Effective game use in neurorehabilitation: user-centered perspectives

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Abstract – Games possess highly favourable attributes to bring to the field of neurorehabilitation in the way of providing motivation and goal-directed exercise tasks. For the use of games to be effectively integrated, however, in the commercial and clinical rehabilitation marketplace, it is necessary that a unified and comprehensive rehabilitation gaming platform be developed following principles of user-centered design. The needed platform must contain compatible modules for the planning and execution of treatment as well as progress assessment, and its development must take into consideration the needs and viewpoints of a number of involved stakeholders and required supporting factors, including: patient, prescriber, therapist, care-provider, family, clinic, as well as supporting research, technology, and policy. A proposed platform and implications are explained and an example prototype rehabilitation platform is provided for discussion.

1 INTRODUCTION

The use of computer games in rehabilitation has increased substantially over the past decade. In particular, games applied in the field of neurorehabilitation are helping to improve the process of motor learning and recovery from incidents of stroke, traumatic brain injury, and other neuromuscular impairment by increasing user motivation during training. A number of devices for upper limb rehabilitation, for example, offer the ability to train specific arm movements at high intensities and longer durations, but maintaining patient interest and preventing abandonment over such durations can be challenging.

Through the combination of engaging games coupled with functionally-targeted training devices, neurorehabilitation training programs offer the potential for improved means of increasing patient motivation as well as increased accessibility and duration of therapy sessions. Games used for this purpose are typically referred to as "serious games". Unlike traditional computer games, whose main purpose is for entertainment, serious games are designed with the intent of being used for education or training. However, while serious games are often thought of as less "entertaining" than games designed for pure recreational play, it is important to note that this is not a prerequisite, and in fact serious games should be designed in such a way as to maximize user motivation for play. In the use of serious games, particularly for neurorehabilitation, the motivational aspect of the game is as important as the learning aspect of the game since without motivation, participation diminishes rapidly.

In the diversely growing field of neurorehabilitation, it is recognized that serious games represent a powerful tool to increase participation and adherence to a multitude of training programs. Although the learning improvement thought to be achieved in the educational setting is still a matter of debate (Pivec, 2009), gaming has become of steadily increasing interest for health care systems worldwide and is on its way to becoming a fundamental component of standard neurorehabilitation practice. Despite this trend, it is clear that for successful integration of gaming within the field of neurorehabilitation, an in-depth user-centered design approach is necessary.

In the current practice of neurorehabilitation, progressive clinics use a multidisciplinary approach where a team of specialists collaborate in assessing and treating the patient in a holistic way, taking into account physical, psychological, emotional, and cognitive dysfunction. It is a complex process involving coordination between medical doctors, physical therapists, occupational therapists, psychologists, patients, and patient family members. As a result, for a given therapy to be successfully prescribed, executed, and followed, it must satisfy the needs of all users involved in the process. In this case, users include all relevant stakeholders: from insurance to medical to therapeutic to patient user. In deploying a technology inside such an integrated system, it would be a grave mistake to consider the patient as the only end user, and would likely compromise the success of the technology.

The potential impact of a user-centered approach is especially true for the area of motor rehabilitation, where there is a growing need for methods to treat increasingly larger patient populations, in part as a result of an increased aging population, and therefore increased absolute incidence of stroke. At the same time, therapists have expressed a need for improved means of quantitative assessment. Both of these aspects are currently being addressed through advances in rehabilitation robotics. However, while the devices themselves provide increased treatment availability, intensity of therapy, repeatability, and quantitative measures, they have yet to be integrated with a comprehensive platform for planning, executing, and assessing therapy session. This lack represents a current and significant gap in rehabilitation technology, and it is believed that without this comprehensive platform, the use of serious games for motivational and educational purposes in neurorehabilitation will remain limited.

In this chapter, the topics of a comprehensive game-based rehabilitation platform will be addressed. The chapter sections are laid out in the following order: *Background*, *User-Centered Neurorehabilitation*, *Discussion and Recommendations*, and *Future Research Direction*. The *Background* section presents some pertinent information related to the rehabilitation process and the use of games and robotics within the field of rehabilitation; the section titled *User-Centered Neurorehabilitation* will illustrate the users of rehabilitation systems and necessary components of a comprehensive software platform, and provides an example prototype rehabilitation platform following an iterative development process; and the *Discussion and Recommendations* section presents a general discussion of game design and use in rehabilitation, including motivational aspects from patient and therapist perspectives. Topics addressed in the *Future Research Direction* section include a brief summary of the suggested directional approach to future rehabilitation gaming, game development for the purpose of rehabilitation, therapy assistance, and devices for the marketplace.

2 BACKGROUND

As a leading cause of long-term disability and a significant and growing burden on global health care costs, stroke deficits will be the primary focus in the discussion and explanation of the rehabilitation process. The prevalence, mortality, impairments, and patterns of recovery are well known, but have yet to be adequately addressed. Worldwide statistics by the World Health Organization state that 15 million people suffer stroke worldwide every year. Of these, 5 million die and another 5 million remain permanently disabled. Averages in Europe show approximately 650,000 stroke deaths every year, (World Health Report 2007). Stroke is the second leading cause of death above the age of 60, and the fifth leading cause of death in persons aged 15 to 59. Approximately one-third of the persons surviving a stroke are left with severe disabilities

(Abrams and Berkow, 1997). Stroke is thus a major health problem in most parts of the world, with the total cost of stroke care expected to rise 30 percent by the year 2023 (Westcott, 2000).

2.1 The rehabilitation process

In general, the deficits caused by a stroke may lead to persistent or permanent functional limitations including paralysis, abnormal control of movements, loss of coordination, loss of range of motion, abnormal posture, spasticity, memory deficits, spatial neglect, aphasia, and dyspraxia, among others. The limitations severely impact a person’s ability to perform activities of dailiy living (ADLs: dressing, walking, eating, etc.), intsturmental ADLs (IADLs: shopping, cooking, laundering, pursuing hobbies, etc.) as well as their capacity for independent living and economic self-sufficiency. Motor impairment following stroke generally begins with *hemiplegia*, a complete paralysis of one side of the body, and is often followed by *hemiparesis*, a severe physical weakness in the same side.

Hemiparetic stroke is accompanied by abnormalities of muscle tone called spasticity, muscle weakness, and disturbances of muscular coordination (abnormal muscle and torque synergies) (Sukal, Ellis, & Dewald, 2007). About 80% of patients are affected by motor impairment, and about 65% to 85% of persons with a stroke show an initial deficit in the function of the upper extremities (Feys et al. 1998; Broeks et al. 1999). For those patients, basic movements might have to be relearned in order to retrieve independence.

Recovery is possible, but most patients will have permanent limitations or impairments. Especially in the first four weeks (Krakauer, 2006), the damaged brain region can recover spontaneously, and another brain region may compensate for the lost function. In true recovery, the same motor units used before the injury are recruited through functional reorganisation in the undamaged motor cortex or through recruitment of undamaged redundant cortico-cortical connections (Jacobs & Donoghue, 1991). New synaptic connections may also be generated in the brain due to the neural plasticity of the central nervous system. (Parasuraman & Rizzo, 2007). This neural plasticity enables the brain to make changes in the organisation and the numbers of connections among neurons, a feature that does not disappear with age (Shumway-Cook & Woollacott, 2007). Different stages can be observed during the recovery after stroke, and patients can be classified as being in a subacute, acute or chronic phase. The different restorative processes can occur together in the different stages (Figure 1). Recovery of impairments and functional independence is most rapid in the first days and few weeks post stroke. Traditionally, stroke rehabilitation has been emphasized during the first 3 months after onset, in accordance with the natural history studies of stroke recovery that show a plateau after 3 months. But plasticity is a process that can last for several months, and functional improvements are possible even in the chronic phase. In any case, the recovery is based on learning processes and thus requires an active participation of the patient in his rehabilitation program.

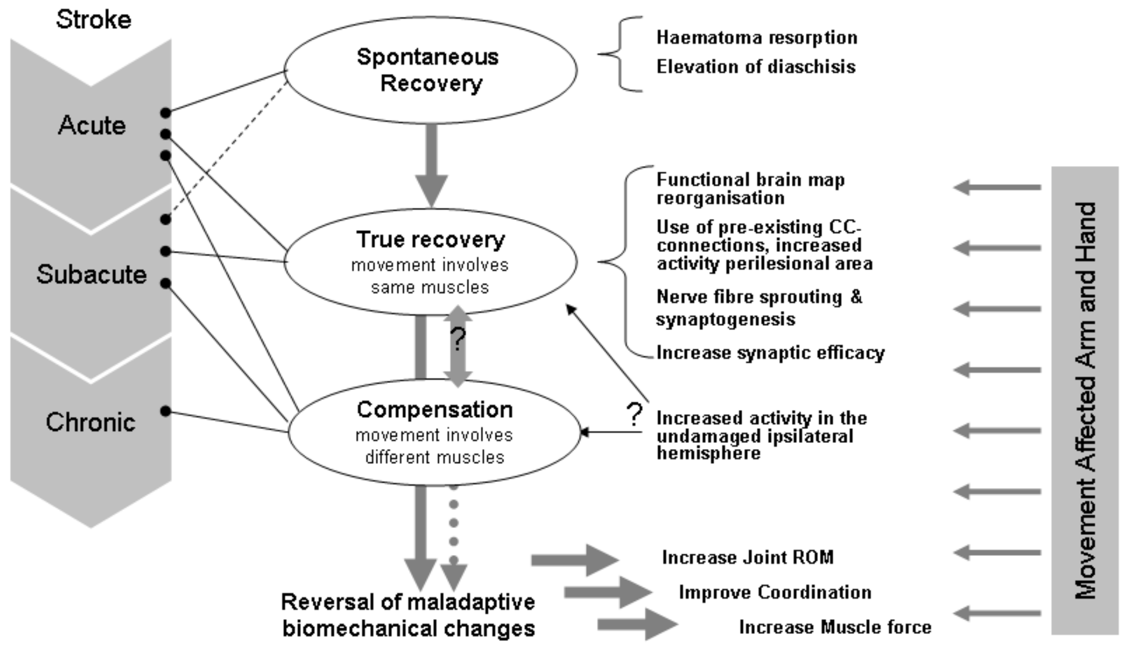

Figure 1. Declarative model of motor recovery, reproduced with permission from Timmermans et al. 2009.

The rehabilitation program starts early after an initial phase in the hospital, in which the aim is to stabilise the patient's condition, control blood pressure and prevent complications. Such a rehabilitation program includes interventions provided by several specialists: physiotherapists, occupational therapists, Speech therapists, Neuropsychologists, etc., depending on the needs of each patient.

There are several ways in which therapists can treat stroke patients. Conventional exercise programs may follow the approaches proposed by Bobath (1990), Brunnstrom (1970), or Carr and Shepherd (Carr & Shepherd, 1998), as well as the Proprioceptive Neuromuscular Facilitation (PNF) program (Knott and Voss, 1957), although the neurophysiological background of all these concepts is still poorly understood. Some of those methods, like the Bobath approach, emphasizes the reduction of the enhanced muscle tone before active movements when others, like the approach proposed by Carr and Shepherd, focus on performing a functional task, regardless of the motor strategies used.

The neuro-developmental approach according to the Bobath theory is probably the most widely accepted theory even if its superiority has not yet been shown. Many authors describe that there is insufficient evidence to prove that one treatment is more effective than any other (Sackley and Lincoln, 1996), and recent reviews of upper limb post-stroke physiotherapy concluded that the best therapy has not yet been found (Coote and Stokes, 2001). Thus, the rehabilitation techniques may vary from one therapist to another and from hospital to hospital. (Loureiro et al., 2003). Rehabilitation programs are partially based on theories but also heavily rely on the therapists training and past experience. Classic rehabilitation training corresponds to non-standardized physiotherapy and occupational therapy rehabilitation care. It is based (in varying proportions according to different authors) on various known rehabilitation techniques (Bobath, proximal or distal functional electrical stimulation (FES), bilateral exercises, compensatory activities with healthy upper limb, etc...). More than using one theory, therapists often use guidelines from several theories in their rehabilitation programs. Such guidelines include recommendations from different studies to maximise the chance of recovery for a patient.

For example, the ability to practice is very important as it has been shown in the rehabilitation literature that early practice (Chae et al, 1998; Johansson, 2000) intensive (Langhorne et al, 1996; Kwakkel et al, 1999) of active functional tasks (Dean and Mackey 1992) in an enriched environment (Ohlsson & Johansson, 1995) leads to more positive outcomes for upper limb rehabilitation, by modifying neural reorganization of the cerebral cortex (Thompson et al, 1996; Traversa et al, 1997).

There are still many gaps and shortcomings in the evidence base for interventions to promote motor recovery after stroke. To a large extent, individual clinical decisions will continue to rely on the knowledge and judgement of the individual therapists. At the present, the evidence base for clinical practice can provide only broad indicative guidance. The main general recommendations seem to be that the alleviation of motor impairment and restoration of motor function should (as much as possible) focus on high-intensity, repetitive task-specific practice with feedback on performance.

The current practice of rehabilitation interventions generally take place within the first six months after stroke onset. However, many stroke patients have persistent disability at one year after stroke, typically because frequency and duration of practice are limited and decrease once the patient has left the hospital (Aziz et al., 2009). By providing opportunities to practice intensive, repetitive, and meaningful tasks without the need for constant therapist supervision, robot-aided therapy may have solutions to offer stroke patients.

2.2 Robot-aided therapy

For patients undergoing rehabilitation, training duration is often shorter than optimal because of the costs associated with rehabilitation sessions with therapists. For therapists, rehabilitation practice is labor-intensive, and training duration and intensity may be limited by personnel shortage or by the fatigue of the therapist that generally has to lift the patient limbs during rehabilitation exercises. This human involvement intrinsically lacks repeatability and objective measurability in following the patient's improvements. When using a robotic device, training regimes can be programmed, and therapists have the opportunity to offer their patient more repetitive movement training, or massed practice (Johnson MJ, 2006). At the same time, available sensors of the robotic device may provide the therapist objective measures about patient motor capabilities, which can help to follow progress or revise treatments.

In order for the patient to be more independent from therapist availability, more and more systems are focusing on tele-rehabilitation or remote monitoring for the patient. Such tele-rehabilitation can be very beneficial for patients that have been discharged from the rehabilitation centre but who still require practice and training in order to retrieve or improve their motor capabilities. The majority of commercial systems, however, remain large, complex, and unaffordable for widespread use.

Robotic devices for lower limb rehabilitation allow the simulation of the phase of gait and a better control of key gait parameters such as stride length and walking speed. Examples include the GT I servo-controlled gait trainer (Uhlenbrock et al.1997; Hesse et al., 2000) and the Lokomat system produced by Hocoma AG (Hidler et al., 2005; www.hocoma.com).

Devices for the upper limbs generally support the weight of the arm of the patient. Supporting the arm has been shown to facilitate movements for stroke patient with motor deficits (Sukal, Ellis, Dewald, 2007) and this technique is often used in clinics, for example in providing pulley-therapy. When compared to classical pulley therapy, robotic devices for the upper extremities have the advantage of several modalities for facilitating the voluntary movement according to the motor command. Most of them are interactive and include actuators and control strategies to react to patient actions. This allows the system to be operated in passive, active, assistive, or resistive modes, adjusted for each session and automated.

Some of the more well-known devices for upper-limb rehabilitation include the Bi-Manu Track (Hesse et al 2005), MIT-MANUS (Krebs et al., 2000), and Armeo (www.hocoma.com). The Bi-Manu Track is a robot designed to rehabilitate wrist flexion/extension and forearm pronation/supination. The system allows passive movement of both arms, active movement of both arms against resistance, and passive movement of the paretic arm to mirror movement of the non-paretic arm. The MIT-MANUS, is a 2 degree-of-freedom device that has received the most publicity and clinical testing. It assists shoulder and elbow movements by moving the patient’s hand in the horizontal plane. The MIT-MANUS, commercialized as the InMotion2 (Interactive Motion Technologies, Inc., Boston, MA), is supplemented by the InMotion3 and InMotion5 robots for wrist and grip rehabilitation. The Armeo line of upper limb products commercialized by Hocoma (Switzerland) offer both active and passive full-arm exoskeleton devices for arm rehabilitation, and also an overhead sling support system. Some devices support only partial arm training in 2D, such as the Bi-Manu Track and MIT-MANUS; while other devices support 3D movement involving only the shoulder and elbow, such as T-WREX (Reinkensmeyer 2007), Gentle/s system (Amirabdollahian et al., 2007), MIME (Masiero et al., 2007), and ARMin I; while a third group allows supported arm movements in a 3-dimentional space involving the shoulder, elbow and wrist, include the ARMIn II (Nef et al., 2006), and the CADEN-7 (Rosen & Perry, 2007).

In many of the devices, the patient grasps a handle on the end-effector of the robotic arm. This may be of concern when trying to work in a task-oriented way, where contact with objects is important for sensorimotor integration. The Activities of Daily Living Exercise Robot (ADLER) provides one of the few robotic environments in which active assistance is provided to patients as they reach toward real, functional objects (e.g., coffee mug, food item) (Wisneski & Johnson, 2007). Devices also exist to train directly the wrist and hand, such as the Rutgers Master 2 (Boian et al. 2002), Hand Mentor (Kinetic Muscles, Inc., Tempe, AZ), or HandTutor (MediTouch, Ltd., Netanya, Isreal). For more details about existing robotic devices, the reader is encouraged to read recently published reviews by Brewer et al. (2007) and Timmermans (2009).

Novel robotic therapies are rehabilitating patients at least as well, if not better, than conventional therapeutic methods. One study conducted by Lum et al. in 2002 compared the effects of robot-assisted movement training with conventional techniques for rehabilitation of upper-limb motor function after stroke. The robot group had larger improvements in the proximal movement portion of the Fugl-Meyer test after one month of treatment and also after two months of treatment. The robot group had larger gains in strength and larger increases in reach extent after two months of treatment. At the six-month follow-up, the groups no longer differed in terms of the Fugl-Meyer test; however, the robot group had larger improvements in the Functional Independence Measure (FIM).

While the use of such devices to address neuromuscular rehabilitative goals represents a technological advance in medical care, the large number of systems being developed and the varying levels of clinical study of the devices make it difficult to follow and interpret the results in this new field. The positive effect observed with robotic devices may be due to an increased motivation for the patient to perform the therapy. Regardless, it is understood that motivation is highest when the systems incorporate interactive games in performing the rehabilitation tasks.

2.3 Rationale for Games in Rehabilitation

Roger Caillois defines in his book "Les jeux et les hommes", "Games and Men" (Caillois, 1991), a game as an activity that has the following characteristics:

- fun: the activity is chosen for its light-hearted character
- separate: it is circumscribed in time and place
- uncertain: the outcome of the activity is unforeseeable
- non-productive: participation does not accomplish anything useful
- governed by rules: the activity has rules that are different from everyday life
- fictitious: it is accompanied by the awareness of a different reality

In the growing field of neuro-rehabilitation, it is recognized that computer games represent powerful tools to increase motivation and active participation during training. Bach-y-Rita and colleagues suggest that motor impairment reduction can be induced by encouraging the stroke survivors to "lose themselves" in a fun task (Bach-y-Rita 2001), and this is where games can play a role. While engaged in gameplay, the patient experiences the difficulties of the training as challenges to gradually overcome the subsequent levels of the game. While exercising in a game environment, training specific skills and performing task oriented movements is not perceived by the user as a repetitive rehabilitation exercise, but as a necessary step in accomplishing the game's task. The instant visual feedback of in-game movements promotes intentional movement by the patient. Moreover, engaging games facilitate active learning and motivate users in spending much greater amounts of time practicing. Games such as these, used for purposes other than pure entertainment, are often referred to as "serious games" (www.seriousgames.org), and are usually classified as either games for learning, games for health, or games for policy and social change.

Another approach to learning and motivation can be found through virtual reality (VR). Over the past decade, VR and gaming has been used and tested for both assessment and rehabilitation of neurological conditions. Interactive VR-games require a person to perform movements that could be of potential therapeutic benefit, as reflected in different studies carried out toward improving motor deficits in stroke (Cameirão et al., 2008). To incorporate more motivating and interactive patient-device interfaces, different task-oriented scenarios have been implemented using VR or related technologies. The interfaces commonly use high- or low-immersion methods and are implemented both with and without robot aided therapy (Brewer et al., 2007). High immersion methods typically utilize head-mounted displays in presenting the virtual environment to users. One example of a high-immersion system can be found at the University of Ulster where groundbreaking work using augmented reality gaming applied to rehabilitation of the upper extremities is taking place (Burke, et al. 2009). Preliminary results have shown promise regarding patient interest, motivation, and general enjoyment of the therapy sessions.

By allowing the user to manipulate virtual objects in environments similar to the "real world", virtual and augmented reality games offers a great opportunity to do task-oriented training. In addition, virtual environments allow for the control of many parameters such as stimulus timing, appearance, auditory properties, etc. One important advantage of using VR and gaming for motor rehabilitation is that the difficulty of the task can be controlled, thus, the difficulty can be adapted to the patient's capabilities, especially with respect to motor skills. VR and games allow users to experience situations that are sometimes impossible in the real world for reasons of safety, cost, time, etc. This allows for training ADL tasks that are essential for patient independence, such as cooking or driving. A patient can thus train with meaningful, task-oriented exercises, in a safe environment. Real-time feedback provided may vary from an approximate target on a screen to total immersion in an interactive virtual environment, and it is believed that augmented feedback may contribute to enhanced motor learning.

Although video games have long been considered activities for youth, the development and generalization of interactive systems have lead to wider categories and ages of game players, making them more applicable than ever for incorporation into rehabilitation regimes. Further, computerized training can provide the therapist with quantitative results of the patient's performance, which can be of help when designing a rehabilitation protocol or when monitoring the improvements of a patient. Along these lines, there are a number of game characteristics that make them well suited for use in rehabilitation gaming. A list of essential components of effective stroke rehabilitation therapy (adapted from Timmermans et al., 2009) are listed in Table 1.

Table 1. Criteria for effective stroke rehabilitation therapy.

Adaptability to motor skill level	Achieving an appropriate balance between task challenge and patient ability is a crucial factor in maintaining motivation while avoiding the extremes of frustration and boredom.
Meaningful tasks	Tasks should be closely related to functional abilities that the therapist wants the patient to regain through the rehabilitation process.
Appropriate feedback	Feedback provided to the user should be intuitively understood. It should be presented appropriately in terms of auditory and visual cues regarding progression and completion of tasks during training and provide cues that reward effort as well as improvement.
Therapy appropriate range of motion	The task range of motion should take into account the physiological ranges of motions needed to perform desired functional tasks, but should be well matched with the patient's stage and level of stability.
Focus diverted from exercise	Each task should be designed such that the patient focuses on achieving a goal rather than performing the exercise.
Intentional movement	While achieving a range of motion is beneficial, more important is that motions are done intentionally by the patient.
Quantitative measures	The ability to measure quantitatively the patient progress is not only a motivational factor for the patient, but a necessary tool for the therapist to effectively monitor and revise training protocol.

2.4 Existing Gaming in neurorehabilitation

Since the advent of the so-called "exergames", in 1980s, there have been many attempts to create low-cost solutions to rehabilitation, exploring the rehabilitation potential of commonly available computer games. One of the early games in the exergames category was Konami's Dance Dance Revolution (www.konami.com), a dance pad that is pressed following rhythm patterns. By adding the engaging elements of video games to physical activities, or vice versa, physical exercise becomes more attractive. Recently, the Nintendo Wii has become the mainstream console considered to hold the most potential for physical prevention or rehabilitation purposes, as a result of its mode of interaction based on a gesture tracking system. The studies that have focused on the possible clinical use of the Wii are numerous. Sugarman et al. (2009) performed a pilot study to test the potential of a Wii Fit gaming system in a clinical setting for treatment of balance problems in elder adults. The results seem very promising and promote the adoption of the Wii Fit system for rehabilitation purposes.

Over recent decades, numerous approaches have been employed to introduce games to the rehabilitation environment, ranging from the use of mainstream consoles and commercial games, to combining robotic devices with adapted existing games, to creating new and specific rehabilitation games. With the development of new ways of interacting, mainstream consoles and commercial pc-based games have become more and more suitable for rehabilitation. Recent studies have employed different types of commercial devices to train stroke patients. For example, in 2007, Flynn et al. employed the Playstation 2 to train post-stroke patients. Other systems like the Playstation EyeToy or the VividGroup's Gesture Xtrem (GX) have been translated to the rehabilitation domain because of their webcam interface. Thanks to the webcam, users can view themselves playing instead of an avatar, and without having to wear specific accessories. These systems have been tested with some success in stroke patients (Rand et al., 2004; Yavuzer et al., 2008) and in children with cerebral palsy (Jannink et al., 2008), as an alternative approach in training upper limbs. Both the groups tested found the systems engaging and motivating.

In 2009, Brosnan et al. investigated the use of the Wii sport games with acute stroke patients and found significant improvements in upper extremity functioning of two stroke patients. Brown et al (2009) recently presented a gaming system for the Wii in which a low cost rehabilitation glove is used to track fine motor skill via the ability of the infrared receiver on Nintendo's Wiimote to pickup the signal from four diodes placed at the patient's fingertips.

As for the majority of commercially available game systems, the main limitation is the lack of specificity in terms of software, hardware and performance metrics. Since these systems have not been intentionally designed for impaired individuals, there is little or no control over the various parameters of the game, making them unsuitable for clinical applications. In a first attempt to produce more enjoyable and motivational games for rehabilitation, Cogan et al. (1977) modified the commercial game Pong into a task interface played with a joystick for the rehabilitation of hemiparetic patients. Continuing this idea, Ellsworth and colleagues created the TheraJoy (Johnson & Winters, 2004), a telerehabilitation environment that uses a modified force-feedback joystick to complete games and tracking tasks created with the custom software, UniTherapy (Feng & Winters, n.d.), a computer-assisted neurorehabilitation tool for tele-assessment and telerehabilitation of arm function.

Reinkensmeyer et al. (2001) introduce a different approach with their web-based force feedback telerehabilitator called "Java Therapy". Java Therapy consists of a web site with a library of evaluation and therapy activities that can be performed with a commercial force feedback joystick, which can physically assist or resist movement as the user performs therapy. It also allows for some level of quantitative feedback of movement performance, allowing users and their caregivers to assess rehabilitation progress via the web. Java Therapy is currently being extended using the T-WREX arm orthosis, the research-oriented precursor to the Armeo Spring.

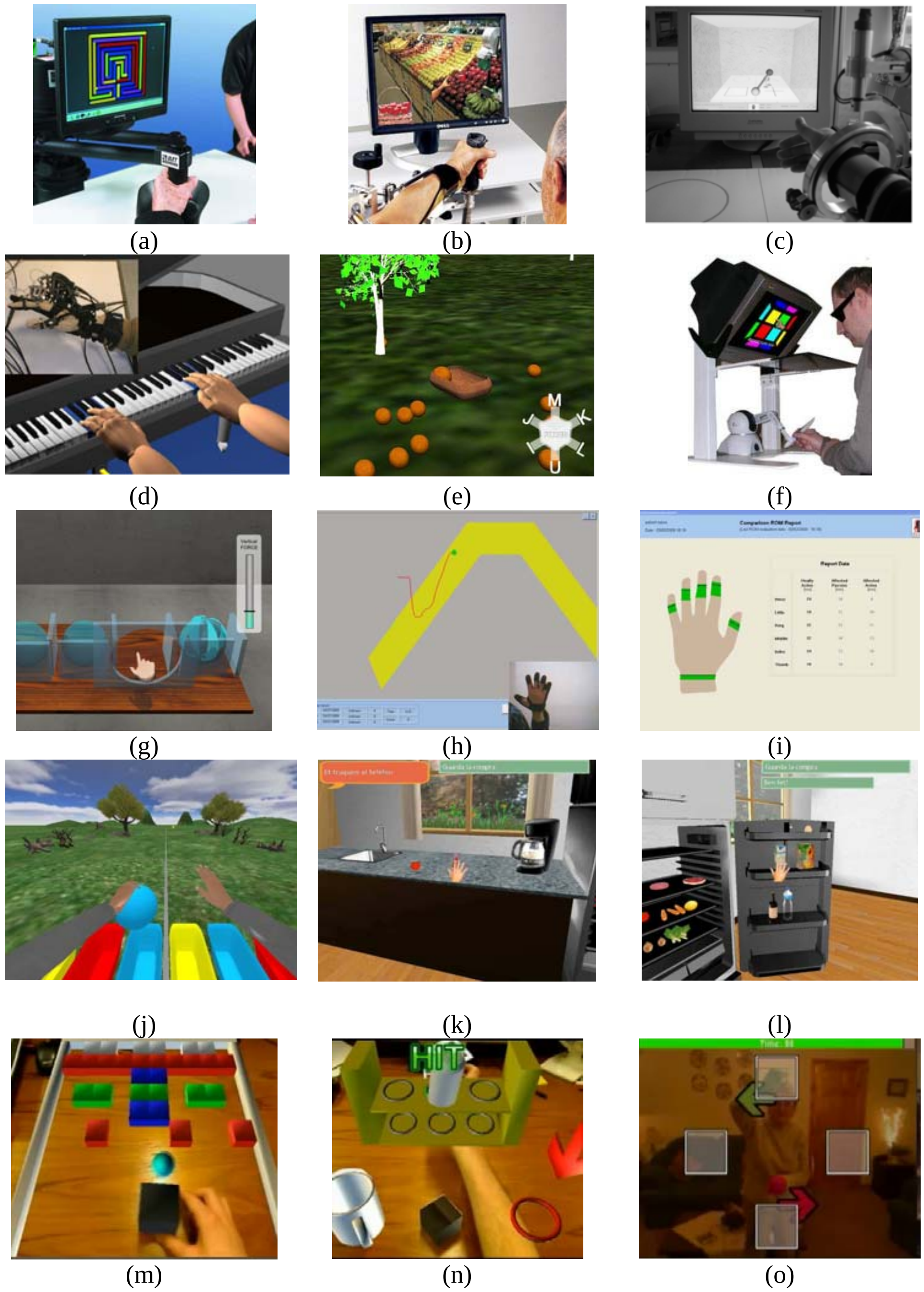

Figure 2. Some existing rehabilitation games and feedback displays used for motor and cognitive neurorehabilitation. Contributions from Interactive Motion Technologies (a), Hocoma (b), University of Reading (c), New Jersey Institute of Technolgoy (d), University of Ulster (e) and (m)-(o), Curictus (f), Fatronik-Tecnalia (g), MediTouch (h) and (i), University of Pomeu Fabra (j), and the Guttmann Institute (k) and (l).

Some examples of rehabilitation gaming systems are illustrated in Figure 2, ranging from clinically-oriented arm rehabilitation (Fig. 2 (a)-(c)), general motor and cognitive training for the hands and fingers (Fig. 2 (d)-(f)), home-based rehabilitation of the arm and hand (Fig. 2 (g)-(i)), and combined arm/hand training using virtual reality (Fig. 2 (j)-(l)) and augmented reality (Fig. 2 (m)-(o)) feedback environments. Clinical rehabilitation games shown in the figure include games used with the InMotion2 and Armeo Spring (commercial devices), and the Gentle/s (University of Reading) systems for arm rehabilitation following stroke. Multi-sensory feedback combining visual, auditory, and haptic stimuli also span the academic and commercial sectors offering combined motor and cognitive rehabilitation approaches. Examples include a virtual reality piano trainer from the New Jersey Institute of Technolgoy (Adamovich et al, 2007), catching task from the University of Southern California (McNeill et al. 2007), and musical game from Curictus AB (www.curictus.com).

Various game tasks and environments targeting home-use and tele-rehabilitation of arm and hand function are also under development, including an object reaching and obstacle avoidance task from Fatronik-Tecnalia (San Sebastian, Spain), and a configurable hand/finger tracking exercise with summary reporting of performance from MediTouch Ltd (Netanya, Isreal). In the case of he finger tracking task, various individual hand or finger joints can be assessed or trained using the same task interface. While this makes for a highly versatile task interface, the motivational and engaging aspects of the task are clearly lower than those of more complex object-oriented VR training environments like those developed at the University of Pompeu Fabra (Barcelona, Spain) for motor rehabilitation and at the Guttmann Institute (Barcelona, Spain) for cognitive training.

Augmented reality environments like those under research at the University of Ulster (Coleraine, Ireland) have only recently been explored for their potential value in rehabilitation training. Further comparative studies are needed to quantify the functional gains using these methods of feedback over other methods, but from a motivational standpoint augmented reality has much to offer the game experience and the ease of identifying with the task environment. Regardless of the choice of environment, a rehabilitation system should be ergonomic and comfortable. The therapy should be enjoyable and the patient should feel completely safe using the system. To meet such diverse criteria, a user-centered design process should be followed.

2.5 User-Centered Design

User Centered Design (UCD) is a broad term for a set of methods, all based on the consideration of user's particular limitations, interests, and needs. There is a long history of UCD in game design (Pagulayan et al., 2002). UCD is particularly important for game based rehabilitation in that it addresses the need for assessing the patients' capabilities and impairments as a necessary and preliminary stage in designing rehabilitation systems. In discussing the user-centered design of game-based robot-aided neurorehabilitation systems, it must be kept in mind that the system in discussion is comprised of mechanical robotic parts, computer interfaces, and functionality.

It is commonly accepted that one of the main reasons for failure in medical technology development is the lack of key user involvement in the development process and the small amount of time invested in usability testing with true end users. Game based rehabilitation, like more traditional assistive technology, needs to be tightly fit to the user's needs and abilities to reduce current abandonment rates of complex assistive technology which may be as high as 70% (Reimer-Reiss 2000). Post stroke individuals often suffer not only from motor impairment, but also from associated cognitive impairments, including sensory deficits and pain (Carr and Shepherd, 1998). This often results in an inability to use the rehabilitation system or carry out the training. To reduce and prevent technology abandonment, a user-centered interactive design approach (Rosson and Carroll 2001) should be employed when designing systems for disabled individuals, especially in the case that the users are also elderly.

Very often medical devices are designed for a ‘typical user`: a young, fit, male user whose abilities stay the same over the time of use and are assumed to be broadly similar for every category of users. This can result in difficulties in use when persons with different needs and abilities attempt to use the system. A large number of movement control, perceptual, and cognitive factors are involved in the interaction with technology.

A sample of key users should be involved in the early stages, such as concept and idea generation, as well as in the design development and prototype testing of the device, and finally in the user testing phase. To design a system to aid task performance, it is important to enumerate the tasks expected and this must be based on stakeholder analysis (Rosson and Carroll, 2001) to determine all the different functions that are needed. In the case of robot-based game rehabilitation systems, the stakeholders will be, of course, the end users but also include the professionals who will setup the stem and (perhaps the same) professionals that use the performance logs to asses the progress of the rehabilitation, and may perform modifications of the therapeutic actions to suit the changed needs of the end user. Further, the system may need to provide facilities to deeply customize its interactions and functionalities to each specific user; this is often necessary in a population where there is a high degree of comorbidity such that each use becomes a ‘universe of one’ (Carmien 2007).

An effective way of pulling together user needs, context and the details of system usage is in the task based design methodology. In task analysis the designer gathers information about the user’s perspective, decomposing the tasks the user habitually performs interacting with a certain product or system into single steps (Lewis and Rieman 1993). Since older users can suffer a limited cognitive capacity or a deteriorated processing activity for visual and auditory information, as well as a reduced ability in memory, attention or psychomotor skills (Hawthorn, 2000; Wattenbergh, 2004; Fisk et al., 2009). Task analysis and usability testing with the end-users can be an effective way to cope with these age induced changes.

3 USER-CENTERED NEUROREHABILITATION

Effectively addressing the current and future needs of neurorehabilitation requires an in-depth look at trends in populations, pathologies, reported effectiveness from RCT outcomes, current methodologies followed in clinical practice, as well as extensive collections of user profile and preference data from media such as user questionnaires and focus group surveys. A key aspect in this approach is the correct identification and representation of the ‘user’ of the system. Answering the question, “*Who are the end-users of the system and what specifically do they need?*” is a challenge that requires a user-centered design process.

3.1 End-users and System Specifications

Before the design specifications of a system can be determined, the modes of operation of the system must be properly identified as well as the users of the system in each mode. In the case of neurorehabilitation, the key end-users are often identified as the patients receiving treatment. It can be legitimately argued, however, that the most crucial end-user is actually the clinical personnel who will prescribe, monitor, and revise the treatment process. Specifically, it has been previously identified that one of the key barriers to the successful integration of neurorehabilitation technologies for use in telerehabilitation is in adequately performing data-reduction to produce clinically-relevant outputs for the therapist (Winters & Wang, 2003). Furthermore, a second important barrier is the general acceptance of rehabilitation technologies by therapists in terms of trusting the measurement accuracy of the system and in their willingness to utilize these measurements as the basis for making alterations to patient training programs

(Theodores & Russell, 2008), whether locally for patients seen within a rehabilitation clinic or remotely for patient performing therapy sessions at home. On the other hand, Theodoros and Russell also refer to a growing shift in the positive attitudes of clinicians toward the inclusion of such rehabilitation technologies.

The need to consider the therapist early in the design process is clear due to their inseparable involvement in the rehabilitation process. Once these barriers have been adequately addressed, there will no doubt be a focal shift toward the needs of the patient side, including patient care-providers and those who might otherwise assist, collaborate, or even compete with the patient during training sessions. As a result, the end users of the system should include the following:

- The patient
- The patient's therapy staff (physical, occupational, speech, etc,)
- The patient's spouse or personal care-provider
- The patient's family and friends

The composition of stakeholders of the system changes over the course of the rehabilitation process, from the stages of acute, to subacute, to chronic, and depending on whether the patient fits the criteria to receive inpatient or outpatient rehabilitation. The operational mode of the system, as well, plays a role in defining the needs of the system regarding, for example, the supporting technologies that are needed in order to facilitate the preferred system implementation. Given the growing stroke population and related growth in demands on the healthcare system, the operational model needs to migrate from the classical one-on-one care towards more parallel and multi-user care models that can be implemented either in a distributed way within a single care center or remotely over a broadband connection serving a greater local, or even potentially international, community (Theodores & Russell, 2008). Other critical factors to consider are the mechanism for implementation at the governmental and medical systemic policy levels. Mechanisms for paying for the technology through medical benefits and reimbursements are long-term changes that are essential for fully-integrated solutions with current medical practice. The following, therefore, are additional criteria to consider when assessing the needs of the system:

- Hospital and rehabilitation clinic general management
- Supporting technologies
- Supporting policies for technology inclusion and insurance coverage

Considering the above listed end users of the system and other supporting factors, the list of system needs can be identified as illustrated in Table 2.

Table 2. Core needs and criteria specification for a comprehensive neurorehabilitation gaming platform. The User/Stakeholder category includes perspectives from supporting (Supp.) research, technology, and policy.

Needs	Criteria	Patient	Prescriber	Therapist	Care-Provider	Family/Friends	Hospital/Clinic	Supp. Research	Supp. Technology	Supp. Policy	Description
Usability	Personalizable	X		X	X						Ability to personalize aspects of therapeutic setting (theme, background, font size, etc.) by or for the patient
	Ease of use	X		X	X						Hardware and software should be ergonomic and easy to setup and use
	Intuitive interface	X		X	X	X					Interfaces to prescribe and accept therapy session should be intuitively understood (layout, icons, color schemes, tabs, etc.)
	Default modes/settings	X		X							Predefined recommended training modes for general use with patients of varying levels and types of impairment
	Modifiable treatment plans			X							Default training modes should be modifiable for indvidual patient use in terms of training difficulty, duration, game selection, etc.
	Efficient setup/reporting			X							Prescribing treatment and receiving reports of summary statistics should always be available as default (or recommended) formats allowing the therapist the quickest access to needed functionality without requiring prior investment of time
	Clinically-oriented setup/reporting			X			X				Default reports of progress and statistical data summaries should include parameters and therapeutic aspects that are currently used to fascilitate a smooth and intuitive transition from current practice to more device-based quantitative assessment and planning
Functionality	Appropriate challenge	X									achieve balance between task challenge and patient ability to maximize motivation while avoiding frustration or boredom
	Appropriate feedback	X									Intuitive and immediate feedback of intentional movements toward or against achieving task goals
	Motivational Feedback	X									Feedback on task progress and completion (visual, auidio, and haptic) that reward effort as well as improvement
	Multi-player support	X				X					Ability to compete or play collaboratively with other patients, family, or friends (local or remote)
	Quantitative and repeatable measures		X	X				X			Reliable quanititative measures are necessary for the therapist to make appropriate remote assessments and training modifications
	Modifiable reporting			X							Aspects of report layouts should be configurable such as format, parameters displayed, statistical methods, summary informational display (graphical, numeric, etc.)
	Maintainence/updates			X	X		X				Regular maintainence and system updates should be infrequently needed, but available when needed
	Progressive upgrades	X		X	X						Routine expansions and upgrades to hardware and software such as new games, new control devices, and new add-on modules for increased system functionality
	Bandwidth								X		Transmission of encrypted patient data: trajectories; assessment parameters; results summaries; session videos; live video conferencing; etc.
Safety	Personal data protection	X		X			X		X		Personal data must be encripted in a secure way to be transmitted and stored while maintaining user privacy
	Safety of operation	X		X			X			X	Safety of operation for the patient and therapist (e.g., system equiped with operational limits, emergency shutoffs and safeguaurs where necessary). Also for the Medical Center from a liability standpoint
	Safe data storage			X					X	X	Data must be securely stored in a way that complies with existing policies regarding available lifetime of stored medical data
Acceptability	Available	X		X							On-demand availability of use of the system to therapist for planning and assessment and to the individual for training execution
	Affordable	X		X			X		X	X	Overall affordability of the technology to all users involved: patient device and telerehab services; therapist presciption, monitoring, and assessment time; cost to insurer for coverage or reimbursement; etc.
	Conventional measures comparisons		X					X			Studies that show the correlation between new and conventional tests for quantitative evaluation of patient functional level and improvement
	Efficacy of treatment	X	X					X			Pilot and RCT subject studies of new neuro-rehabiltation devices documenting functional improvement using conventional measurement tests
	Coverage and Reimbursements		X							X	Coverage for rental or purchase of neurorehabilitation tools for assessment and training incorporated into social and private healthcare plans
	Favorable systemic cost-benifit relationship		X				X	X			General view that telerehabilitation technologies will increase quality and quantity of care at equal or lesser cost. High dependence on development of truly low-cost (affordable) input controllers (rehabilitaiton devices) for clinical- and home-based therapy
	Medical endorsements	X	X	X			X			X	Following sufficient supporting research, further publicity from notable medical professionals endorsing the benefits offered by neuro-rehabilitation gaming platforms to help stimulate policy change
	Relative Stake Share	15	6	17	5	2	7	4	4	5	

Grouped according to need type, the system requirement fall under the four categories of Usability, Functionality, Safety, and Acceptability. The Usability and Functionality are primarily of concern to the patient and therapist as the principal end-users of the system. The stakeholders of Safety and Acceptance of the technology are more varied as seen in the table. The requirements of highest interest in terms of applicability across the spectrum of stakeholders are system affordability and endorsements, followed by personal data protection and safety of operation. Ultimate system affordability addresses affordability of services at each level of users from government subsidization and insurers, to hospitals and rehabilitation clinic, down to the level of the patient at home. A major advantage of a comprehensive rehabilitation platform is the potential to extend the availability of rehabilitation care. On one hand, the system can offer increased efficiency to rehabilitation regimes in the same way that powerful project management software packages improve efficiency in the corporate environment. But even further, such systems offer the capacity to reduce therapist overhead time to enable efficient and effective parallel monitoring of multiple patients, and this modality can be extended to inpatient rehabilitation, outpatient centers, and remote home users.

Considering the needs of the stakeholders, the patient is clearly interested in the functional benefits of therapy, but it should be noted that an important underlying requirement for the patient is that the required costs do not outweigh the perceived short- and long-term benefits. The cost may be measured in terms of effort, duration, attention, finance, or other expense. As with any cost/benefit analysis, when the perceived cost outweighs the perceived benefit, a process of abandonment will begin. The more entertaining and engaging the training tasks can be, the higher the likelihood that the cost perceived by the patient will be lower. In other words, through appropriate design and feedback in games for rehabilitation, a reduction in the patient’s perceived cost can help to tip the cost/benefit balance comparison in the direction of maintained treatment durations and intensities. To sustain interest and motivation long-term, however, it is recognized that subjects need sufficient variety in game tasks as well as training environments.

The therapist too has a high interest in perceived patient improvement, but in general is satisfied with receiving feedback on a less frequent basis. From an objective analysis of Table 2, it is interesting to note that all aspect of usability pertain directly to the therapist while a subset pertain also to the patient. This illustrates the high importance of usability for the therapist. As with other tools, a rehabilitation platform with low usability will be quickly discarded before the benefits of functionality can be fully appreciated. In this sense, the usability may even trump the importance of functionality. Contrary to usability, aspects of functionality are nearly mutually exclusive for the patient and therapist, as each have clearly differing functional needs from a rehabilitation platform.

3.2 Rehabilitation Gaming Platform Overview

As previously discussed, neurorehabilitation is a highly coordinated effort between the patient, therapy staff, and patient support group. The therapist devises a treatment plan utilizing appropriate exercises and training techniques for the patient based on assessed levels of functional ability and improvement. The patient relies on the experienced planning of the therapist regarding training exercises for reducing deficits and coping techniques for lost function, while the therapist relies on the patient’s cooperation and participation in the therapeutic program established. Barriers to therapy performance on the part of the patient, or to appropriate modification of the treatment plan on the part of the therapist, would produce a sub-optimal environment for therapeutic effectiveness.

In the ideal configuration, the rehabilitation process would be fully integrated in a unified platform as depicted in Figure 3. The high-level platform is composed of three integrated modules for treatment PLANNING, game/task EXECUTION, and performance ASSESSMENT. Similar to the development of other learned skills, the rehabilitation process needs to be cyclic and iterative. Following an initial assessment, the iterations move in the direction of planning, execution, assessment, after which point the treatment plan would be revised and the cycle repeated. Revised treatment plans should be the direct result of an assessment of both the current and previous level of ability and deficit.

Depending on the early assessments and prognosis of recovery, the treatment plan may be optimistically focused on alleviating impairments to obtain a near functional recovery without the need for assistive aids. Alternatively, in a more common scenario, the treatment plan may take an early focus on incorporating functional aids as it is believed to be easier for the patient to accept this reality from the beginning than to face their new level of dependence at a later stage in the rehabilitation process. Regardless of the approach, the iterative rehabilitation process and the unified rehabilitation gaming platform can be applied.

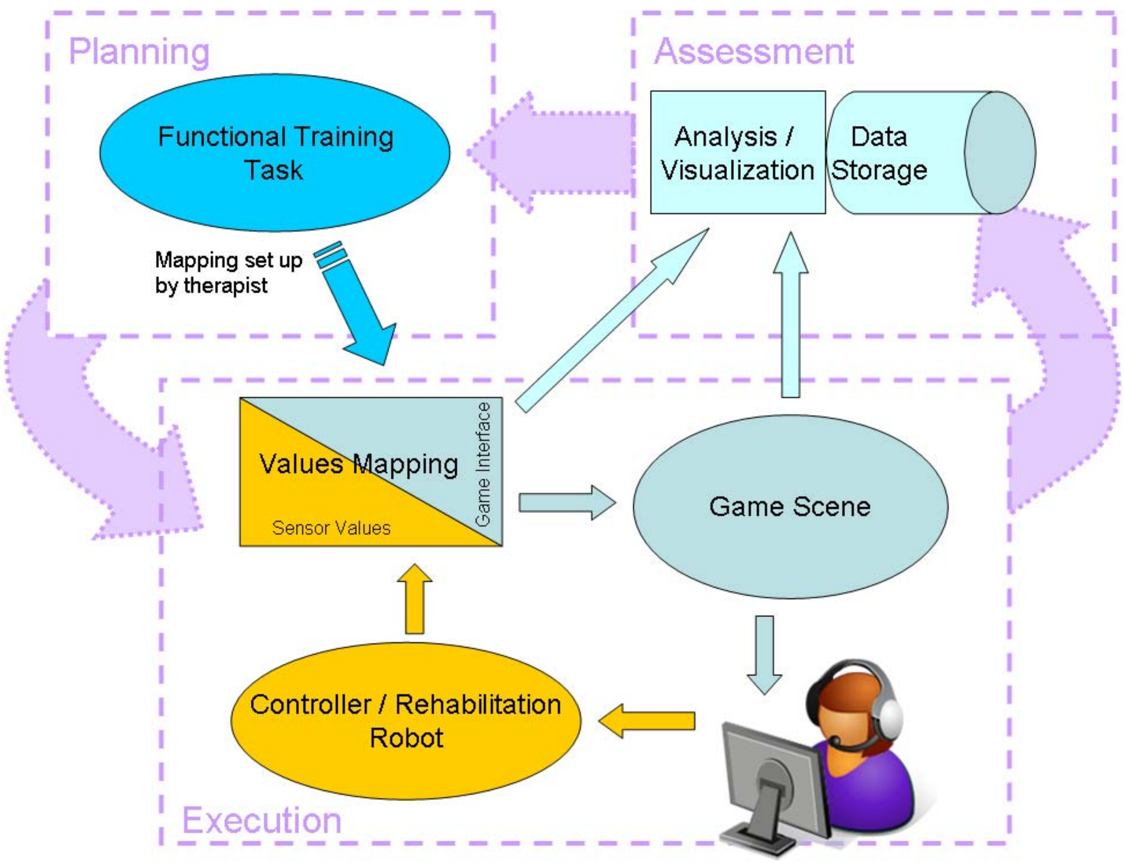

Figure 3. A system overview of a unified platform for rehabilitation gaming. The process of treatment planning, execution, and performance assessment is performed in a cyclic and iterative manner to refine the targeted therapy and ability-dependent challenge of game tasks.

3.2.1 Initial Assessment

From the onset of stroke throughout the acute phase, there is a period of flaccidity where there is minimal or no muscle tone and the patient is considered highly unstable. This is also a period during which the patient can undergo the most substantial spontaneous improvements (Krakauer, n.d.). During this period, the main focus of acute-care clinicians is to assess the patient’s ability to swallow and the amount of assistance needed to perform daily activities. Once admitted to inpatient rehabilitation, typically starting from week 2 after stroke onset, the initial assessment focus is shifted toward specifying the level of impairment and defining the goals of rehabilitation (Dobkin, 2005). As soon as the patient reaches a satisfactory level of muscle tone and is able to begin more progressive training, the patient is provided compensatory techniques such as one-handed hygene tasks and food and liquid swallowing techniques (Dobkin, 2005).

The initial assessment of the patient's status is typically performed through administering a number of functional, motor, and cognitive impairment tests. Classical methods are numerous and varied (Hsieh et al., 2009) including for example Fugl-Meyer, Functional Independence Measure, or Mini Mental tests, for motor, functional, and cognitive assessment, respectively. For incorporation with a unified rehab platform, the tests could use such methodologies following a conventional manual approach, in which the score would then need to be manually entered into the assessment module of Figure 3. Alternatively for some assessments, the procedure could be integrated with function-specific hardware and linked with game-based motor, functional, and cognitive assessment software that perform a similar assessment, however, in a more repeatable and quantitative manner. From the perspective of the potential value of cross-discipline and polycentric assessment comparisons between similar patient populations, the latter approach is highly favourable. Once the initial patient status is adequately assessed, a plan for the treatment of the illuminated deficits can be devised.

3.2.2 Treatment Planning

The ultimate goal of a training program is to maximize the patient's functional independence in order to successfully reintegrate into social and home life. In the planning phase, the therapist tries to adapt a training program for the patient that will best work towards achieving the goals previously defined through the assessment process, while at the same time trying to respect the patient's individual ability level and constraints. The importance of tailoring the training program to the patient, particularly the training load, is an important aspect regardless of the therapeutic approach taken (Timmermans, et al., 2009). Timmermans et al., state that to obtain improved motor performance, the treatment plan should adapt the training load so that fatigue occurs after 6-12 repetitions of a given exercise. Furthermore, they point out the value of distributed practice with intervals of rest and variability of exercises in the role of improving performance and retention of learning effects.

In a non-unified rehabilitation gaming system, the games would be independently selected and configured for difficulty, sequenced to provide variability, and manually started for each patient. The effort would be repeated for each patient, each session, and in each rehabilitation clinic without a quantitative means for cross-comparison between patients and clinics. In this treatment model, performance results from a training session may be displayed to the patient and therapist, but are not stored in a meaningful way in a collective database.

The proposed rehabilitation gaming platform of Figure 3 would provide the therapist with pre-grouped games, sequenced with appropriate duration, intensity, periods of rest, and variability, according to pre-determined patient ability level. Under this mode of operation, the therapist selects the functional training tasks that will be the focus of training and the pre-existing training programs associated with improving these functional goals are enabled. The therapist would retain the ability to modify the routine, levels of difficulty, or patient-specific training parameters of interest, but can take advantage of existing treatment plans as well as personalized treatment plans that were modified and shared by other therapist.

The therapist can be as proactive in the setup and monitoring of the rehabilitation as he/she desires, but is given the opportunity to take a more passive observatory role in the initial treatment process and reserve his/her valuable time for fine-tuning treatments and holding one-on-one consultations with patients. The therapist can also define global parameters in the rehabilitation process such as the frequency of each iteration to the treatment plan or the threshold of performance at which point he/she wants to be notified.

On each iteration of the rehabilitation cycle, a set of automated assessments are done based on the gaming applications with which the patient has trained and resulting scores determine the suggested modifications to the treatment plan, pending therapist approval and/or revision.

3.2.3 Game/Task Execution

Once the treatment plan has been established and approved by the therapist, the patient will have access to a personalized set of games and training tasks through a secure user login. Default settings in the training program should prompt the user automatically toward the next training session and, when appropriate, provide notices of upcoming session appointments or incoming requests from his/her therapist(s). A patient homepage should also be accessible that allows the patient to manoeuvre between the training session and other system operations such as viewing the training calendar, general progress results, and messaging. Patient help regarding how to perform each training exercise (e.g., video demonstrations, virtual animations, etc.) and the training objective associated with each exercise will be accessible directly from the corresponding game execution mode.

The game scene is presented to the patient on a standard monitor, and the user interacts with the scene through one of a number of input device as prescribed by the therapist and the medical doctor. The device may be a generic mouse, joystick, or keyboard, or a specialized rehabilitation robot, and its degrees of freedom are registered with the known degrees of freedom of the game through a values mapping matrix (Figure 3). The configuration of the values mapping matrix is established based on the training program being executed, and can be modified by the therapist depending on the game training tasks of interest and the rehabilitation device prescribed.

3.2.4 Follow-up Assessment

At the end of each training session, pre-processed trajectory data is backed-up on a central server under encryption awaiting access by the therapist. The data is minimally pre-processed only to reduce artifacts of the collection process, and to downsample, if necessary. The stored data is then retrieved from storage by the therapist’s assessment module and performance results of patient training sessions can be displayed in the desired format and reviewed or compared with other patients undergoing similar treatment. Based on trends in the assessed data and a stored history of modifications to treatment, the planning module should make intelligent recommendations for the next iteration of training. The automated recommendation is designed to save therapist time in reviewing results and to take advantage of the strengths of power computing in data reduction and trend analyses, toward more efficient and accurate treatment planning.

3.3 Example Prototype rehabilitation gaming platform

Following the vision of a unified rehabilitation platform as illustrated in Figure 3, an example prototype platform has been developed. The purpose of the platform as a prototype is not to fulfil the complete functional requirements of the stakeholders, but to represent their appearance and model the interrelated workings between functional modes of the platform. The development of the prototype follows an iterative process (Figure 4) composed of phases of research, definition, and design, and is intended to provide a visual and explanatory reference for other developers of similar technology.

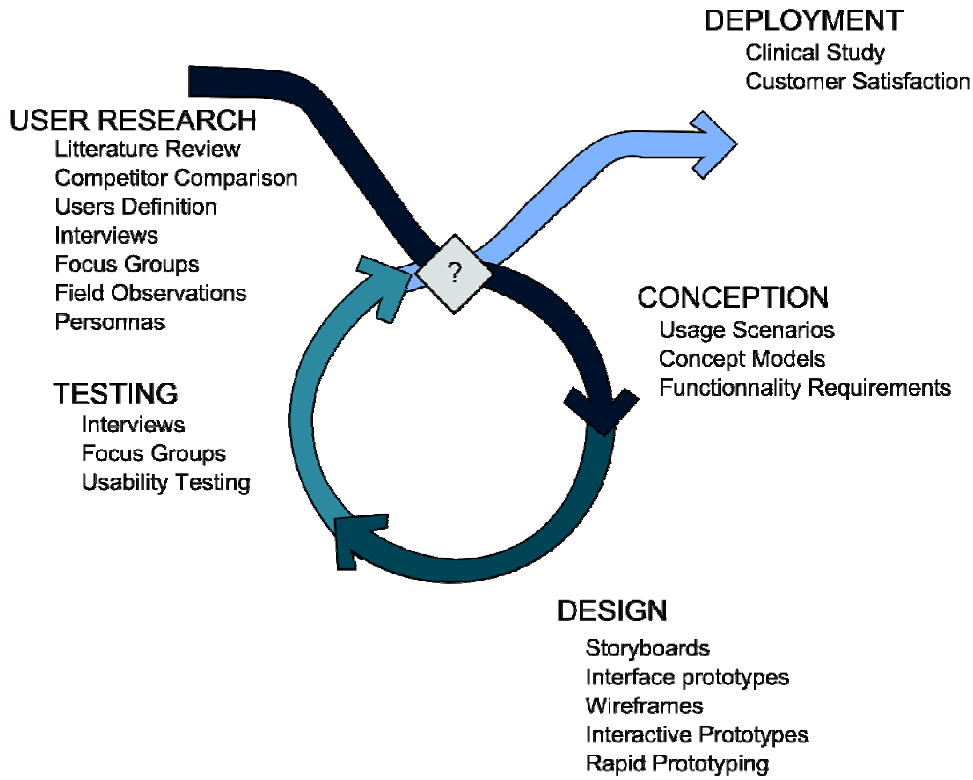

Figure 4. Iterative development process for the

3.3.1 Research phase

Stakeholder analysis - A first task in neurorehabilitation game design is correctly identifying who are the stakeholders of the system (illustrated in Table 2) that would use, or enable the use of, the final product. In the case of robotic systems for stroke rehabilitation, the typical user is logically a stroke patient. But since stroke can affect potentially any brain function, it is difficult to define precisely a typical "stroke" user. Moreover, when talking about a rehabilitation system, designers should also consider therapists (i.e. Physiotherapists, Occupational Therapists, Neuropsychologists or Speech Therapists) as part of the final user group. In fact, such therapists will also use the system, and prescribe this type of therapy to their patients. The needs of the therapists in terms of software functionalities differ significantly from the needs of a patient, and particular care should be taken when thinking about the use case of a system. Since a rehabilitation device cannot be used without the consent of the patient's therapist, designers should not consider this type of product as a rehabilitation solution on its own, but as a tool that can be integrated into a rehabilitation process that also includes other types of interventions and machines. Although a fully automated solution which assesses the patient´s capabilities and uses this assessment to create a custom rehabilitation plan for each patient is virtually possible, such a solution has little chance to be accepted by the medical community. The therapists' experience in defining rehabilitation objectives and selecting tools and exercises to attain those objectives has to be considered.

Designers have to describe precisely the profile of their future users, which include information such as the typical age, their experience with technology, their daily activities, their tasks, their capabilities/limitations. They should also describe the environment in which the system will be used and the interactions between users. Such an analysis can be achieved in many different ways. A large variety of user research techniques can be used throughout the project lifecycle, either to understand the users or to test their behavior on versions of your product.

User interviews and observations – It can be hard to gather information about attitudes and context, and here, user interviews can provide valuable insight. A user interview is a one-one conversation with a participant who belongs to one of the defined user groups. Ethnographic research and field study techniques are commonly used in the first stage of project cycle to establish a clear understanding of user tasks, goals, and workflow. These consist of on-site visits with participants to observe and learn about how they work in their normal, everyday environment. Data collection methods such as shadowing, interviews, and questionnaires provide a view of the “real-world” conditions in which users operate to provide context around the use of proposed technologies. The main issue with this technique is that it is sometimes hard to gain access to participants. Going to users’ environment may raise concerns about security, intellectual property, and intrusiveness.

Surveys – Surveys are also commonly used. A survey consists of a series of questions consisting of mainly closed-end answers (multiple choice) used to identify patterns among a large number of people. It may be difficult to get an appropriate sample. As an example, we can cite a survey of therapists that was published in 1991 (Dijkers 1991) which showed therapists felt that the robotic device was able to maintain a patient’s attention and provided good exercise, forcing patients to work harder and reach further. Therapists also liked some of the treatment programs available but wanted the ability to program custom movement patterns to use in the treatment of specific individuals. They were very interested in modules for cognitive training and auditory feedback. It is also clear that set-up time is crucial; it is not surprising that therapists would prefer not to use a robotic device if time to set it up with the patient exceeded 5 minutes.

Focus groups – Focus groups are group discussions where a moderator leads participants through questions on a specific topic. It focuses on uncovering participants’ feelings, attitudes, and ideas about the topic. A good approach is to include one round during the early phases of the project (Research phase or Definition phase) to better understand the users, and then include one or more additional rounds just before starting the development phase in order to validate the design.

3.3.2 Definition phase

Based on the research phase, the objective of the definition phase is to generate user requirements. These requirements are statements of the features and functions that the system may include to satisfy the stakeholders, and contribute to defining such things as the task movements, game objectives, levels of difficulty, and user feedback.

Movement definition – When designing motor rehabilitation games, an important aspect to take into consideration is the type of movements that will be asked of the patient in order to be able to interact with the games. Defining those movements has to be done considering the input device limitations (e.g., what movements are possible with the input device, and in what range?), recognizing that the movements must also have a therapeutic interest. Individual joint movements (for example, elbow flexion/extension, shoulder flexion/extension, shoulder adduction/abduction, forearm pronation/supination) can be of interest since some therapists use this type of movement to retrain control over individual joints. Coordinated movements (movements that involve more than one articulation at the same time) are also of interest, since coordination is something that is often impaired following stroke. In stroke subjects, for example, coordinated movements of the shoulder and elbow often elicit an abnormal synergy between shoulder flexion and elbow extension (Ellis & Dewald, 2002). Due to the movement synergies that have been described in scientific literature (Twitchell, 1951, Brunnström, 1970, Bobath, 1990) many coordinated movements are difficult following stroke and are movements on which the therapists place a high priority on trying to retain. In general, any coordinated movement that goes against the synergies is of interest. On the other hand, according to the therapists, it is essential to avoid movements that can reinforce the flexor muscles, since those muscles are already over-activated due to spasticity.

Dyspraxia is another common condition following stroke. It is a neurological disorder of motor coordination that manifests as difficulty in thinking through, planning out, and executing planned movements or tasks, even if movements are possible and muscles respond correctly. Thus, it is important to include games in the rehabilitation program that require a series of movements.

Rehabilitation objectives of the games – Stroke affects several aspects of reaching. Depending on the patient, it can affect for example range of motion, speed, coordination, precision, or the ability to regulate forces. For a description of motor impairments following stroke, the reader is invited to read papers studying arm kinematics in stroke patients (Levin 1996, Cirstea & Levin, 2000, Kamper 2002). Knowing that for an effective rehabilitation, the therapy has to be goal oriented and requires active participation of the patient, and knowing that even for the same hand trajectory, arm kinematics and motor control strategies are affected by the goal of the task (Fitts, 1954; Shumway-Cook & Woollacott, 2007, Wisneski & Johnson, 2007), it is assumed that different types of tasks are necessary to retrain all the impaired aspects of reaching. As a result, the RESPECT training goals are proposed as listed in Table 3.

Table 3. Enumeration of the RESPECT training goals for neurorehabilitation.

R	Range of motion	Angle, area, or volume swept during ROM tasks (device-dependent)
E	Exerted force	Maximum and average values of exerted force
S	Speed	Maximum and average values of movement speed and velocity
P	Precision and accuracy	Position- and time-oriented target tracking/timing error and repeatability
E	Endurance	Measure of workload or task time limit until onset of fatigue
C	Control	Coordination and smoothness of force, speed, and position control
T	Task execution time	Speed or frequency at which tasks/goals are achieved

It is also possible to make a difference between continuous, repetitive movements (like cycling or rowing), and independent movements, since those types of movements involve different neural pathways.

Finally, movements and objectives can be inspired by popular rehabilitation techniques commonly used in clinics, such as the neurodevelopmental technique (NDT) developed by Bobath (Bobath 1990), the Proprioceptive Neuromuscular Facilitation (PNF) proposed by Kabat (Knott and Voss, 1968; Voss et al., 1985), the motor relearning program proposed by Carr and Shephard (1998), and the sensorimotor integration, as proposed by Rood (Rood, 1954; Stockmeyer, 1967), or by Perfetti (Perfetti, 1986; Lion, 1987). Even if it is still not clear which of these techniques has the best efficacy for rehabilitation, they have the advantage of being well known by most of the therapists, who consider from their experience that the techniques are effective.

Evolution of game level of difficulty – To be able to keep a patient motivated by the therapy, and in order to promote effective rehabilitation, the difficulty of the games must be adapted to the patient's capabilities. In doing so, two methods are considered. In a first method, this adaptation can be made by the therapist. It is possible to provide the therapist with games that include several levels of difficulty. The therapist can then choose the level that would be most suitable for the patient. It is also possible to include parameters in the games that can be controlled externally by the therapist, such as sensitivity of the input controller, object sizes, object locations, or trajectories. This method is interesting in the sense that, as noted in focus groups, therapists want to have some control over the content of the therapy. But one possible limitation of this approach is that changing parameters for each patient can be very time-consuming for the therapist. Due to their already demanding time and energy constraints, some of them may not spend the time necessary to do such customizations. This can result in a less effective game-based rehabilitation regime.

Another approach would be to have automated adaptive games, in which the difficulty of the game is changed based on the patient profile and on his in-game results. Assessment sessions can be included in the game-based therapy to fully measure the patients' capabilities and define a training program based on this assessment. Along these lines, McNeill and his collaborators (2007) proposed a Virtual-Reality based training program in which a therapist can create a suitably challenging set of exercises for the patient, based on a previous assessment made with standardized tests. Then, for each game, a number of adaptive elements change dynamically according to how well or poorly the user is performing. The game has been programmed to enable automatic progression between three levels (Beginner, Intermediate, and Expert) under preset conditions.

The best solution is probably a compromise between a fully automated solution and a fully therapist-dependant solution. It is then important to think about the collaboration between an autonomous decision system and a human agent. What decisions can the rehabilitation system take without the control of the therapist? How can the system best advise the therapists to make rehabilitation choices? And what parameters must be decided by the therapists? These questions are still open and the answers are probably system-dependant.

Recorded parameters and user feedback – As we said earlier in the chapter, the patients' therapists have to play a role in the choice of exercises that will be performed. They would also be required to change some parameters of the games (for example target positions, sensitivity, frequency, duration, etc.) to adapt the difficulty of the game to the patient's capabilities, and to design a game-based rehabilitation that will be part of their general therapy. To do so, therapists must be provided with information about patient's capabilities inside the gaming environment. Defining which parameters are necessary for the therapists in order for him/her to follow the improvements of a patient and to be able to customize the games for each patient may be a delicate operation. For the therapist part, results and data from the device and the games must contain both results for each game and summary results that can be followed over time to see improvements. Results from the games can include, apart from in-game results such as scores, time played, levels achieved, or data about arm kinematics. Arm kinematics may include position of the different joints in a 3D space, trajectories, speed, acceleration, or jerk, and can be interpolated directly from the input device sensor data.

For each session, a summary can be created which contains averages of parameters for the whole session time. To give information about the performance of the patient on the different training modalities, we propose to give a score for each of the aspects stated above in Table 3. These scores ranged from 0 to 100 and are calculated based on different information sources. Depending on the game and its objective, several parameters can be used and balanced to define a score. For example, the calculation of the speed score will not be the same in a reaching task requiring precision or in a task training gross movements and speed.

Usability objectives – The definition phase is also the phase in which usability objectives have to be defined for future tests. We recommend using measurable objectives, such as the maximal number of errors tolerated, the time necessary to complete a task, or satisfaction scores measured by questionnaires. Such objectives will be necessary in an iterative design phase in which modifications are made after each usability test in order to know when to stop the iterations.

3.3.3 Design phase

Interface prototype – To put together the functionalities of the software and visually have an idea of the future possibilities of the system, designers should create interface prototypes early in the development phase. This prototype has to be composed of different screens showing how the different functionalities of the system will be organized and grouped. The goal here is not to have a functional prototype, and hence it is not useful at this stage of the project to spend time implementing the different functions and algorithms.

An example prototype interface for the therapist is shown in Figure 5. The interface displays the therapist logged in, a set of general setup and configuration tabs, and a set of patient-specific planning and assessment tabs. Tabs should be functional only insofar as they open a visual representation of the material contained within. The general setup and configuration tabs (Games, Routines, and Patients, in this example) enable the user to filter and modify the games displayed, assign games to create or modify training routines, or view general patient data and progress results. The planning and assessment tabs (Profile, Training, and Results, in this example) are available on selecting a patient. They allow a detailed view of the patient profile, allow training routines to be assigned to the patient, and display the history of progress results.

From the Games tab (Figure 5, top), selecting a game allows the user to view details of the particular game and the specific configuration settings available, from which the game can be modified and saved to the available set of games. In this way, existing games can be configured by the therapist (time-permitting) for individual patients and incorporated into training routines. From the Results tab (Figure 5, bottom), the results of the RESPECT training goals can be viewed, displaying overall playing statistics, scores, or detailed summary data for individual training goals. A linear calendar across the lower portion of the screen suggests the ability to view or scroll through data from particular dates or periods.

Such an interface prototype can be used in focus groups with therapists and usability testing with patients to get feedback about the content of the software. Focus groups can provide ideas of functionalities that have not yet been considered by designers but can be of interest for therapists; while usability testing, in which a user performs a typical task (for example, setting up a therapy program) under the supervision of the developer, may also be beneficial in reaching a more intuitive interface solution.

Figure 5. Example prototype therapist interface for configuration, planning, and assessment of games and training routines for neurorehabilitation.

Defining rehabilitation exercises – Based on the research phase, especially the literature review, treatment recommendations, guidelines and therapists' insights about neurological impairments, stroke rehabilitation exercises, and rehabilitation goals, several rehabilitation exercises can be extracted. Not all the rehabilitation exercises are possible for game-based rehabilitation using a single input device. A device, whether it is a classic controller (mouse, joystick, etc.) or a robotic device for stroke rehabilitation, has limited degrees of freedom and ranges of motion. It is then necessary to select from the set of identified rehabilitation exercises those that are possible with the device. Such exercises can then be used to interact with the virtual environment. These movements should be performed as interactions within a game for benefits explained previously in the section titled *Rationale for Games in Rehabilitation*, such as motivation, focus diverted from the exercise, feedback, etc. Games that can use these movements as input from the patient can be identified from an established collection (available commercial games, previous works, etc.). These exercises can also suggest new game ideas that can be designed. A single game setup can be used for different rehabilitation objectives, depending on the movements the patient is asked to perform during the in-game interactions. A rehabilitation game is then the integration of those gaming aspects and the rehabilitation exercises defined earlier.

Defining game composition – A game is composed of several elements, including graphics, objectives, obstacles, subconscious and conscious choices, and feedback. Graphics represent the visible part of the game. In games applied to rehabilitation, is important to pay particular attention to the choice of graphics, because of the particular capabilities of the users. Since stroke patients are generally elderly individuals that may have perceptual and/or cognitive impairments due to age or to the consequences of stroke, graphics have to be adapted accordingly. Appropriate graphics are important to increase the feeling of immersion in the virtual environment, which is a key element in all virtual reality applications or game-based trainings. A game also has to contain different objectives and possible in-game interactions. In 2007, Goude and colleagues proposed a game design approach for stroke rehabilitation using a taxonomy focusing on motor impairments and rehabilitation techniques in order to define game design patterns. Connections were identified between particular sources of impairment such as muscle weakness, coordination problems, and learned non-use, and the game-related features that may be of interest, such as precise maneuvering to combat scaling problems associated with discoordination.

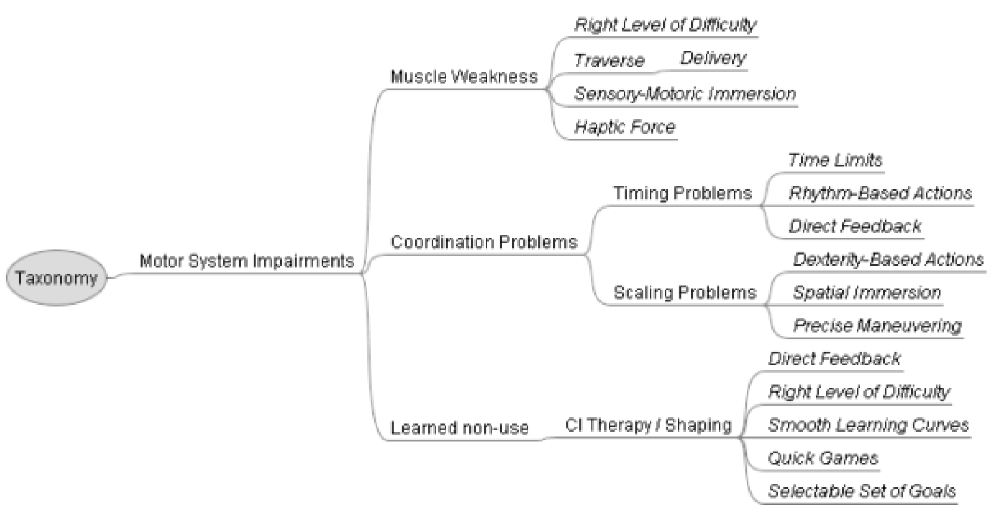

Figure 6. A subset of the taxonomy proposed by Goude et al. (2007), reproduced with permission. Game design patterns italicized.

Defining in-game feedback – Finally, games are a good way to provide the patient with augmented feedback about his/her motor performance. In-game feedback can be categorized as knowledge of results or knowledge of performance, summary feedback (overview of results of previous trials) or average feedback (average of results of previous trials), bandwidth feedback, qualitative or quantitative feedback, and can be given concurrently or at the end of task performance (terminal feedback). An appropriate use of feedback can greatly influence the motor learning mechanisms and thus the recovery of motor functions. It is recommended developers take extreme care when thinking about the feedback given to the patient during games. For recommendation about feedback use and other recommendations for technology-assisted stroke rehabilitation, interested parties are invited to read the article written by Timmermans and colleagues (Timmermans 2009).

Once rehabilitation game scenarios have been defined, it is recommended that feedback be gathered from therapists and patients about the games to ensure that they are adequately adapted for therapy and appealing for the target audience. After this evaluation, the defined ideas and strategies are ready for prototyping.

Rapid prototyping – For an effective, user-centered design, we recommend the avoidance of implementing the final solution directly, but rather to use rapid prototyping and iterative testing. After the first prototype design, the UCD process typically entails an iterative process of evaluation and redesign. Evaluations often consist of observation of users in performing typical tasks and polling them for their experience both in the process of doing the tasks and their opinions about the system. Sometimes instrumentation can be added to the application to capture the interaction and use these results to tailor the system to more effectively deliver the rehabilitative therapy. After collection and analysis of the data, the design team then refines the design, which may require a shallow GUI tune-up or deeper structural re-implementation of the system. Particularly when the latter is needed, the time savings earned through rapid prototyping can be substantial.

4 DISCUSSION AND RECOMMENDATIONS

From an objective analysis of the various stakeholders and needs involved in the deployment and use of a comprehensive neurorehabilitation system (Table 2), the need for a user-centered design (UCD) approach is evident. UCD is especially important in the success of emerging technologies such as tele-health and tele-rehabilitation as a result of the complex relationship between stakeholders. Approaching the design task from a UCD perspective additionally brings significant benefits in the deployment of successful products, thereby attracting higher sales and profits for manufacturers, while simultaneously increasing the benefit to the patient population at large.

To fully realize this benefit to patients, however, the development of a multitude of compatible user-oriented task-specific games are also of high importance. In the following sections, the topics of game design and use in rehabilitation will be discussed from the perspectives of function for the patient and motivation for the patient and the therapist.

4.1 Game Design for Neurorehabilitation

The desired outcome of neurorehabilitation training is to achieve clinically-relevant improvements in ADL or IADL activities. Toward this goal, game design should primarily target the following aims: (1) improving function through task-oriented objectives, and (2) maximizing patient adherence to training.

4.1.1 Gaming for functional improvement

Many methods used to improve functional gain are diverse and not well supported scientifically in terms of the underlying mechanisms of action. When the goal of gaming is to reduce motor deficits in the execution of daily tasks, it is important to consider pathways of motor learning and brain plasticity. Studies have empirically shown that motor learning is increased through repetition, intensity, and duration of treatment. But what about the types of games and training tasks that are best suited for improving function in motor learning? In other words, if a person struggles to simultaneously elevate the shoulder and extend the elbow, for example, what required motions, tasks, and environments are required in the game task in order to optimally reduce the deficit? Is the important aspect of motor learning encapsulated in the muscle group combinations used (the task), the context in which motor patterns are used (the environment), or both? According to recent work by Timmermans in 2009, motor behaviour is closely linked to both the task and the environment in which the task is performed (Timmermans2009). Thus, learned motor behaviour for a specific task in one environment may not translate to performing the same task in a different surrounding in light of new environmental inputs to consider. Games should be closely matched with the functional goal of the task and also with the expected environment in which the task will normally be performed.

Along with appropriate specification of the task and environment properties, it is suggested that there are eight key elements for functional gain in rehabilitation gaming:

1. Create high intensity interactions
2. Provide clear task-oriented training goals
3. Use of task-appropriate tools
4. Appropriate and adaptable challenges
5. Appropriate and customizable feedback
6. Therapy-appropriate ranges of motion
7. Engaging tasks and environments
8. Avoidance of distractions that degrade subject experience

Because of the extent to which motor impairment varies from one patient to the next, successful stroke rehabilitation requires that the game used with a robotic device be able to adapt to a patient's motor level. Adaptability is equally important for individuals so that the level of difficulty can be raised as the patient's motor skills improve over time. Meaningful tasks should be incorporated so that the patient can have a direct correlation between use of their disabled limb during therapy and use in ADLs (Johnson, 2006). The game must also provide appropriate feedback for both patient and therapist. This feedback is used to determine how well the patient is doing, how much he or she is improving, and provides some encouragement to the patient to continue with the therapy. Charting the history of recorded feedback can also help to steer the direction of future therapy sessions. Therapy-appropriate range of motion (ROM) refers to the extent to which the game demands the therapeutic motions needed for the particular motor rehabilitation program of each patient. Skills need to be practiced extensively, requiring high levels of intensity, repetition, and duration. Studies on motor rehabilitation therapy suggest that patients with hemiplegia need an environment where they can practice skills as the demands of that environment change in a variety of ways, in order to develop versatile motor schemata that will allow them to perform daily activities under natural conditions (Sabari, 1991). It follows that the game should divert the focus away from the conscious effort of moving the impaired arm, toward performing various aspects of simulated ADL task objectives in a lively game environment.

4.1.2 Gaming for the patient population

Since the probability of stroke increases exponentially with age, the majority of stroke survivors are older adults above the age of 65. Many patients have visual and/or cognitive deficits that limit their ability to read or comprehend detailed instructions. Similarly, there are a number of age- and disability-related usability guidelines to follow when implementing games that target this population of users (Flores 2008, Ijsselsteijn et al., 2007). An example of selected criteria can be derived from the ElderGAMES project (Gamberini et al., 2008) which works closely with older populations to find the most motivating and enjoyable games for the elderly population.

Although game playing has long been practiced as a common activity at senior centres, retirement communities and other social hubs for the elderly community, among elderly users, playing is often not an activity that is considered to be prestigious. Stroke patients, and elderly people are in general not familiar with video games or virtual reality interfaces and they do not typically enjoy the same genres that younger generations play. It has been reported that elderly video game players prefer simple games in thought-based genres such as history and word trivia, and they enjoy the social aspects of video games, both in side-by-side multiplayer games on the same console and in large multiplayer games played over a network (Griffiths 2004).

Gaming entertainment for elderly should be related to content familiar to the user, preferably from their daily personal lives, it should avoid religion and politics as central themes, and it should not present violent content. Elderly people usually like educational or historical information and prefer collaborative games to competitive ones. Furthermore, the use of written text and explanation should be minimized and where necessary, should be easy to read and understand. Games designed for the elderly should also take into consideration a decreased sensory acuity and longer response time (i.e. using large font size, allow delayed responses, etc.) (Fabregat 2006).

As a result, the following is a list of game criteria targeting the patient population, particularly addressing post-stroke and elderly considerations:

1. Appropriate motor and cognitive challenge
2. Simple task objective / intuitive interface
3. Element of social activity
4. Appropriateness of genre
5. Creation of new learning
6. Promotion of cognitive capacities enumerated in ElderGames project (www. eldergames.org)
7. Sensitivity to decreased sensory acuity and slower response time

Engaging and motivating the patient is a core challenge in maintaining an environment that is conducive to long-term functional rehabilitation. As discussed in Table 2, an important aspect in the success of rehabilitation games from the patient perspective is being able to maintain an appropriate balance between the challenge associated with performing a task and the patient’s ability to perform tasks. The challenge should be matched appropriately in terms of both the patient’s motor and cognitive abilities, in order to avoid boredom and loss of interest if the challenge is set too low, and on the other hand to avoid the opposite extreme of frustration if the challenge is set too high. The game must be challenging enough to keep the interest and attention of the player and also to push the player to perform tasks near the boundary of his or her ability in order to promote increased functional gains.

After reviewing many of the gaming interfaces used in the previously mentioned robotic and VR systems (summary in Flores et al. 2008), it appears that the current state of the art in games for neurorehabilitation are games that are not designed to be entertaining or motivating for post stroke users. Although patient motivation for using the system is commonly evaluated through questionnaires or captured in observations of meaningful components in the system (Colombo et al., 2007; Johnson and Schmidt, in press), to date in the literature there has not been a study of stroke rehabilitation game design based on factors that influence function, motivation, and specific user profiling. Although there is a growing pool of game contributions to the rehabilitation field, new games are still required that better address the needs of the patient from both functional therapeutic perspectives and motivational perspectives.

One recent effort to bridge these two aspects is through introducing augmented reality to the game interface (Burke et al., 2009). In this approach to the game interface, a real-time image of the user arm and workspace is projected on the screen and blended with other virtual objects. The user can then interact simultaneously with physical objects in the real environment while at the same time interacting with simulated objects in the safety of a virtual environment. The real objects themselves can be represented in the virtual environment as objects for specific tasks. The user receives instantaneous visual feedback on the location of his/her actual arm with respect to the virtual objects and can potentially engage in a variety of tasks that require true ADL movements in a real scene. Combined with an appropriate environmental scene that can be matched to the task and also the environment in which the user normally performs the task, this provides the user with a functional training tool and a higher probability of developing skills that will transfer to daily living environments.

4.2 Motivational Aspects of Rehabilitation Gaming

Considering the patient, one of the most critically lacking elements of rehabilitation games and rehabilitation game design theory is a fundamental understanding and methodological assessment of the motivational factors for the individual. Motivation is a characteristic that is highly personal and objective, in the literal sense. It would be advantageous, for the benefit of each stakeholder, to know the personal motivators for various personality profiles and to allow sufficient adaptability and user-specific functionality in game and platform interfaces in order to maximize patient involvement and adherence to rehabilitation training.

4.2.1 Patient Motivation

In general, motivation can be defined as providing “an impetus towards a goal for all current processes” (Rheinberg, 1997). Two forms of motivation are often distinguished: Firstly, when patients are intrinsically motivated, they engage in an activity, such as neurorehabilitative training, because they are interested and enjoy the activity (Eccles & Wigfield, 2002). Secondly, when extrinsically motivated, patients engage in activities for instrumental or other reasons, such as receiving a reward (Eccles & Wigfield, 2002). Patients may be intrinsically motivated to do neurorehabilitation since they realize it may restore functionality, but the required effort is great and the effects not immediately visible. Thus, games in rehabilitation may be designed such that they leverage the intrinsic motivation of the patient. For example, tasks and activities have been found to be more intrinsically motivating when they are challenging, they encourage the fantasy and arouse and satisfy our curiosity (Malone, 1981). A task can be made challenging by providing goals which are personally meaningful and the attainment of which is neither too certain nor too uncertain (Malone, 1981). Malone further suggests that self-esteem, a concept comparable to Bandura’s concept of self-efficacy (Bandura, 1997) or Vollmeyer’s concept of mastery confidence (Vollmeyer, 2000), will lower when a person fails in a challenging task, which in turn will lower interest in the task (Malone, 1981).

To evoke curiosity a task should be novel and surprising but not completely incomprehensible (Malone, 1981). Berlyne has found that people spend more time looking at more complex or incongruous stimuli in a pair of similar pictures or patterns (Malone, 1981; Berlyne, 1964) and are thus assumed to be more curious when complexity of a task or activity increases. However, there might be limits to the amount of complexity that people find interesting (Berlyne, 1965), especially in the presence of conflicting neural or cognitive impairment.

There are various sources of motivation, and motivational factors may vary widely from person to person; what is highly motivational for one patient may be entirely uninteresting for another. Naturally, a variety of rehabilitation games from different genres and with different themes, conceptual objectives, and environmental settings, should be available during therapy. For any given functional arm reach exercise, for example, an array of user-specific personalizations should be made in order to target the personal affiliations, behaviours, and characteristics of the particular user. A short interview or written survey could be issued to gather a broad view of the patient's motivational profile and personal interests.

A prior involvement in sports, as a personal interest example, can be utilized effectively in gaming to increase user motivation. The game theme, objective, or competitive strategy can be modelled after athletic events or tasks, such as moving an object (e.g., throwing, shooting, passing, or blocking), by tracking and selecting pass receivers (e.g., based on positions of offensive and defensive players), or controlling biomechanical trajectory and orientation (e.g., during swing mechanics to contact a stationary or moving object). By taking advantage of a person's prior experience and interest, the user can more easily identify with the objectives of training tasks and maintain a higher level of motivation while at the same time work toward a improving a functional task that he or she would like to regain.

Similarly, this example can be extended to other genres, such as domestic activities like cooking, shopping, or cleaning, as well as specific extracurricular hobbies such as fishing, doing word puzzles, or playing card games. Such specific activities in some cases require intensive programming efforts to achieve a graphical realism that mimics the actual activity, but the true level of realism needed for learned skills to transfer to daily life is still unknown. What is clear, however, is that when a sufficient level of motivation is not maintained throughout the duration of therapy, a loss of interest in training results in failure of the rehabilitation program because the patient will likely reject either the frequency or duration of training, both needed aspects of successful rehabilitation. This can be averted if the playing activity is sufficiently engaging and the system is conceived having in mind the appropriate characterization of the user.

Still, in developing robotic systems for stroke rehabilitation, to design games that are well-aligned with the goals of therapy is a challenge. The games should not only be created so as to fulfill rehabilitation criteria, but should also be appealing for the users who are often elderly patients. Particularly important in this patient population, are the modes and styles of feedback displayed to the user from a motivational standpoint.

4.2.2 Motivational Feedback

The question of optimal feedback to the user for therapeutic effectiveness has not been definitively answered. Some studies suggest multi-modal sensory feedback (haptic, visual, and auditory, etc.) provides improved conditions for task learning (Adams, Klowden, & Hannaford 2001; Hayward, 2004). Here the distinction can be made between "virtual" feedback and "augmented" feedback, where virtual expresses a likeness to reality, while augmented refers to something that has been altered with respect to reality. Game developers often seek to create scenery with ever increasing likeness to reality. But for the topic of motor learning and rehabilitation, it is still in question whether a high level of realism is truly warranted or not. Is it more motivational, or does too much reality create confusion and distraction for the patient population? These are important questions that require further research to answer.

In considering the use of multi-sensory feedback in rehabilitation games, it is clear that elements of virtual reality can enhance the richness, or multimodality, of the game interactions. However, we are also familiar with the use of non-realistic informational feedback to provide indications of status such as arbitrary auditory cues to indicate success or failure. These can be presented with sounds that intuitively indicate a positive or negative action, but understanding the context-specific meaning usually requires a learning period. Similarly, haptic force feedback can be provided to indicate displacement error from a desired path.

Augmented feedback can also refer to presenting natural cues but with a distinct offset from the real or actual value, such as presenting scaled visual displacements to the user in comparison to actual movement to encourage increased range of motion or control. Such alterations to user feedback can be used to adjust task difficulty to maintain the proper user challenge, and also to "trick" the subject into improving task performance without awareness.

Timing and frequency of stimuli seem to be key aspects of rehabilitation feedback. Some therapists are suggesting that the specific movement trajectories in therapy are less critical than the movements themselves, which are intentionally made under direct and active participation of the user. To this end, the feedback should be provided to reward intentional movements, providing awareness of movement initiation and direction. From a motivational standpoint, patients need feedback on a regular and frequent basis. Multi-modal feedback should be given to show task progress as well as task completion, but more importantly, should follow a model of rewarding effort (i.e., active participation) over improvement.

The potential for improved user interaction experience and motivation in gaming through multi-modal feedback is commonly acknowledged, however research to quantify improvements in neurorehabilitation under varying levels of sensory feedback has not been carried out. In general, it is clear that user feedback is a necessary component in motor learning, and the richer the feedback, the better, provided the user has the capacity to process the information (Shumway-Cook2007).

4.2.3 Therapist Motivation

From the viewpoint of the therapist, a strong motivation for using gaming in rehabilitation is clearly the motivational benefit to the patient. Increased treatment adherence, translates to increased functional outcomes and positive feedback on the rehabilitation planning cycle. Additional benefits include quantitative measurement of results, and the ability to customize the difficulty to the level of the patient. The ability to control the difficulty of tasks in virtual environments or augmented reality games is a major advantage for the therapist. As previously discussed, having adequate flexibility to tailor difficulty to patient ability is a need not only for functional improvement, but also as motivational incentive for cognitive and motor engagement.

Appropriately adaptive games should provide the therapist with easy control over task training objectives, motion trajectories, and levels of difficulty. The therapist's control should be maintained in the upper hierarchy setting global game profiles for the patient, while the lower level parameters are correspondingly adjusted automatically such as stimulus timing, appearance, and auditory properties, task tolerances on positional errors, desired trajectory deviations, and completion time limits. A further advantage to the use of games is the easy extension of clinically-used gaming platforms to the home environment.

4.3 Barriers to game use in neurorehabilitation

Therapist willingness to incorporate robotic devices – Recalling the stated importance of usability for the therapist, it is acknowledged that without incorporation of the technology by the therapist into his/her daily clinical practice, technology abandonment will occur before ever reaching the patient. It is crucial, therefore, that therapists be fully considered and included in the early phases of development, be it hardware, software, practical, or methodological considerations. The technology must be functional from the perspective of the therapist, not the designer, and an important aspect of functionality (particularly during the introduction of new technologies) is the ease with which users can assimilate the new technology into their prior daily routines.

An additional issue to address with regard to therapists is a fear of loosing control over therapeutic planning or the ability for hands-on-assessment. Therapists rely extensively on experience of assessment through physical contact and express concern over systems that lessen this level of this proximity. These are concerns that have to be heard and addressed through iterative testing of system usability and functionality to serve as a therapeutic tool, and not as an independent or automated therapist. Therapy-assistance systems should likened to the automotive industry in provide mobility tools for the population. Vehicles allow more efficient access to goals but a driver is always necessary.

Unclear carry-over effects – A secondary issue regarding potential roadblocks to greater success of games in rehabilitation is the lingering uncertainty of carry-over effects. It is still unknown precisely what core elements of task execution are necessary to train in order to maximize the transfer of learned skills in the virtual environment to learned skills in real environments. For global reach and positioning tasks, it is considered that intentional movement and feedback are key, ranking above the specific task or trajectory of movements. For reach and grasp, however, it is know that the task and environment directly influence the motor control strategies employed, and thus, the correct motor behavior must be learned for specific task/environment combinations.

The question remains whether simply using the appropriate task object in the corresponding task environment is the key, or if the level of object-specific detail is important down to the “make and model” of the virtual object and environment?

Another unknown is whether there exists a comprehensive set of elemental motor tasks that form the building blocks of all other tasks. To this end, one could train first from a set of skill block and later train to assemble the blocks to form functional tasks. It is believed that training one task does not carry over to other tasks in the real environment, but at the same time, it seems clear that users don’t have to learn how to pick up every available size of marking pen in order to pick up one of a new diameter. So some learning, then, can transfer from one real task to another of sufficient similarity, at least in real environments.

5 FUTURE RESEARCH DIRECTION

Acknowledging the current and future trends in stroke (Kelly-Hayes M. et al., 1998; Tohm, 2006) and other causes of neuro-muscular impairment, it follows that new strategies of addressing patient, therapist, and systemic needs are necessary.

5.1 Unified rehabilitation gaming platform

In 2006, the direct and indirect costs of stroke in the US were estimated at $57.9 billion, where over half of this sum resulted from direct costs (Tohm 2006). This figure is nearly twice that of estimates from 1993. Furthermore, approximately 5% of direct costs of stroke, or nearly $2 billion, is currently spent on inpatient rehabilitation (Prigatano and Pliskin 2003). However, despite the fact that 90% of survivors are left with lifelong post-stroke deficits, existing facilities are able to provide rehabilitation services for only 10-15% of patients (Dobkin 1995). Without the vital introduction of new treatment interventions, the outlook on stroke rehabilitation for future patients is under rapid decline. If the current treatment numbers of (Prigatano and Pliskin 2003) persist, then by year 2050, fewer than 5% of stroke patients will receive the treatment they need as a result of insufficiencies in the capacity for patient throughput. The lack of treatment availability is presumably a result of a combination of high cost of inpatient rehabilitation and a lack of trained therapists.

This situation creates a pressing need for new strategies to increase productivity while optimizing the quality of neurorehabilitation care. The growing ratio of potential patients to trained therapists must be addressed by a multi-disciplinary systemic approach that considers the needs of all involved stakeholders. A very promising foreseeable solution is in the collaborative development of a web-based tele-rehabilitation platform and compatible low-cost rehabilitation devices. Web-based services under encryption allow secure access and can be used in internal network setups as well as long-distance public networks for remote patient access from home. Such systems could be utilized both in the clinical setting for inpatients and outpatients, and also with at-home patients under long-term periodic therapist supervision.

In the clinical environment, a comprehensive rehabilitation platform would allow patient profile information to be linked to training histories and progressions to provide faster access to trends and statistical analyses, as well as patient treatment management and intra- and inter-center treatment comparisons. Addressing the issue of treatment capacity, under a parallel treatment model, a single therapist could manage parallel sessions for multiple patients by observing real-time task and postural feedback on a master therapy console. From the master console, the therapist could select which of the patients to observe, what progress parameters to display, as well as in what format of display. Examples of display options might include: live streaming video of the patient’s movements or the patient’s display screen, a 3D virtual representation of the patient’s movements, a numeric performance score, or graphical parameter display. The introduction of such a platform combined with an appropriate interface device frees the therapist from the conventional burden (physical and temporal) of manual therapeutic interactions with the patient, without removing the therapist’s control over therapeutic assessment and planning.

Similarly, the parallel treatment model can be extended to remote treatment of patients at home. The critical phase of initiation to the rehabilitation methods, new devices, and gaming software can be addressed during inpatient rehabilitation and then continued at home after the patient reaches a sufficient level of proficiency with the system tools. In this way, rehabilitation accessibility can be dramatically extended for higher patient throughput with minimal impact to the workload of the therapist. Additionally, a comprehensive platform can provide highly beneficial tools for long-term quantitative comparisons and faster iteration cycles in improving the treatment methods.

Development of a successful rehabilitation platform must acknowledge the critical role of the therapist and offer itself as a tool at his/her disposal. It should aid in the repetitive execution of therapy and perform necessary data reduction to present the therapist with the most relevant patient statistics in order for the therapist to make educated and efficient judgments toward planning the most effective therapeutic intervention. It should also have the capacity to make “intelligent” suggestions regarding the interventional regime to use, based on patient profile information, assessment trends, and statistical comparison to similar trends in the database. It is worth noting that automated suggestions are useful ways to minimize setup and prescription time for the therapist, which will be especially important in the early period of introduction when the therapist is getting acquainted with configuring the system. Consequently, this is also the time when the therapist is most unfamiliar with the technology and therefore most likely to distrust the “intelligence” of the system.

5.2 Games applied to neurorehabilitation

Game development and application must focus on utilizing games for what we know they are useful: motivation and engagement. The motivational and even addictive characteristics of games are well known, and there is a wealth of knowledge about motivational theories (Herzberg, F., et al., 2004) and persuasive technologies (Fogg BJ, 2002). The future direction of gaming in the field of rehabilitation will be to combine known theories used in creating enjoyable work (Herzberg, F., et al., 2004) and captivating computer (Fogg BJ, 2002) experiences toward the ultimate benefit for rehabilitation.

Games must be leveraged to take advantage of a patient’s intrinsic motivation in order to make repetitive therapeutic movements more stimulating for the adult and elderly populations. As previously proposed for recreational gaming, one method of increasing interest is by presenting the user with tasks that first arouse a sense of curiosity and then satisfy that curiosity (Malone 1981). In repeating this pattern, a person can earn a sense of accomplishment and improve self confidence and thereby maintain interest in the task, a view that is also supported by some long-standing theories on effective work practice (Herzberg, F., et al., 2004). The intrinsic reward or motivation in this philosophy is provoked directly from the user in response to the appropriateness of the game task and environmental properties. This summarizes and strengthens what has been published regarding the importance of having an appropriate level of difficulty for the user. Users must be challenged, but not over- or under-challenged. It is especially important in the patient population to monitor the task difficulty because persons with neuromuscular impairments can change dramatically from one day to the next, particularly in the acute and subacute phases of rehabilitation. Tasks that a patient performed during the previous session may be getting too easy (from the context of motor learning), or to the contrary, tasks that the patient could previously perform may be too challenging on a given day and should be reduced in difficulty for the duration of the session. For these reasons, it would be strongly advantageous to develop a platform module for routine automated assessment of the appropriateness of task difficulty settings.

Automatic adjustment of difficulty settings to achieve the optimal challenge for motor improvement and motivation should be addressed from a systemic approach such that all games can be modulated under the same adaptive scheme with minimal administration. Specifying which types of task parameters for a given genre of tasks are the ideal components to adjust is work for a future study.

5.3 Automatic vs. Optional Assistance

Another promising direction for future research is toward the development of a “Virtual Therapist”, or “Virtual Helping Hand”. In approaching this topic, it is important that the context is clearly understood and not misinterpreted as a tool that provides more than it should. The goal of a “Virtual Therapist” should never be to control or automate therapy. It should be developed as a tool at the therapist’s disposal that can be turned on or off, or adjusted as desired. It can be likened to the functions of cruise control or navigational assistance in the automobile, and should not be confused with the function of the steering wheel or the brake.

Having some basic level of intelligence built into the rehabilitation platform about the natural progression of planning routines based on assessments, the “Virtual Helping Hand” can provide the therapist with suggestion and roadmaps, and automatically report on the progress as well as deviations from the selected roadmap. The roadmaps are training regimes composed of sets of training goals, measured parameters, and threshold settings before revisions are made. It allows a plan to be devised, modified, and set in motion under periodic approval and direction.

To this end, the therapist remains an integral and irreplaceable part of the therapeutic process, and as such, developers must fit therapy-assistance technologies within the context of therapists needs.

5.4 Devices for the marketplace

As a final important point of future research, it is clear that success of a rehabilitation gaming platform for use in the rehabilitation of motor deficits is largely dependent on an availability of a host of low-cost rehabilitation devices that can be sold commercially in the range of $500-$5000. The current devices in this pool are few. Furthermore, clinicians acknowledge this market deficit and express a desire for new tools to lessen their burden, improve efficiency, and provide more quantitative feedback.

As a result, there is a tremendous opportunity to deliver cost-effective solutions to a significant and growing need in clinical neurorehabilitation. These same solutions, coincidently, are applicable and needed also in the home environment where patients have the opportunity to train at higher frequencies and durations. It is predicted that the directional trend in therapy will be moving rehabilitation away from the traditional clinical setting and making effective but affordable treatment modalities available to users from the comfort of their home or a nearby dedicated remote therapy station. Home rehabilitation solutions will ultimately offer reduced per-patient cost to the patient and healthcare system. The challenge for hardware developers is twofold: first, to develop functional devices that lend themselves to economical manufacturing practice, and second to develop devices that serve greater populations of users.

6 CONCLUSION

Gaming offers a powerful opportunity to increase patient motivation and adherence to training in neurorehabilitation, but is currently limited in its systemic applicability. It is believed that a necessary step in the successful implementation of games in mainstream rehabilitation programs is the development of an integrated rehabilitation software platform that supports existing systemic relationships and methodologies. Furthermore, it is believed that without the vital introduction of new treatment interventions, the availability of treatment for persons with neuro-muscular impairments will continue to decline.

At present, a major criticism of existing gaming scenarios for rehabilitation is that they have been designed primarily by engineers, scientists, and health professionals whose intent is to build and test the overall functionality of specific research-based hardware. The games themselves often lack the qualities required to be motivational long-term and are therefore less engaging for the patients. On the other hand, popular games for recreational use have typically not been designed with the criteria for neurorehabilitation in mind, and thus often lack essential components for therapeutic effectiveness. Games that are effective for therapy require the user to engage in what is known as the mass-practice method and even though it has been proven to produce positive results in terms of motor skill improvement, it often results in a decreased interest in training. As active participation and intentional movements are key aspects of motor learning, careful attention must be given to the way in which we design the patient-system interface to incorporate motivation for active user involvement. It is extremely important to keep the level of challenge optimal in order to stimulate intrinsic motivation. This means that the task should be challenging, but not too difficult to achieve. The task should have a goal and an uncertain outcome, with feedback that rewards effort as much as success. The task should be presented in a playful manner and should elicit a game-like experience, but it should be designed to reflect daily activities of the user, while the parameters recorded should be determined based on the neurorehabilitation practice.

Gaming in rehabilitation promotes motivation, fun, and active engagement in training tasks, where engagement seems to be higher in cases where the play is relevant to the player. Incorporating games helps to facilitates social interaction, cooperation, participatory relationships, and may instigate real world actions. Gaming may also improve cognitive skills, and reinforce learning. According to Prensky (2000), “players of computer and video games not only learn how to do things in terms of the conceptual procedures, but they also practice the skills until the learning is internalized and becomes second nature”. In this way, a successful game design could significantly increase not only skill acquisition during rehabilitation therapy, but also long-term retention after therapy cessation.

By embedding therapeutic activities in games, the level of play can be tailored precisely to the ability and need of the user. Furthermore, through the use of robotic input devices, the therapeutic task movements can be quantitatively measured and/or repeated as long as necessary without the need for continuous professional supervision. It is believed that the combination of robot-aided therapy and a user-centered rehabilitation software platform can deliver the expansive treatment modality needed to address the growing deficit in availability of neuro-rehabilitative care.

In closing, it is believed that development of a successful platform for game-based training in neurorehabilitation must follow a user-centered design process. The method of planning, executing, and assessing therapy sessions for patients must be integrated into a single comprehensive platform taking special care to adhere to current strategies in clinical practice. It is expected that with increased awareness of the needs of users and stakeholders, considering particularly the therapist and the patient, new and existing games and gaming platforms can be developed to better suit the diverse needs for effective game use in neurorehabilitation.

REFERENCES

Abrams, W. B., Berkow, R., & Fletcher, A. J. (1990). The Merck manual of geriatrics. Merck Sharp & Dohme Research Laboratories.

Adamovich, S., Qiu, Q., Talati, B., Fluet, G., & Merians, A. (2007). Design of a virtual reality-based system for hand and arm rehabilitation. In IEEE 10th International Conference on Rehabilitation Robotics, 2007. ICORR 2007 (pp. 958-963).

Adams, R. J., Klowden, D., & Hannaford, B. (2001). Virtual training for a manual assembly task. Haptics-e, 2(2), 1. Citeseer.

Amirabdollahian, F., Loureiro, R., Gradwell, E., Collin, C., Harwin, W., Johnson, G., et al. (2007). Multivariate analysis of the Fugl-Meyer outcome measures assessing the effectiveness of GENTLE/S robot-mediated stroke therapy. Journal of NeuroEngineering and Rehabilitation, 4(1), 4. BioMed Central Ltd.

Aziz, N. A., Leonardi-Bee, J., Phillips, M. F., Gladman, J., Legg, L. A., Walker, M., et al. (2008). Therapy-based rehabilitation services for patients living at home more than one year after stroke. status and date: Edited (no change to conclusions), published in, 1.

Bach-y-Rita, P. (2001). Theoretical and practical considerations in the restoration of function after stroke. Topics in Stroke Rehabilitation, 8(3), 1-15. Thomas Land.

Bandura, A. (1997). Self-efficacy: The exercise of control. Worth Publishers.

Berlyne, D. E. (1964). A DECADE OF MOTIVATION THEORY. American scientist, 52, 447.

Berlyne, D. E. (1965). Structure and direction in thinking. Wiley New York.

Bobath, B. (n.d.). Abnormal postural reflex activity caused by brain lesions. 1965. Heinemann Medical, London.

Boian, R., Sharma, A., Han, C., Merians, A., Burdea, G., Adamovich, S., et al. (2002). Virtual reality-based post-stroke hand rehabilitation. Medicine meets virtual reality 02/10: digital upgrades, applying Moore's law to health, 64. Ios Pr Inc.

Brewer, B. R., McDowell, S. K., & Worthen-Chaudhari, L. C. (2007). Poststroke upper extremity rehabilitation: a review of robotic systems and clinical results. Topics in stroke rehabilitation, 14(6), 22-44. doi: 10.1310/tsr1406-22.

Broeks, J. G., Lankhorst, G. J., Rumping, K., & Prevo, A. J. (1999). The long-term outcome of arm function after stroke: results of a follow-up study. Disability & Rehabilitation, 21(8), 357-364. Informa Healthcare.

Brosnan et al., (2009). The potential of Wii-rehabilitation for persons recovering from acute stroke. Physical Disabilities Special Interest Section Quarterly. Bethesda, MD: The American Occupational Therapy Association.

Brown, R., Sugarman, H., & Burstin, A. (2009). Use of the Nintendo Wii Fit for the Treatment of Balance Problems in an Elderly Patient with Stroke: A Case Report. The Official Journal of the European Federation for Research in Rehabilitation.

Brunnstrom, S., Hislop, H. J., & Carson, P. (1970). Movement therapy in hemiplegia: a neurophysiological approach. Harper and Row New York.

Burke, J. W., McNeill, M. D., Charles, D. K., Morrow, P. J., Crosbie, J. H., McDonough, S. M., et al. (2009). Optimising engagement for stroke rehabilitation using serious games. The Visual Computer, 25(12), 1085-1099. Springer.

Caillois, R. (1991). Les jeux et les hommes (1958). Gallimard, Folio essais. 374 pages.

Cameirão, M. S., i Badia, S. B., & Verschure, P. (2008). Virtual reality based upper extremity rehabilitation following stroke: A review. JCR, 1(1), 63.

Carmien, S. (2007). Leveraging Skills Into Independent Living: Distributed Cognition and Cognitive Disability. VDM Verlag Dr. Muller.

Carr, J. H., & Shepherd, R. B. (1998). Neurological rehabilitation: optimizing motor performance. Butterworth-Heinemann Medical.

Chae, J., Bethoux, F., Bohinc, T., Dobos, L., Davis, T., Friedl, A., et al. (1998). Neuromuscular stimulation for upper extremity motor and functional recovery in acute hemiplegia. Stroke, 29(5), 975. Am Heart Assoc.

Cirstea, M. C., & Levin, M. F. (2000). Compensatory strategies for reaching in stroke. Brain, 123(5), 940. Oxford Univ Press.

Cogan, A., Madey, J., Kaufman, W., Holmlund, G., & Bach-y-Rita, P. (1977). Pong game as a rehabilitation device. In Fourth Annual Conference on Systems and Devices for the Disabled. Seattle, Wash: University of Washington School of Medicine (pp. 187-188).

Colombo, R., Pisano, F., Mazzone, A., Delconte, C., Micera, S., Carrozza, M. C., et al. (2007). Design strategies to improve patient motivation during robot-aided rehabilitation. Journal of neuroengineering and rehabilitation, 4, 3. doi: 10.1186/1743-0003-4-3.

Coote, S., & Stokes, E. K. (2001). Physiotherapy for upper extremity dysfunction following stroke. Physical Therapy Reviews, 6(1), 63-69. Maney Publishing.

Dean, C., & Mackey, F. (1992). Motor assessment scale scores as a measure of rehabilitation outcome following stroke. Australian Journal of Physiotherapy, 38(1), 31-35.

Dijkers, M. P., DeBear, P. C., Erlandson, R. F., Kristy, K., Geer, D. M., Nichols, A., et al. (1991). Patient and staff acceptance of robotic technology in occupational therapy: a pilot study. Journal of rehabilitation research and development, 28(2), 33.

Dobkin, B. (1995). The economic impact of stroke. Neurology, 45(2 Suppl 1), S6-S9.

Dobkin, B. H. (2005). Rehabilitation after stroke. The New England Journal of Medicine, 352(16), 1677. Mass Med Soc.

Eccles, J. S., & Wigfield, A. (2002). M OTIVATIONAL B ELIEFS, V ALUES, AND G OALS. Annual review of psychology, 53(1), 109-132. Annual Reviews.

Ellis, M., Dawson, M., Beer, R. F., & Dewald, J. P. (2002). Reduced torque coupling and increased arm strength following isometric multidegree of freedom strength training in chronic stroke subjects. In Soc Neurosci Abstr (Vol. 32, p. 169).

Feng, X., & Winters, J. M. (n.d.). UniTherapy: a computer-assisted motivating neurorehabilitation platform for teleassessment and remote therapy. In *Rehabilitation Robotics, 2005. ICORR 2005. 9th International Conference on* (pp. 349-352).

Feys, H. M., De Weerdt, W. J., Selz, B. E., Cox Steck, G. A., Spichiger, R., Vereeck, L. E., et al. (1998). Effect of a therapeutic intervention for the hemiplegic upper limb in the acute phase after stroke: a single-blind, randomized, controlled multicenter trial. Stroke, 29(4), 785. Am Heart Assoc.

Fisk, A. D., Rogers, W. A., Charness, N., Czaja, S. J., & Sharit, J. (2009). Designing for older adults: Principles and creative human factors approaches. CRC.

Fitts, P. M. (1954). The information capacity of the human motor system in controlling the amplitude of movement. Journal of Experimental Psychology, 47(6), 381-391.

Flores, E., Tobon, G., Cavallaro, E., Cavallaro, F. I., Perry, J. C., Keller, T., et al. (2008). Improving patient motivation in game development for motor deficit rehabilitation. In Proceedings of the 2008 International Conference on Advances in Computer Entertainment Technology (pp. 381-384).

Fogg, B. J. (2002). Persuasive technology: using computers to change what we think and do. Ubiquity, 2002(December), 2. ACM.

Gamberini, L., Alcaniz, M., Barresi, G., Fabregat, M., Prontu, L., Seraglia, B., et al. (2008). Playing for a real bonus: Videogames to empower elderly people. JCR, 1(1), 37.

Goude, D., Bj, S., & Rydmark, M. (2007). Game Design in Virtual Reality Systems for Stroke Rehabilitation. Virtual Reality, 146-148.

Griffiths, M. D., Davies, M. N., & Chappell, D. (2004). Online computer gaming: a comparison of adolescent and adult gamers. Journal of adolescence, 27(1), 87-96. doi: 10.1016/j.adolescence.2003.10.007.

Hawthorn, D. (2000). Possible implications of aging for interface designers. Interacting with Computers, 12(5), 507-528. Elsevier.

Hesse, S., Uhlenbrock, D., Werner, C., & Bardeleben, A. (2000). A mechanized gait trainer for restoring gait in nonambulatory subjects. Archives of physical medicine and rehabilitation, 81(9), 1158-1161. Elsevier.

Hesse, S., Werner, C., Pohl, M., Rueckriem, S., Mehrholz, J., Lingnau, M. L., et al. (2005). Computerized arm training improves the motor control of the severely affected arm after stroke: a single-blinded randomized trial in two centers. Stroke, 36(9), 1960. American Heart Association.

Hidler, J., Nichols, D., Pelliccio, M., & Brady, K. (2005). Advances in the understanding and treatment of stroke impairment using robotic devices. Topics in stroke rehabilitation, 12(2), 22-35. Thomas Land.

Hsieh, Y., Wu, C., Lin, K., Chang, Y., Chen, C., Liu, J., et al. (2009). Responsiveness and validity of three outcome measures of motor function after stroke rehabilitation. Stroke; a journal of cerebral circulation, 40(4), 1386-91. doi: 10.1161/STROKEAHA.108.530584.

Ijsselsteijn, W., Nap, H. H., de Kort, Y., & Poels, K. (2007). Digital game design for elderly users. Proceedings of the 2007 conference on Future Play - Future Play '07, 17. New York, New York, USA: ACM Press. doi: 10.1145/1328202.1328206.

Jacobs, K. M., & Donoghue, J. P. (1991). Reshaping the cortical motor map by unmasking latent intracortical connections. Science, 251(4996), 944. AAAS.

Jannink, M. J., van der Wilden, G. J., Navis, D. W., Visser, G., Gussinklo, J., Ijzerman, M., et al. (2008). A low-cost video game applied for training of upper extremity function in children with cerebral palsy: a pilot study. CyberPsychology & Behavior, 11(1), 27-32. Mary Ann Liebert, Inc. 140 Huguenot Street, 3rd Floor New Rochelle, NY 10801-5215 USA.

Johansson, B. B. (2000). Brain plasticity and stroke rehabilitation: the Willis lecture. Stroke, 31(1), 223. Am Heart Assoc.

Johnson, M. J. (2006). Recent trends in robot-assisted therapy environments to improve real-life functional performance after stroke. Journal of NeuroEngineering and Rehabilitation, 3(1), 29. BioMed Central Ltd.

Johnson, M. J., & Schmidt, H. (2009). Robot Assisted Neurological Rehabilitation at Home: Motivational Aspects and Concepts for Tele-Rehabilitation. In Public Health Forum (Vol. 17, p. 8).

Johnson, L. M., & Winters, J. M. (2004). Enhanced TheraJoy technology for use in upper-extremity stroke rehabilitation. In *Engineering in Medicine and Biology Society, 2004. IEMBS'04. 26th Annual International Conference of the IEEE* (Vol. 2)

Kamper, D. G., Mckenna-cole, A. N., Kahn, L. E., & Reinkensmeyer, D. J. (2002). Alterations in reaching after stroke and their relation to movement direction and impairment severity. Archives of Physical Medicine & Rehabilitation, 83, 702-707.

Kelly-Hayes, P. M., Robertson, J. T., Broderick, J. P., Duncan, P. W., Hershey, L. A., Roth, E. J., et al. (1998). The American heart association stroke outcome classification. Stroke, 29(6), 1274. American Heart Association.

Knott, M., & Voss, D. E. (1957). Proprioceptive Neuromuscular Facilitation (Pattern and Techniques). The American Journal of the Medical Sciences, 233(1), 490.

Krakauer, J. W. (2006). Motor learning: its relevance to stroke recovery and neurorehabilitation. Current opinion in neurology, 19(1), 84-90. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/16415682.

Krebs, H. I., Volpe, B. T., Aisen, M. L., & Hogan, N. (2000). Increasing productivity and quality of care: robot-aided neuro-rehabilitation. Development, 37(6), 639-652.

Kwakkel, G., Wagenaar, R. C., Twisk, J. W., Lankhorst, G. J., & Koetsier, J. C. (1999). Intensity of leg and arm training after primary middle-cerebral-artery stroke: a randomised trial. The Lancet, 354(9174), 191-196. Elsevier.

Langhorne, P., Wagenaar, R., & Partridge, C. (1996). Physiotherapy after stroke: More is better? Physiotherapy research international: the journal for researchers and clinicians in physical therapy, 1(2), 75.

Levin, M. F. (1996). Interjoint coordination during pointing movements is disrupted in spastic hemiparesis. Brain, 119(1), 281. Oxford Univ Press.

Lewis, C. H., & Rieman, J. (1993). Task-centered User Interface Design: A Practical Guide. Retrieved December, 16, 2004.

Lion, J. (1987) L'approche sensorimotrice de la rééducation de l'hémiplégie. Concilia Medica 1987 ;1/6 :159-66

Loureiro, R. U., Amirabdollahian, F., Topping, M., Driessen, B., & Harwin, W. (2003). Upper Limb Robot Mediated Stroke Therapy—GENTLE/s Approach. Autonomous Robots, 35-51.

Lum, P. S., Burgar, C. G., Shor, P. C., Majmundar, M., & M. (n.d.). Van der Loos, "Robot-assisted movement training compared with conventional therapy techniques for the rehabilitation of upper-limb motor function after stroke,." Arch Phys Med Rehabil, vol, 83no7pp952--959.

Malone, T. W. (1981). Toward a theory of intrinsically motivating instruction. Cognitive science: a multidisciplinary Journal, 5(4), 333-369. Psychology Press.

Masiero, S., Celia, A., Rosati, G., & Armani, M. (2007). Robotic-assisted rehabilitation of the upper limb after acute stroke. Archives of physical medicine and rehabilitation, 88(2), 142-149. Elsevier.

Mcneill, M., Charles, D., Mcdonough, S., Crosbie, J., Oliver, L., Mcgoldrick, C., et al. (2007). Adaptive Virtual Reality Games for Rehabilitation of Motor Disorders. Access, 681-690.

Nef, T., Mihelj, M., Colombo, G., & Riener, R. (2006). ARMin - robot for rehabilitation of the upper extremities. Proceedings 2006 IEEE International Conference on Robotics and Automation, 2006. ICRA 2006., (May), 3152-3157. Ieee. doi: 10.1109/ROBOT.2006.1642181.

Ohlsson, A. L., & Johansson, B. B. (1995). Environment influences functional outcome of cerebral infarction in rats. Stroke, 26(4), 644. Am Heart Assoc.

Oinas-Kukkonen, H., Raisanen, T., & Hummastenniemi, N. (2008). Patient relationship management: an overview and study of a follow-up system. Journal of healthcare information management: JHIM, 22(3), 24.

Pagulayan, R. J., Keeker, K., Wixon, D., Romero, R. L., & Fuller, T. (2002). User-centered design in games. In The human-computer interaction handbook (pp. 883-906).

Parasuraman, R., & Rizzo, M. (2007). Neuroergonomics: The brain at work. Oxford University Press, USA.

Perfetti C. (1986). Conaime terapeutiche per la reeducatione moteria del l'emiplegico. Milano: Ghedini, 1986.

Pivec, P. (2009). Does Game-Based Learning Exist or is it Merely Game-Based Teaching?, Proceedings of the 3rd European Conference on Games Based Learning, FH JOANNEUM University of Applied Sciences, Graz, Austria, 12-13 October 2009.

Prigatano, G.P., Pliskin N.H., (Ed.) (2003). Clinical Neuropsychology and Cost Outcome Research, N.H. Psychology Press, Inc. New York, NY, 2003, pp.113-115.

Rand, D., Kizony, R., & Weiss, P. L. (2004). Virtual reality rehabilitation for all: Vivid GX versus Sony PlayStation II EyeToy. In 5th Intl. Conf. On Disability, Virtual Environments and Assoc. Technologies (pp. 87-94).

Reimer-Reiss, M. (2000). Assistive technology discontinuance. In Technology and Persons with Disabilities Conference.

Reinkensmeyer, D. J., & Housman, S. J. (2007). "If I can't do it once, why do it a hundred times?": Connecting volition to movement success in a virtual environment motivates people to exercise the arm after stroke, 44-48.

Reinkensmeyer, D. J., Pang, C. T., Nessler, J. A., & Painter, C. C. (2001). Java therapy: Web-based robotic rehabilitation. Integration of Assistive Technology in the Information Age. Citeseer.

Rheinberg, F. (1997). Motivation. Stuttgart: Kohlhammer.

Rood, M. S. (1954). Neurophysiological reactions as a basis for physical therapy. The Physical therapy review, 34(9), 444.

Rosen, J., & Perry, J. C. (2007). Upper limb powered exoskeleton. International Journal of Humanoid Robotics, 4(3), 529-548.

Rosson, M. B., & Carroll, J. M. (2002). Usability engineering: scenario-based development of human-computer interaction. Morgan Kaufmann Pub.

Sabari, J. S. (1991). Motor learning concepts applied to activity-based intervention with adults with hemiplegia. The American journal of occupational therapy.: official publication of the American Occupational Therapy Association, 45(6), 523.

Sackley, C. M., & Lincoln, N. B. (1996). Physiotherapy treatment for stroke patients: a survey of current practice. Physiotherapy Theory and Practice, 12(2), 87-96. Informa Healthcare.

Shumway-Cook, A., & Woollacott, M. H. (2006). Motor control: translating research into clinical practice. Lippincott Williams & Wilkins.

Stockmeyer, S. A. (1967). An interpretation of the approach of Rood to the treatment of neuromuscular dysfunction. American journal of physical medicine, 46(1), 900.

Sugarman, H., & Weisel-eichler, A. (2009). Use of the Wii Fit system for the treatment of balance problems in the elderly: A feasibility study. Design, 111-116.

Sukal, T. M., Ellis, M. D., & Dewald, J. P. (2007). Shoulder abduction-induced reductions in reaching work area following hemiparetic stroke: neuroscientific implications. Experimental Brain Research, 183(2), 215-223. Springer.

Twitchell, T.E. (1951). The restoration of motor function following hemiplegia in man. Brain, 74(4), 443. Oxford Univ Press.

Theodoros, D., & Russell, T. (2008). Telerehabilitation: current perspectives. Studies in health technology and informatics, 131, 191-209. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/18431862.

Thom T. et al.; Heard Disease and Stroke Statistics – 2006 Update. AHA Statistical Update; Circulation Journal of the American Heart Association. Feb. 14, 2006.

Thompson, M. L., Thickbroom, G. W., Laing, B. A., Wilson, S. A., & Mastaglia, F. L. (1996). Transcranial magnetic stimulation studies of the corticomotor projection to the hand after sub-cortical stroke. Movement Disorders, 11(25.1).

Timmermans, A. a., Seelen, H. a., Willmann, R. D., & Kingma, H. (2009). Technology-assisted training of arm-hand skills in stroke: concepts on reacquisition of motor control and therapist guidelines for rehabilitation technology design. Journal of neuroengineering and rehabilitation, 6(figure 1), 1. doi: 10.1186/1743-0003-6-1.

Traversa, R., Cicinelli, P., Bassi, A., Rossini, P. M., & Bernardi, G. (1997). Mapping of motor cortical reorganization after stroke: a brain stimulation study with focal magnetic pulses. Stroke, 28(1), 110. Am Heart Assoc.

Uhlenbrock, D., Sarkodie-Gyan, T., Reiter, F., Konrad, M., & Hesse, S. (1997). Development of a servo-controlled Gait Trainer for the rehabilitation of non-ambulatory patients. Biomedizinische Technik-Biomedical Engineering, 42(7), 196-202. Berlin, Fachverlag Schiele & Schon.

Vollmeyer, R., & Rheinberg, F. (2000). Does motivation affect performance via persistence? Learning and Instruction, 10(4), 293-309. Elsevier.

Voss, D. E., Ionta, M. K., Myers, B. J., & Knott, M. (1985). Proprioceptive neuromuscular facilitation: patterns and techniques. Harper & Row Philadelphia, PA.

Wattenberg, T. (2004). Beyond standards: reaching usability goals through user participation. ACM SIGACCESS Accessibility and Computing, (79), 10-20. ACM.

Westcott, P. (2000). Stroke-Questions and Answers, The Stroke Association. Stroke House, Whitecross Street, London.

Winters, J., & Wang, Y. (2003). Wearable sensors and telerehabilitation. IEEE Engineering in Medicine and Biology Magazine, (22), 56-65.

Wisneski, K. J., & Johnson, M. J. (2007). Quantifying kinematics of purposeful movements to real, imagined, or absent functional objects: implications for modelling trajectories for robot-assisted ADL tasks. Journal of neuroengineering and rehabilitation, 4, 7. doi: 10.1186/1743-0003-4-7.

Yavuzer, G., Selles, R., Sezer, N., Sutbeyaz, S., Bussmann, J. B., Koseoglu, F., et al. (2008). Mirror therapy improves hand function in subacute stroke: a randomized controlled trial. Archives of physical medicine and rehabilitation, 89(3), 393-398. Chicago, Ill.: American Congress of Physical Medicine and Rehabilitation, 1953-.

World Health Statistics (2007). Retrieved May 15, 2009 from http://www.who.int/whosis/whostat2007_10highlights.pdf

ADDITIONAL READING SECTION

Cirstea, M. C., & Levin, M. F. (2000). Compensatory strategies for reaching in stroke. Brain, 123(5), 940. Oxford Univ Press.

Levin, M. F. (1996). Interjoint coordination during pointing movements is disrupted in spastic hemiparesis. Brain, 119(1), 281. Oxford Univ Press.

Kamper, D. G., Mckenna-cole, A. N., Kahn, L. E., & Reinkensmeyer, D. J. (2002). Alterations in reaching after stroke and their relation to movement direction and impairment severity. Archives of Physical Medicine & Rehabilitation, 83, 702-707.

King, T. (1999). Assistive technology – essential human factors. Boston: Allyn & Bacon.

Scherer, M. J. (1996). Living in the state of stuck: How technology impacts the lives of people with disabilities (second ed.). Cambridge: Brookline Books.

KEY TERMS & DEFINITIONS

Rehabilitation, Robotic Therapy, Therapy, Rehabilitation Gaming, Stroke, Motivation, Computer Games, Serious Games, Elderly, Biofeedback, Motor Rehabilitation, Assistive Technologies.