have as much to learn about the “perils and promise” of hybrid or blended learning from technology enthusiasts as we do from the technology skeptics. He encourages this conversation go beyond the classroom and faculty to include all stakeholders in higher education and to identify potential perils while recognizing effective current practice and potential promise as technology and our use of it advances.

In Chapter 2, many of the challenges facing higher education, such as the competition for resources and retention of students, are presented. While these challenges may be addressed through hybrid learning, the author prods the reader to think about the implications that technology-based curricula may have on the nature of the learning experience. Thus, the “perils and promise” must be evaluated from the perspective of all stakeholders (ie, administrators, faculty, students) when determining a course of action. Chapter 3 provides a look at how as a culture we are interacting with each other through the interface of technology. Varied examples from popular media sites clarify how such interactions occur. Chapter 4 transitions the focus of the book and a brief, and somewhat limited, historical perspective of hybrid learning is presented. This chapter closes with some references to how current technologies may continue to evolve.

In Chapters 5 and 6, the author provides practical application of hybrid learning to the classroom. In Chapter 5, exemplars of several undergraduate hybrid courses and of 1 hybrid graduate education program are presented. In addition, 1 student’s experience in an online program is presented as a case study to present perils and promise from a student’s perspective. Chapter 6 then presents the benefits and pitfalls of numerous technological tools, including course management systems, blogs, wikis, social bookmarking, and virtual reality sites, such as Second Life. This text ends with Chapter 7 in which the author, a self-described “early resistant adopter of technology,” makes the case for informed application of hybrid learning in higher education. There is an appendix that provides points to consider from student, instruction, faculty, and institutional perspectives. These points would be of value to guide discussion in any planning phase among stakeholders.

The text is effective in opening the dialogue about how to integrate hybrid learning into classrooms and across institutions. The strength of the text lies in recognizing the pros and cons of this technology transition from multiple stakeholder perspectives. While several exemplar courses and 1 program are presented, the depth of examples are limited when compared to other texts. Thus, it may be most appropriate for individuals at the conceptualization stage of course or program development.

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The Journal of Physical Therapy Education considers for publication manuscripts pertaining to all aspects of education in physical therapy. Manuscripts are invited describing qualitative and quantitative investigations and descriptions of educational interventions and innovative methods used in academic, clinical, community, or patient education. The author(s) must have methodically examined the outcomes of the educational intervention or innovation and drawn conclusions about its usefulness in physical therapy education and practice.

The Journal of Physical Therapy Education endorses the Uniform Requirements for Manuscripts Submitted to Biomedical Journals put forth by the International Committee of Medical Journal Editors (ICMJE).

Manuscripts submitted to the Journal of Physical Therapy Education are reviewed under 1 of 6 categories: research papers, position papers, reviews of the literature, method/model presentations, case reports, and brief reports.

Research papers should prescribe to the following format. An introduction, should briefly state the relevance of the study for physical therapy education, the specific purpose of the study, and the research question(s) or hypothesis(es). The review of literature section of a research paper should briefly describe the methodology and findings from published literature germane to the study being presented (eg, justify the variables, hypotheses, sample, or methodology). A summary at the end of the review of literature section should point out the relevance of the review to the study at hand. The methods section should describe the sample, including selection criteria and process, the research design and procedures, the nature of the data, the data collection instrument(s), and methods of data collection, reduction, and analysis. The results section should give a verbal summary of the results together with any statistical summary of the data or other representations of the findings and analyses (tables, figures). The discussion and conclusion section should first state conclusions based directly on the results of the findings and analyses (tables, figures). The discussion and conclusion section should provide a critical overview of the results of the findings and analyses (tables, figures). The discussion and conclusion section should provide a critical overview of the results of the findings and analyses (tables, figures). The discussion and conclusion section should provide a critical overview of the results of the findings and analyses (tables, figures). The discussion and conclusion section should provide a critical overview of the results of the findings and analyses (tables, figures). The discussion and conclusion section should provide a critical overview of the results of the findings and analyses (tables, figures). The discussion and conclusion section should provide a critical overview of the results of the findings and analyses (tables, figures). The discussion and conclusion section should provide a critical overview of the results of the findings and analyses (tables, figures). The discussion and conclusion section should provide a critical overview of the results of the findings and analyses (tables, figures).

In position papers, authors should adopt and defend a position on some issue of current concern and importance to physical therapy educators (eg, professional-level doctoral degree education). A brief introduction states the purpose of the article; the position and the author’s rationale for taking that position are elucidated. Issues should be stated clearly and theoretical foundations with literature citations for the rationale stated. The logic of the argument and stance on the position should be clear. A conclusion should summarize the position relative to the concern or issue addressed. An abstract is required (see Manuscript Preparation and Requirements).

Reviews of the literature should provide a critical overview of the research on specific topics related to physical therapy education. These reviews may be qualitative in nature, providing a summary of relevant work; they may be systematic reviews following a specific analysis format; they may also be statistically based meta-analyses of relevant literature. In all cases, the authors should include an introduction (background and purpose), materials and methods (selection criteria and search strategy), results (description of studies, methodological quality and results of studies reviewed), discussion and authors’ conclusions. When applicable, they should include tables and figures showing characteristics of the reviewed studies, specification of the interventions that were compared, and the results of studies. Parameters for excluding studies in the review should also be included. The value of the conclusions in guiding educational policy and practice will be a determining factor in the decision to publish the review. An abstract is required (see Manuscript Preparation and Requirements).

A method/model presentation should describe the development and implementation of an innovative approach to education used in physical therapy. Evidence of testing the reliability and validity of the method or model to education and a clear description of its elements should be included. Evidence from the literature supporting the use of the method or model should be cited. Educational outcomes related to the implementation of the method or model must be included. Essential in the summary of this method/model presentation should be conclusions about its usefulness and the feasibility and generalizability of the application of the innovation to physical therapy education. Areas for future investigation based on the method/model should be identified. An abstract is required (see Manuscript Preparation and Requirements).

Case reports are descriptions of educational practice and interventions not previously described in the literature. Case reports differ from method/model presentations insofar as they may describe an intervention or educational innovation with a smaller sample of individuals (or even an N=1). Case reports must state the purpose of the case report, citing relevant literature. Case reports should provide a clear and thorough description of the case, including the following: the rationale for and implementation of an educational intervention, methods or instruments used to evaluate the intervention, and out comes. Since case reports cannot document efficacy, discussion of the case should include recommendations for further study (eg, method/model or research investigations). An abstract is required (see Manuscript Preparation and Requirements).

Authors are also encouraged to submit letters or brief reports of several types. Of greatest interest would be brief, but complete, research reports (perhaps of work in progress or with small samples) or “Tips From the Field” (innovative tips for classroom and clinical instruction); these brief reports are peer reviewed. Also welcome are more typical letters to the editor that add data to support or refute material in the last issue, make pertinent comments on current issues, or encourage future discussion in the physical therapy education community and journal.

Authorship
As noted in the Uniform Requirements for Manuscripts, an author is generally considered to be someone who has made substantive intellectual contributions to a published study. Authorship credit should be based on (1) substantial contributions to conception and design, or acquisition of data, or analysis and interpretation of data; (2) drafting the article or revising it critically for important intellectual content; and (3) final approval of the version to be published. Authors should meet conditions 1, 2, and 3.

Groups of persons who have contributed materially to the paper but whose contributions do not justify authorship may be listed under a heading such as “clinical investigators” or “participating investigators,”
and their function or contribution should be described—for example, “served as scientific advisors,” “critically reviewed the study proposal,” “collected data,” or “provided and cared for study patients.” Authors will be required to disclose their role in manuscript preparation.

Ethical Standards on Protocol Approval
Research submitted to the Journal of Physical Therapy Education must comply with ethical standards for human and animal research. For any research involving humans or animals, authors must confirm that their institution or other similar body approved the protocol. For studies involving human subjects, authors must also indicate in the manuscript that they obtained informed consent from participants or that the requirement of informed consent was waived by the institution’s internal review board.

Conflict of Interest
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