Research Project:
Virtual Reality Based Neurocognitive Rehabilitation

by

Alexander Sacha Panic

Bachelor of Electrical Engineering
Hogere Technische School, Arnhem, 1997

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1 Introduction

1.1 Background

The advent of new technologies is widening the gap between the ‘technology enabled’ and the ‘technology disabled’. The ‘technology enabled’ group consists mainly of the younger generation, born into a world saturated with automation through computers, machines and gadgets. In contrast, those who have had only limited exposure to technology are unable to easily construct mental representation of how technology works, and therefore have difficulties in learning how to use these tools (Ijsselstein, Nap, de Kort, & Poels, 2007). This technology-disabled group increasingly consists of the elderly population. In the coming years, the percentage of elderly people in the population will increase: one in four Europeans by 2020 (Ijsselstein, Nap, de Kort, & Poels, 2007), and about one in four Americans by 2030 as reported by the United States’ Department of Health & Human Services[1].

The elderly population is particularly susceptible to acquiring cognitive deficits, either through dementia caused by a typical aging process, or through neurodegenerative diseases such as Alzheimer’s and Parkinson’s. Computer games are widely enjoyed as a leisure activity, but a relative new use for computer games is in the area of cognitive rehabilitation. If computer games can be designed to be rehabilitative, and to be used in a home environment, they may enable a larger part of the clinical population to prevent cognitive deficits or restore lost cognitive skills.

Designing virtual reality technology specifically for the elderly adds its own challenges. Fisk, Rogers, Charmes, Czaja and Sharit (2009) noted that this group is more heterogeneous than younger adults, due to a large variability in cognitive and motor skills. More than 50% of the problems reported by focus groups who tested out new technologies involved the usability of input/output devices and graphical interfaces. Another challenge is that both conventional and game-based rehabilitation exercises are typically not designed to be motivating (Flores, et al., 2008, Ijsselstein, Nap, de Kort, & Poels, 2007, Rizzo, & Kim, 2005) and not enough clinical studies have been done to evaluate their effectiveness.

1.2 Research questions

The background information provided in the previous section introduces the driving question for this research project:

> *“How can cognitive rehabilitation therapy effectively be supported by virtual reality? “*

While conducting the research study it became clear that there are opportunities for increasing patient motivation and adherence by using game-based rehabilitation scenarios. This provided a further focus for this research study. The goal of this research project became to gain insights in cognition and cognitive rehabilitation, virtual reality and game-based learning (see Figure 1). The following three subquestions have

[1] http://www.aoa.gov/AoARoot/Aging_Statistics/Profile/2009/4.aspx

been used during a review of the available literature.

1. *What is 'cognition' and how can it be assessed or rehabilitated?*

2. *How can cognitive rehabilitation be supported with virtual reality applications?*

3. *How can game-based learning environments be designed to be engaging and motivating for the learner?*

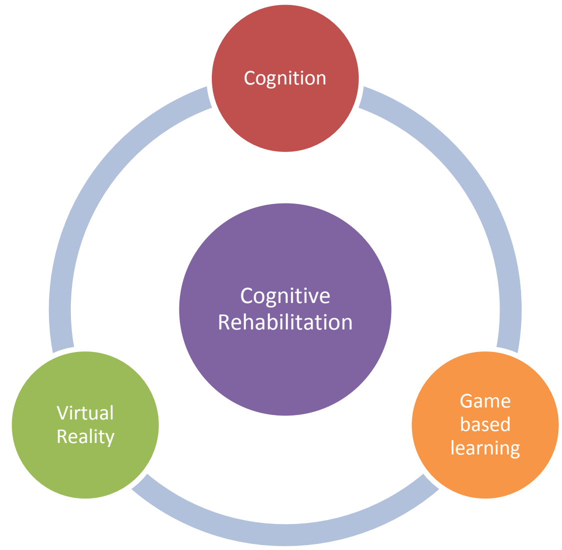

Figure 1 - The main topics related to the driving research question

This document presents the results from this literature review. The remaining sections of this chapter elaborate on the background and motivation for the choice of research questions (section **Error! Reference source not found.**), and ow the literature review was approached (section 1.3). The next three chapters present an overview of literature related to each of the three questions listed above. The final chapter discusses the findings and to what extent they answer these three questions.

1.3 Approach

For accessing the literature a few online repositories will be queried on a combination of keywords. These repositories include but are not limited to Web of Knowledge, IEEE, ACM and Google Scholar. Information from Wikipedia may be used as a background for more specific topics from papers published through the repositories. The keywords include but are not limited to cognition, cognitive- and neuro-rehabilitation, therapy, training, learning, assessment, validation, virtual reality, games, motivation, affect, emotion and design.

The findings from papers that are relevant to the topics presented in Figure 1, will be presented in the next chapters. The following chapter provides a brief introduction to cognition and cognitive interventions. Chapter 3 will present an overview of virtual reality based cognitive interventions, and Chapter **Error! Reference source ot found.** will provide an overview of current approaches to designing motivational games. Chapter 5 will discuss the bearings of the surveyed literature on the research questions posed in the previous section.

2 Cognition and neurocognitive rehabilitation

According to the Merriam-Webster[2] online dictionary, the term cognition originates from the Latin expression '*cognoscere'* which means 'to come to know'. How the process of cognition exactly works has for long been the subject of multidisciplinary research. This chapter investigates the topics cognition and cognitive rehabilitation (see Figure 1), in order to provide a basic representation of the terminology, processes and procedures involved with the latter. A refinement of the fist research question from section 1.2 resulted in the following literature review questions:

1. *What is 'cognition' and how can it be assessed or rehabilitated?*

    1a. *What is 'cognition'?*

    1b. How can it be clinically assessed?

    1c. What are the available strategies for clinical interventions?

    1d. Are there any evidence based recommendations?

The most relevant information found in literature has been summarized in the following sections of this chapter.
Section 2.1 starts with providing a brief overview of the key stages of cognition which have been identified.
Section 2.2 discusses the cognitive aspects of emotion, and how they can influence these stages of cognition.
Section 2.4 identifies of three general levels of cognitive functioning, each of which could be targeted by rehabilitation.
Section 2.5 introduces the theory of, and evidence for 'cognitive reserve' (Stern, 2009), a surplus of mental capacity which helps with acquiring, sustaining and increasing cognitive skills or coping with brain pathology. Sections 2.6 and 2.7 identify methods and instruments to assess the various levels of cognitive functioning, as well as strategies and methods for interventions which aim to restore a loss of cognitive functioning.
Section **Error! Reference source not found.** outlines which standards and ecommendations exist for rehabilitating specific cognitive functions.

2.1 Cognition in a nutshell

Although the brain and mind are not susceptible to being described in block diagrams, these diagrams can be a valuable tool in gaining a high level understanding of the underlying processes. Figure 2 shows how Groome and Duwart illustrate this process of knowing by identifying several key cognitive stages which are related to the flow of information (Groome, & Dewart, 1999). Perception involves the process of making sense of the environment that is perceived through the human senses. These include the ability to see, hear, smell, touch, and the sense of balance and

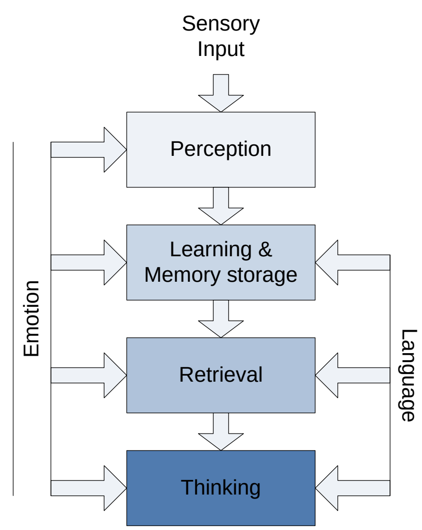

Figure 2 - A simplified representation of the stages of cognitive processing (after Groome, & Dewart, 1999)

[2] http://www.merriam-webster.com/

acceleration of the body. These abilities may be further subdivided into more detailed processes. For instance visual perception comprises the processing of color, form, depth, size and subsequent pattern recognition (Eysenck, & Keane, 2005). Perception also involves processes of attention, which help with discriminating between relevant and irrelevant information, and making appropriate selections of such information for further cognitive processing. In a similar way each of the stages of cognition in Figure 2 can be further divided into more detailed sub stages that are executed sequentially or in parallel.

Both the Learning & Memory storage stage and the Retrieval stage that Groome identified are related to memory. The process of learning involves the encoding of perceived information into meaningful representations. Baddeley and Hitch introduced the multi store model of memory (Groome, & Dewart, 1999), where working memory allows for further analysis and processing of information, while long term memory makes passive storage of such information possible. As can be seen in Figure 3, working memory exists of two passive short term stores for auditory (the phonological loop) and visual (the visuospatial sketchpad) information, and one central executive component where active processing is done. The output of the memory processes comprises information retrieval by the central executive from one of the available memory stores. The final stage of cognitive processing that was identified by Groome and Dewart, involves a range of different mental activities. The process of thinking may include problem solving, creativity, decision making and theorizing (Groome, & Dewart, 1999). This process can also be interpreted to comprise the application of knowledge in the appropriate situation (Cicerone, et al., 2005).

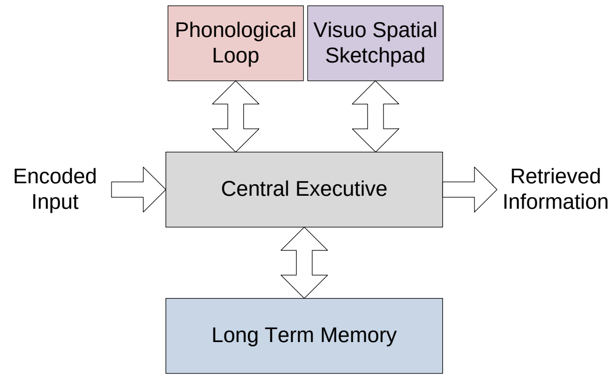

Figure 3 - A multistage model of working memory (after Groome, & Dewart, 1999).

Language is an important construct which influences cognitive processes. According to Cicerone et al, linguistic processes play a very important role in the general acquisition of knowledge as well as the mediation of several cognitive processes. Cognitive impairments often produce impairments in communicative skills (Cicerone, et al., 2005). Eysenk and Keane (2005) noted that the results from several studies suggest that language influences the ability to think, perceive, memorize and retrieve.

Emotion is another construct which influences cognitive processes. Since emotion is believed to have a cognitive part and is more closely tied to most if not all of the stages of cognitive processing, it will be discussed separately in the following section.

A degradation of cognitive abilities and subsequently a degradation of functional behavior can result from a number of different circumstances. According to the Diagnostic and Statistical Manual of Mental Disorders (DSM-IV, 1994) it may result from the normal aging process, traumatic brain injury (TBI), or neurodegenerative disorders such as Alzheimer's and Parkinson's diseases and dementia. Stroke, which is a loss of brain function due to disturbances in the blood supply to the brain, and several developmental disabilities such as Attention Deficit Disorder and learning disabilities, all may lead to loss of cognitive abilities (Rizzo, Buckwalter, Neumann, Kesselman, & Thiebaux, 1998)

2.2 Emotion and cognition

Emotion can be defined as a psychological response which is associated with the level of desirability of an occurred event (Dolan, 2002). The perception and subsequent memory storage of emotional events can happen both with conscious direction of attention and with absence of attention or awareness. Experiments have consistently shown that visual imagery that is associated with emotion, such as spiders or snakes, are detected more rapidly than emotionally neutral visual imagery (Dolan, 2002). Thus, emotion causes a capture of attention leading to a more rapid detection of emotional events. Sounds and music can capture attention and solicit or produce an emotional response in a similar way (Tajadura-Jimenez, & Vastfjall, 2008, Picard, 2000).

The enhanced memory for emotionally relevant events is one example of how emotion influences memory. Both positive and negative feelings associated with earlier behavior aid in pruning the mental search space when making similar decisions in the future (Picard, 2000, Dolan, 2002). Not only too much but also too little emotion can impair the decision making processes. Thus emotion may introduce a bias in reasoning towards, or away from a particular behavioral option. This construct may help explain anxiety disorders such as phobias or Post Traumatic Stress Disorders (Dolan, 2002, Eysenck, & Keane, 2005). Through memory emotions enter into processes which are used on an everyday basis, such as reasoning, decision making, creativity, planning, curiosity and fascination (Picard, 2000). The latter two may be at the base of many effective learning episodes (Picard, 2000).

To a certain degree, emotion has a cognitive aspect to it. Emotional influences are considered cognitive when they involve appraisal, comparison, categorization, inference, attribution or judgment (Picard, 2000). However investigating the exact nature of cognitive aspects of emotions is a complicated task, due to many possible confounding factors. Examples of such confounding factors are that emotions may appear as unobservable thoughts only, and are subject to cognitive interpretation as well as interpersonal differences (Picard, 2000).

2.3 Aging and cognition

Gamberini et al. (2006) noted three negative influences on an individual's cognitive abilities which are commonly emphasized in theories of psychological aging: a decline in the speed of information processing, a decrease in available mental resources, and a reduced capacity of working memory. Furthermore, older individuals also experience a number of other age-related changes, such as changes in visual perception, auditory perception, and physical dexterity (Gamberini, et al., 2006, Ijsselstein, Nap, de Kort, & Poels, 2007, Fisk, Rogers, Charmes, Csaja, & Sharit, 2009).

Decrements in the capabilities for visual perception are related to the ability to perceive detail, the range of possible focal adjustments, sensitivity to contrast, adaptation to low lighting environments, sensitivity to color, and a heightened susceptibility to problems with glare. Decrements in the capabilities for auditory perception are related to the sensitivity for pure and high tones, and the capabilities to localize sound. Decrements in mental resources involve working memory, attention, discourse comprehension, reasoning and problem solving, and the encoding to and retrieval from memory. Decrements in physical capabilities, such as postural stability and dexterity may be caused by arthritis, while tremors (caused by e.g. Parkinson's disease) affect the ability to manipulate objects and to perceive sensorial feedback such as pressure, vibration, roughness, length, orientation and spatial acuity (Gamberini, et al., 2006).

Other evidence provided in the literature suggests that age may be related to which strategies are preferred for dealing with for instance novel computer interfaces or tasks (Gamberini, et al., 2006). The preferred strategy may shift from a 'trial and error' based approach to a more reflective one. Band and Kok noted (2000) similar changes in strategy in response monitoring on a mental rotation task.

It may not be possible to rehabilitate all the influences on cognition that were mentioned in this section. Some of them may need to be addressed as usability concerns, as with the novel computer interfaces, while others require compensatory mechanisms for dealing with the decline in skill. These and other strategies for cognitive rehabilitation will be discussed in the following section.

2.4 Levels of cognitive functioning

For the purpose of this thesis three different levels of cognitive processing should be identified. First, basic cognitive processing entails elementary processing skills such as perception or memory. Although these processes may take the output of other processes as their input, they are not in control over the other processes. The second level of processing is related to 'executive functions' (Spreen, & Strauss, 1998). These processes can control other cognitive processes and are involved with planning, decision making and using feedback. Executive functions play an important role in exercising behavior that is appropriate in a given context. The third level of cognitive processing is on the level of general intelligence. Two subcomponents of general intelligence are of particular interest (Buschert, Teipel, Hampel, & Burger, 2009). Fluid intelligence encompasses all functions available for information processing, abstract thinking and problem solving, independent from specific knowledge about the environment or culture. Crystallized intelligence on the other hand is the ability to reason and reflect on acquired knowledge about the surrounding environment or culture.

2.5 Neuroplasticity and cognitive reserve

In the literature on child development a correlation between a measurable Intelligence Quotient and brain volume has been reported upon (Scarmeas, & Stern, 2003). Similarly, activities of everyday living which stimulate cognitive processes have been correlated to an increase in neuroplasticity (Stern, 2009, Snowdon, 2003). Neuroplasticity is the ability of the brain to alter existing connections between cells, to form new connections, to create new cells, and to resist to cell death. Stern embedded these psychological and physiological phenomena in the theoretical framework of 'cognitive reserve' (Stern, 2009). Cognitive reserve operates on two distinct levels. First on the level of neural reserve, which is explains the differences in neuron count that can be found among healthy individuals. And second on the level of neural compensation, which implies that the brain can alter the neural configuration underlying cognitive processes in order to cope with brain pathology.

Studies of healthy elderly concluded that an increase in cognitive reserve lead to an increase in their fluid intelligence (Buschert, Teipel, Hampel, & Burger, 2009). Evidence suggests that physically and mentally stimulating activities such as higher educational and occupational attainment, degree of literacy, and leisure activities are the most stable factors that contribute independently to cognitive reserve (Stern, 2009, Buschert, Teipel, Hampel, & Burger, 2009) The level of cognitive reserve is not fixed, meaning that at any point during a person's lifetime it results from a combination of exposures to cognitively stimulating activities (Stern, 2009). In healthy elderly it has been shown that cognitive reserve improves their performance in everyday activities, and increases their learning abilities for new content and strategies (Buschert, Teipel, Hampel, & Burger, 2009). Cognitive reserve may play a significant role in the brain's ability to cope with neurodegenerative diseases such as dementia or Alzheimer's disease. Studies on aging and cognition have reported that some subjects suffer from substantial neuropathology from Alzheimer's disease, but do not suffer from the commonly associated degradation of cognitive skills, if any (Snowdon, 2003). Cognitive reserve can slow down the emergence of cognitive impairments due to the consequences of the normal aging process or neurodegenerative diseases such as Alzheimer's disease (Scarmeas, & Stern, 2003). The exact consequences depend in part of location, type and amount of neurodegeneration: some regions of the brain are more important than others for cognitive, social and physical functioning (Snowdon, 2003). Although neurodegenerative diseases reduce brain plasticity and learning abilities, the cognitive reserve theory may explain why these consequences have been observed to be at least partially reversible or preventable (Buschert, Teipel, Hampel, & Burger, 2009).

2.6 Assessment of cognitive functioning

Several approaches for the assessment of an individual's mental functioning exist. Integrative approaches provide an indication of an individual's overall cognitive capabilities. The Intelligence Quotient test is a commonly known example of such a test. Other assessment approaches aim at measuring more specific cognitive skills such as the processes underlying perception. Two examples are the Stroop task shown in Figure 4, which is used to measure processing speed, selective attention and to evaluate executive functions (Spreen, & Strauss, 1998). Figure 5 shows another example, the mental rotation task (Shepard, & Metzler 1971) which can be used to measure spatial reasoning skills. Spatial reasoning is used as a general problem solving strategy, and thus is a measure of general intelligence (Cohen, et al., 1996). For a comprehensive overview of assessments for cognitive functioning see Spreen and Strauss' 'Compendium of neuropsychological testing' (1998).

Figure 4 - The Stroop task: reading the words on the second line is impaired due to the incongruent font color (Spreen, & Strauss, 1998).

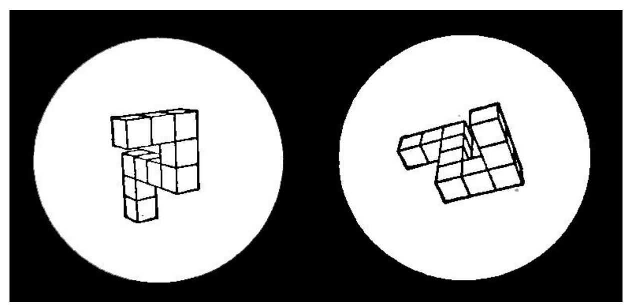

Figure 5 - The mental rotation task (Shepard, & Metzler, 1971)

Clinical assessments of cognitive functioning may have a different approach, in that they aim to verify correct functioning of cognitive systems contained in specific brain areas. Alternatively their aim may be to investigate the general performance on activities which are part of everyday life. Brief screening tests are one instrument used in the diagnosis of cognitive impairments associated with the degree of mental health. The patient's answers to a questionnaire are rated by the clinician, resulting in a final score which indicates the test subject's cognitive functioning in relation to the average scores of the (healthy) population. Examples of such screening tests are the Mini Mental State Examination (MMSE), Frontal Assessment Battery (FAB) and the General Practitioner assessment of Cognition (GPCOG). For an extensive overview of screening tests see (McDowell, 2006). These tests vary in reliability, mainly due to their susceptibility to be influenced by test subject's gender, age, ethnicity and intelligence, or by differences in how they are administered by different clinicians (Brodaty, Kepm, & Low, 2004).
Interviews and direct observations are an alternative method for assessing cognitive functioning. Clinicians may use information obtained by interviewing family member and caregivers about the everyday behavior of the patient in their diagnoses of Alzheimer's or dementia, or rate the patients behavior using direct observation and a behavioral assessment scale such as BEHAVE-AD (Sclan, et al., 1996).

Two main criteria that determine the adequacy of any measurement are reliability and validity (Rizzo, Buckwalter, Neumann, Kesselman, & Thiebaux, 1998). The reliability of an assessment implies that consistent results can be obtained, when it is applied to an individual with the same physiological or psychological symptoms. The validity of an assessment implies that the assessment (only) measures what it is supposed to measure. Traditional assessments often pose both reliability as well as validity issues.

2.7 Methods and strategies for neurocognitive rehabilitation

Cognitive rehabilitation methods can be classified in three categories (Buschert, Teipel, Hampel, Burger, 2009). The first category, cognitive training or cognitive therapy, aims to practice skills with standardized tests while assuming that an increased skill level generalizes to an increased performance in non-practiced areas. The second category, cognitive stimulation, consists of therapeutic activities and group discussions aiming to improve general cognitive and social skills. The third and final category, cognitive behavior therapy, is an individual and personalized intervention by a clinician (possibly cooperating with family members or caregivers) that aims to improve cognitive functioning in activities of everyday life. Cognitive behavior therapy makes no assumptions on a generalizing effect.

Besides a categorization in how cognitive rehabilitation is administered, the existing approaches can also be described according to their strategic goals. Cicerone et al. (2000, 2005) discerned the following cognitive rehabilitation strategies:

1. To reinforce, strengthen or reestablish patterns of behavior that were learned prior to the loss of cognitive functioning.

2. To establish new patterns of cognitive activity through compensatory mechanisms for impaired neurological systems.

3. To establish new patterns of cognitive activity through external mechanisms of compensation, such as providing environmental support (for instance by using virtual reality to evaluate how to create 'dementia friendly' public spaces, as in (van Schaik, et al., 2006).

4. To enable individuals to adapt to their disability or handicap, in order to improve their overall level of functioning and quality of life.

During talks with a cognitive psychologist at the Swiss Federal Institute of Technology in Zürich in 2010, the three possible stages of the therapeutic life cycle as shown in **Error! Reference source not found.** ere identified. During these stages an individual may have different needs for rehabilitation support. If an individual suffers from traumatic non-permanent brain injury which prevents him from independent living, the rehabilitation needs are acute and the he may be admitted to a clinical program, supervised by a therapist. When his cognitive skills are partially restored, the individual may receive chronic rehabilitation in the form of exercises which can be carried out in a home environment, possibly supervised by a caregiver (either professional or family member). If a cognitive skill such as short term memory cannot be fully restored through rehabilitation, then an individual may benefit from in-situ assistance, for instance through a Personal Digital Assistant which can be used to keep a list of activities for the day (such as maintaining a shopping list for the grocery store).

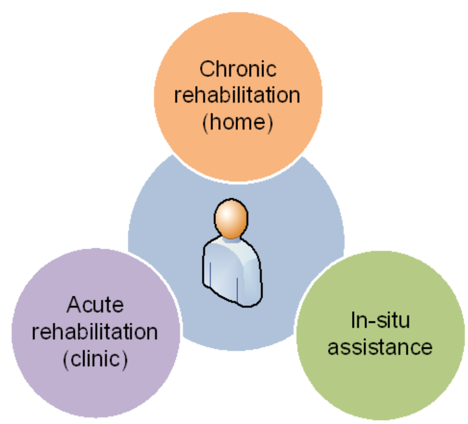

Figure 6 - Different needs for rehabilitation support during the therapeutic life cycle

There appears to be a variety of methods and strategies for cognitive rehabilitation with widely divergent approaches and goals. Without any further evidence on their effectiveness it may be difficult to choose a suitable method or strategy. Therefore the following section will look at what evidence about the effectiveness of various approaches to cognitive rehabilitation is available in the literature.

2.8 Evidence based neurocognitive rehabilitation strategies

Cognitive rehabilitation can either aim to be restorative, in that cognitive processes are systematically retrained. Or it can aim to be functional, in that the training of observable behavior is emphasized (Rizzo, et al., 2000). A clearly defined and agreed upon theoretical basis for deciding which type of cognitive rehabilitation is the most effective does not appear to exist (Rose, 1996, Cicerone et al., 2000, 2005, Buschert, Teipel, Hampel, & Burger, 2009, Cappa et al., 2005).

A group led by Cicerone performed a methodological review of the scientific literature in which the evidence for the effectiveness of cognitive rehabilitation for persons with TBI or stroke was investigated (Cicerone, et al., 2000, 2005). These extensive reviews led to evidence based recommendations for clinical interventions for the rehabilitation of attention deficits, visuo-spatial abilities, language and communication deficits, memory deficits, executive functioning and problem solving and motor planning deficits. A group led by Cappa reported on a study with a similar setup and focus on cognitive rehabilitation (Cappa, et al., 2005).

It is beyond the scope of this thesis to list all of the recommendations that were noted, as they may be specific to the cognitive functions that were addressed in the studies that were reviewed. However some generalizing remarks can be discerned from the literature. Interventions can focus on the rehabilitation of basic cognitive skills as well as executive functioning. It is arguable that a comprehensive or holistic approach is the best way (Cicerone, et al., 2000, Rose, 1996). This approach combines individualized treatment (of basic skills, or skills oriented at psychosocial or vocational functioning) with group treatment (of social skills). During these interventions the clinician may act out different roles and responsibilities. They include actively engaging the patient in exercises, and more passively monitoring the patient’s performance and offering feedback and deciding on the teaching strategies (Cicerone, et al., 2000).

If a computer program is used as an aid for training skills such as language and communication, it should always keep the clinician involved, informed and responsible for the teaching strategies and content that is used. Computer based training should aim to aid clinicians, not replace them (Cicerone, et al., 2000). Furthermore, the patient’s performance can significantly improve if the interventions should include training with different stimulus modalities, level of complexity and response demands (Cicerone, et al., 2000). This appears to increase the benefits of the intervention and may facilitate the generalization of the learned skills to (instrumental) activities of daily living (ADL). As an example consider a visuo-spatial ability such as the Mental Rotation Task, which requires the two images to be visually scanned and processed into working memory before a decision on their equality can be made. Visual scanning is a key cognitive ability which is required in many everyday situations involving reading, writing, driving a car, and solving arithmetic problems (Cicerone, et al., 2000).

Cognitive interventions seem to have the most effect on those with mild to severe cognitive impairments (Cicerone, et al., 2000). It appears that cognitive rehabilitation produces greater improvements than pseudo treatments such as mentally challenging leisure activities (Cicerone, et al., 2005). However this conclusion is in contrast with the results obtained by Snowden where brain pathology associated with Alzheimer’s disease did not lead to the loss of cognitive functioning, presumably because of leisure activities (Snowdon, 2003). More controlled clinical studies are needed in order to increase the available evidence upon which future recommendations can be made.

3 Virtual reality based cognitive rehabilitation

In 2005 Rose noted that virtual reality applications for cognitive rehabilitation face the same challenges as in the 1990s (Rose, 2005). This chapter will not provide a detailed overview of the virtual reality based applications that have been made to support cognitive interventions, but more so to find out what can be learned from them when designing or implementing new applications. Research question 2 (see section 1.2) was further specified before it was investigated. This resulted in the following sub questions:

2. *How can cognitive rehabilitation be supported with virtual reality applications?*

    2a. What is 'virtual reality?

    2b. How can it support cognitive interventions?

    2c. What are the human factors involved?

    2d. What relevant recommendations have been done in prior work?

The following sections present the results from the literature survey related to these subquestions.
Section 0 introduces a virtuality continuum which helps with identifying applications which aim to present an alternate reality to one or more observers. The continuum encompasses reality and virtual reality as two extreme opposites, and all forms of mixed or augmented reality in between them.
Section **Error! Reference source not found.** investigates the strengths, weaknesses, opportunities and threats f virtual reality based neurocognitive rehabilitation.
Section 3.3 outlines some of the human factors that are involved with virtual reality based applications, focusing on human performance, side-effects such as cyber sickness, and health and safety issues.
Section 3.4 investigates using games technology for neurocognitive rehabilitation.
Section 3.5 discusses design recommendations for the virtual environments and the rehabilitation protocol that have been identified in the literature that was reviewed.

3.1 From reality to virtual reality

In 1962 the US Patent Office awarded a patent to Morton Heilig for what he called a Sensorama Simulator[3] (Heilig, 1962). This device, shown in Figure 7, could provide the illusion of an alternate reality to one to four users by presenting them with visual, olfactory, auditory and tactile stimulations. Heilig saw potential for such a device to be used to provide industry professionals with training and instructions on the maintenance and manufacturing of complex machinery. In 1968 Ivan Sutherland proposed and later created a computer system that used a head mounted display that had to be worn by the user, as shown in Figure 7 (Sutherland, 1968). The partially opaque nature of the head mounted device enabled the user to still see the environment that surrounded him, but partially augmented with computer generated imagery.

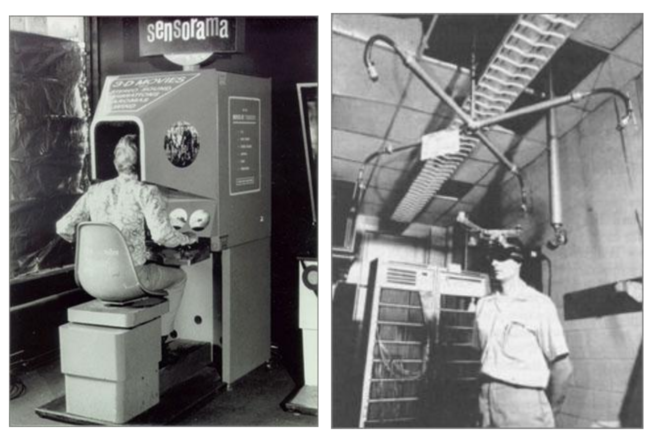

Figure 7 – The Sensorama Simulator on the left (Heilig, 1962), and Sutherland's head mounted display (Sutherland, 1968)

[3] http://www.mortonheilig.com/InventorVR.html

Physical movements of the users head were measured by position and orientation sensors, which enabled the computer to update the perspective of the generated visual imagery accordingly.

Milgram, Takemura, Utsumi and Kishino (1994) devised the virtuality continuum as shown in Figure 8, and an accompanying taxonomy to classify applications that aim to create an illusion of an alternate reality. Since Sutherland's system did not completely replace the user's perspective on reality, but augmented it with graphical elements modeled with a computer, it is classified as an 'augmented reality' application. Similarly since Heilig's Sensorama Simulator completely replaced the user's perspective on reality, it is commonly perceived as the first instance of a 'virtual reality' application.

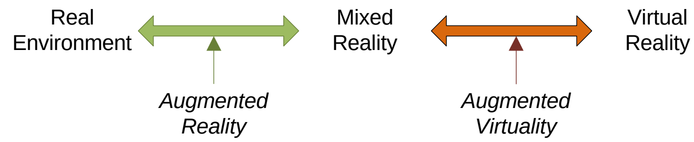

Figure 8 - The virtuality continuum in simplified form.

These initial technologies for presenting the user with interactive virtual or mixed reality environments have been succeeded by many more. Desktop computer monitors can be used to present the user with a non-immersive 'window on the world' (Milgram, Takemura, Utsumi, & Kishino, 1994), while stereoscopic projection displays provide only partial immersion by creating the illusion of a virtual objects floating in front of the display surface. Similarly the diversity of interaction devices has increased, offering a variety of computer mice, joysticks, data gloves, game pads and inertial sensors, among others. Finally the commonly available computing technology has become more capable of performing the calculations required for representing smoothly animated, visually rich and dynamic virtual environments.

3.2 An analysis of Strengths, Weaknesses, Opportunities and Threats.

3.2.1 Strengths

Rizzo and Kim published (2005) an analysis of the Strengths, Weaknesses, Opportunities and Threats (SWOT) that are involved with using virtual reality based applications for cognitive rehabilitation. A Strength is an attribute that is internal to the application and that is helpful to achieving the objective, while a Weakness is an attribute internal to the application that is harmful to achieving the objective. An Opportunity is an environmental attribute (that is external to the application) and is helpful to achieving the objective, while a Threat is an environmental attribute that is harmful to achieving the objective. The analysis provided by Rizzo and Kim served as a base for the analysis that will be presented in the following paragraphs. Some of the issues they noted were omitted, and some others have been added that were collected from other relevant publications. This has lead to a SWOT analysis as shown in Figure 6, which is more tailored towards virtual reality based rehabilitative applications for use in a home environment.

The primary strength of virtual reality based cognitive intervention is related to the fidelity of the assessment and intervention environments that it can offer. The clinician can have precise control over the exposure to as well as complexity of the environmental stimuli (Rizzo et al., 1998, Burdea, 2003). Furthermore virtual reality offers the possibility to improve the standardization of the stimuli that are presented, through quantification of multiple characteristics of the stimuli (Rizzo et al., 1998). The training environments themselves can be designed to rehabilitate basic cognitive skills, executive functions as well as fluid intelligence. They can offer graded exposure to ecologically valid training environments, to allow practicing activities of everyday life. All these capabilities extend the differential diagnostic capabilities of conventional methods of assessment (Rose, 1996). Examples of ecologically valid environments are V-STORE to practice with the activity of grocery shopping for patients diagnosed with Dysexecutive Syndrome (Castelnuovo, Lo Priore, Liccione, & Cioffi, 2003),

	HELPFUL **In achieving the objective**	**HARMFUL** **In achieving the objective**
INTERNAL ORIGIN **Attributes of the system**	• High fidelity assessment environment • High fidelity and progressively complex training environment • Ecologically valid training environments • Semi-autonomous training at home can free up clinicians time for other activities • Interfaces can be modified to match the users specific sensory-motor impairments • Low cost consumer grade computing and graphics hardware commonly available • Gaming factors can enhance users motivation • Economy of scale S	• Interface challenge: wires, displays and peripherals • Interface challenge: Providing universal access for entire (clinical) patient population may be impossible • Side-effects during or after usage may never be completely avoidable • Engineering challenge: Usability affects both clinicians and patients • Engineering challenge: performance measure extracting, management, analysis and visualization • Engineering challenge: creating 'ecologically valid' environments can be a significant amount of work • Cognitive deficits can be individualized and diverse W
EXTERNAL ORIGIN **Attributes of the environment**	• Emerging technologies: ergonomic and wireless interaction devices • Emerging technologies: wearable computing providing physiological monitoring • Create rehabilitation applications with widespread intuitive appeal to the public • Address cognitive deficits during preclinical stages of neurodegenerative diseases • Increase cognitive reserve, delaying or preventing clinical effects of neurodegenerative diseases • Situated cognitive intervention • Telerehabilitation O	• Safety and health issues, not just for cognitive or sensorimotor impaired • Sideeffects lawsuit potential • Ethical challenges • Privacy issues with telerehabilitation T

Figure 9 – SWOT analysis of virtual reality based rehabilitation for home use, after Rizzo and Kim (2005)

or Virtual Reality Exposure Therapy for the treatment of the fear of flying (Brinkman, Sandino, & van der Mast, 2009). If such environments are made available for practicing at home while keeping the clinician informed about the patients progress, the clinician may not need to spend as much time administering repetitive exercises and can spend that time on other activities or patients.

Engineering methods from human-computer interaction research may provide the means to create universally accessible applications, both with regards to the graphical user interface (GUI) as well as the input device configuration(s) being adapted to the diverse physiological abilities of the clinical population. Commodity (consumer grade) computing hardware currently has enough processing and graphics power to support virtual reality based applications. When this technology is combined with internet connectivity and becomes readily accessible to a large group of people, there is an increased potential for rehabilitative applications to be distributed to patients' homes. As Burdea noted (2003), therapists are often unevenly geographically distributed. They are more likely to operate in or near urban areas than in rural areas, meaning that not every potential client has equal access to specialized health care such as cognitive rehabilitation.

One other strength which this thesis project has focused on is that investigating the design and engineering of computer games technology may lead to useful suggestions about how to design rehabilitation exercises that engage and motivate the patient. This will be further investigated in section **Error! Reference source not found.** f this document.

3.2.2 Weaknesses

Even though the availability and performance of computing and graphics hardware has increased drastically in the last decades, the development of head-mounted displays (HMDs) and other peripheral devices is lagging behind (Rizzo, Strickland, & Bouchard, 2004). Immersive virtual reality applications thus remain costly and affordable only to research institutes and large organizations. Furthermore, those peripherals that are available often suffer from ergonomic issues, such as the weight of HMDs or the wiring that still is common to many input devices. Even when these problems are resolved, providing truly universal access for the entire target audience will likely remain an elusive goal. There will always be individuals who, due to physiological impairments, cannot operate input devices. Individual user characteristics may make some people more susceptible to cyber-sickness, or less capable of adapting to operate a virtual environment (Stanney, Mourant, & Kennedy, 1998). The side effects may be minimized by increasing the quality of peripheral devices such as HMDs, but the problem is likely to remain an issue for some individuals (Rizzo, Strickland, & Bouchard, 2004).

A number of the weaknesses relate to engineering challenges. In theory they should not have to be weaknesses because the engineering methods and best practices are well known and documented, however in practice, as noted by Rizzo and Kim (2005), immature engineering processes often lead to suboptimal results. The usability of a virtual reality based rehabilitation system is often perceived in terms of the user that is engaged with the virtual environment. However the clinician, who may also be present and to some extent engaged in direct control over the presented stimuli, is another user who is often overlooked. Since most clinicians are rarely also trained as computer scientists, they need to be accommodated with automated performance measure extraction, analysis, and graphical visualizations. The clinicians may even be novice computer users instead of experts, so that the graphical interfaces for them must be tailored to match their needs and capabilities (Rizzo, & Kim, 2005). During a therapeutic session their primary concern may be to interact with the patient, and not with controlling the simulation. This must be taken into consideration when designing a GUI which supports the clinician with the appropriate level of automation or abstraction from the details.

Another related engineering challenge is that it may take a significant amount of effort to engineer ecologically valid training environments (Rose, 1996). A common criticism of these environments is that they are built with the assumption of a static world in which few changes can be made to satisfy situational demands (Morganti, 2004). Furthermore, given the diversity in manifestations of cognitive impairments (see section **Error! eference source not found.**), it may be that many such ecologically valid, complex, and dynamic virtual environments would be required to accommodate the needs of the entire targeted population.

3.2.3 Opportunities

Virtual reality based rehabilitative applications for use in a home environment may benefit from a number of emerging technologies. During recent years some input devices have become available with ergonomic properties that may be more suitable to people with little to no experience with computers. A few of these devices are shown in Figure 10. They include custom keyboards such as the XKeys from Pi Engineering[4], which can be configured with differently sized and colored keys to match the user's perceptual and motor skills. Some of these new input devices allow for more embodied interactions, such as the Nintendo Wii Remote[5], which allows users to interact with virtual objects with natural motions. Objects in virtual environments can be selected by pointing the device at the objects and pressing one or more buttons for further manipulation. In a

[4] http://www.xkeys.com
[5] http://www.nintendo.com/wii/console/controllers

similar vein, Microsoft's announced Kinetic[6] technology is an input device that allows users to interact with virtual environments by speech recognition, facial recognition, and full body gestural movements. This completely eliminates the need for the user to physically hold and manipulate an input device. Touch based interactions are also enabled by devices such as Apple's iPad[7].

Figure 10 - Emerging input device technology, from left to right: XKeys, Kinetic, Wii Remote, and the IPad.

Another emerging technology which may play a role in virtual environments is wearable computing. Sensors can be embedded in clothing in order to monitor the user and provide physiological measures of the user's state, such as heart beat rate and galvanic skin response. This data could then be sent to the clinician while the patient is engaged with therapeutic tasks (Burdea, 2003). If applications can be created which assess, rehabilitate, and increase cognitive skills, as well as have a widespread appeal to the public, the opportunity may arise for addressing cognitive deficits during the preclinical stages of neurodegenerative diseases.

Situated cognitive intervention may be able to provide patients with therapeutic activities in their home-environment. For instance, the patient could be asked to perform practice tasks such as "Do you remember where your car keys are? Could you please go find them?" A variation of this concept is tele-rehabilitation, in which the patient engages with rehabilitation exercises at home while the clinician remotely monitors the progress. Tele-rehabilitation only extends the clinical part of the treatment, it does not replace it. It may make rehabilitation more accessible to patients who do not live in close vicinity to the clinics, which usually are located in urban areas (Rizzo, Strickland, & Bouchard, 2004). As it reduces the time that a clinician must spend on the one-to-one administration of repetitive exercises, it frees up the clinician's time to engage with other tasks or other patients. Compared to traditionally prescribed home exercises, the remote monitoring may increase the patient's compliance and reduce the variability in treatment outcome. Furthermore, tele-rehabilitation may reduce the total cost for health care (Burdea, 2003).

3.2.4 Threats

There are also a number of threats to the application of virtual reality for rehabilitation of cognitive skills. A number of potential health and safety issues may be unavoidable, due to the interpersonal characteristics that may cause cyber-sickness or other side effects (Stanney, Mourant, & Kennedy, 1998). Side effects such as postural instability may not be significantly present with younger and healthy users of virtual environments, but with the elderly these side effects may become more relevant. Cognitive impairments caused by aging, traumatic brain injuries, or neurodegenerative diseases may further increase the susceptibility to side effects and the risk of injuries during or after exposure to the virtual environment. This may result in lawsuits against the providers of the technology, with perhaps in some cases a fair chance of winning the argument.

[6] http://www.xbox.com/en-US/kinect/
[7] http://www.apple.com/ipad/

A number of ethical challenges accompany the introduction of virtual reality based technology. Although the pilot studies that have been conducted provide promising results, the rehabilitation protocols in used have not yet been validated. This implies that patients could potentially receive greater benefits from traditional rehabilitation approaches (Castelnuovo, Lo Priore, & Liccioni, 2003). The remote monitoring that tele-rehabilitation makes possible may also raise some ethical issues. Patients may be concerned about their privacy being safeguarded with sensitive medical information being sent across the internet, or they simply may not be open for someone scrutinizing their behavior in their private home environment (Rizzo, Strickland, & Bouchard, 2004). Just as is the case with some computer games, users may also develop a dependence on, or addiction to these virtual environments (Rizzo, Strickland, & Bouchard, 2004). These ethical issues need to be considered when creating virtual reality applications for use in a home environment.

3.3 Human factors in virtual reality based applications

At least three categories of human factors appear to be relevant for virtual reality based applications. The following sections will discuss which characteristics affect human performance in virtual environments: the issues posed by cyber-sickness and other side effects that can occur from exposure to virtual environments, and the health and safety issues that may be caused by these factors and thus need to be taken into consideration when designing a virtual environment.

3.3.1 Human performance in virtual environments

Stanney , Mourant, and Kennedy identified (1998) three categories of factors that influence human performance in virtual environments. These categories are task characteristics, individual user characteristics, and the limitations of human sensory motor physiology.

Some tasks may be better suitable for embedding in a virtual environment than others. Identifying which tasks are suitable to perform in virtual reality requires understanding the relationship between task characteristics and the corresponding virtual environment characteristics, such as the need for stereoscopic or monoscopic presentation, the level of immersion, and the amount of required interactivity (Stanney, Mourant, & Kennedy, 1998). The control and the speed of movement in the virtual environment also influence human performance (Stanney, 1995).

Users can differ in their capabilities for information input, throughput, and output (Stanney, Mourant, & Kennedy, 1998). Examples of information input differences are inter-pupillary distance, which affects the suitability of a HMD, and disabilities such as color blindness. Information throughput differences relate to cognitive and perceptual styles. For instance, some people prefer visually presented information, while others prefer auditory information (Holbrook, Chestnut, Oliva, & Greenleaf, 2009). The user’s level of experience with computers and computer games may also influence task performance, as it influences the skill level and the manner in which the task-related information is organized and understood. Expert and novice users may have different requirements and capabilities which may not necessarily be compatible. Deficits in perception and cognition, possibly related to age, also influence human performance, as they may impair the ability to learn or execute the task in the virtual environment.

The third category of factors that influence human performance in virtual environments relates to the properties of human sensory motor physiology, including visual, auditory, haptic, and kinesthetic perception (Stanney, Mourant, & Kennedy, 1998). The human visual system is very sensitive to anomalies in perceived visual imagery, especially when motion is involved. If a virtual environment is not able to approximate optical visual flow cues and timings then the sense of presence ('really being there') will decrease (Stanney, 1995; Stanney, Mourant, & Kennedy, 1998). When stereoscopic imagery is presented to the user, it is critical that the images are adjusted to the user's inter-pupillary distance. Furthermore, the limited field of view (FOV) offered by HMDs is a major factor in limiting the sense of presence.

For auditory perception, the 3D localization of sound may be the most important property to properly simulate in order to maintain a sense of presence. This is however dependent on the task that is presented in the virtual environment. For instance, in a virtual environment that aims to train a user to safely cross a busy street, it may be essential to incorporate sounds that can be perceived from distinct directions. When a virtual environment aims to train basic visual cognitive skills, this may be of less importance.

Tactile and kinesthetic perception may be of even less importance for virtual environments supporting the rehabilitation of cognitive skills. All of these properties of human sensory motor physiology may affect human performance in virtual reality, but may also play a role in producing side effects during or after exposure to a virtual environment. These side effects are briefly discussed in the next section.

3.3.2 Cyber-sickness and other side effects of exposure to virtual environments

Cyber-sickness has been identified as one of the most important side effects of exposure to virtual environments, as it may have consequences for health and safety (Stanney, 1995). Symptoms of cyber-sickness include, but are not limited to, nausea, disorientation and postural instability. These symptoms may have a lasting effect, for a brief period after the exposure to the virtual environment has ended. Theories of sensory conflict are often used to explain the phenomenon (e.g. Stanney, 1995, Rizzo, & Buckwalter, 1997, Cobb, Nichols, Ramsey, & Wilson, 1999). These theories postulate that the symptoms may occur as a result of a perceived conflict between the three major spatial senses: the visual system, the vestibular system (balance and spatial orientation), and the proprioceptive system (relative position of body parts). A virtual environment can cause sensory conflict when an individual moves through the virtual environment without physically moving his or her body. The visual system receives signals that indicate self motion, but the expected signals from the vestibular system are absent. Another common example occurs when an individual changes their head position or orientation, but the visual representation of the virtual environment changes only after a small delay. This lag in the computer system can produce cyber-sickness.

Much research has been conducted on cyber-sickness and other virtual reality side effects. Cobb, Nichols, Ramsey and Wilson (1999) reported on an investigation of possible symptoms and their effects on human behavior and performance both during and after exposure to the virtual environment. Physical symptoms in the form of bodily discomfort were caused by the ergonomic aspects of the HMD and the handheld input devices that were being used. Physiological symptoms that were reported included an increased heart rate during exposure to the virtual environment. Lewis lists an overview of additional symptoms that were reported such as eyestrain, visual fatigue, headache, and difficulties in focusing (Stanney, Mourant, & Kennedy, 1998). Changes in performance related to postural stability, psychomotor control, visual perception, and concentration were noted by both Cobb and Lewis in a period following the exposure to the virtual environment. Variability has been noted in the duration of the aftereffects. For 25% of the participants who reported them, the side effects lasted for more than 1 hour. For 8% they lasted for more than 6 hours (Stanney, Mourant, & Kennedy, 1998). Similarly Cobb, Nichols, Ramsey and Wilson noted (1999) individual differences between the participants in the presence of these side effects, and concluded that individual differences may be the most important determinant for participant's experiences of side effects. 20% of the participants did not report any side effects at all, 75% reported only mild side effects, while the remaining 5% reported severe cases of side effects. A confounding factor may be that some participants adopted strategies for interacting with the virtual environment that reduced the possibility of side effects but also may harm their performance, such as reducing the amount of head and body movement. Lewis presented and discussed a list of factors that influence all these side effects of virtual reality, grouped together in several categories (Stanney, Mourant, & Kennedy, 1998). The first category relates to user characteristics such as age, gender, medication, and prior exposure to virtual reality systems. The second category relates to system characteristics, such as display properties and lags. The last category relates to task characteristics such as movement through and interaction with the virtual environment.

3.3.3 Health and Safety issues

Although the side effects that have been described in the reviewed literature are all transient in nature, they may pose serious dangers to personal health and safety. Stanney discerned three levels of effects that may potentially be harmful to personal health and safety (Stanney, 1995). Examples of direct microscopic effects are eye damage caused by ocular problems during prolonged use of HMDs. Direct macroscopic effects may arise from reduced performance after exposure to virtual environments, due to cyber-sickness or postural imbalances. The latter may lead to postural sway and increase the risk of falling (Stanney, Mourant, & Kennedy, 1998). Indirect effects may be caused by decreased performance due to some side effects, such as reduced hand-eye coordination. These aftereffects may be harmful to real world tasks such as participating in traffic. A criticism on using virtual reality for rehabilitation of social skills is that it may cause an over-reliance on, possible addiction to, or obsession with the virtual environment. Ultimately this may result in the patient declining real-world social interactions. In this way the preference for the ‘safe haven’ that virtual environments provide may actually hinder the development of ‘real world’ social skills (Standen, & Brown, 2005).

3.4 Using games technology

Another area in which applications of virtual reality have emerged is in the videogame industry. Since the late 1970s, computer games have attracted and engaged many enthusiastic players; however, in order to be able to play these games, an individual had to have an above average understanding of how to operate computers and their software. In recent years, technology and game manufacturers such as Nintendo have been at the forefront of marketing their gaming platforms to a broader audience. Their focus has been on creating consoles (such as their handheld console the Nintendo DS) and input devices (such as the Wii Remote) that allow for more intuitive patterns of interaction which are accessible by not just the technology savvy but by a much broader audience. These are complemented with games which target the casual player, such as for instance ‘party games’ enjoyed in a social setting.

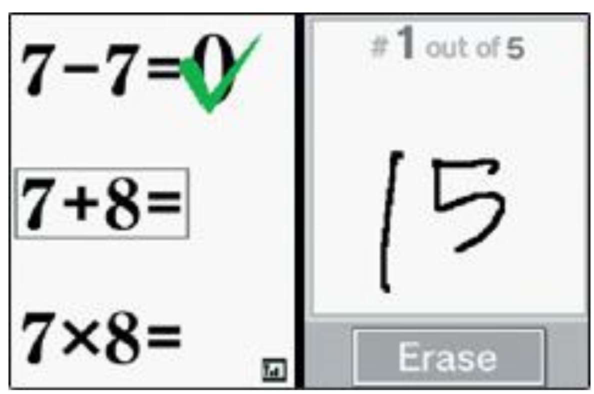

Figure 11 - Dr. Kawashima's Brain Training game

One of the available casual games is ‘Dr. Kawashima’s Brain Training’[8] for the Nintendo DS (see Figure 12). This game title consists of several short games which require only a few minutes to play. Each of these mini-games requires the player to complete simple cognitive tasks, such as reading aloud or

[8] http://www.braintraining.com.au

performing arithmetic calculations. Some of these tasks appear to be based on standard cognitive tests, as found in Spreen and Strauss' compendium (1998). A clinical study with patients diagnosed with Alzheimer's was conducted by Kawashima et al. (2005). Some of the patients practiced with reading aloud and performing arithmetic calculations two to six days a week for a period of six months. The control group of patients did not receive this training. Based on standard assessments, the researchers concluded that the mental functioning of the patients who had received the training had improved significantly.

Another study performed by Haier, Karama, Leyba and Jung (2009) used brain imaging techniques to investigate the impact on brain plasticity of structural practice with a simple visuo-spatial task. Test participants were required to play a computer game (Tetris) for about 1.5 hours a week for three months. Tetris[9] (see Figure 11) is a puzzle game in which falling geometric shapes must be rotated and moved so that they stack up tightly at the bottom of the screen. After three months of playing, the magnetic resonance image (MRI) scans of the participants' brains showed an increase in brain plasticity in an area which is considered to play a critical role in multimodal perceptual analysis. These changes were not present in the MRI scans of test subjects from the control group who did not practice with the game. Although their findings suggest that playing a game of Tetris is processed as a general cognitive puzzle instead of a memorized procedure that leads to a solution, the researchers also noted that it remains to be determined if these changes generalize to performance changes in other cognitive domains such as working memory, processing speed or spatial reasoning (Haier, Karama, Leyba, & Jung, 2009).

Figure 12 - Tetris game

More studies are needed that investigate three questions related to computer games used for rehabilitation. The first question is what the design criteria are that satisfy both the nature of the rehab program as well as preferences of most elderly users in order to create a motivational program that promotes patient adherence (Flores, et al., 2008). The second question is whether off the shelf commercial games suitable for rehabilitation purposes or if specific games must be developed (Flores, et al., 2008). The third question is whether games should be designed to train particular cognitive skills, or if they should have a more holistic approach and train comprehensive activities of daily life. The general conclusion found in relevant literature is that games designed for cognitive training do improve the targeted skills (Kawashima, et al., 2005, Haier, Karama, Leyba, & Jung, 2009, Owen et al. 2010), but that more (clinical) research must be conducted to investigate if these improvements generalize to activities of daily life (Rizzo, Wiederhold, & Buckwalter, 1998, McGee et al., 2000, Haier, Karama, Leyba, & Jung, 2009, Owen, et al. 2010).

3.5 Recommendations

This section includes a number of design and engineering recommendations, based on the SWOT analysis and literature survey presented in the previous sections.

[9] http://www.tetris.com

3.5.1 Virtual environment recommendations

A number of basic questions should be considered when evaluating virtual reality as a potential tool for cognitive rehabilitation. Rizzo published a list of these considerations (Rizzo, Wiederhold, & Buckwalter, 1998) which has been repeated in subsequent literature (e.g. McGee, et al., 2000).

First, the development and deployment of a virtual reality system may require a significant investment of time, money and other resources. The benefits that result from the developed application must outweigh these costs. One consideration that must be made is whether the same rehabilitation objectives can be accomplished using a simpler and less expensive approach. As an example, Murray et al. reported (2006) on an immersive virtual reality application for the rehabilitation of phantom limb pain, while Ramachandran and Rogers-Ramachandran (2000) reported that an ordinary mirror from a “five and dime” store produced similar clinical results: the reduction of perceived phantom limb pain. Although there may be benefits to using an immersive virtual reality based system, according to Rizzo, Buckwalter, Neumann, Kesselmann and Thiebaux (1998) the primary aim should be “elegant simplicity” instead of technological prowess. Riva notes (2009) that in virtual environments aimed at cognitive rehabilitation, reproducing precise physical aspects of a real environment may be less important than the possibility of interaction that it allows. In clinical oriented environments the level of presence has been found to depend on the level of interaction and possible interactivity (Castelnuovo, Lo Priore, & Liccione, 2003).

Another important consideration is whether a virtual reality based approach can be optimized to match the characteristics of the target clinical population. The target audience may be very heterogeneous in areas including apprehensiveness to use a HMD, differences in the capacity to learn to operate a virtual environment, and in the susceptibility to cyber sickness and other aftereffects. This suggests that it may be beneficial to involve user representatives during the design of the system. They should be chosen so as to represent as many different user types as possible, including end-user (patient), clinician, and researcher. Furthermore, design methods such as those proposed by Grammenos, Savidis and Stephanidis (2004), which promote universally accessible interfaces, could be used and may increase the accessibility and usability for the targeted audience. This covers both the GUI as well as the input device (e.g gamepad, keyboard), although users who are not able to adapt to one particular input device may be able to adapt to another and still use the virtual environment. For instance, instead of a HMD a projection screen may be used to present the virtual environment to the users.

A few recommendations for preventing side effects such as cyber-sickness have also been noted by Stanney (1995). If HMDs are used, then the amount of required head movement should be minimized. If cognitive travel in the virtual environment is required, then it should be initiated by natural means if possible. Moving images that are perceived by the peripheral vision, in absence of the accompanying vestibular and somatosensory information such as body movement and bone and joint positions, can induce a strong sense of vection (self motion) and can be highly nauseating. Perceived vection may cause inappropriate postural adjustments, so physical support such as hand rails or harnesses may be particularly useful for increasing the user’s safety. Alternatively the input devices that are used could allow the user to sit down while using the virtual environment. Some ethical issues such as the possibility for addiction to the virtual environment may be reduced by incorporating a feature which, when the patient makes sufficient progress with regaining cognitive skills, gradually starts suggesting that the patient finds leisure activities that require more real-world interactions.

3.5.2 System recommendations

To prevent cyber-sickness and related side effects, the latency in the system should be minimized, while the update rate for the visual displays should be maximized. A rehabilitation system consists of more than just the virtual environment which is presented to the user. It may also include software which allows the therapist to process or view performance measures recorded while the user engages with the virtual environment. During the design phase, care should be given to determining which performance-related data should be recorded (Rizzo, & Kim, 2005), and how the therapist can easily analyze the data to answer questions such as "Which cognitive skills have improved during the sessions? Which have not?" This in turn may aid the therapist with determining the therapeutic strategy.

The system will likely also include software that allows the therapist to control the stimuli which are presented in the virtual environment. One of the findings of the Virtual Reality Exposure Therapy research conducted at the Delft University of Technology is that too much control over the stimuli in a virtual environment may lead to cognitive and task overload for the therapist (Brinkman, Sandino, & van der Mast, 2009). A desire for fine-grained control over the stimuli often results in a complex GUI which demands the attention of the therapist, decreasing the attention that is available to spend monitoring the patient. Fine-grained control over the presented stimuli may also increase the possibility for errors, resulting in inconsistent presentation of stimuli in the virtual environment which detracts from the sense of presence. An alternate approach is to provide the therapist with the means to determine the stimuli before the session. The therapist can then turn his or her attention towards the patient during the session, at the possible expense of being able to adapt to the specific needs of the patient as they arise.

3.5.3 Rehabilitation protocol recommendations

A number of recommendations with regards to the rehabilitation protocol have been made in the literature. Since individual user characteristics can contribute to the possibility of side-effects, special measures need to be taken into consideration.

1. Prior to exposure to the virtual environment, participants should be screened to detect those individuals who are at increased risk of suffering from side effects. The screening procedure may include the general state of mental health (Mini Mental State Exam, MMSE) (Folstein, Folstein, & McHugh, 1975), medication history, static and dynamic balance disorder history (Berg, 1989), motion sickness history (Motion Sickness History Questionnaire, MSHQ) (Griffin, & Howarth, 2000), and/or a test of ocular function if a HMD is used (Stanney, 1995).

2. The initial exposure to the virtual environment should be guided and monitored by a clinician, to ensure that the patient can rapidly adjust to the virtual environment and the interactions that it requires, while reducing the risk for side effects to occur (Stanney, 1995).

3. There should be a procedure for monitoring for unexpected side effects occurring during or after exposure to the virtual environment (Stanney, 1995).

4. After the exposure, some time should be reserved for the senses to re-adapt to the real world (Stanney, Mourant, & Kennedy, 1998).

5. After the exposure, standard questionnaires should be used to record side-effects and presence factors. These can include the Presence Questionnaire (PQ) and Immersive Tendencies Questionnaire (ITQ) (Witmer, & Singer, 1994) and the Simulator Sickness Questionnaire (SSQ) (Kennedy, Lane, Berbaum, &

Lilienthal, 1993).

It should be kept in mind that a thorough screening process may require the patients to fill in many different questionnaires, which can lead to mental fatigue (Rizzo et al., 1998) and influences on performance (McGee, et al., 2000). It may be possible to defer the participant screening process to the clinicians, eliminating the need for the patient to fill in (some) questionnaires prior to being introduced to the virtual environment.

3.5.4 Recommendations on preventing age related usability issues

The age-related changes in mental and physical skills described in section **Error! Reference source not found.** an cause a number of problems when using virtual reality based applications. The changes in visual perception may lead to difficulties with perceiving small elements on the screen and with locating information on complex screens (Ijsselstein, Nap, de Kort, & Poels, 2007). The changes in auditory perception may diminish the ability to localize sound and to comprehend computer-generated speech (Ijsselstein, Nap, de Kort, & Poels, 2007, Gamberini, et al., 2006). The changes in mental resources may lead to more comprehensive problems, where apparently easy tasks, such as remembering information from one screen to the next, may prove challenging. Changes in physical skills, such as postural instability, may cause personal injury if the individual must stand in front of a monitor.

These potential problems may be mitigated by taking them into account during the design of technology. Problems caused by visual perception may be prevented by making appropriate use of color and contrast in the GUI, and by improving the legibility of text by adjusting the font size (Gamberini, et al., 2006). Problems caused by auditory perception may be mitigated by increasing the sound level, controlling the ratio of high and low level frequencies, using redundant (multimodal) and well-structured speech materials, and by adapting the rate of speech (Gamberini, et al., 2006). Problems caused by physical skills may be mitigated by using unified interface design methods and techniques (Savidis, & Stephanidis, 2004) and by creating polymorphic interfaces which can support different interaction strategies for solving a single task, such as allowing for both sedentary and physically active interaction. Since it is likely not possible to design virtual reality based applications which are accessible to everyone, it may also be more efficient to adjust the selection criteria to include people who are able-bodied enough to use the technology, and to find other (technology-supported) ways to offer cognitive rehabilitation to those with special conditions.

Fisk, Rogers, Charmes, Czaja and Sharit provide a detailed overview on how technology can be designed for older adults. Their general guidelines are that technology should both have utility and usability. Utility means that technology should provide the functionality that is needed. Ijsselstein, Nap, de Kort, and Poels (2007) as well as Gamberini et al. (2006) advocate a ‘Keep It Simple, Stupid!” approach. The usability of technology is defined by five attributes: how easy it is to learn (learnability), how efficient the required objectives can be completed (efficiency), how easy it is to remember how to use it (memorability), error recoverability (supported by feedback), and the pleasantness of the experience that the user has.

4 Game based learning and motivation

In the previous chapter it was noted that a strength of virtual reality based neurocognitive rehabilitation is that gaming technology could be used to increase patient motivation and promote adherence to the therapeutic program. This chapter investigates this topic further, by exploring the literature on the intersection of game-based learning and motivation. A refinement of the third research question from section 1.2 resulted in the following literature review questions:

3. *How can game-based learning environments be designed to be engaging and motivating for the learner?*

   3a. What are games, and how can they be used as a basis for learning experiences

   3b. How can player motivation and behavior be interpreted in terms of established psychological constructs?

   3c. How can game technology be designed that explicitly focuses on player motivation?

The following sections present the results from the literature survey related to these subquestions.
Section 4.1 introduces the concept of rule-based games as a playful activity that humans may pursue.
Section **Error! Reference source not found.** surveys the relationship between games, motivation and learning. hen truly engaged and immersed with playing instructional game, players motivation is increased as well as their attention to the instructional content and the resulting learning outcomes.
Section 4.3 investigates psychogenic needs which drive goal based behavior, which in turn may be a source for motivation in players.
Section 4.3 also looks at how motivation can be embedded in instructional games.
Section 0 introduces the notion of 'affective gaming', games which actively detect or infer the player's affective state and adapt the presented game environment accordingly.

4.1 Why do people play games

Some examples of playful activities include but are not limited to sports, hobbies and leisure activities. According to Deci they have in common that a certain amount of time is spent on activities that are enjoyable "for their own sake" (Holbrook, Chestnut, Oliva, & Greenleaf, 1984). For some reason people are provided with an incentive to engage in these activities. This motivation can be intrinsic (for instance when an activity is perceived as enjoyable and interesting) or extrinsic (for instance when the outcome of an activity is desirable or important) (Garris, Ahler, & Driskell, 2002). Common prerequisites for motivation to be present is that the task at hand is valued enough to warrant spending the time on it, and that by actually spending the time the task can be successfully completed (Paras, & Bizzocchi, 2005).

Huizenga defined games as a type of playful activity that is distinguished by its conformity to a set of rules (Holbrook, Chestnut, Oliva, & Greenleaf, 1984). A consequence of having explicit or implicit rules is that the player can make mistakes and therefore perform poorly. The characteristics of any game can be described using 6 key dimensions (Garris, Ahler, & Driskell, 2002). The first dimension is fantasy, which Lepper and Malone defined as the degree to which the game invokes "mental images of physical or social situations that do not exist" (Garris, Ahler, & Driskell, 2002). The second dimension considers the rules of the game and how they are related to the goals. The third dimension is related to the alternate reality that a game presents through the sensory stimuli that it offers. The fourth dimension centers on the level of challenge that a game offers. The fifth dimension is the level of curiosity that a game offers. And the final dimension is the sense of control that the game invokes, which is the ability to regulate, direct or command something. Each of these dimensions may be related to invoking motivation in the player(s).

4.2 The relationship between games, motivation and learning

Several studies seem to indicate that a relationship exists between the design of games, the motivation of the people who play them, and the learning effects that are facilitated. An empirically conducted study conducted by Whitehall and Macdonald concluded that incorporating a variable payoff scheme in a game leads to a greater persistence on the task as well as to improved performance (Garris, Ahler, & Driskell, 2002). In another experiment, Ricci concluded that when games are used to train people, their attention to the instructional content increased. Feather noted that the successful performance on a task leads to better subsequent performance due to a learning or a motivational effect (Holbrook, Chestnut, Oliva, & Greenleaf, 1984).

This section will further describe the relationship between game design, motivation, and learning effects, using three theoretical frameworks. These frameworks can also offer guidelines on how to design games that aim to create 'motivated learners'.

The first theoretical framework is ARCS, which was proposed by Keller and consists of four strategies for modeling motivating, instructional content (Paras, & Bizzacchi, 2005). Attention strategies aim to arouse and sustain curiosity, which keeps the learner engaged with the educational content. Relevance strategies ensure that the educational content is both of interest and import to the learner. Confidence strategies involve creating positive expectations for successful achievement. And lastly, Satisfaction strategies are concerned with providing intrinsic as well as extrinsic reinforcement for the effort that was spent by the learner.

The second theoretical framework is Csikszentmihalyi's flow theory, which describes a psychological state during which the performance at a task is optimal and attention is fully invested (Csikszentmihalyi, 2002). A person in flow state is completely focused, without experiencing any distracting thoughts or irrelevant feelings. During the experience, hours seem to pass by in minutes, and the activity becomes worth doing for its own sake. The flow state has a number of prerequisites (Csikszentmihalyi, 2002). First, a clear set of goals must be present, as well as the rules and actions that must be applied in order to achieve these goals. Second, flow activities must provide immediate feedback and provide information on the progress towards the goals. Thirdly, flow experiences provide challenges that are matched with a person's skill. Figure 13 shows how the relationship between challenge and skill can result in a variety of affective states, including flow. Note that other representations of this relationship, such as Csikszentmihalyi's prior work (1990), may include fewer affective states, e.g. only anxiety, flow and boredom. Chan and Ahem suggest that flow theory, which is consistent with Keller's ARCS theory, can be used as a method for understanding and implementing emotions in educational games (Paras, & Bizzocchi, 2005).

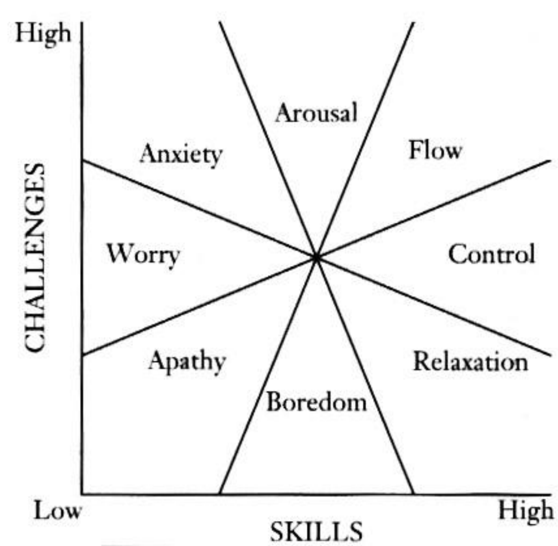

Figure 13 - Affective states as a function of the relationship between challenge and skills

The third and final theoretical framework is Norman's seven basic requirements for creating learning environments (Paras, & Bizzocchi, 2005). These requirements are:

1. There must be a high intensity of interaction and feedback
2. There must be specific goals and established procedures for reaching those goals
3. The environments must evoke motivation from the learner
4. The environments must present an appropriate level of challenge to the learner
5. The environments must provide a sense of direct engagement
6. The environments must provide appropriate tools that do not distract the learner
7. Distractions that intervene with the subjective experience must be avoided

When combined, the three theoretical frameworks from Keller, Csikszentmihalyi, and Norman allow the relationship between games, motivation and learning to be investigated and better understood. Figure 14 shows how games as a playful activity may lead to a state of flow, during which the player is fully engaged with an activity of appropriate difficulty. This should increase the motivation of the player, and lead to improved learning outcomes.

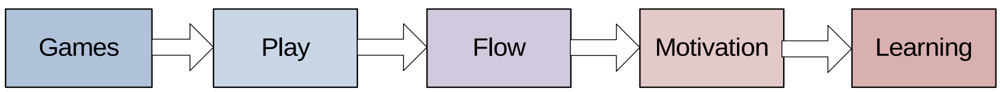

Figure 14 - The relationship between games, motivation and learning, based on Paras and Bizzacchi (2005)

4.3 Motivation in players of instructional games

This section will provide an overview of the origin of motivation in games. Two perspectives will be considered. Section 4.3.1 presents a model of motivation in players based on several studies of motivation in games. According to Bostan, this model is the only one which maps these factors onto an underlying psychological framework based on human needs driving goal-directed behavior. Section 4.3.2 provides an overview of a model presented by Garris, which can be used for the research and practice of motivation in instructional games (Garris, Ahler, & Driskell, 2002).

4.3.1 Motivation in players

The motivation of players of computer games can be investigated in a broader sense by investigating models of motivation in humans. The difference between the models lies in the emphasis placed on different constructs and dimensions. Some models use dimensions of expectancy and valence, while others, such as Keller's ARCS model, emphasize attention, relevancy, confidence, and satisfaction (Garris, Ahler, & Driskell, 2002).

According to Bostan, the two major influential studies on motivation are the intrinsic motivation taxonomy developed by Malone and Lepper, and the flow theory developed by Csikszentmihalyi (Bostan, 2009). Malone and Lepper listed the most important factors in making activities intrinsically motivating as challenge, curiosity, and fantasy. Sweetser & Wyeth used flow theory to develop a model for evaluating the enjoyment of players of computer games. Yee investigated motivational factors for playing online games. Figure 15 shows the motivational factors that these three studies identified. Since Malone and Lepper's study focused on the analysis of learning situations, Csikszentmihalyi's flow theory aimed to identify the attractiveness of an activity, and Yee's work on online games extended Bartle's prior study on play styles (achievers, explorers, socializers, or killers) it should be noted that although these studies might be valid in their own context, they do not provide an integrated model of player motivation in computer games because they lack a psychological foundation.

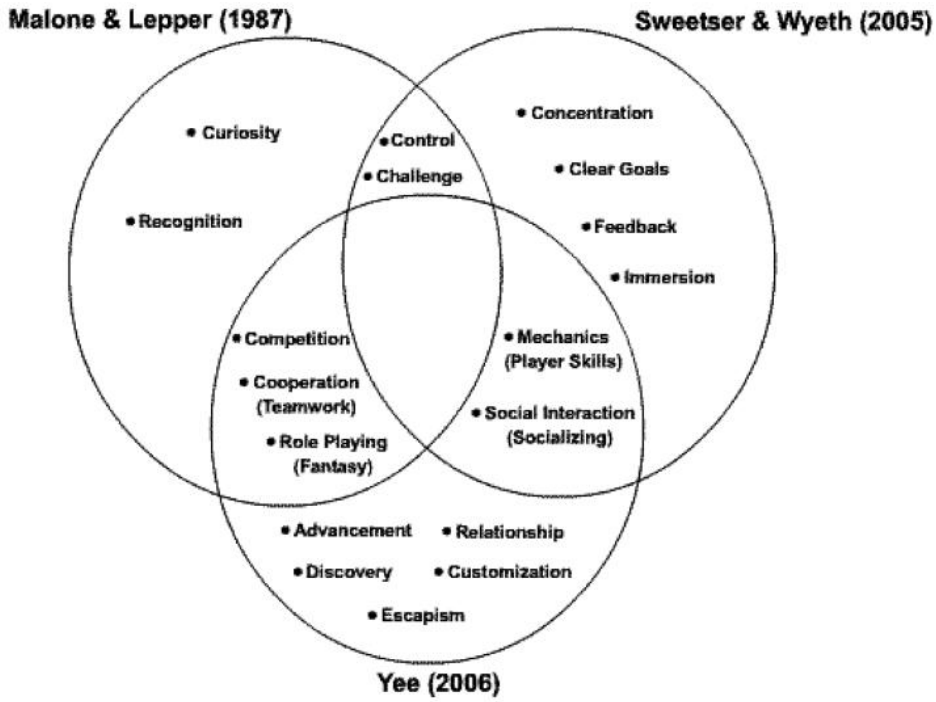

Figure 15 - A comparison of three motivational studies (Bostan, 2009)

In 1938, Murray formalized a study of psychological needs which arise from the interactions that a person has with his or her environment. These psychological needs lead to the formation of goals, which in turn provide motivation for behavior and actions (Bostan, 2009). Viscerogenic needs are physiological in nature and can be characterized by periodic body changes, such as the need for food, water and urination. Psychogenic needs are psychological in nature and are concerned with a person's mental and emotional state. Murray identified 27 psychogenic needs that affect goal directed behavior, which Bostan (2009) grouped into six categories consistent with different gaming situations. These categories are:

1. Materialistic needs: represent the motive to gather or collect inanimate objects
2. Power needs: represent the motive to be in charge of, and to be noticed by others
3. Affiliation needs: represent the desire for positive social relationships with others
4. Achievement needs: represent the desire for success and to overcome obstacles
5. Information needs: represent the desire to gather and analyze information
6. Sensual needs: represent the tendency towards sensually exciting and gratifying experiences

Table 1 - Murray's goal-directed behavior components and psychogenic needs, mapped to motivational variables

Motivational variable	**Murray's Goal Directed Behavior component**	**Murray's psychogenic need**
Clear goals	Goal specificity	
Feedback	Feedback	
Challenge	Goal difficulty	
Challenge	Outcomes	

Challenge	Feedback	
Challenge	Self esteem	
Advancement		Achievement: to strive to do something difficult as well and as quickly as possible
Advancement		Acquisition: to gain possessions; to bargain and gamble.
Advancement		Dominance: to lead and direct.
Curiosity	Feedback	
Curiosity		Cognizance: to explore, ask questions, satisfy curiosity.
Curiosity		Understanding: to analyze experience
Curiosity		Sentience: to seek and enjoy sensuous impressions.
Advancement		Acquisition
Advancement		Achievement
Advancement		Dominance
Social interaction		Affiliation: to form friendships and associations.
Social interaction		Nurturance: to express sympathy.
Concentration	Concentration	

Bostan has shown how the psychogenic needs and components of goal-directed behavior identified by Murray can be mapped to previously mentioned studies on motivation, which may help to provide a more integrated model of player motivations. Table 1 shows a partial list of how motivational variables correspond to psychogenic needs and components of goal-directed behavior. The achievement need can corresponds to a number of motivational variables that have been identified in the three studies shown in Figure 15, such as Advancement (Yee), Cooperation and Competition (Malone and Lepper, Yee), and Mechanics (Sweetser and Wyeth, Yee).

Game genres are defined by their content (Bostan, 2009). For instance strategy games such as Command & Conquer are concerned with resource management, object acquisition, and organization. Social online worlds such as Second Life are built on affiliation. Yet other games are a mixture of both, such as World of Warcraft. The subject, setting, presentation, perspective, and game playing strategies are what define a game genre (Bostan, 2009). Thus, different game genres satisfy different psychogenic needs, and may appeal (only) to players with specific personality or character traits. Holbrook, Chestnut, Oliva, and Greenleaf (1984) found evidence for a 'facilitating effect of personality-game congruity', where the personality type of players (e.g. visualizer or verbalizer) can more strongly influence the performance on a game if the type of game matches their personality. They concluded that in general, player performance and emotion depends on how personality traits (e.g. variety seeking, sensation seeking, hedonistic) interact with the nature of a game being played.

4.3.2 Motivation in instructional games

Prior research has been conducted on designing instructional games which can help to create self-directed and self-motivated learners. Garris, Ahler, and Driskell proposed the model shown in Figure 16. An instructional program can be designed which incorporates certain features or characteristics of games. These features or characteristics trigger a game cycle which includes three distinct stages. The system feedback stage provides the player with knowledge of results, which is critical to support performance and motivation. The effect of system feedback on the performance can be both positive and negative. In the user judgment stage, the feedback received is compared to standards or goals, which in turn regulates the user behavior. This is the judgment-behavior-feedback cycle (Garris, Ahler, & Driskell, 2002). If the pairing of instructional content with characteristics and features of games is successful, this cycle results in recurring and self-motivated game play. This engagement may lead to the achievement of training objectives and learning outcomes. Also, persistent player engagement may lead to a sustained involvement which is the cornerstone of computer game play.

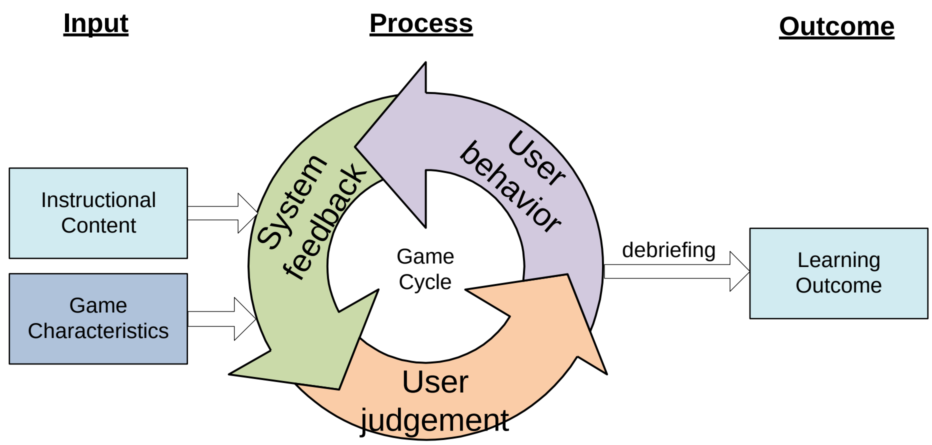

Figure 16 - Input-Process-Outcome game model, based on Garris, Ahlers and Driskell (2002).

4.4 Affective gaming

Picard defined affective computing as computer programs which infer or measure the user's emotional state and adjust the presented content accordingly (Picard, 2000). Contrary to such closed loop environments where sensing indicators of the user's emotions are a key factor, open loop environments do not require sensing of the user's emotion in order to actively manipulate the presented content to ensure engagement (Hudlicka, 2008). An affective computer game must provide the player with an appropriate amount of assistance, while presenting a level of challenge that is matched with the player's skills. Gilleade, Dix, and Allanson (2005) identified three high level design heuristics to create affective games: "assist me, challenge me, emote me".

Emotions in players can be triggered by three possible characteristics of a game environment (Hudlicka, 2008). Gameplay events, such as scoring a goal against an opponent in a soccer game, can trigger both positive and negative emotions. Behavior of a game character is another possible trigger of emotions. And finally emotions such as enjoyment or boredom may result from interacting with the game itself.

To support games which adapt to affective states of its players, the underlying affective game engine needs to infer a broad range of player emotions in real-time within a variety of game contexts. The game engine then needs to adapt the game content that is presented to the player. This may include changing the game play reward structure or a realistic portrayal of appropriate emotions by the game characters that populate the game environment (Hudlicka, 2009). The inference of emotions can be based on multi-modal sensory input such as speech recognition and facial recognition (Picard, 2000), or be based on measurements of human physiology such as electrocardiogram (ECG), an electromyogram (EMG) based on facial muscles involved with smiling, or a galvanic skin response (GSR) (Setz, Schum, Lorentz, Anrich, Troster, 2009). Alternatively, the inference can be based on the measurement of automatic and volitional behavioral responses (Munih, et al., 2009).

It is also possible to infer psychological emotional states by analyzing the occurrence of events within the virtual environment itself (Broekens, 2007). For many games, a very simple computational model of affect is adequate enough to be able to meet these requirements. A small set of game play or player behavior features is mapped onto a limited set of elements in the game environment which adapt to these behavioral features.

This ‘black box’ model of interpreting or generating emotions makes no attempt to represent the underlying affective and cognitive mechanisms (Hudlicka, 2008). Cognitive appraisal theory can be used to understand the affective and cognitive mechanisms that underlie the generation of emotion, as well as the effect that they may have. The theory investigates the role of conscious and subconscious cognition in the generation of emotion, and may facilitate computational modeling of emotions provided that the appraisal dimensions can be determined. Emotions are (still) a complex and not well understood phenomena, and the effect that emotions may have is even less understood (Hudlicka, 2008).

Three requirements are at the basis of every affective game engine (Hudlicka, 2009). They are:

1. There must be a shared emotion knowledge base that contains definitions of possible emotional states and their transitions. This knowledge base is used for both the recognition as well as the generation of emotions.

2. They must be an affective user model, which stores information about the affective make-up of the user, including information about which game events and which behaviors trigger which emotions. An affective user model facilitates emotion recognition as well as emotion generation (Hudlicka, 2008, 2009).

3. The expression of emotions by both player and non-player game characters must be modeled. This procedure can be subdivided into generating the appropriate emotions (based on game events), and implementing those emotions across various modalities (behavioral, facial expression, vocal).

From these requirements a number of key issues can be distilled which need to be addressed by the game designer (Hudlicka, 2008). The first key issue is related to game character development. The game designer needs to decide on questions such as ‘Which emotions, mood’s and personality traits should the game character be able to express, and how can these be expressed appropriately?’ and ‘Are deep computational models of emotions really necessary?’. Another key issue is related to designing the affect-adaptive game play features. The game designer needs to decide on questions such as ‘What role do player emotions play?’, ‘Which emotions need to be recognized?’, and ‘Which elements of game play should be adapted accordingly?’

5 Discussion and conclusions

In chapter 1 the driving research question for this research study was introduced as *"How can cognitive rehabilitation therapy effectively be supported by virtual reality?"*. The driving research question was used to specify the three sub questions as noted in section 1.2. The three subsequent chapters presented the results from the literature survey that was conducted on these three subquestions related to the topics 'cognition', 'virtual reality' and 'motivation and game based learning' (see Figure 1).

This chapter discusses the bearings of the results from the previous chapters on the three sub questions as noted in section 1.2. Sections 5.1, 5.2, and 5.3 will each discuss one of the three sub questions.

5.1 What is 'cognition' and how can it be assessed or rehabilitated?

How cognition exactly works, and which cognitive faculties make up the human mind, is not entirely understood yet. Although there are some ideas about cognitive faculties on a functional level, as pointed out by Groome, Dewart, Esgate and Kemp (1999), the biological bases for them is not always very clear. Neurodegenerative conditions such as Alzheimer's disease can have a debilitating effect on one individual, but may have different effects (if any) on other individuals, as shown by the Nun Studies carried out by Snowdon (2003). Differences in brain plasticity seems to allow some individuals to, through a physically and mentally active lifestyle, build up a 'cognitive reserve' which shields them from immediate development of cognitive deficits (Scarmeasn, & Stern, 2003, Whalley, Deary, Appleton, & Starr, 2004, Fratiglioni, & Wang, 2007, Buschert, Teipel, Hampel, & Burger, 2009). However the results from many prior studies into effective strategies for cognitive rehabilitation do not appear to provide much significant evidence with generalizable and prospective characteristics (Cicerone, et al., 2000, 2005, Cappa et al., 2005). Classical rehabilitation exercises have been perceived as repetitive by nature, tend to decouple the mind and reduce motivation, and can not or are costly to be conducted in a home environment (Burdea, 2003). There also seems to be an ongoing discussion about different approaches to cognitive rehabilitation: should it focus on investigating effective rehabilitation of particular cognitive skills, or on a more holistic approach and investigate rehabilitation of instrumental activities of daily life? From the information found in the surveyed literature it can be concluded that more studies are needed to further investigate all of these open issues.

5.2 How can cognitive rehabilitation be supported with virtual reality applications?

Virtual reality has been used to create applications aiming at both cognitive therapy (rehabilitation of particular skills) and cognitive behavioral therapy (which focuses on behavioral measures instead of particular skills). It still faces many of the same challenges as in the mid 1990's (Rose, Brooks, & Rizzo, 2005). Although cognitive training of particular skills does seem to improve that skill, whether or not that improvement aids in improved performance in activities of daily life is still being questioned (e.g. Rizzo, Wiederhold, & Buckwalter, 1998, Castelnuovo, Lo Priore, Loccione, & Cioffi, 2003, Rizzo, & Kim, 2005). Much of the existing research seems to focus on rehabilitation, and not on assessment (Standen, & Brown, 2005). This may signify an opportunity to combine both into a single application. Due to the complexity involved with the engineering of virtual reality based applciations (related to hardware and software) the cost is high. The technology gap still present with many members of society, such as elderly people or therapists, may prevent their acceptance of the technology because they can't, won't or don't know how to interact with it (Rizzo, & Kim, 2005, Burdea, 2003). Two other weaknesses of virtual reality based rehabilitation technology are the front end flexibility, and the level of support that the back-end provides related to data extraction, management, analysis and visualization (Rizzo, & Kim, 2005), which in turn may increase the rate of acceptance by the clinical community. The open issues to which no conclusive answers and solutions have been found include the side effects (such as motion sickness and postural instabilities) which possibly can never be completely prevented for each possible individual. Furthermore there are ethical issues involved: the aforementioned technology gap may exclude a large part of the population from being able to use the technology, and some part of the population (e.g. the elderly) could suffer from injuries while using the technology (for instance, from falling down due to postural instabilities already present because of their age, and strengthened by experiencing the virtual worlds). The effectivity of, and strategy for designing computer game based exercises for cognitive rehabilitation, is subjected to the same questioning as the classical approach: although initial studies have shown that the trained particular skills seem to improve (Kawashima, et al., 2005, Haier, Karama, Leyba, & Jung, 2009, Owen et al. 2010), more clinical studies are needed to investigate whether there is a generalizing effect. Before any game-based rehabilitation technology can be tele-operated in a home environment, practice guidelines and safety parameters must be established which specify how, where and for whom the technology is appropriate, similar to classical mental health approaches (Rizzo, Strickland, & Bouchard, 2004).

5.3 How can game-based learning environments be designed to be engaging and motivating for the learner?

In the past few decades many computer games have appeared on the consumer market which seemingly engaged entire generations (e.g. Tetris, Doom, Mario), not much literature seems to be available on how to explicitly design games to be motivating. Although the connection between games, motivation and learning has been documented (Paras, & Bizzocchi, 2005), no information was found which game design and play mechanics foster a motivated learner. The affective game engine, as proposed by Hudlicka (2009) combined with Bostan's (2009) study which provides a psychological perspective on how motivation drives (game player's) behavior, provide a framework for game design which makes it possible to explicitly address player motivation- both during the design phase of a game and while the player is playing the game itself. Although more studies are needed to engineer machines, sensors and software which can more reliably recognize human emotions, affective computing and affective gaming seem to provide usable frameworks for creating game-based learning environments that are engaging and motivating for the learner.

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