Virtual reality based cognitive intervention

Master's thesis project
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1 Introduction

1.1 Background and motivation

Until 1960 it was thought that the human brain was hardwired for functionality [ref rose]. As a result the loss of cognitive functioning due to brain injury was considered to be irreversible and untreatable. There was no active development of treatment or rehabilitation strategies to cope with the consequences of brain damage. When the concept of neuroplasticity gained support in the 1980s, this view of the hardwired brain started to change and the potential for brain damage rehabilitation was acknowledged. Neuroplasticity entails 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. It allows the neural networks in the brain to reorganize their architecture and functioning through exposure to new sensory experiences [ref Wikipedia]. The idea was first proposed in 1892 by Santiago Ramón y Cajal, and subsequently neglected for the next 50 years. Along with the support for the concept of neuroplasticity and how it may enable brain damage rehabilitation, virtual reality was investigated as an enabling technology for cognitive interventions [ref wiederhold 1998]. Wikipedia describes Cognitive Interventions as "a set of techniques and therapies practiced in counseling" [ref Wikipedia].

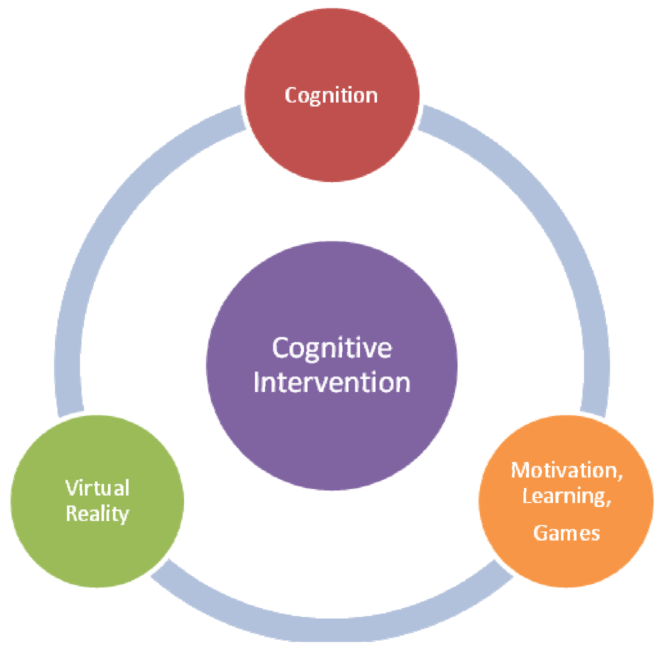

Figure 1 The main topics related to this thesis assignment

The 1980s also saw the introduction of home computers to a broad audience. These personal computers were more versatile than the console and arcade machines that were used in the computer games industry. This industry thrives on the player to come back for more play time. This willingness to engage with a task such as playing a game has been termed motivation [ref Garris]. In some cases computer games have engaged its players to such an extent that categories dealing with compulsive behavior found in The American Psychiatric Association's Diagnostic and Statistical Manual of Mental Disorders – Fourth Edition are applicable. According to Young excessive and compulsive video game play may be interpreted as a type of addiction, with pathological consequences [ref Garris]. At the same time a common remark found in the literature on virtual reality based cognitive intervention is that the exercises themselves are not very motivating and challenging [ref]. These two extremes found in games for entertainment and games for rehabilitation seem to indicate that there are possibilities for games used in cognitive interventions to use knowledge of games used for entertainment, especially on how to motivate their players.

1.2 Literature review questions

The central topic of this thesis is virtual reality based cognitive intervention in clinical and home environments. The available scientific and academic literature will be reviewed on the following three questions:

1. What is 'cognition'? How can it be clinically assessed? What are the available strategies for clinical interventions?
2. What are the do's and don'ts of creating virtual reality applications for cognitive interventions, preferably in a home environment?
3. How can the design of computer games be interpreted or approached in terms of the engagement and

motivation of the player?

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, 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 4 will provide an overview of current approaches to designing motivational games.

2 An introduction to cognition and cognitive interventions

According to the Merriam-Webster 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. Section 2.1 starts with providing only a brief introduction to some the key stages of cognition that have been identified. They include Perception, Learning & Memory storage, Retrieval and Thinking [ref Groome]. Section 2.2 discusses the cognitive aspects of emotion, and how they influence these stages of cognition [ref Dolan]. Section 2.3 identifies of three levels of cognitive functioning which are relevant to the discourse of this thesis. Cognition can operate on the level of basic cognitive skills, executive functioning and fluid intelligence. Section 2.4 introduces the theory and evidence for 'cognitive reserve' [ref Stern], a surplus of mental capacity which helps with acquiring, sustaining and increasing cognitive skills or coping with brain pathology. Sections 2.5 and 2.6 identify methods and instruments to assess the various levels of cognitive functioning [ref spreen], as well as strategies and methods for interventions which aim to restore a loss of cognitive functioning [ref buschert, cicerone 2000]. The final section 2.7 outlines which standards and recommendations exist for rehabilitating specific cognitive functions [ref cicerone 2000, 2005, ref efns guidelines].

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 illustrates this process of knowing by identifying several key cognitive stages which are related to the flow of information. 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 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 [ref eysenck p56]. 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.

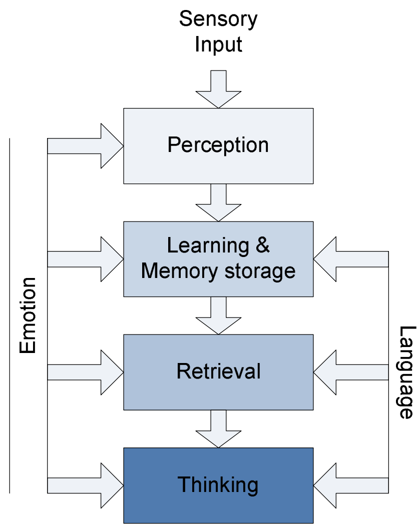

Figure 2: A simplified representation of the stages of cognitive processing, which are influenced by language and emotion.

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 [ref Groome p63], 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.

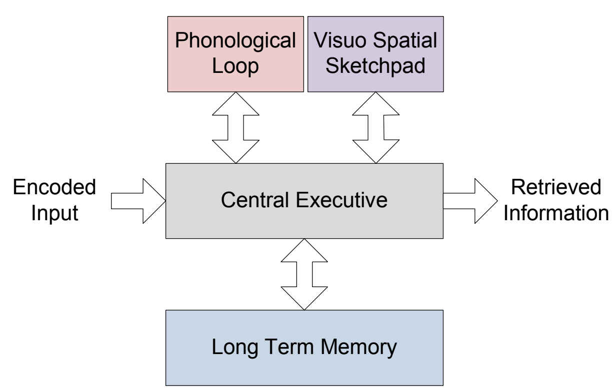

Figure 3: A multistage model of working memory.

The final stage of cognitive processing that was identified by Groome, involves a range of different mental activities. The process of thinking may include problem solving, creativity, decision making and theorizing [ref Groome p101]. This process can also be interpreted to comprise the application of knowledge in the appropriate situation [ref Cicerone 2000 p1598].

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 [ref Cicerone p1602]. Eysenk noted that the results from several studies suggest that language influences the ability to think, perceive, memorize and retrieve [ref Eysenk, p427].

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. 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 [ref dsm-iv]. 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 [ref Rizzo 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 [ref Dolan]. 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 [ref Dolan]. 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 [ref Tajadura-Jimenez, p70, Picard p41].

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 p11, dolan p1994]. 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 [ref Dolan, ref eysenck p563]. Through memory emotions enter into processes which are used on an everyday basis, such as reasoning, decision making, creativity, planning, curiosity and fascination [ref picard]. The latter two may be at the base of many effective learning episodes [ref Picard p93].

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 p35]. 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 [ref Picard p39.]

2.3 Three 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' [ref spreen, p171]. 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 [ref Buschert]. 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.

2.4 Cognitive reserve

In the literature on child development a correlation between a measurable Intelligence Quotient and brain volume has been reported upon [ref stern]. Similarly, activities of everyday living which stimulate cognitive processes have been correlated to an increase in neuroplasticity [ref stern, ref snowden]. 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' [ref stern]. 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 [ref stern].

Studies of healthy elderly concluded that an increase in cognitive reserve lead to an increase in their fluid intelligence [ref buschert]. 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 [ref stern, ref buschert]. 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 [ref stern]. 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 [ref buschert].

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 [ref snowden]. 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 [ref stern]. 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 [ref snowden 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 [ref buschert].

2.5 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 showin in Figure 4, which is used to measure processing speed, selective attention and to evaluate executive functions [ref spreen]. Figure 5 shows another example, the mental rotation task [ref Shepard p702] 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 [ref Cohen, p89]. For a comprehensive overview of assessments for cognitive functioning see [ref spreen].

Figure 4: The Stroop task: reading the words on the second line is impaired due to the incongruent font color.

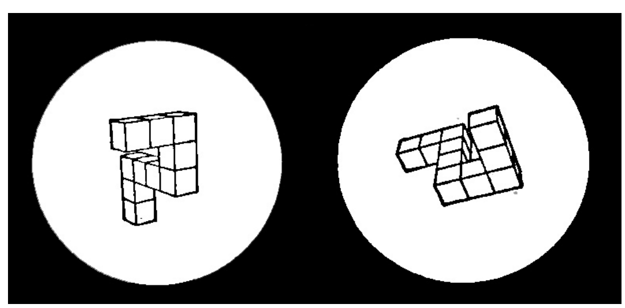

Figure 5: The mental rotation task: is the right object the same shape as the left one, or not ? [ref shepard]

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 [ref brodaty, p870].

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 [ref sclan, p819].

Two main criteria that determine the adequacy of any measurement are reliability and validity [ref Rizzo 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 [ref Rizzo 1998].

2.6 Methods and strategies for cognitive intervention

Cognitive intervention methods can be classified in three categories [ref buschert]. The first category, cognitive training, 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 rehabilitation, 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 rehabilitation makes no assumptions on a generalizing effect.

The different cognitive rehabilitation strategies can be interpreted in terms of the degree to which cognitive functioning differs for what is considered to be normal for a healthy human being [ref Rose]. An impairment implies an "abnormality of psychological, physiological or anatomical structure or function". A disability implies a lack of ability to perform an activity in a way that normal, healthy people can do. And finally a handicap implies a disadvantage resulting from either a disability or an impairment, which prevents the fulfillment of activities or roles that are considered normal. With respect to these gradations of cognitive functioning, a number of rehabilitation approaches were discerned by Cicerone [ref Cicerone]. The different cognitive rehabilitation strategies can be:

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 [ref van schaijk]).
4. To enable individuals to adapt to their disability or handicap, in order to improve their overall level of functioning and quality of life.

2.7 Standards and recommendations for the practice of cognitive intervention

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 [ref Rizzo]. A clearly defined and agreed upon theoretical base for which type of cognitive rehabilitation is the most effective, does not appear to exist [ref rose, ref Cicerone, ref buschert ref Cappa].

In 2000 and 2005, Cicerone et al 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 [ref cicerone 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. Cappa et al reported on a study with a similar setup and focus on cognitive intervention [ref cappa 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 [ref cicerone 2000, ref rose]. 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 [ref cicerone 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 [ref cicerone 2005]. Furthermore, the patient's performance can significantly improve if the interventions should include training with different stimulus modalities, level of complexity and response demands [ref cicerone 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 and arithmetic problems [ref cicerone 2000].

Cognitive interventions seem to have the most effect on those with mild to severe cognitive impairments [ref cicerone 2000]. It appears that cognitive rehabilitation produces greater improvements than pseudo treatments such as mentally challenging leisure activities [Cicerone 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 the leisure activities [ref Snowden]. More clinical studies need to be conducted that perform a well defined controlled experiment, to increase the available evidence upon which future recommendations can be made.

3 Virtual reality based cognitive interventions

In 2005 Rose noted that virtual reality applications for cognitive rehabilitation face the same challenges as in the 90s [ref rose]. 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. Section 0 will start with providing a virtuality continuum [ref Milgram] for identifying applications that 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. In section 3.2 a brief summary will be provided of the different kinds of virtual reality based applications for cognitive interventions [ref Wiederhold], with a side step to computer games which are based on tasks that have been shown to improve neuroplasticity and cognitive skills [ref Haier].

Section 3.3 outlines some of the human factors that are involved with virtual reality based applications. The categories of factors which affect human performance are introduced, which are related to task characteristics, individual user characteristics and the limitations of human sensory motor physiology [ref Stanney 1998] Cybersickness and other side effects are mediated by user characteristics, system characteristics and task characteristics, and may never be completely prevented [ref Cobb, ref Lewis]. All these factors present potential Health and Safety issues [ref Stanney] that need to be considered when designing a virtual environment. Section **Error! Reference source not found.** identifies and discusses the Strengths, Weaknesses, Opportunities and Threats associated with virtual reality based rehabilitation [ref Rizzo] for use in a home environment. The final section 3.5 discusses design recommendations for the virtual environments and the rehabilitation protocol [ref rizzo, lewis] that have been identified in the reviewed literature.

3.1 From reality to virtual reality

In 1962 the US Patent Office awarded a patent to Morten Heilig for what he called a Sensorama Simulator [ref Heilig]. This device, shown in Figure 6, 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 1965 Ivan Sutherland proposed [ref Sutherland] and later created a computer system that used a head mounted device that had to be worn by the user, as shown in Figure 6. 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. 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.

Figure 6: Heilig's Sensorama Simulator on the left, and Sutherlands head mounted [image source: google images].

Milgram devised the virtuality continuum as shown in Figure 7, and an accompanying taxonomy to classify applications that aim to create an illusion of an alternate reality [ref Milgram]. Since Sutherland's system did not completely replace the users 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.

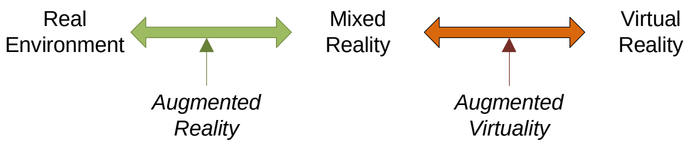

Figure 7: Milgram's virtuality continuum in simplified form.

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' [ref Milgram], 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 Addressing cognitive functioning with virtual reality based applications

Some areas of particular interest in which applications of virtual reality are being researched and developed are in clinical psychology, and in the cognitive and neuro sciences. Virtual reality can be used as an assessment or intervention instrument for the clinical treatment of psychological disorders. Studies have been conducted which focused on cognitive behavioral therapy for the rehabilitation of anxiety disorders such as fear of heights (acrophobia) [ref tudelft], fear of flying (aviophobia) [ref tudelft], fear of open spaces (agoraphobia) [brinkman, 2008] and social phobia [brinkman, 2008]. Other applications involve the rehabilitation of anxiety disorders such as Post Traumatic Stress Disorders for war veterans (Vietnam, Iraq and Afghanistan) [ref Rizzo, Rothbaum]. For a more comprehensive review on how virtual reality has been used for treatment of anxiety disorders, see [ref krijn 2004]. Virtual reality applications have also been developed to clinically rehabilitate a degradation of cognitive functioning resulting from a range of diseases including Alzheimer's [ref rizzo], schizophrenia [da costa, 2004] or conditions such as autism [parsons, 2002] and intellectual disabilities [ref standen 2005]. A functional overlap exists in many of these applications in that they can aim to achieve similar goals such as training with activities of daily life which support more independent living, enhancing cognitive performance and improving social skills.

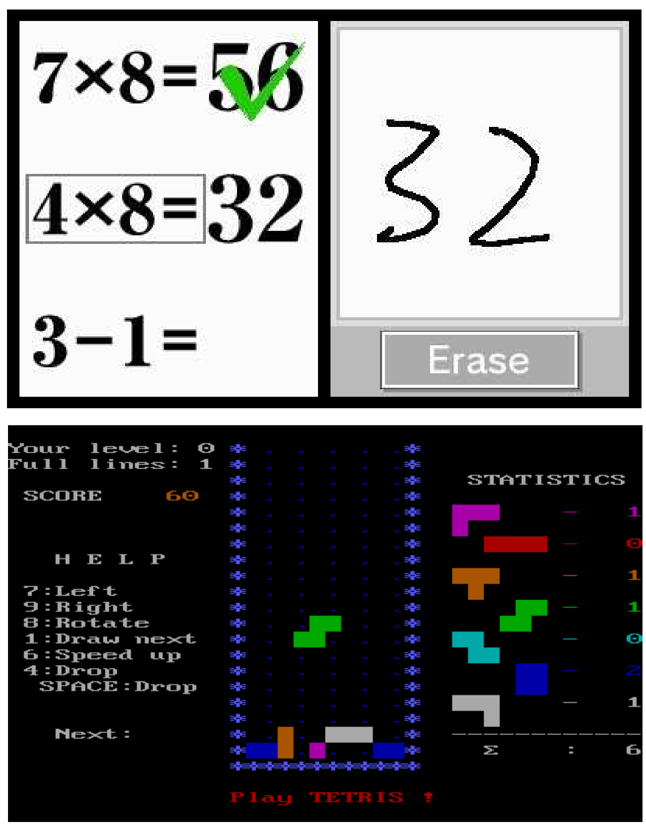

Figure 8: Brain Training (top) and Tetris (bottom), two simple computer games which exercise cognitive functioning [image source: google images].

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 the 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.

One of the games that Nintendo published for their DS handheld console is 'Dr. Kawashima's Brain Training' (see **Error! Reference source not found.**). In essence this game consists of a collection of mini-games, 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 and performing arithmetic calculations. A clinical study with patients diagnosed with dementia of the Alzheimer type was conducted by a group of researchers led by Kawashima [ref Kawashima]. Some of the patients practiced with reading aloud and performing arithmetic calculations two to six days a week for a period of six months in total. Other patients did not receive this training as part of a control group. Based on standard methods for assessment they concluded that the mental functioning of the patients who had received the training had improved significantly.

Another study performed by Haier et al used brain imaging techniques to investigate the impact on brain plasticity of structural practice with a simple visuo-spatial task [ref Haier]. Test participants were required to play a computer game for about 1.5 hours a week for the duration of three months. Tetris (see Figure 8) is a puzzle game in which falling geometric shapes must be rotated and moved so that they stack up at the bottom of the screen in such a way that no holes are left open. After three months of playing the game the Magnetic Resonance Image (MRI) scans of the participants brains showed an increase in brain plasticity in an area which is suggested 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, they 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) [ref Haier, p]. The effectiveness of cognitive rehabilitation using different computer game scenarios has not been researched sufficiently, and games created specifically for rehabilitation purpose are not designed to be motivational [ref flores]. More studies are needed that investigate two 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. The second question is whether off the shelf commercial games suitable for rehabilitation purposes, or if specific games must be developed.

3.3 Human factors in virtual reality based applications

Three categories of human factors are relevant for virtual reality based applications. The following sections will discuss which characteristics affect human performance in virtual environments, the issues posed by cybersickness 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 identified a number of categories of factors that influence human performance in virtual environments. These factors include task characteristics, individual user characteristics and the limitations of human sensory motor physiology [ref Stanney 1998]. Some tasks may be better suitable for embedding in a virtual environment than others. As an example, a virtual reality based Mental Rotation Test may offer additional perspective and depth cues which support the task, while a virtual reality based Stroop test might not provide any additional beneficial cues to the task (see Figure 4). Identifying which tasks are suitable to perform in virtual reality requires obtaining an understanding of 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 interactivity required [ref stanney]. The control and the speed of movement in the virtual environment also influence human performance [ref lewis 1998]. As an example, orienting the view in a specific direction may be performed quicker and more precise in an immersive environment with head tracking as an input paradigm, rather than in a window on the world environment with a gamepad as an input paradigm.

Individual user characteristics are also a category of factors that influences human performance in virtual reality. Individual differences can be related to information input, throughput and output [stanney 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 relates to the individual differences in cognitive and perceptual styles. Some people give preference to visually presented information, while others prefer auditory presented information [ref Holbrook]. 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 concern the properties of human sensory motor physiology. The relevant physiological and perceptual issues are related to visual, auditory and haptic and kinesthetic perception [stanney, 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 then the sense of presence will decrease [ref stanney]. When stereoscopic imagery is presented to the user, it is critical that they are adjusted to the user's pupil distance. Furthermore the limited Field of View (FOV) that HMD's offer is a major factor. Display characteristics such as contrast, luminance and resolution can also be sources of perceived anomalies. Furthermore system lags can also be sources of perceived anomalies [ref lewis]. Examples are the update rate of the visual representation and any delays between user input and the accompanying updating of the representation of the virtual environment. For auditory perception the 3D localization of sound may be the most important property to understand, in order to maintain a sense of presence. However this is dependent on the task that is presented in the virtual environment. For instance, a virtual environment that aims to train a user how to cross a street that is busy with traffic, 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 these properties of human sensory motor physiology may affect human performance in virtual reality. They also may play a role in causing side effects during or after exposure to a virtual environment, which in turn may affect performance. These side effects are briefly discussed in the next section.

3.3.2 Cybersickness and other side effects of exposure to virtual environments

Cybersickness 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 [ref stanney]. Symptoms of cybersickness include, but are not limited to, nausea, disorientation and postural instability. These symptoms may have a lasting effect, until some time after the exposure to the virtual environment has ended. Theories of sensory conflict are most widely used to explain the phenomenon [ref cobb]. 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 which contributes to a sense of balance and spatial orientation, and the proprioceptive system which contributes to a sense of the relative position of parts of your own body. A virtual environment can cause sensory conflict during exposure to virtual environments in the situation where a handheld input device is used to move through the virtual environment, without physically moving the body. The visual system receives signals that indicate self motion, but the expected signals from the vestibular system are absent. Another example is when changing the head position or orientation results in a (due to system lag) delayed update of the visual representation of the virtual environment.

Much research has been done to investigate cybersickness and other side effects which can be caused by exposure to virtual environments. Cobb reported on an investigation of possible symptoms and their effects on human behavior and performance both during and after exposure to the virtual environment [ref cobb]. Physical symptoms in the form of body part discomforts 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 [ref lewis]. 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 [ref lewis]. Similarly Cobb noted 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 [ref cobb]. 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 [ref lewis]. The first category relates to of 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 [ref stanney]. Examples of direct microscopic effects are eye damage caused by ocular problems during prolonged use of HMD's. Direct macroscopic effects may arise from reduced performance after exposure to virtual environments, due to cybersickness or postural imbalances. The latter may lead to postural sway and increase the risk of falling [Lewis 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 overreliance 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, 2005].

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

Rizzo published an analysis of the Strengths, Weaknesses, Opportunities and Threats (SWOT) that are involved with using virtual reality based applications for cognitive rehabilitation [ref rizzo swot]. 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. Rizzo's analysis served as a base for the analysis that will be presented in the following paragraphs. Some of the issues he 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 9, which is more tailored towards virtual reality based rehabilitative applications for use in a home environment.

3.4.1 Strengths

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 [ref rizzo mr, burdea]. Furthermore virtual reality offers the possibility to improve the standardization of the stimuli that are presented, through quantification of multiple characteristics of the stimuli [ref rizzo 1998 mr project]. 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 [ref Rose]. Examples of ecologically valid environments are V-STORE to practice with the activity of grocery shopping for patients suffering from Alzheimer's disease [ref], or Virtual Reality Exposure Therapy for the treatment of the fear of flying [ref]. 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 as well as the input device configuration(s) being adapted to the diverse physiological abilities of the clinical population. Commodity (consumer grade) computing hardware nowadays 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. As Rizzo (check?) noted, normally the therapists are distributed geographically uneven among the populations [ref]. They are more likely to operate in or near urban

	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	• 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
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	• Safety and health issues, not just for cognitive or sensorimotor impaired • Sideeffects lawsuit potential • Ethical challenges • Privacy issues with telerehabilitation

Figure 9 SWOT analysis of virtual reality based rehabilitation for home use

areas than rural areas, meaning that not every citizen has equal access to specialized health care such as cognitive rehabilitation.

Examining the design and engineering of computer games technology may lead to some useful suggestions about how to design therapeutic exercises that engage and motivate the patient. According to Burdea, some of the characteristics of conventional therapeutic exercises are that they are repetitive in nature and tend to decouple the mind, which may reduce the motivation from the patient to engage with these exercises [ref burdea 2003]. Which aspects of the design and engineering of computer games may contribute to an increase in patient motivation will be examined in another chapter of this literature research.

3.4.2 Weaknesses

Even though in the last decades the availability and performance of computing and graphics hardware has increased drastically, the development of HMD's and other peripheral devices is lagging behind [ref Rizzo 2004]. Immersive virtual reality applications thus remain costly and affordable only to research institutes and large organizations. Furthermore those peripherals that are available may suffer from ergonomic issues, such as the weight of HMD's or the wiring that still is common to many input devices. Accomplishing truly universal access that allows the entire target audience to use the system may also be impossible. Even with the diversity of input and output devices that are available, there may always remain some people who due to physiological impairments cannot operate conventional input devices. And as mentioned in the previous chapter, individual user characteristic may make some people more susceptible to cybersickness, or less capable of adapting to operate a virtual environment [ref lewis]. The side effects may be partially marginalized by an increased quality of peripheral devices such as HMD's. However due to the individual user characteristics that contribute to them, they might not be completely avoidable in the future [ref Rizzo, 2004].

A number of weaknesses are related 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 Rizzo noted, immature engineering processes often lead to suboptimal results [ref Rizzo SWOT]. 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 stimuli that are presented in the environment, is another type of user that is often overlooked. Since most clinicians are rarely also trained computer scientists, they need to be accommodated with automated performance measure extraction, analysis and graphical visualizations. The clinicians may even be novice instead of expert computer users, so that the graphical interfaces for them must be tailored to match their needs and capabilities [ref rizzo]. 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 engineering challenge that is slightly related to the usability argument is that it may take a significant amount of work to engineer 'ecologically valid' training environments [rose 2005]. A common criticism on these environments is that the assumption of a static world is being made, with very few changes in situational demands [ref morganti]. And given the diversity in manifestations of cognitive impairments, it may be that many of such ecologically valid, complex and dynamic virtual environments are required to accommodate the needs of the entire clinical population.

3.4.3 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. They include custom

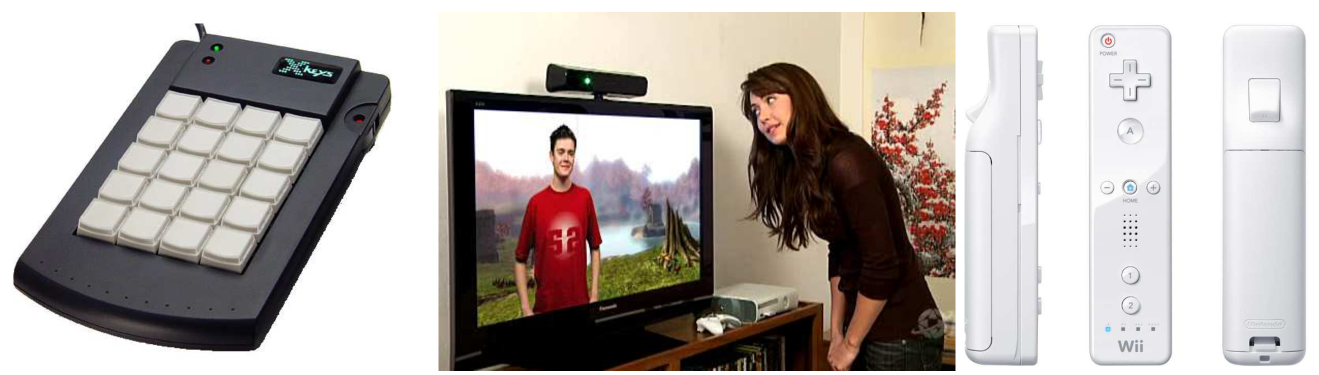

Figure 10 Emerging input device technology: Pi Engineering XKeys (left), Microsoft Natal (center) and the Nintendo Wii Remote (right) [image source: google images]

keyboards that can be configured with differently sized and colored keys, to match the user's perceptual and motor skills such as shown in Figure 10. Another category of input devices allow for more embodied interactions. Devices such as the Nintendo Wii Remote allow users to interact with virtual objects in more naturalistic ways. Objects in virtual environments can be selected by pointing the device at them and pressing one or more buttons for further manipulation. Microsoft's announced technology with codename Natal is an input device that allows for users to interact with virtual environments by speech recognition, facial recognition and full body and gestural movements. This completely eliminates the need for the user to physically hold and manipulate an input device. Another emerging technology of interest may be in the area of wearable computing. Sensors embedded in clothing may monitor the user and provide physiological measures of the user's state, such as heart beat rate and galvanic skin response, when engaged with the therapeutic tasks [ref burdea]. If applications can be created that 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. Backman noted that for a period of up to eight years prior to the clinical diagnosis of Alzheimer's disease, impairments in multiple cognitive domains can typically be observed [ref backman]. Furthermore measures of executive functioning, episodic memory and processing speed may be helpful in identifying individuals who are at risk of developing dementia or Alzheimer's disease at a later stage. If these games are designed to be challenging in different cognitive domains, as well as played regularly, then they may lead to an increase in cognitive reserve. This in turn may delay or prevent the degradation of cognitive skills due to the neurodegenerative diseases [ref Stern, Buschert].

Situated cognitive intervention may provide the patients with therapeutic activities in their home-environment. This could for instance be by presenting and supporting the patient with practice tasks (such as 'do you remember where your car keys are? Could you please go find them?') which must be performed. The final opportunity of interest is the possibility for tele rehabilitation. This involves the patient engaging with some rehabilitation exercises at home, with the clinician remotely monitoring the progress. Telerehabilitation 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 [ref]. As it reduces the time that a clinician must spend on the one-to-one administration of repetitive exercises, it frees up the clinicians 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, telerehabilitation may reduce the total cost for health care [Burdea].

3.4.4 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 cybersickness or other side effects [ref]. Side effects such as postural instability may not be significantly present with younger and healthy users of virtual environments, but with elderly these side effects may become more relevant. Cognitive impairments caused by aging, TBI 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 people filing lawsuits against the providers of the technology, with perhaps in some cases a fair chance of winning the argument.

A number of ethical challenges accompany the introduction of virtual reality based technology. Although pilot studies that were conducted provided promising results, the rehabilitation protocols that are used have not yet been validated. This implies that patients could receive more benefits with traditional approaches [castelnuovo, 2003]. The remote monitoring that telerehabilitation 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 to scrutinize their behavior in their private home environment [ref Rizzo 2004]. Just as is the case with some computer games, users may develop a dependence on, or addiction to these virtual environments [ref Rizzo 2004]. These ethical issues need to be considered when creating virtual reality applications for use in a home environment.

3.5 Design recommendations

A number of design and engineering recommendations will be listed here that are based on the SWOT analysis that was presented in the previous section. According to Rizzo [ref Rizzo, 2005] an effective strategy for the design and engineering of applications is to take advantage of the Opportunities by employing its Strengths. The Threats should be proactively addressed while correcting or compensating for the Weaknesses that were identified. The design recommendations that can be noted are related to the virtual environment itself, and to the rehabilitation protocol that is used.

3.5.1 Virtual environment recommendations

When considering the use of virtual reality applications for cognitive rehabilitation, finding the answer to a number of basic questions may help with exploring the possible design space. Rizzo published a series of questions or considerations [ref rizzo] which were often repeated in subsequent literature [ref mcgee, ref]. The development and deployment of a virtual reality system may require a significant investment of time, money and other resources. The benefits that results 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 on an immersive virtual reality application for the rehabilitation of phantom limb pain [ref Murray et al] while Ramachandran reported on using an ordinary mirror from a "five and dime" store [ref ramachandran] with 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 the primary aim should be "elegant simplicity" [ref rizzo 1998] instead of technological prowess.

Another important consideration posed by Rizzo is to question how 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 with the design of some specific aspects of the system. They should be chosen to represent all the different user types which will interact with the system, including end-user (patient), clinician as well as researcher. Furthermore, design methods such as [ref Grammenos 2004] that promote universally accessible interfaces could be used to increase the accessibility and usability for the target audience. This covers both the Graphic User Interface as well as the input (e.g gamepad, keyboard) interaction that is required. Users that are not able to adapt to one particular input device, may be able to adapt to another and still use the virtual environment. Furthermore, affordances may be designed that assist the users in interacting with the virtual environment much as they would interact with the real world [ref].

Some clinical populations such as the amnesic, may not be able to distinguish correct from incorrect responses, and can use errors as cues for successive performance [ref morganti]. For them the virtual environment must support error-free learning. For others virtual *un*reality may be a more appropriate paradigm to take into consideration, as an unnaturally high speed of presentation of stimuli in the virtual environment requires a higher cognitive information processing speed [ref mroganti]. Riva notes that in virtual environments aimed at cognitive rehabilitation, reproducing precise physical aspects of a virtual 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 [ref Castelnuovo 2003].

A few recommendations for preventing side effects such as cybersickness have also been noted by Lewis [ref Lewis]. The latency in the system should be minimized, while the update rate for the visual displays should be maximized. If HMD's are used, then the amount of head movement that is required 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.

The Threats that were identified in the previous section may be partially avoided by the design of the virtual environment. The possibility for cyber sickness and other side effects may be reduced by careful design of the task characteristics and the system characteristics. For instance instead of a HMD a projection screen may be used, and 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

The application may consist of more than a virtual environment which is presented to the user. For example it may incorporate a tool which allows the therapist to process or view performance measures that may have been recorded while the user was engaged with the virtual environment. This may happen during or after the user is engaged with the virtual environment. This leads to a number of design recommendations which are aimed at how the system functions. The first recommendation is that during the design phase it should be considered which performance related data should be recorded [ref rizzo swot]. This recorded data often must be further processed for analysis. This may help the therapist to perform a differential performance analysis, or find answers to questions such as ‘Which cognitive skill has improved during the sessions? Which have not?’. This in turn may aid the therapist with determining the therapeutic strategy. Another recommendation is related to how much control the therapist has over the stimuli that are presented in the virtual environment. One of the findings of the Virtual Reality Exposure Therapy research done 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 [ref Brinkman]. Cognitive overload results from the GUI becoming too complex for the therapist, who might not be an experienced computer user, due to this requirement for fine grained control. This complex GUI solicits a lot of attention of the therapist, which decreases the attention that is available to spend on engaging with the patient. And finally such fine grained control over the presented stimuli may increase the possibility for errors which result in an inconsistent presentation of stimuli in the virtual environment, which may harm the sense of presence. At the opposite of such fine grained control over the presented stimuli is that the therapist determines the content of the virtual environment prior to the session with the patient. This allows the therapist to engage with the patient almost exclusively, at the possible expense of being able to adapt to specific needs (of the patient) for practice that may arise during a session.

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 are a contributing factor in the possibility for side-effects to occur, special measures need to be taken into consideration. This leads to the following suggestions for the rehabilitation protocol [ref Rizzo]:

- Prior to exposure to the virtual environment, participants are to be screened to detect those individuals who are at risk of suffering from side effects. The screening procedure may include questionnaires to address the general state of (mental) health such as the Mini Mental State Exam (MMSE) [ref folstein], medication history, static and dynamic balance disorder history [ref berg], motion sickness history with for instance the Motion Sickness History Questionnaire (MSHQ) [ref Griffin], and a test of ocular function (if a HMD is used) [ref Lewis].
- 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.
- There should be a procedure for monitoring for unexpected side effects occurring during or after exposure to the virtual environment.
- After the exposure some time should be reserved for the senses to re-adapt to the real world [ref Lewis].
- 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) [ref Witmer] and the Simulator Sickness Questionnaire (SSQ) [ref kennedy]

It should be kept in mind that the screening process, if done properly, may require the patients to fill in many different questionnaires. This may lead to mental fatigue with patients [ref]. If they subsequently are only assessed with the virtual environment, this mental fatigue may also influence their performance. It may be possible to defer the screening process to the clinicians, eliminating the need for the patient to fill in (some) questionnaires prior to be allowed the use of the virtual environment.

4 Motivation in computer games

In this chapter the existing literature is reviewed with a focus on motivation in computer games. Section 4.1 introduces the concept of rule-based games as a playful activity that humans may pursue. Section 4.2 surveys the relationship between games, motivation and learning. When 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 4.4 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" [ref Holbrook]. 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 interersting) or extrinsic (for instance when the outcome of an activity is desirable or important) [ref garris]. 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 2005].

Huizenga defined games as a type of playful activity that is distinguished by its conformity to a set of rules [ref Holbrook 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 [ref garris]. 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" [ref garris]. 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

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 an improved performance [ref Garris]. 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

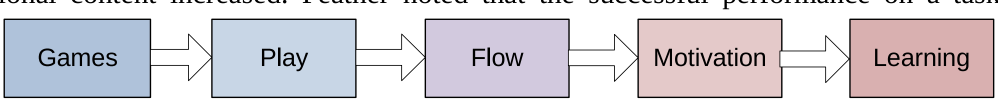

Figure 11 The relationship between games, motivation and learning [ref Paras]

subsequent performance due to a learning or a motivational effect [Holbrook]. All these 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.

To investigate this relationship three theoretical frameworks must be used together. 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 that can be used to create and model motivating instructional content [ref Paras]. 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 as well as important to the learner. Confidence strategies involve creating positive expectations of the learner for successful achievement. And 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 which is involved with understanding the relationship between games, motivation and learning is Csikszentmihalyi's flow theory. Flow theory describes a psychological state during which the performance at a task is optimal and attention is fully invested [ref csik p31]. 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 state of flow has a number of prerequisites. First of all 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. Tasks should neither be too easy nor too hard [ref csik p30]. 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 [ref paras]. The third and final theoretical framework which is involved with understanding the relationship between games, motivation and learning are Norman's seven basic requirements for creating learning environments [ref Paras].

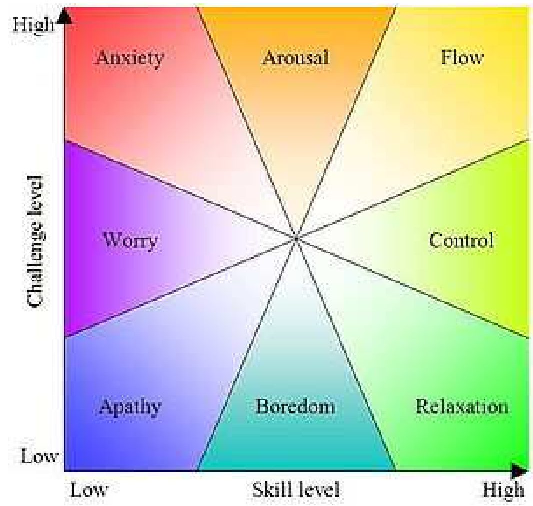

Figure 12 Flow state as a function of the relationship between challenges and skills. Image source: wikipedia

1. They must have a high intensity of interaction and feedback
2. They must be based on specific goals and established procedures for reaching those goals
3. They must evoke motivation from the learner
4. They must present an appropriate level of challenge to the learner
5. They must provide a sense of direct engagement
6. They 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 11 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 may increase the motivation of the player, and lead to improved learning outcomes.

4.3 Motivation in players and instructional games

In this section an overview will be presented of where motivation in games originates from. Two perspectives will be taken into consideration. Section 4.3.1 will provide an overview of 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 to an underlying psychological framework based on human needs which drive 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 [ref Garris].

4.3.1 Motivation in players

Motivation in players of computer games can be investigated in a broader sense. There are different psychological constructs which try to model motivation in humans. The difference between them is that the emphasis is 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 [ref garris].

According to Bostan two major influential studies about motivation are the intrinsic motivation taxonomy developed by Malone and Lepper, and flow theory by Csikszentmihalyi [ref bostan]. According to Malone and Lepper, the most important factors which make any activity intrinsically motivating are 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 13 shows the motivational factors that these three studies have 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) which has not been empirically verified, 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 [ref bostan].

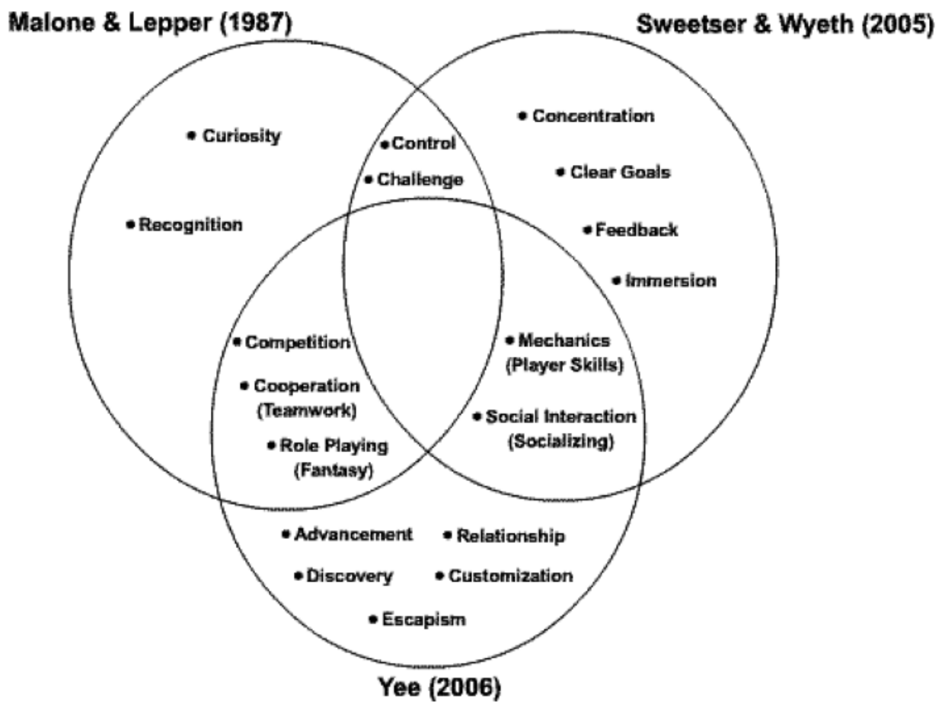

Figure 13 A comparison of three motivational studies [Bostan 2009]

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 [ref Bostan]. 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 grouped into six categories which are consistent with different gaming situations [ref Bostan]. 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

Murray defined each of the 27 needs with accompanying effects and desires, related emotions and feelings, attitudes and character traits, matching actions and the relationship to other needs. Each of the categories mentioned above contains a number of specific needs. For instance the ‘achievement needs’ can be further subdivided into the following needs: achievement (nAch), autonomy (nAuto), harmavoidance (nHarm), infavoidance (nInf), recognition (nRec) and exhibition (nExh). Bostan provides a detailed description of all these needs [ref Bostan]

Variable	Defined By[6]	Corresponding To[7]
Concentration	S & W, 2005	GDB: cocentration
Clear Goals	S & W, 2005	GDB: goal specificity
Feedback	S & W, 2005	GDB: feedback
Immersion	S & W, 2005	nSen, GDB: cocentration
Control	S & W, 2005; M & L, 1987	nDom, nAuto
Challenge	S & W, 2005; M & L, 1987	GDB: goal difficulty, outcomes, feedback, self-esteem
Mechanics	S & W, 2005; Y, 2006	nAch, nUnd, GDB: reinforcers
Social Interaction	S & W, 2005; Y, 2006	nAff, nNur
Curiosity	M & L, 1987	nUnd,nSen, nCog, GDB: feedback
Recognition	M & L, 1987	nRec
Competition	M & L, 1987; Y, 2006	nAff, nAch
Cooperation	M & L, 1987; Y, 2006	Aff, nAch , nRec
Fantasy	M & L, 1987; Y, 2006	nPlay, nUnd, nSen
Advancement	Y, 2006	nAch, nAcq, nDom
Relationship	Y, 2006	nAff
Discovery	Y, 2006	nCog, nUnd, nSen,
Customization	Y, 2006	nSen, nExh
Escapism	Y, 2006	nPlay, nSen

Figure 14 Murray's psychogenic needs mapped to player motivation [ref Bostan]

Bostan has shown how the psychogenic needs identified by Murray can be mapped to previously mentioned studies on motivation, to provide a more integrated model of player motivations [ref Bostan]. Figure 14 shows a complete list of how motivational variables correspond to psychogenic needs. For instance the achievement need (nAch) corresponds to a number of motivational variables that have been identified, such as Advancement (Yee), Cooperation and Competition (Malone and Lepper, Yee), and Mechanics (Sweetser and Wyeth, Yee).

Game genres are defined by their content [ref Bostan]. 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 [ref Bostan]. Thus, different game genres satisfy different psychogenic needs, and may appeal (only) to players with specific personality or character traits. Holbrook found evidence for a ‘facilitating effect of personality-game congruity’, where the personality type of players (e.g. visualizer or verbalizer) can more strongly influenced the performance on a game if the type of game matches their personality [ref Holbrook]. He concluded that in general, player performance and emotion depends on how personality traits interact with the nature of a game being played (e.g variety seeking, sensation seeking, hedonistic).

4.3.2 Motivation in instructional games

Prior research has been conducted to investigate how to design instructional games which aim at creating self directed and self motivated learners. Garris proposed the model as shown in Figure 15. 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. Performance can increase as well as decrease as an effect of receiving feedback. In the user judgement stage the feedback received is compared to standards or goals, which in turn regulates the user behavior. This is the judgement-behavior-feedback cycle [ref Garris]. According to Garris, if the pairing of instructional content with characteristics and features of games is successful, this cycle results in recurring and self-motivated game play [ref Garris]. 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.

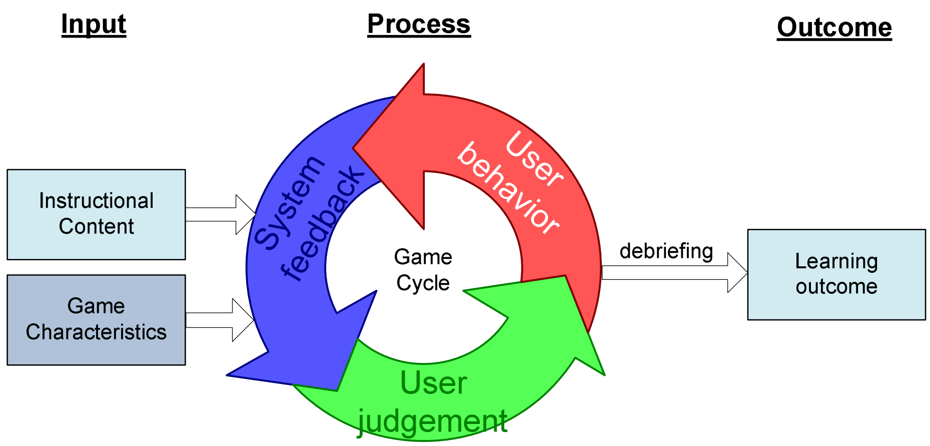

Figure 15 Input-Process-Outcome game model [ref Garris]

4.4 Affective gaming

Picard defined affective computing as computer programs which take the user's emotional state into account, and adjust the presented content accordingly [ref picard]. Contrary to such closed loop environments where the users 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 [ref Hudlicka]. Gilleade identified three high level design heuristics to create affective games: "assist me, challenge me, emote me" [ref gilleade]. 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.

Emotions in players can be triggered by three possible characteristics of a game environment [ref Hudlicka]. 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. An example is an opponent's avatar tackling a player's avatar in a soccer game. 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 would need to facilitate the recognition of a broad range of player emotions in realtime, within a variety of game contexts. Subsequently the game engine would need to generate effective adaptations of the game content that is presented to the player. This may include changing the gameplay reward structure or a realistic portrayal of appropriate emotions by the game characters that populate the game environment [ref Hudlicka 2009].

For many games a very simple computational model of affect is adequate enough to be able to meet these requirements. A small set of gameplay 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 [ref Hudlicka 2008]. Cognitive appraisal theory can be used to understand the affective and cognitive mechanisms that underly the generation of emotion, as well as the effect that emotion 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 [ref Hudlicka 2008].

Three requirements are at the basis of every affective game engine [ref Hudlicka 2009]. They are:

1. They must have a shared emotion knowledge base, which is used for both the recognition as well as the generation of emotions
2. They must have an affective player model, which stores information about the affective makup of the player. This encompasses information about which game events and what behaviors trigger which emotions. An affective user model facilitates emotion recognition as well as emotion generation [ref 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 [ref Hudlicka 2008]. The first key issue is related to game character development. The game designer needs to decide on questions such as ‘which emotions, moods 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 gameplay 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 gameplay should be adapted accordingly?’.

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