Developmental Neurorehabilitation, August 2009; 12(4): 224–238

informa healthcare

SUBJECT REVIEW

Virtual reality in paediatric rehabilitation: A review

THOMAS D. PARSONS[1], ALBERT A. RIZZO[1], STEVE ROGERS[2], & PHILIP YORK[2]

[1]*Institute for Creative Technologies, University of Southern California, CA, USA and* [2]*Psychology, Westmont College, Montecito, CA, USA*

(Received 19 April 2009; accepted 22 April 2009)

Abstract

Objective: To provide a narrative review of studies regarding the outcomes of Virtual Reality (VR)-based treatment and rehabilitation programmes within the paediatric population.

Methods: Studies related to the use of VR across a number of paediatric areas (e.g. cerebral palsy, autism, foetal alcohol syndrome and attention deficits) were identified and summarized.

Results: Outcomes from the studies reviewed provide preliminary support for the use of VR.

Conclusion: VR may be an effective treatment method for specific disorders, although the generalizability of this literature is hindered by several methodological limitations, such as small samples and the absence of appropriate control participants.

Keywords: *Virtual reality*, *rehabilitation*, *neurocognitive*, *neuopsychology*, *paediatric*, *virtual environment*

Introduction

Children with neurocognitive impairments may experience decreased functioning in multiple domains including: attention, self-awareness, memory, reasoning and judgement. Such impairments represent significant obstacles to the child's activities of daily living. Neurocognitive rehabilitation has become an integral component of paediatric rehabilitation. Within neurocognitive rehabilitation, the child may perform systematically presented and functionally-oriented therapeutic activities that are based upon an assessment and understanding of the child's brain-behaviour deficits [1]. From a clinical perspective, neurocognitive rehabilitation typically connotes methodical intervention intended to aide the child impacted by cognitive and/or behavioural deficits. In general, the goal is to enable children to increase their ability to perform activities of daily living [2].

Therapeutic interventions occurring within neurocognitive rehabilitation often aim at the achievement of functional changes through reestablishing previously learned behaviour patterns or establishing new patterns of cognitive activity or compensatory mechanisms [1]. Other approaches focus upon increasing activities of daily living by systematically evaluating current performance and reducing impairment by equipping the child with success strategies from a range of settings [3–5]. Traditionally, these approaches to treatment and rehabilitation of the cognitive, psychological and motor sequelae of central nervous system dysfunction have relied upon assessment devices to inform diagnosis and to track changes in clinical status. Although typical assessments employ standard paper-and-pencil psychometrics and training methodologies for impairment assessment and rehabilitation, these approaches have been criticized as limited in the area of ecological validity, that is the degree of relevance or similarity that a test or training system has relative to the real world and in its value for predicting or improving daily functioning [6–8].

A further common method applied in the rehabilitation sciences employs behavioural observation and ratings of human performance in the real world or via physical mock-ups of functional environments [9]. Activities of daily living within mock-up environments (i.e. kitchens, bathrooms, etc.) and

Correspondence: Dr Thomas D. Parsons, PhD, University of Southern California, Institute for Creative Technologies, 13274 Fiji Way, Marina del Rey, 90292-4019, USA. E-mail: tparsons@ict.usc.edu

ISSN 1751–8423 print/ISSN 1751–8431 online/09/040224–15
DOI: 10.1080/17518420902991719

workspaces (i.e. offices, factory settings, etc.) are typically built, within which persons with motor and/or neurocognitive impairments are observed while their performance is evaluated. Aside from the economic costs to physically build these environments and to provide human resources to conduct such evaluations, this approach is limited in the systematic control of real-world stimulus challenges and in its capacity to provide detailed performance data capture.

Virtual reality (VR) has now emerged as a promising tool in many domains of therapy and rehabilitation [9–11]. The unique match between VR technology assets and the needs of various clinical application areas has been recognized by a number of authors [5, 11–16] and an encouraging body of research has emerged [5, 10]. Continuing advances in VR technology along with concomitant system cost reductions have supported the development of more usable, useful and accessible VR systems that can uniquely target a wide range of physical, psychological and cognitive clinical targets and research questions. What makes VR application development in the assessment, therapy and rehabilitation sciences so distinctively important is that it represents more than a simple linear extension of existing computer technology for human use. VR offers the potential to create systematic human testing, training and treatment environments that allow for the precise control of complex, immersive, dynamic three-dimensional (3-D) stimulus presentations, within which sophisticated interaction, behavioural tracking and performance recording is possible. Virtual environments (VEs) can be developed to present simulations that can assess, treat and rehabilitate human functional performance under a range of stimulus conditions that are not easily deliverable and controllable in the 'real-world'.

This article will review results pertaining to the effectiveness of various virtual reality scenarios for the treatment and rehabilitation of children. Through an evaluation of these studies, ideas are generated for future research into the development of virtual environments for paediatric rehabilitation. With current advances and continued cost reductions in both the hardware and software tools needed to use VR for clinical applications, a case will be made for the idea that significant benefits are looming on the horizon for the further integration of this form of simulation technology in the mental health and paediatric rehabilitation sciences.

Method

This qualitative review describes studies that have used VR in the rehabilitation of specific paediatric disabilities. This was not meant to be a comprehensive or exhaustive review of all the possible studies in this area, but to instead capture a representative sample of the existing literature. To accomplish this, a search was performed of the MEDLINE, PubMed and PsychInfo electronic databases using the search term 'virtual' in combination with the terms 'child', 'paediatric', 'rehabilitation' and 'adolescent'. Studies were excluded if they exclusively assessed adults, if they did not examine some form of explicit rehabilitation or if they did not include some form of outcome evaluation. The reference section in each of the included articles was then assessed for additional studies relevant to this review. The final sample was comprised of 34 studies assessing rehabilitation for paediatric forms of cerebral palsy, pain distraction, autism spectrum disorders, foetal alcohol syndrome, attention deficits and visual and perceptual impairment.

Results

Cerebral palsy

Cerebral palsy (CP) has been the target population for a number of VR treatment studies conducted by Denise Reid at the University of Toronto's Virtual Reality Laboratory [17–21]. This research has focused upon investigating the effects of VR on feelings of self-efficacy, upper-extremity control, postural control and feelings of control and competency. Each of these studies immersed children in a series of interactive VR games involving a projected image of the child into a virtual setting that responded to the child's movements (Table I). In the first of three controlled studies [17], interviews and performance measures were used to determine the effects of this immersion on children's self-efficacy. Findings indicated that this immersion allowed the children to participate in activities that were within their physical capacity, thus creating a sense of mastery of the activity and increased feelings of self-efficacy compared to pre-test patient reports.

Findings from two follow-up studies were mixed. In a control study of upper-extremity efficiency [18], tests of motor skills were used to examine the effects of the same virtual environments on children's abilities. Although results were inconclusive, a slight general improvement was found when compared to the control group. Contrariwise, results from research investigating the effectiveness of these virtual environments on postural control [19] were more definitive. Children who participated in the VR treatment displayed improved postural control and alignment than did those in the control group. Additionally, two of the children in the experimental

Table I. Cerebral palsy.

Reference	Condition(s)	*n* compl.	*n* drop	Sessions	Dependent variables	Outcome (effectiveness)
[24]	2 (between subjects) VRE or SE	21	3	6 or 8	SFT (4)	Most severe cases did not benefit. Greater improvement in spatial functioning for others.
[27]	2 (between subjects) pVRE or PT	16	0		EOAA, VAS (for fun)	Children in the pVRE group displayed greater range of ankle movement and more control of active ankle dorsiflexion. Participants in this condition reported a higher level of enjoyment with the treatment than those in PT.
[22]	1 pVRE	16	0		PVQ	VR provides a good environment for fostering volition.
[23]	1 (individual interviews)	19	0	2–6 ($M = 3.5$)	Interviews	Children reported difficulties playing typical play activities. Participants enjoyed the interactive aspect of VR. Overall, participants felt they had control over the VR experience. The VR helped many participants to have a more positive self-image.
[17]	2 (within-subjects) pVRE and baseline	3	0	8	COPM	VR allowed children to participate in activities that helped children to develop a sense of mastery and greater self-efficacy than regular therapeutic activities.
[18]	2 (within subjects) pVRE and baseline	4	0	8	QUEST, BOTMP (5,6) APAS	Two of the subjects showed an improvement in the QUEST scores from pre- to post-tests. All participants showed improvement on the BOTMP item at post-test. APASs showed varied results.
[19]	2 (between subjects) pVRE and control	6	0	8	SACND	All children displayed improved postural control and alignment both at rest and during voluntary reach. Two of the experimental participants also improved in proximal stability and postural tone, one of the two also showed improvement in balance. No change was seen in any of the control group.
[20]	1 pVRE	4	0	1	CSR Children self reports	Children reported experiences that could be described as flow during VR experiences.
[21]	1 pVRE	13	0	8 (3 were selected randomly for analysis)	TOP	Environments which allowed creativity, expression and control over the activity were most motivating. Environments should not be too challenging so that the skills of the user match the requirements of the programme.
[25]	1 pVRE with CyberGloves	1	0		fMRI, BOTMP, PMAL, FMA	The use of the affected hand improved from 1–3 (PMAL). VR enhanced active movement control, reflex activity and coordination in upper extremity movement. Movement of the affected limb activated previously unused contralateral SMC, M1 and S1 in the same way that they would have been initially activate.
[26]	2 (within subjects VRE [HMD] and control)	24	0	2	Proprioception test, VR survey	Children each indicated high motivation to play the game. No significant differences were found between pre- and post-intervention on proprioception tests.

Treatments: pVRE = Projected virtual reality environment.
Dependent variables: SFT = Spatial functioning tests; EOAA = Electrogoneometer output of ankle angle; PVQ = paediatric volition questionnaire; COPM = Canadian Occupational Performance Measure; QUEST = Quality of upper extremity skills test; BOTMP = Bruininks-Oseretsky test of motor proficiency; APAS = average percentage accuracy score; SACND = Sitting assessment for children with neuromotor dysfunction; TOP = test of playfulness; PMAL = Paediatric motor activity log; FMA = Fugl-Meyer assessment.

group demonstrated improvement in proximal stability and postural tone and one of these also showed improvement in balance. No improvements were observed in the control group.

In a non-controlled study of the effects of VR on children's feelings of competency and control [20], children previously involved in regular VR treatment were interviewed to determine their opinions of the therapy. Although no standardized tests or questionnaires were administered, Reid reported that children expressed generally positive and flow-like experiences associated with the VR therapy, similar to Reid's earlier findings. Collectively, this research found that children with CP generally enjoyed their experience with VR, although the results were not always significant for the variables investigated.

Using the same procedures documented above, Reid [21] later investigated the influence of VR on the playfulness of children with CP. She found that the virtual environments that allowed children to be creative and challenging (without being overly difficult) proved to be motivating for participants. In a similar non-controlled study, Harris and Reid [22] used the Paediatric Volition Questionnaire to determine how VR impacted children's motivation and volition. Overall, VR treatment was determined to be a positive environment for fostering volition. Relatedly, Miller and Reid [23] conducted interviews with 19 children with CP who were then currently involved in a VR rehabilitation programme. Most of the children reported difficulty with typical play activities, but enjoyed the interactive aspect of VR and the control they had over the experience. VR seemed to help many participants develop a more positive self-image.

A study by Akhutina et al. [24] was completed to determine whether spatial functioning in children with cerebral palsy could be improved through immersion in a virtual environment. Twelve children with CP received VR therapy and were compared to a control group of nine children with CP who did not receive the VR treatment. Using a battery of virtual environments related to spatial functioning examinations, such as clown assembly and a virtual maze, experimenters found that those who participated in the VR treatment did not uniformly benefit from the therapy relative to the control group. A few higher functioning children in the experimental group, however, did show some improvement. The lack of overall improvement was attributed to the finding that the children involved in the control group did not suffer from conditions as severe as those in the experimental group, which may have allowed them to achieve improved spatial functioning outside of virtual reality treatment.

In a 2005 case study investigating whether VR could induce cortical reorganization, You et al. [25] immersed an 8 year-old boy with hemiparetic CP in several interactive virtual environments to enhance motor functioning. The use of the impaired hand improved significantly. Furthermore, VR enhanced active movement control, reflex activity and coordination in upper extremity movement. Results from fMRI revealed that movement of the affected limb activated previously unused contralateral SMC, M1 and S1 in the same way that they would have been activated prior to hemiparesis. In a related study, Stansfield et al. [26] investigated the effects of a virtual reality game (VRG) on upper-extremity movements in children with motor impairments. Some of the 24 children had CP, although it is not clear whether all the children had this condition. In general, the children indicated high motivation to play the game, described it as fun and expressed interest in playing it again. Although there was no aversive effect related to the game, no significant differences were found in proprioceptive or motor tests between pre- and post-intervention.

Bryanton et al. [27] report on a study in which 10 children with CP and six healthy children were divided into either a VR therapy group or a standard therapy group to increase strength and flexibility of participants' ankles. The VR therapy engaged the children in the same exercises, but in an interactive way. Researchers measured the children's range of motion, as well as contraction-hold-time and VASs for participant ratings. Children in the VR group displayed greater range of ankle movement, increased control of active ankle dorsiflexion and reported a higher level of enjoyment from the treatment than those in the control group.

Conclusions. Virtual reality treatment appears to be an effective rehabilitation tool for use with children with CP. These results may reflect VR's capacity for making otherwise impossible or uninteresting activities to be accomplished in an engaging, challenging environment. Nevertheless, more research is needed to give a broader perspective on the benefits and limitations of VR in this population.

Pain distraction

Some of the most conclusive research has been in the area of VR as a method of pain distraction for paediatric patients (Table II). One of the first reported studies was done by Holdenet et al. [28] in 1999. They administered an online interactive game (*Starbright World*) on a desktop computer to nine children hospitalized for various painful medical conditions, such as paediatric cancer. Compared to baseline individual and medical treatment, these children displayed significantly less pain intensity

Table II. Pain distraction.

Reference	Condition(s)	*n* compl.	*n* drop	Sessions	Dependent variables	Outcome (effectiveness)
[31]	2 (within-subjects) VRE [HMD] + SA or SA	7	2	1, 2 and 3	FPS (modified)	Every child but one obtained an improvement in pain scoring of at least 2 points on the faces scale.
[35]	3 (between subjects) VRE [HMD] + SA, NonVD[desktop display] + SA, or SA	59	1	1	VAS, CHEOPS, HR	Significantly lower HR during procedure for VRD compared to control. Significantly more observer-reported muscle tension in torso of control compared to VRD during procedure and leg tension compared to VRD and NVRD.
[36]	3 (within subjects) VRE [HMD] + SA, NonHMD distraction + SA, or SA	1	0	2	MASC, VAS, CBCL, CHEOPS, HR	Parents ratings of pain and anxiety decreased steadily during the first three conditions with the lowest during the VRD condition. Lowest rating of pain during VRD, an equal number of pain behaviours were observed during the other conditions. HR was more than 30 bpm lower than any other condition during VRE.
[38]	2 (within subjects) VRE [HMD] + SA or SA	20	0	1	VAS, FPS, CASI, CSSQ, Satisfaction Questionnaire	Children in the control reported a significant 4-fold increase in affective pain during the procedure, there was no significant change in the experimental group (FPSR).
[30]	2 (within subjects) VRE [HMD] + SA or control (Nintendo 64) + SA	2	0	2	Pain and Presence ratings, VAS	Both patients provided evidence that VRD can help distract from the pain during burn wound care. Patient 1 showed dramatically less reported sensory pain, affective pain and anxiety during VRD and both patients showed a dramatic reduction in time spent thinking about the pain during the VRD condition. Presence was rated high and, for patient 1, remained high for three immersions showing no signs of habituation.
[32]	2 (within subjects) VRE + SA or SA	7	0	3	VAS (5)	Pain ratings in the five VAS tests were consistently lower during VRD than the control. Further there was no significant decrease in the magnitude of pain reduction across the three sessions. VRD was seen to be a powerful analgesic pain distraction.
[33]	1 VRE + SA	11	1	1	OEIE, Length of time in different VR scenarios	82% said this intervention helped compared to previous interventions, 18% said it made no difference. 82% had no problem using the HMD (45% said that it was comfortable), 55% did not have any problem seeing the image. 100% of participants reported that they enjoyed using the VR treatment and that they would use it again.
[34]	2 (within subjects) VRE [HMD] + SA or SA	1	0	6	FPS, Parent and Physiotherapist ratings, Goniometer reading of knee flexion	Patient reported a 41.2% decrease in perceived pain throughout all sessions for the VRD condition compared to the control. Parent and therapist reported lower pain scores and anxiety during VRD. VRD is an effective and appropriate analgesic due to the fully immersive nature.
[37]	2 (between subjects) VRE [HMD] + SA or SA	20	3	1	How-I-Feel Questionnaire, VAS, HR, CHEOPS	Children in the VRD group, though not statistically different from the control on measures before the procedure (anxiety levels, etc.) did display significantly lower HRs and CHEOPS scores during procedure that led to trends of lower HR and VASs even after the procedure was completed.
[28]	2 (within subjects) VRE or no game control	7	2	20	EMA, VAS, CAS, FAS	Individually, there were no significant differences for the majority of children. However, as a whole, children reported significantly less pain intensity and pain aversiveness as well as less anxiety in the VRG condition.

Treatment: SA = Standard Analgesics; HMD = Head mounted display.
Dependent variables: FPS = Faces Pain Scale; VAS = Visual Analogue Scales; CHEOPS = Children's Hospital of Eastern Ontario Pain Scale; HR = heart rate; MASC = Multidimensional anxiety scale for children; CBCL = Child behaviour checklist; CASI = Childhood anxiety sensitivity index; CCSQ = Child simulator sickness questionnaire; OEIE = Open-Ended Independent Evaluation of Intervention.

and pain aversiveness while engaged in the virtual reality game (VRG). They also exhibited non-significant, but decreased scores on a test of anxiety.

In the following year, Sullivan et al. [29] gathered a group of 30 children going through two dental reconstruction procedures. They projected that the children would benefit from administration of a 5-minute VR video during anaesthetic injection. The children (half receiving the VR during the first procedure and half during the second) completed a test of human figure drawing before and after each procedure. They also had their heart rate monitored and their behaviours recorded and rated by observers. Although results revealed no statistically significant differences in anxiety or behaviours in either condition, heart rates were significantly lower during the VR administration.

Another VR procedure was used in a pair of controlled case studies with paediatric patients suffering from burn wounds [30]. VR in an interactive environment called *Spiderworld* was administered during routine wound care, when the burns were unwrapped and rewrapped. Using pain and presence ratings, along with VAS for perceived pain, this study provided evidence that VR can help distract from pain during burn wound care, even when compared to a video game control condition (*Nintendo 64*). Patients showed a dramatic reduction in time spent thinking about the pain during the VR condition and Patient 1 in their study reported dramatically less sensory pain, affective pain and anxiety during VR. Presence was also rated highly during VR and remained high for three immersions in one patient, who showed no signs of habituation. Two other studies examining burn wounds report similar findings. Das et al. [31] administered the Faces Pain Scale (FPS) to seven children with burn wounds. Compared to a control condition, they found that all but one of the children reported a two-point decrease in pain while playing a VR game based on the video game *Quake*. Hoffman et al. [32] examined both child and adult participants who suffered from severe burn wounds to determine whether the magnitude of pain reduction tapered over time. In the experimental condition, the participants were administered either *Spiderworld* VR or *SnowWorld* VR (where the patient experienced the illusion of flying through the snow world). Using VAS for pain, they found that the magnitude of pain reduction from the baseline condition to the VR conditions did not significantly reduce over three sessions. This suggests that the efficacy of VR cannot be limited to its initial novelty and intrigue, which would wear off over time.

In a non-controlled study [33], 11 children who were undergoing chemotherapy were immersed in several different VREs (*Magic Carpet*, *Sherlock Holms Mystery* and *Seventh Guest*) and could go back and forth between each virtual environment during the entire procedure. Afterwards, children went through an open-ended evaluation to determine their feelings about the treatment. Relative to previous interventions, a majority (82%) of the children reported that the VR helped with pain control. The same percentage of children reported that the HMD was easy to use, although only 45% felt that it was comfortable.

In 2003, Steele et al. [34] examined whether VR would be helpful for reducing pain in a child with CP who was going through physical rehabilitation after a single-event, multi-level surgery. A first-person shooter environment was created as the VR and outcome measures included the FPS and interviews with parents and physiotherapists. Based on these measures, the participants reported a 41.2% decrease in perceived pain compared to the non-VR control group. Observers also reported lower levels of perceived pain and anxiety among the children participating in the VR therapy.

Gershon et al. [35, 36] examined differences in the effectiveness of pain distraction between two forms of VR, namely HMD and presentation on a desktop screen (*Virtual Gorilla*). A total of 59 children with paediatric cancer were assigned to the experimental (HMD) group, a desktop display group or a control group. Using standardized tests for anxiety and pain ratings, as well as heart rate monitoring, the researchers found that the heart rate of participants were significantly lower during the HMD condition relative to the other conditions. Similarly, when participants and observers were asked to rate the participants' pain and anxiety, the ratings decreased in each condition, with HMD having the lowest ratings. The authors concluded that HMD is more effective in reducing anxiety, pain and heart rate because it is more immersive than a similar environment on a desktop display (i.e. the children cannot see the procedure in their peripheral vision or by turning and looking directly at it).

The final two studies on pain distraction focus on children undergoing a port access procedure [37] and IV placement [38]. Both studies found that children reported significantly reduced levels of pain while in the VRD condition with analgesic procedures, as opposed to the control condition of standard analgesic procedures. Wolitzky et al. [37] reported significantly lower CHEOPS scores and heart rate during VR, similar to the studies previously mentioned. Gold et al. [38] also found that the control condition had a four-fold increase in reported pain relative to pre-procedure ratings, but there was no significant increase in pain among those in the experimental condition.

Conclusions. Treatment using VR has been found to be an efficient and beneficial analgesic component to pain distraction during a variety of painful medical procedures among children. Overall, it has been reported that VR, paired with standard pharmacological analgesics, is extremely effective in reducing a child's perception of pain. An important aspect of effective virtual reality distraction is the level of immersion that the treatment allows; therefore, all but one of the studies used an HMD.

Autism

Two case studies of autistic children have been conducted to determine the utility and efficacy of VR technology among children with the autistic spectrum disorder (ASD) [39, 40]. The general findings indicated that the children interacted well with the virtual environments and followed most of the experimenter's instructions. The children's responses suggested that VR could be an effective learning tool when applied to children with autism (Table III).

Max and Burke [41] conducted a controlled study aimed at determining the effects of VR on two particularly difficult challenges for children with ASD: distractibility and time spent on a task. Relative to baseline levels, in the children with ASD group results revealed less distractibility and more time spent on a task during VR than in those within a non-ASD control group. This was accurate despite the fact that the virtual environments contained high levels of multidimensional stimulation that may generally be distracting to children. The children with ASD also displayed a high level of interest in the VRE.

In recent controlled studies on children with ASD, Parsons et al. [42, 43] matched children with ASD with two groups of children without ASD. One group was matched for verbal IQ (VIQ) and the other was matched for performance IQ (PIQ). Both studies recorded scores on a measure of dysexecutive syndrome (BADS), as well as the general number of errors and time required to complete each VRE exercise. In the first study, the children with ASD and PIQ control group showed trends of improvement after immersion in a virtual environment, whereas the VIQ group showed no signs of improvement after immersion. An additional finding of interest was that the children with ASD group displayed more errors related to bumping into or walking too close to virtual persons. Therefore, the second study used a similar method, but recorded socially appropriate behaviours. Unfortunately, the results were inconclusive because the children did not consider socially appropriate behaviours to be within the realm of the virtual environment, even if they could understand how the behaviour would not be appropriate in the real world.

Conclusions. It appears that VR holds promise for the rehabilitation of certain skills in children with ASD. Even so, it is unclear what symptoms of autism could be improved through the use of VR. Research of the effects of VR on children with ASD has faced difficulties inherent within the disorder. Children generally cannot participate in sessions longer than 5 minutes, may have difficulty cooperating with the use of VR headsets and struggle to understand and stay attuned to the tasks. Nevertheless, more attention is beginning to be devoted to the important contributions that the controlled environment (provided by VR) may offer.

Foetal alcohol syndrome

The authors were only able to find one study examining the effectiveness of VR for children diagnosed with foetal alcohol syndrome (FAS) (Table IV) [44]. Using a within-subjects controlled study, a group of five students with FAS were exposed to a virtual game that taught fire safety skills, such as the appropriate steps to take in the event of a fire. Before the intervention, none of the children could describe appropriate actions when a fire occurred. After the intervention, however, the children reached 100% accuracy rates on safety questionnaires. Even 1 week later, the children were still able to perform well on a real-world generalization of what they had learned.

Conclusions. This study points to the possible value of VR for children with FAS, however one of the main weaknesses is that no educational alternative to VR was evaluated. Therefore, more research is necessary to determine whether VR is more effective than other possible treatments.

Attention deficits

In a study by Cho et al. [45] VR rehabilitation was applied to attention deficits. Thirty participants were assigned to a VR group with an HMD, a desktop equivalent training group or a control group (the virtual environment was that of a classroom where participants performed training sessions). After attention training in one of the two experimental groups or no training in the control group, participants' attention abilities were assessed by completing a continuous performance task (CPT) that required responding to specific target stimuli presented for only 250 ms. Those in the VR group had significantly elevated rates of correct responding and decreased perceptual sensitivity and response bias. Furthermore, the participants who had the opportunity to use *both* the HMD and the desktop

Table III. Autism.

Reference	Condition(s)	*n* compl.	*n* drop	Sessions	Dependent variables	Outcome (effectiveness)
[41]	2 VRE (HMD)- (Autistic and non-Autistic control)	9	0	1	Distractibility and time on task (baseline and post-test reported for subjects by experimenter)	Autistic children displayed a substantial interest in the VRE, showing less distractibility and more time on task behaviours even in an environment of high visual and auditory complexity.
[42]	1 VRE (desktop display), (matched ASD, VIQ, and PIQ).	36 (12 ASD, 12 VIQ, 12 PIQ)	0	5	BADS, Performance (time and errors made)	Autistic children showed trends of improvement along with the PIQ group, whereas the VIQ group showed no signs of improvement after immersion in a VRE. This was seen more consistently between ASDs when compared to VIQ matched controls, but also when compared to some PIQ matched controls.
[43]	1 (VRE [HMD]: 8 VRE conditions; 4 appropriate and 4 innappropriate conditions)	34 (12 ASD, 11 VIQ, 11 PIQ)	0	1	BADS, Performance, Participant Explanation of Routes taken	No significant differences in socially appropriate routes taken, children did not seem concerned with the social appropriateness of walking through virtual people. Similarly, no significant differences were seen between participants' times or BADS scores, however in the PIQ group there was a significant association between mean time taken and BADS tasks.
[39]	1 VRE (HMD)	2	0	21	Level of acceptance of VR equipment, ability to be immersed in and pay attention to the VRE.	Children complied with most requests. They wore the helmets without a problem, identified with familiar objects and qualities in the environment.
[40]	1 VRE (HMD)	2	0	45+	Level of acceptance of VR equipment, ability to be immersed in and pay attention to the VRE.	Children displayed an ability to use VR equipment and behaviours that suggest an advantage to using VR as a learning tool for autistic children.

Conditions: ASD = Autistic Spectrum Disorder; VIQ = Verbal IQ; PIQ = Performance IQ.
Dependent variables: BADS = Behavioural Assessment of the Dysexecutive Syndrome.

Table IV. Foetal alcohol syndrome.

Reference	Condition(s)	*n* compl.	*n* drop	Sessions	Dependent variables	Outcome (effectiveness)
[44]	2 (within subjects) VRE and baseline	5	0	2	Verbal inquiry and Picture arrangement	Children were able to generalize fire safety concepts they had learned in VR to the real world, though some had difficulty generalizing to the picture arrangement task.

Table V. Attention deficits.

Reference	Condition(s)	*n* compl.	*n* drop	Sessions	Dependent variables	Outcome (effectiveness)
[45]	3 (between subjects) VRE [HMD], equivalent desktop display or control group	26	6	8	CPT	Increased correct responses and decreased perceptual sensitivity and response bias for those in the VRE group than the equivalent desktop group and the control group.

Dependent variables: CPT = Continuous Performance Task.

Table VI. Visual impairments.

Reference	Condition(s)	*n* compl.	*n* drop	Sessions	Dependent variables	Outcome (effectiveness)
[48]	1 VRE (auditory and visual)	9	0	4	EUQ, PIE, PSU	Blind children were able to create mental representations of the virtual audio space. Both the blind children and those with residual vision were able to orient themselves in the virtual world and navigate efficiently through the environments. Although children with residual vision reported slightly higher levels of motivation for using the VRE, blind children did report high levels of motivation.
[47]	1 VRE	6	0	7–15 ($M = 11.3$)	Glasgow LogMar crowded acuity card test	No statistical measures were run.

Dependent variables: EUQ = End user questionnaire; PIE = Prototype interface evaluation; PSU = Problem-solving understandability.

equivalent reported that the desktop equivalent was more boring and less motivating than the HMD.

Conclusions. This study provides preliminary hope and promise for VR as a form of rehabilitation for attention deficits. Rizzo et al. [46] appear to be making progress toward establishing more controlled studies in this area (Table V).

Visual impairments

Two studies assessed different aspects of rehabilitation in children with visual impairments (Table VI). The first study [47] investigated the effectiveness of VR in treating amblyopia (a common refractive error) in children. In the pilot study, three children who had not received previous treatment were compared to three children who had received previous treatment, but had not benefitted from it. The researchers developed a system that displayed videos and games in a 3D virtual environment where the child could view stereo images on a monitor with a fixed viewing window. The key aspects of the environments were only displayed to the amblyopic eye in order to increase visual acuity in that eye without neglecting the good eye. Each participant went through several sessions until their vision remained stable with no more improvement. Compliance with the therapy was high and researchers suggested that there was 'rapid improvements in the vision of five of the six children following only minimal treatment' (p. 377). However, no statistical analyses were conducted because the authors felt the sample was too small to warrant such calculations.

The second, non-controlled study [48] was designed to determine whether VR can be effective among a sample of blind and nearly blind children. Five children with low vision and four children with complete blindness participated in four sessions of

Table VII. Perceptual auditory impairments.

Reference	Condition(s)	*n* compl.	*n* drop	Sessions	Dependent variables	Outcome (effectiveness)
[49]	3 (between subjects) VRG (3D tetris), Conventional 2D Tetris or no game.	44 Deaf and HH 16 normal hearing	0	12	Circles sub-test to measure flexible thinking (before and after)	After the intervention, a clear difference was found between the Deaf and HH experimental and control groups and a smaller difference was found between the experimental and normal hearing groups in flexible thinking tests.
[50]	2 (between subjects) VRG (3D tetris) or conventional 2D tetris	44 (21 VR, 23 control)	0	12	KFAT, FRT	After intervention the children in the VR group showed significantly greater ability in the spatial rotation tests than the children in the 2D tetris game.

Treatments: VRG = Virtual reality game.
Participants: HH = Hard of hearing.
Dependent variables: KFAT = Kuhlman-Finch Aptitude Test; FRT = Feuerstein and Rand test.

VR immersion with 3D-orienting auditory cues, which allowed participants to navigate around the multilevel environment. Following each session, participants completed a series of questionnaires relating to problem-solving understandability, interface evaluation and end-user ratings. Results indicated that children with blindness were able to create mental representations of the virtual audio space. Both the children with complete blindness and those with residual vision were able to orient themselves in the virtual world and navigate efficiently through the environments. Both sets of children reported high levels of motivation, but the ratings of motivation were slightly higher for those with residual vision.

Conclusions. VR may be an effective method of rehabilitation for children with visual deficits. However, more controlled studies and strict statistical analyses are needed to determine the effectiveness of VR for these children.

Perceptual auditory impairments

Passig and Eden [49, 50] conducted a pair of studies which investigated the effects of VR for children with perceptual auditory impairments (Table VII). In the first, they divided 44 children with deafness and hard of hearing (HH) into an experimental group that played a 3D VR version of Tetris and a control group that played a normal 2D version of the same game. Sixteen children with normal hearing (NH) served as an additional control group. Each child was then administered the Circles sub-test to assess his or her ability to engage in flexible thinking. The results suggest that, prior to intervention there was no significant difference in flexible thinking between the two children with deafness and HH groups. As expected, there was a considerable difference between these groups and the children within the normal hearing control group. After the intervention, however, children in the experimental group demonstrated significantly improved ability to think flexibly. A smaller difference was found between the experimental and normal hearing groups. The second test divided 44 children with deafness and HH into a VR Tetris or 2D Tetris group to determine whether the VR version helped the children in their visual-spatial abilities, specifically their spatial rotation skills. Using two tests of spatial rotation ability, the Kuhlman-Finch Aptitude Test and Feuerstein and Rand test (KFAT and FRT, respectively), they found that children in the VR group showed significant improvement compared to the non-VR Tetris group after 3 months of training (one session per week).

Conclusions. These studies suggest that VR may be an effective method for improving flexible thinking and visual-spatial abilities among children with perceptual auditory deficits. It would be beneficial for future studies to incorporate a non-virtual method of training for these cognitive abilities to use as controls against VR.

Discussion

Virtual reality (VR) is a recently emerging form of rehabilitation therapy. While this novel treatment approach has exciting implications for neurocognitive rehabilitation, little has been done to review the studies applying VR rehabilitation of children. This review provides a qualitative review of studies that implement VR as a rehabilitation implement for children suffering from various conditions, which provides an evaluation of VR's effectiveness and limitations. The studies reviewed focused upon children experiencing cerebral palsy (CP), pain distraction, ASD, foetal alcohol syndrome (FAS), attention deficits, visual impairments and perceptual auditory impairments. Across almost all of the studies, a common finding was that children reported enjoyment of their experience within virtual environments and that the virtual environments provided them with high levels of motivation, interest and intrigue. Even among children who had difficulty with typical play activities, there seemed to be enjoyment resulting from the interactive elements of VR and the control children had over their experience. This frequently translated into an increasingly positive self-image. Whether or not this enjoyment translated into greater efficacy seems to depend on the domain of rehabilitation that was assessed.

The effectiveness of VR seems most conclusive as a method of dealing with the symptoms of CP and as a distracter for painful and anxiety-provoking procedures. Among children with CP, VR seems to be effective in elevating self-efficacy, volition, playfulness and motor functioning, including proximal stability, postural tone and even greater range of ankle movement. Much of its efficacy seems related to its ability to allow children to perform actions within a controlled setting that are otherwise difficult to achieve (due to safety and motivational issues). There is little uniformity, however, in the variables studied and more research is needed to provide a clearer understanding of the facets of VR that are most beneficial to these children. One commonly reported challenge in using VR among children with CP is the difficulty associated with integrating an apparatus that is both immersive and not physically overwhelming for the child. Therefore, many of the studies that were evaluated did not use any form of head mounted display (HMD) and only two of the studies [24, 26] used some form of additional input device for the patients (hand-held joystick and computer mouse, respectively). Recent improvements in the technology of HMDs, making them lighter and more maneouverable, may allow children with CP to participate in a more immersive and engaging VR experience.

When paired with standard analgesics, VR has also proven to be an effective tool in the reduction of perceived pain and anxiety among children undergoing various procedures, including burn wounds, paediatric cancer and dental reconstruction. In most cases, it also represents a way to manage and control the child's heart rate. Unlike studies among children with CP, researchers in pain distraction were able to implement HMDs, which increased the immersive nature of the treatment and increased the effectiveness. Despite the established efficacy of VR as a method of pain distraction, it would be beneficial for future studies to include a non-VR control group that does not permit subjects to see or hear the procedure taking place. Many children reported experiencing pain related to the visual and auditory perception that the procedure was taking place, which may have confounded their subsequent pain ratings.

It may be that part of the efficacy of VR in CP and pain distraction is because both areas have considerably more research than other domains, which has allowed researchers to investigate a number of different aspects and symptoms of each arena. For example, the effectiveness of VR as a pain distractor has been not only tested against the standard procedures, but has also been tested against alternate forms of distraction, such as comparable desktop scenarios. Furthermore, the fact that VR appears to be more engaging and immersive than previous forms of treatment in CP and pain distraction seems to be paramount to its effectiveness. Research seems to suggest that the more immersive the VR, the more effective it will be in a number of different settings.

To date, only limited preliminary research has been conducted in the other areas of paediatric rehabilitation. Although there have been some studies investigating the effectiveness of VR among children with autistic spectrum disorders, there has not been significant research to determine which specific symptoms could be treated through the use of VR. Reductions in distractibility, time on tasks and executive difficulties have all been associated with VR, but the efficacy and utility of VR has been questioned because children with autistic spectrum disorder generally cannot participate in sessions longer than 5 minutes, may have difficulty cooperating with the use of VR headsets and struggle to understand and stay attuned to the tasks. Future studies should be designed to better determine the ways in which these complications may be prevailed over and to partition the specific benefits of VR in rehabilitation of children with ASD.

There has been only one study assessing the effectiveness of VR as a rehabilitation device for children with foetal alcohol syndrome (FAS) [44]. This study showed that VR could be used as an educational device in assisting children to learn fire safety skills; however, the study did not compare VR to an alternative educational method, making it unclear if VR is superior to existing approaches. Similarly, the one study examining attention deficits [45] suggests that VR is effective in increasing attention and response accuracy in children with ADD and ADHD, but the absence of replicating research or the use of measures other than continuous performance tasks suggests that the optimism about this approach should be guarded.

There is reason for interest in studies of VR for treating children with visual and auditory impairments. Research among children with deafness and hardness of hearing suggests that VR may be helpful in improving certain cognitive abilities like flexible thinking and spatial rotation. A study among children with amblyopia suggests that VR can foster the creation of mental representations of virtual audio space, which can aid orientation and navigation through the environments. Yet, none of these studies incorporated a non-virtual method of training for these cognitive abilities to use as control conditions, so the relative or comparative benefit is uncertain.

Methodological considerations and recommendations for future research

As these findings suggest, VR rehabilitation in children seems like a promising field, although not without its limitations. Interpretation of the VR and paediatric rehabilitation literature is hampered by several methodological problems that limit its internal validity, conclusions and generalizability. Perhaps one of the main limitations is a lack of rigour in creating and defining control groups. Several of the studies chose not to compare VR to any alternative at all or opted to compare VR against therapeutic alternatives that were not the most effective alternatives available. It would be beneficial to measure the effects of VR against the prominent non-VR therapies available. If effective rehabilitation can occur outside of the costly VR scenario and in an analogous amount of time, it is less certain that VR would be the most beneficial option. In many cases, this has not been determined.

Another limitation is whether or not the expected behaviours or actions that are being measured can be expected to generalize into a virtual environment. Although children may be engaged in realistic environments that include virtual persons, it may be that children will not behave the same way in this new environment that they would in a real world scenario. This is particularly true in cases like autism, where the measurement of certain behaviours, like social interactions, is confounded by their inability to perceive how these behaviours could be consistent with the virtual world environment. Current research has yet to determine the degree to which real world behaviours, intentions and personalities can be directly mapped onto a virtual environment.

Heterogeneity in sample characteristics also obfuscates conclusions to be drawn from these initial studies. First, there is variability in patient selection techniques and inclusion/exclusion criteria used. Further, several studies reported on overlapping patient samples. Thirdly, ~85% of the studies reviewed included less than 30 participants with sample sizes in all studies ranging from 1–58 participants. Small samples limit researchers' ability to detect post-treatment changes or significant group differences (i.e. increased risk of committing a Type II error). The typically large number of statistical tests carried out in small sample studies also heightens Type I error probability. Increasing the number of participants will strengthen the statistical power, complexity and robustness of these research findings [51–55].

A related issue is whether post-treatment changes are reliable and/or of clinical significance. Several different statistical procedures exist to assess the clinical significance of changes in test scores, including effect sizes, individual change scores, reliable change indices and various regression formulae [56–59]. Such analyses are particularly relevant to the study of outcomes after virtual reality treatment given that myriad factors other than VR might explain differences between pre- and post-treatment test scores (e.g. practice effects, poor test–re-test reliability, floor and ceiling effects, the duration of test–re-test interval and/or individual patient characteristics [59]). Unfortunately, none of the studies reviewed reported effect sizes and many had limited reporting of descriptive statistics. Furthermore, none utilized a reliable change index or comparable regression formula. To more carefully examine the clinical significance of VR findings, it is recommended that investigators report appropriate group means, individual change scores, statistical analyses of change and effect sizes whenever possible. Researchers are encouraged to carefully consider which combination of these statistical procedures is most appropriate to their particular research design, dependent variables and sample size.

It is also uncertain how the varying levels of severity in children's conditions impacted their overall rates of improvement. There is a certain level of cognitive skill required to participate in VR rehabilitation, which may restrict the largest benefit to those children who are at the higher end of the spectrum of functioning. At the same time, it seems equally likely that those who are higher functioning have more resources external to VR and therefore are less likely to immediately benefit from this approach relative to their lower functioning peers. These possibilities have been hinted at by some of the studies that were examined, but very few explicitly examined the interaction between symptom severity and VR effectiveness.

Conclusion

The findings from this review of VR treatment within paediatric rehabilitation suggest that the field of VR rehabilitation is still in an early phase of development characterized by successful 'proof of concept' systems, encouraging initial research results and a few applications that are finding their way into mainstream use and clinical practice. Rizzo and Kim [60] have pointed to a number of VR strengths to provide a justification for evolving existing applications and creating new ones. As they have noted, while weaknesses exist (e.g. interface and display technology), these do not threaten the viability of the field in light of recent thoughtful system design targeting clinical and research applications that are well matched to current technology assets and limitations.

Although there are areas that need improvement, the reviewed studies have provided some essential information that should be considered for future research. First, the level of engagement is crucial. Children, especially with disorders such as attention deficits, autism and CP, seem to respond well to programmes that are creative and challenge them, without being overwhelmingly difficult. The VR interaction cannot be boring, but it cannot be out of the reach of the child's abilities. Secondly, as previously mentioned, the equipment does make a difference. From a number of studies, it seems clear that there are benefits to implementing some form of HMD in cases where it is applicable [19, 20, 33, 34].

Overall, VR has been shown to be a novel and effective form of rehabilitation for children dealing with a number of disabilities. It appears to be intrinsically exciting and motivating to children and, although the research is still relatively limited and warrants cautious optimism, the majority of the effects are positive and promising. There is much more to be determined regarding the application of VR to specific rehabilitation scenarios and its efficacy in comparison to other viable options. As the number of studies dealing with this topic grows, VR researchers will develop a better picture about which children, struggling with which conditions and under what circumstances will most clearly benefit from VR.

Declaration of interest: The authors report no conflicts of interest. The authors alone are responsible for the content and writing of the paper.

References

1. Harley JP, Allen C, Braciszewski TL, Cicerone KD, Dahlberg C, Evans S, Foto M, Gordon WA, Harrington D, Levin W, et al. Guidelines for cognitive rehabilitation. Neurorehabilitation 1992;4:62–67.
2. Ylvisaker M. Brain injury rehabilitation, children and adolescents. 2nd ed. Boston, MA: Butterworth-Heinemann; 1998.
3. Ylvisaker M, Szekeres S, Feeney T. Communication disorders associated with traumatic brain injury. In: Chapey R, editor. Language intervention strategies in aphasia and related neurogenic communicaion disorders. 4th ed. Philadelphia, PA: Lippincott Williams, & Wilkins; 2001. pp 745–808.
4. Rizzo A, Buckwalter J. Virtual reality and cognitive assessment and rehabilitation: The state of the art. In: Riva G, editor. Virtual reality in neurophysiology. Amsterdam: IOS Press; 1997. pp 123–146.
5. Rizzo AA, Buckwalter JG, van der Zaag C. Virtual environment applications for neuropsychological assessment and rehabilitation. In: Stanney K, editor. Handbook of virtual environments. New York: L.A. Earlbaum; 2002. pp 1027–1064.
6. Neisser U. Memory: What are the important questions? In: Gruneberg MM, Morris PE, Sykes RN, editors. Practical aspects of memory. London: Academic Press; 1978. pp 3–24.
7. Wilson BA. Cognitive rehabilitation: How it is and how it should be. Journal of the International Neuropsychological Society 1998;3:487–496.
8. Christiansen C, Baum C. Person-environment occupational performance: A conceptual model for practice. In: Christiansen C, Baum C, editors. Occupational therapy: Enabling function and well-being. 3rd ed. Thorofare, NJ: SLACK; 2004. pp 46–71.
9. Weiss P, Jessel AS. Virtual reality applications to work. Work 1998;11:277–293.
10. Glantz K, Rizzo AA, Graap K. Virtual reality for psychotherapy: Current reality and future possibilities. Psychotherapy: Theory, Research, Practice, Training 2003;40:55–67.
11. Rizzo AA, Schultheis MT, Kerns K, Mateer C. Analysis of assets for virtual reality applications in neuropsychology. Neuropsychology of Rehabilitation 2004;14:207–239.
12. Pugnetti L, Mendozzi L, Motta A, Cattaneo A, Barbieri E, Brancotti S. Evaluation and retraining of adults cognitive impairments: Which role for virtual reality technology? Computers in Biology and Medicine 1995;25:213–227.
13. Rizzo AA. Virtual Reality applications for the cognitive rehabilitation of persons with traumatic head injuries. In: Murphy HJ, editor. Proceedings of the 2nd International Conference on Virtual Reality and Persons with Disabilities. Northridge, CA: California State University; 1994. pp 1–8.
14. Rizzo AA, Wiederhold M, Buckwalter JG. Basic issues in the use of virtual environments for mental health applications. In: Riva G, Wiederhold B, Molinaria E, editors. Virtual reality in clinical psychology and neuroscience. Amsterdam: IOS Press; 1998. pp 21–42.
15. Rose FD, Attree EA, Johnson DA. Virtual reality: An assistive technology in neurological rehabilitation. Current Opinion in Neurology 1996;9:461–467.
16. Rose FD, Brooks BM, Rizzo AA. Virtual reality in brain damage rehabilitation: Review. CyberPsychology & Behavior 2005;8:241–262.
17. Reid DT. Benefits of a virtual play rehabilitation environment for children with cerebral palsy on perceptions of self efficacy: A pilot study. Pediatric Rehabilitation 2002;5:141–148.
18. Reid DT. The use of virtual reality to improve upper-extremity efficiency skills in children with cerebral palsy: A pilot study. Technology & Disability 2002;14:53–61.
19. Reid DT. Changes in seated postural control in children with cerebral palsy following a virtual play environment rehabilitation intervention. Israel Journal of Occupational Therapy 2002;11:451–462.
20. Reid DT. Virtual reality and the person-environment experience. CyberPsychology & Behavior 2002;5:559–564.
21. Reid DT. The Influence of virtual reality on playfulness in children with cerebral palsy. Occupational Therapy International 2004;11:131–144.

22. Harris K, Reid D. The influence of virtual reality play on children's motivation. Canadian Journal of Occupational Therapy 2005;72:21–29.
23. Miller S, Reid D. Doing play: Competency, control, and expression. CyberPsychology & Behavior 2003;6:623–632.
24. Akhutina T, Foreman N, Krichevets A, Matikka L, Narhi V, Pylaeva N, Vahakuopus J. Improving spatial functioning in children with cerebral palsy using computerized and traditional game tasks. Disability and Rehabilitation 2003;25:1361–1371.
25. You SH, Jang S-H, Kim Y-H, Kwon YH, Barrow I, Hallett M. Cortical reorganization induced by virtual reality therapy in a child with hemipharetic cerebral palsy. Developmental Medicine in Child Neurology 2005;47: 628–635.
26. Stansfield S, Dennis C, Suma E. Emotional and performance attributes of a VR game: A study of children. Studies in Health Technology and Informatics 2004;11:515–518.
27. Bryanton C, Bosse J, Brien M, McLean J, McCormick A, Sveistrup H. Feasibility, motivation, and selective motor control: Virtual reality compared to conventional home exercise in children with cerebral palsy. CyberPsychology & Behavior 2006;9:123–128.
28. Holden G, Bearison DJ, Rode DC, Rosenberg G, Fishman M. Evalutation the effects of a virtual environment (STARBRIGHT World) with hospitalized children. Research on Social Work Practice 1999;9:365–382.
29. Sullivan C, Schneider PE, Musselman RJ, Dummett CO Jr, Gardiner D. The effect of virtual reality during dental treatment on child anxiety and behavior. ASDC Journal of Dentistry for Children 2000;67(3):193–196.
30. Hoffman HG, Doctor JN, Patterson DR, Carrougher GJ, Furness TA III. Virtual reality as an adjunctive pain control during burn wound care in adolescent patients. Pain 2000;85:305–309.
31. Das D, Grimmer KA, Sparnon AL. The efficacy of playing a virtual reality game in modulating pain for children with acute burn injuries: A randomized control trial. BMC Pediatrics 2005;5:1–10.
32. Hoffman HG, Patterson DR, Carrougher GJ, Sharer SR. Effectiveness of virtual reality-based pain control with multiple treatments. The Clinical Journal of Pain 2001;17(3): 229–35.
33. Schneider SM, Workman ML. Virtual reality as a distraction intervention for older children receiving chemotherapy. Pediatric Nursing 2000;26:593–597.
34. Steele E, Grimmer K, Thomas B, Mulley B, Fulton I, Hoffman H. Virtual reality as a pediatric pain modulation technique: A case study. CyberPsychology & Behavior 2003;6:633–638.
35. Gershon J, Zimand E, Lemos R, Rothbaum BO, Hodges L. A pilot and feasibility study of virtual reality as a distractor for children with cancer. Journal of the American Academy of Child and Adolescent Psychiatry 2003;43:1243–1249.
36. Gershon J, Zimand E, Lemos R, Rothbaum BO, Hodges L. Use of virtual reality as a distractor for painful procedures in a patience with pediatric cancer: A case study. CyberPsychology & Behavior 2003;6:657–661.
37. Wolitzky K, Fivush R, Zimand E, Hodges L, Rothbaum BO. Effectiveness of virtual reality distraction during a painful medical procedure in pediatric oncology patients. Psychology and Health 2005;20:817–824.
38. Gold JI, Kant A, Kim S, Kant A, Joseph M, Rizzo A. Effectiveness of virtual reality for pediatric pain distraction during IV placement. CyberPsychology & Behavior 2006; 9:207–212.
39. Strickland D, Marcus LM, Mesibov GB, Hogan K. Brief report: two case studies using virtual reality as a learning tool for autistic children. Journal of Autism and Developmental Disorders 1996;26:651–659.
40. Strickland D. Virtual reality for the treatment of autism. Studies in Health Technology and Informatics 1997; 44:81–86.
41. Max ML, Burke JC. Virtual reality for autism communication and education with lessons for medical training simulators. Studies in Health Technology and Informatics 1997; 39:46–53.
42. Parsons S, Mitchell P, Leonard A. The use and understanding of virtual environments by adolescents with autistic spectrum disorders. The Journal of Autism and Developmental Disorders 2004;34:449–466.
43. Parsons S, Mitchell P, Leonard A. Do adolescents with autistic spectrum disorders adhere to social conventions in virtual environments? Autism 2005;9:95–117.
44. Padgett LS, Strickland D, Coles CD. Case study: Using a virtual reality computer game to teach fire safety skills to children diagnosed with fetal alcohol syndrome. Journal of Pediatric Psychology 2006;31:65–70.
45. Cho B-H, Ku J, Jang DP, Kim S, Lee JH, Kim SI. The effect of virtual reality cognitive training for attention enhancement. CyberPsychology & Behavior 2002;5:129–137.
46. Rizzo AA, Buckwalter JG, Humphrey L, van der Zaag C, Bowerly T, Chua C, Neumann U, Kyriakakis C, van Rooyen A, Sisemore D. The virtual clasroom: A virtual reality environment for the assessment and rehabilitation of attention deficits. CyberPsychology & Behavior 2000;3:483–499.
47. Waddington PE, Butler TK, Cobb SV, Moody AD, Comaish IF, Haworth SM, Gregson RM, Ash IM, Brown SM, Eastgate RM, Griffiths GD. Preliminary results from the use of the novel interactive binocular treatment (I-BiT) system in the treatment of straibismic and anisometropic ambyopia. Eye 2006;20:375–378.
48. Sanchez J, Saenz M. Three-dimensional virtual environments for blind children. CyberPsychology & Behavior 2006; 9:200–206.
49. Passig D, Eden S. Improving flexible thinking in deaf and hard of hearing children with virtual reality technology. American Annals of the Deaf 2000;145:286–291.
50. Passig D, Eden S. Virtual reality as a tool for improving spatial rotation among deaf and hard-of-hearing children. CyberPsychology & Behavior 2001;4: 681–686.
51. Cohen J. Statistical power analyses for the behavioral sciences. 2nd ed. Mahwah, NJ: Lawrence Erlbaum Associates; 1988.
52. Cohen J. A power primer. Psychological Bulletin 1992;112:155–159.
53. Cohen J. The earth is round ($p < .05$). American Psychologist 1994;49:997–1003.
54. Sedlmeier P, Gigerenzer G. Do studies of statistical power have an effect on the power of studies? Psychological Bulletin 1989;105:309–316.
55. Wilkinson L. The American Psychological Association Task Force on Statistical Inference. Statistical methods in psychology journals: Guidelines and explanations. American Psychologist 1999;54:594–604.
56. Chelune GJ, Naugle R, Luders H, Awad IA. Prediction of cognitive change as a function of preoperative ability status among temporal lobectomy patients seen at 6-month follow-up. Neurology 1991;41:399–404.
57. Heaton RK, Temkin N, Dikmen S, Avitable N, Taylor MJ, Marcotte TD, Grant I. Detecting change: A comparison of three neuropsychological methods using normal and clinical samples. Archives of Clinical Neuropsychology 2001; 16:75–91.

58. Frerichs RJ, Tuokko HA. A comparison of methods for measuring cognitive change in older adults. Archives of Clinical Neuropsychology 2005;20:321–333.
59. Temkin NR, Heaton RK, Grant I, Dikmen SS. Detecting significant change in neuropsychological test performance: A comparison of four models. Journal of the International Neuropsychological Society 1999;5:357–369.
60. Rizzo AA, Kim G. A SWOT analysis of the field of virtual rehabilitation and therapy. Presence. Teleoperators and Virtual Environments 2005;14:119–146.