Addressing Patient Motivation in Virtual Reality Based Neurocognitive Rehabilitation

by

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Abstract

Cognitive rehabilitation exercises are typically not designed to be motivating. The use of virtual reality and gaming technology can help with increasing the patient's motivation and adherence. A physically active gaming experience leads to an increased adherence and affective attitude and an increased incentive to engage with healthy behavior. A psychological perspective on player motivation allows game design to explicitly focus on motivational variables, while affective gaming mechanisms allow games to infer the player's affective state and change their content accordingly.

This research project investigated if neurocognitive rehabilitation exercises based on affective gaming and physically active interaction lead to an increase in motivation of elderly people, while improving their cognitive skills. Part of this project was carried out at the Sensory-Motor Systems (SMS) lab[1] , under supervision of the lab's director Prof. Dr. – Ing. R. Riener. The SMS lab is associated to the Swiss Federal Institute of Technology in Zürich, and the University Hospital Balgrist, Medical Faculty, University of Zürich, Switzerland. The goal of this project presented has been to develop and evaluate the hypotheses, methodology, and system prototype to enable the SMS lab to conduct a clinical experiment which investigates patient motivation in virtual reality based neurocognitive rehabilitation.

A prototype system was created consisting of an affective gaming based training and assessment environment for the mental rotation task. This prototype system was used in a pilot study with 9 able-bodied and healthy participants aged 55 to 80. The results support the hypothesis that use of affective game design elements (e.g. incorporation of high scores, achievement medals, adaptive difficulty, different game modes and offering affective feedback) is motivating to the elderly population to engage with rehabilitation exercises. The results also support the hypothesis that a physically active gaming experience (provided by e.g. embodied interaction mechanisms) is motivating to the elderly. However more data is needed for the results to be more conclusive.

[1] http://www.sms.mavt.ethz.ch

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1 Introduction

This research project investigates the use of computer games for cognitive rehabilitation of elderly people, which is elaborated on in section 1.1. A concise problem statement is introduced in section 1.2, along with this project's goals side issues. This problem statement translates into a central research question and its associated hypothesis, introduced in section 1.3. Section 1.4 provides an overview of the system that was envisioned which supports training and assessment of a visuo-spatial skill in a home or clinical environment. The scientific contributions of this work, including the results of a small pilot study with elderly participants, are enumerated in section 1.5. Section 1.6, which concludes this chapter, contains a brief overview of the Situated Cognitive Engineering (Neerincx, & Lindenberg, 2008) engineering method used during this project. In the remaining chapters of this document, the information and results for one cycle in will be presented.

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[2].

Computer games are widely enjoyed as a leisure activity, but a relative new use for computer games is in the area of cognitive rehabilitation. 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. 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. Benefits for the clinicians would include the ability to automate the (remote) administration of rehabilitation exercises, and an extension of the differential diagnostic potential of current testing methods (Rose, Brooks, & Rizzo, 2005), enabling clinicians to more precisely pinpoint which cognitive skills have deteriorated.

Creating virtual reality- and game-based rehabilitation exercises poses many of the same challenges now as it did in the mid 1990s, such as the high complexity and cost of developing hardware and software (Rose, Brooks, & Rizzo, 2005). Designing 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 that tested out new technologies involved

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

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 (Rizzo, & Kim, 2005) and not enough clinical studies have been done to evaluate their effectiveness.

1.2 Problem statement, goal and side issues

Panic (2010) surveyed the literature on motivation in game-based neurocognitive rehabilitation. This resulted in a problem statement, introduced in section 1.2.1. The goal for this project is outlined in section 1.2.2, and followed by an overview of the approach suggested by Panic (2010) and the resulting side issues related to this project in section 1.2.3.

1.2.1 Problem statement

During a review of the related literature resulted in the following problems emerged, needing further investigation in future work.

1. Rehabilitation exercises are not designed to be motivating for the patient. Furthermore supporting the cognitive rehabilitation process can be a time consuming and repetitive process, for patient, therapist, or caregiver.

2. Engineering virtual reality based neurocognitive rehabilitation so that it is usable by the elderly population is a challenge.

Related to these problems is the issue that due to the aging population, more people will need cognitive (re)habilitation than currently have access to or can be treated in the existing clinics, allowing the symptoms to progress.

1.2.2 Goal

The goal of the research project presented in this document has been to develop the hypotheses, methodology, and prototype system to enable the SMS lab to conduct a clinical experiment which investigates which particular aspects of game and interaction design are perceived as motivating by the elderly population, and to validate the effectiveness of the novel training and assessment program. This development was done at the Delft University of Technology and included a pilot study using the system in a simulated home environment. Figure 1 illustrates this two-stage approach to the design and evaluation of technology for mental health interventions.

1.2.3 Suggested approach and side issues

Patient motivation in neurocognitive rehabilitation can be addressed by applying principles affective gaming. The learning material is provided in the patient's living room, and is automatically adjusted to the patient's skills and inferred emotional state. During the rehabilitation exercises a virtual assistant provides the patient with affective feedback that is appropriate to the current situation. The involved clinician can monitor the patient's progress, assess his skills, and adjust the content of the exercises provided to the patient. Human computer interaction devices which allow more natural and embodied interaction is the most likely to be usable (intuitively) by the elderly population. This approach covers each of the three issues from the problem statement.

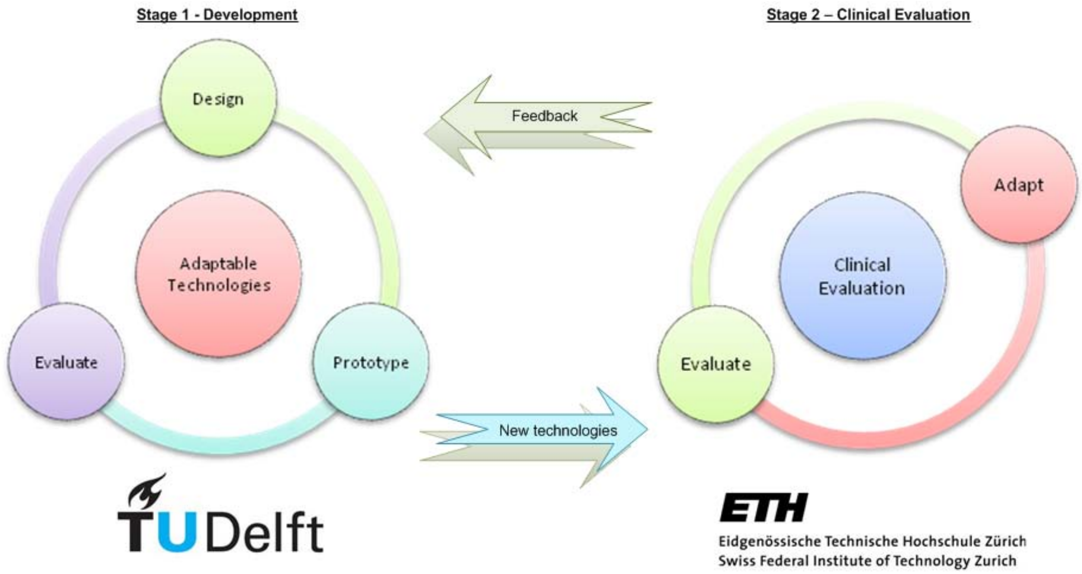


Figure 1 - Cyclic design and evaluation of technology for mental health interventions, after Coyle et al. (2007)

Diversity in cognitive and physical skills in the targeted population is one side issue that came up during this project. Selection criteria for the targeted population enabled the recruitment through friends and family of participants for a pilot study.Within the elderly population there may be diversity in cognitive as well as physical skills. The natural aging process and/or the presence of a pathological condition such as Alzheimer's disease may have degraded certain cognitive skills, and physical capabilities may have been impacted by conditions such as arthritis. In order for this initial research to be carried out, a healthy subset of the population was targeted. The following criteria were used to narrow the targeted population down:

- Age between 55 and 80
- Standard vision, or vision corrected to standard with glasses or contact lenses
- Able bodied and capable of independent living
- No (or at most, mild) cognitive impairments
- Ability to stand in front of a TV to play a computer game
- No history of motion sickness (e.g. car sickness, cybersickness)

Localization of exercises is another side issue that came up during this project. Assuming that cognitive rehabilitation should be administered in the patient's natively spoken language, the system had to be designed to allow localization. At least the part of the user interface to which a patient is exposed, had to be localizable into different languages (e.g. any of the languages spoken in the Netherlands and Switzerland).

1.3 Research question and hypotheses

During a literature survey on the topic 'virtual reality based cognitive rehabilitation' conducted by the author (2010), it became clear that an issue with both conventional and virtual reality based cognitive rehabilitation is that the exercises are typically not designed to be motivating for the elderly population. This provided the context in which the main research question was formulated:

> *How can virtual reality- and game-based cognitive rehabilitation exercises be designed to be more motivating for the elderly population?*

A literature survey on the topic 'motivation and games' introduced the concept of 'affective gaming', as defined by Picard (2000). Affective computing advocates designing and engineering technology to explicitly take the user's emotional state into account by adjusting the presented content. Hudlicka (2008) proposed that this concept can be applied to designing more motivating and engaging gaming technology. Based on the surveyed literature, affective gaming technology may be potential solution to the main research question. This will be investigated in a pilot study that is conducted at the Delft University of Technology.

Table 1 - Hypotheses to be investigated in a pilot study at the DUT

H1	Rehabilitation exercises that are designed using principles of affective gaming increase the motivation to engage with the exercise in the elderly population.
H1.1	Incorporating high scores as a game design element contributes to increasing motivation and willingness to engage.
H1.2	Incorporating achievement medals as a game design element contributes to increasing motivation and willingness to engage.
H1.3	Incorporating adaptive difficulty as a game design element contributes to increasing motivation and willingness to engage.
H1.4	Incorporating different game modes as a game design element contributes to increasing motivation and willingness to engage.
H1.5	Incorporating virtual characters providing affective feedback as a game design element contributes to increasing motivation and willingness to engage.
H2	Rehabilitation exercises utilizing reality based interaction increase the motivation to engage with the exercise in the elderly population.
H2.1	Rehabilitation exercises utilizing (head) tracking increase the motivation to engage with the exercise in the elderly population.
H2.2	Rehabilitation exercises utilizing gesture based interaction increase the motivation to engage with the exercise in the elderly population.

To investigate the hypotheses from table 1, a system was designed which supports cognitive training and assessement. The next section introduces this system.

1.4 Envisioned system

This section provides an overview of the envisioned system, as shown in Figure 2. There are three users of the system. The patient is in his home environment, and uses the system for training and assessment purpose. The therapist is in a clinical environment, and can prepare

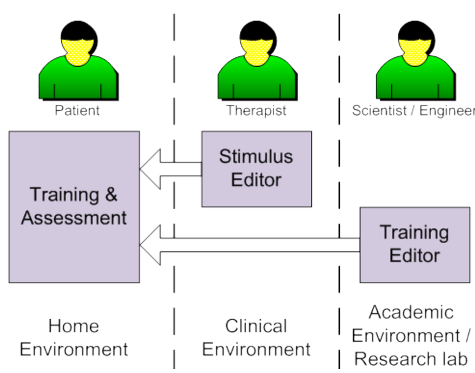


Figure 2 - An overview of system components and their typical users and contexts

the content for the training and assessment exercises using the system. A scientist or engineer can modify the configuration of the system for patients and therapists.

1.5 Scientific contributions

The results from this project have provided the following scientific contributions:

- It has resulted in a requirements baseline for virtual reality based neurocognitive rehabilitation of the elderly population, which can be used as a starting point for the research or development of applications.

- A virtual reality mental rotation assessment program was created, which allows precise control over the content of the assessment, and can be used by researchers who want to administer this test to the elderly population.

- A virtual reality mental rotation training program which incorporates patient motivation into its design has been created, which can be used to experimentally investigate the hypotheses from section 1.3. The results from a pilot study support these hypotheses.

1.6 A Situated cognitive engineering approach

The Situated Cognitive Engineering (SCE) method (Neerincx, Bos, Olmedo-Soler, Brauer, & Wolff, 2008) has been applied in this research project, because it explicitly takes human, technological, operational, and situational factors into account. Other similar methods exist, such as Benyon, Turner and Turner's (2007) whose analysis of People, Activities, Contexts and Technologies may yield similar results. However the SCE methodology does not only facilitate the iterative drafting of design requirements, but it also explicitly incorporates the development of one or more technology prototypes and use them to conduct an evaluation of claims made about the system's functions. This makes the SCE methodology particularly useful for this research project.

The Situated Cognitive Engineering (SCE) is an extension of Hollnagel and Woods (1983) Cognitive Engineering (CE) approach and facilitates the design and evaluation of technology which is tailored to the specific needs of a user within a given application domain. To achieve this, theories and models from cognitive psychology and human factors are used which enable a system to be designed which can accommodate user characteristics, tasks, and contexts in order to provide the right information and functions at the right time. CE is an iterative approach in which (initial) requirements are evaluated, and these results are then used to further refine the requirements. One advantage of the CE method is that it focuses on creating requirements aimed at a user in a specific application domain.The Situated Cognitive Engineering (SCE) method, proposed by Neerincx and Lindenberg (2008), extends the CE method with a technological perspective. SCE adds an explicit focus on users situated in specific circumstances. Blanson Henkemans adapted the SCE method to the medical domain (Blanson Henkemans, 2009), resulting in the schematic representation as shown in Figure 3.

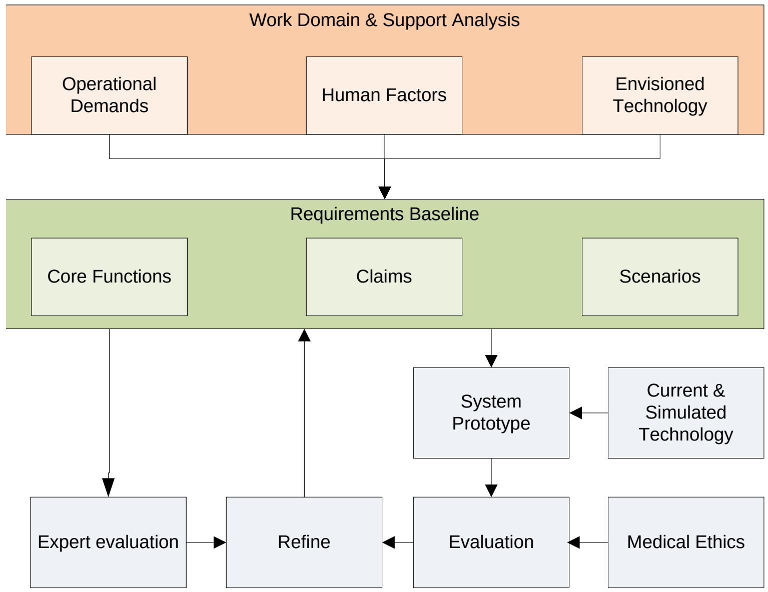


Figure 3 - Situated Cognitive Engineering in the medical domain (after Neerincx, & Lindenberg, 2008, Blanson Henkemans, 2009)

The engineering activities start with a Work Domain & Support (WDS) analysis. This analysis covers all relevant operational demands and human factors as well as the envisioned technology. Section 2.1 of this document summarizes relevant findings from a literature survey performed by the author. The WDS analysis is provided in section 2.2. This information is then used to create a first Requirements Baseline (RB) specification, a design rationale derived from of a list of core functions, related claims about what the system does and does not do, and use-case scenarios. Section 2.3 contains the requirements baseline for virtual reality based neurocognitive rehabilitation.

The requirements baseline then enters two cyclic and parallel processes. In the first process, it is subjected to an expert review which results in their refinements. This is outlined in section 4.3 of this document. In the second cyclic process it is then used to guide the design of a technology prototype, which may incorporate both existing and not yet existing (simulated) technology. Chapter 3 provides an overview of the prototype which was created in the course of this project. Ethical issues surround the application of the created technology, which are discussed in section 4.2.

This prototype can be used to experimentally verify claims made in the requirements baseline. Chapter 5 provides the details of a pilot study which has been conducted in order to test the system, and to investigate the hypotheses posed in section 1.3. Within this project one iteration of both cyclic processes involved with Situated Cognitive Engineering has been completed.

2 Requirements for virtual reality based neurocognitive rehabilitation

This chapter presents the design requirements for a virtual reality based neurocognitive rehabilitation environment, which can be used to experimentally investigate the hypotheses as noted in section 1.3. A review of literature related to cognitive rehabilitation, motivation and virtual reality is presented in section 2.1. The results from the WDS analysis are provided in section 2.2, and the resulting RB in section 2.3.

2.1 Theoretic background: virtual reality in neurocognitive rehabilitation

Three main topics are related to the research question posed in section 1.3: cognition and neurocognitive rehabilitation, virtual reality, and game-based learning (see Figure 4). This prompted the following subquestions, which have been used to survey the relevant literature:

1. *What is 'cognition' and how can it be assessed or rehabilitated?*
2. *How can cognitive rehabilitation be supported with virtual reality based applications? Which human factors aspects are relevant when designing or using virtual reality based applications for neurocognitive rehabilitation?*
3. *How can game-based learning environments be designed to be engaging and motivating for the learner?*

Panic (2010) provides a broad overview of the theoretic background for these questions. The following sections provide the information that is relevant for the design of the system envisioned in Figure 2.

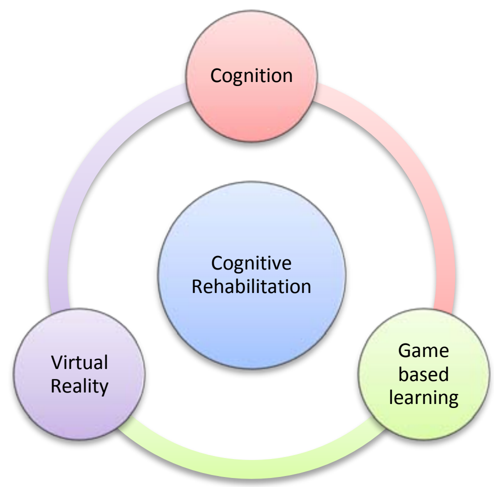


Figure 4 - Three main topics related to the research question

Suggestions and recommendations for cognitive rehabilitation strategies are discussed in section 2.1.1. Suggestions and recommendations for virtual reality based neurocognitive rehabilitation are discussed in section 2.1.2 And lastly, suggestions and recommendations for addressing patient motivation in games are discussed in section 2.1.3.

2.1.1 Approaches to neurocognitive rehabilitation

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 on other individuals, as shown by the study with nuns carried out by Snowdon (2003). Differences in brain plasticity seem to allow some individuals to use a physically and mentally active lifestyle to build up a 'cognitive reserve' which shields them from immediate development of cognitive deficits (Scarmeas, & 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). An ongoing discussion in the literature on the most effective approach to cognitive rehabilitation is about whether it should focus on individual skills, or have a more holistic focus on improving performance during activities of daily life. A third option is a complementing approach in which individual skills are rehabilitated prior to the rehabilitation of Activities of Daily Life.

The following sections will provide an overview of evidence based cognitive rehabilitation strategies (section 2.1.1.1) and a summary of information that is relevant for the system design (section 2.1.1.2).

2.1.1.1 Evidence based cognitive 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.

2.1.1.2 Summary and conclusion

One issue noted in the literature is that rehabilitation exercises are typically not designed to be motivating (Flores, et al., 2008, IJsselstein, Nap, de Kort, & Poels, 2007, Rizzo, & Kim, 2005). According to Burdea (2003) the characteristics of conventional therapeutic exercises are that they are simplistic and repetitive in nature and tend to decouple the mind, which may reduce the motivation from the patient to engage with them. These exercises may not only be repetitive to the patient, but also to the therapist involved with administering them.

During talks with a researchers of rehabilitation technology of the ETH Zürich in 2010 it was noted that often during such repetitive exercises, the therapist that is present is trying to motivate the patient by providing verbal feedback (such as ‘you can do it’ and ‘do not give up’). This can get repetitive for the therapist as well, and upon repetition the feedback may lose its effectiveness on the patient. Furthermore in their experience patients responded differently when presented with rehabilitation exercises. Some patients are motivated for a particular exercise, while others are not.

Another issue is related to the available rehabilitation strategies, as described in the previous section. These strategies all assume that a decline in cognitive skill has been clinically diagnosed, and must be targeted by treatment. However Small et al. noted (2003) 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. The currently available cognitive rehabilitation strategies do not seem to focus on pre-clinical training to reinforce or strengthen cognitive skills. Such preventive training may contribute to a cognitive reserve (Stern, 2009) which increases the resilience to subsequent degradation of cognitive skills due to aging, dementia or pathological conditions. Pre-clinical measurements 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 (Buschert, Teipel, Hampel, & Burger, 2009).

The next section will provide an overview of the literature on virtual reality based neurocognitive rehabilitation, and how that could help with addressing the issues brought forward in this section.

2.1.2 Virtual Reality based neurocognitive rehabilitation

Virtual reality can be used as an assessment or rehabilitation instrument for the clinical treatment of psychological disorders. This section presents the results of a survey of available literature on studies related to virtual reality based neurocognitive rehabilitation.

2.1.2.1 Human factors in virtual reality based applications

The following sections provide the information that is relevant for the design of the system envisioned in Figure 2. Human performance in virtual environments is discussed in section 0, followed by section 0 which discusses cyber-sickness and other side effects of exposure to virtual environments. Related health and safety issues are discussed in section 0.

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, 1984). 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.

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.

Human behavior and performance can be affected by cyber-sickness and other virtual reality side effects through a range of symptoms, both during and after exposure to a virtual environment. Physical symptoms include bodily discomfort caused by ergonomics of the system (Cobb, Nichols, Ramsey, & Wilson, 1999), and physiological symptoms such as an increased heart rate, 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.

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).

2.1.2.2 Recommendations

In the literature that was surveyed (Panic, 2010), recommendations for the design of the envisioned system (section 1.4) have been found. These recommendations can be related to the virtual environment, the system, the rehabilitation protocol, age related usability issues, and health and safety issues. Each category will be discussed in the remaining paragraphs of this section.

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.

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.

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.

Recommendations on preventing age related usability issues

Age-related changes in mental and physical skills described in can 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.

2.1.2.3 Discussion and conclusion

The adoption of virtual reality for cognitive therapy (rehabilitation of particular skills) and cognitive behavioral therapy (rehabilitation of behavior) still faces many of the same challenges as it did in the mid 1990's (Rose, Brooks, & Rizzo, 2005). Although cognitive training of a particular skill does seem to improve that skill, it is still an open question whether that improvement aids in the other activities of daily life (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 training, rather than assessment (Standen, & Brown, 2005). This may signify an opportunity to combine both into a single application.

New technology may not be readily accepted by some individuals, including the elderly and/or therapists, because of insecurities about how to use it (Rizzo, & Kim, 2005, Burdea, 2003). Two other potential problem areas with computer-based rehabilitation technology are the front-end flexibility, such as the internationalization of graphic user interfaces, and the level of support that the back-end provides, relating to data extraction, management, analysis, and visualization (Rizzo, & Kim, 2005). Addressing these issues may increase the rate of acceptance by the clinical community.

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, wher,e and for whom the technology is appropriate, similar to classical mental health approaches (Rizzo, Strickland, & Bouchard, 2004).

One issue with cognitive rehabilitation that was noted in section 2.1.1.2 was that rehabilitation exercises are typically not designed to be motivational. Another issue was that different patients have different affective responses to the exercises. These two issues can be addressed in virtual reality technology by using game design techniques when designing rehabilitation exercises. Conversely, the use of virtual reality technology can also make these issues worse, because of the challenge of designing usable interfaces. Although some studies have investigated what kind of games the elderly population prefers (e.g. Castelnuovo, Lo Priore, & Liccione, 2003, Flores, et al., 2008, Torres, 2009), no information was found which particular game design elements contribute to the motivation of the player. Only general recommendations are provided, such as that games must provide tasks of growing difficulty, provide appropriate cognitive challenge, have a simple objective and user interface, and stimulate motivation and enterprise. This implies that further literature research is required to find information about how to explicitly address patient motivation with the design of game-based rehabilitation.

The third issue that was noted in section 2.1.1.2 relates to the existing rehabilitation strategies focusing only on rehabilitation of cognitive skills and not on preventing a deterioration of existing ones. Virtual reality technology can be used for tele-rehabilitation in a home environment, which allows cognitive reserve to be addressed before clinical assessment of symptoms is possible. Deferring the administration of repetitive exercises to virtual reality technology also frees up time from the therapist, which is related to the fourth and final issue noted in section 2.1.1.2 (the repetitiveness of administering the exercises).

Using virtual reality technology for the creation and administration of rehabilitation exercises provides the means to address some, but not all, of the issues related to cognitive rehabilitation. The next section presents the results of a further investigation of existing literature, which aimed to determine how games can be designed to motivate the player.

2.1.3 Player motivation in instructional games

This section introduces the literature relevant to motivation in (computer) games, to provide a theoretic framework for designing therapeutic games to be motivating and engaging for the patients. According to Deci, playful activities such as sports, hobbies, games and other leisure activities are enjoyable "for their own sake", and therefore people are willing to spend time on them (Holbrook, Chestnut, Oliva, & Greenleaf, 1984). The motivation to engage with such activities can be intrinsic when an activity is perceived as enjoyable and interesting, or extrinsic when the outcome of an activity is desirable or important (Garris, Ahler, & Driskell, 2002). Common prerequisites for motivation to be present are that the task is valued enough to warrant spending time on it, and that by spending the time the task can be successfully completed (Paras, & Bizzocchi, 2005). Holbrook, Chestnut, Oliva and Greenleaf (1984) noted that intrinsic motivation may be undermined by the introduction of extrinsic rewards, such as interpersonal competition. Huizinga defined games as a type of playful activity that is distinguished by its conformity to a set of rules (Holbrook, Chestnut, Oliva, & Greenleaf, 1984). However, a consequence of having explicit or implicit rules is that the player can make mistakes and therefore perform poorly.

2.1.3.1 Addressing player motivation in games

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).

Bostan (2009) investigated evidence in the social and computer sciences for motivation, particularly in the context of computer games, and presented an approach to integrate 'player motivation' into the process of designing a game. 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, such 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. 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.

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

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 2 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, such as Advancement (Yee), Cooperation and Competition (Malone and Lepper, Yee), and Mechanics (Sweetser and Wyeth, Yee).

Table 2 - 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	

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.

2.1.3.2 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?'

2.1.3.3 Discussion and conclusion

The benefit of having a motivated learner is that they appear to be more capable of mastering instructional content than an unmotivated learner. Bostan (2009) describes how the results of previous studies of motivation have shown that what motivates people may be dependent on personality traits. Bostan's work provides an overarching framework which ties several studies of goal based behavior and related motivational factors together with studies into motivation in computer games. The result is a psychology-driven framework which can be used as a context to discuss game design elements, and how they may contribute to creating a motivated learner.

Prior work has investigated how to design games which aim to motivate their players. Gilleade, Dix and Allanson (2005) presented high level design heuristics for creating affective games, which may be useful when designing game-based rehabilitation exercises. Hudlicka (2009) described how to design affective game engines, which allow the creation of games which continuously monitor the player and look for signs of emotional states. Based on an inferred emotional state, a game can then adjust its content accordingly. This principle can be useful for creating game-based rehabilitation exercises which present an appropriate cognitive challenge to the patient. Alternatively, it can be used to create a virtual assistant avatar, which can be used to provide affective feedback to the patient while engaged with the exercises. Even though more research is needed on using multimodal sensory data to successfully infer the player's affective states, Hudlicka stated that incorporating simple measures that are not necessarily based in human psychology or physiology may already have the desired effect.

2.2 Work Domain & Technical Support analysis

Table 3 lists the activities which were carried out for the Work Domain & Support (WDS) analysis. These activities consisted of web searches, a literature survey, document analyses, and finally of interviews conducted with domain experts. This analysis needs to consider three aspects related to the envisioned system: the Operational Demands which indicate the circumstances in which the system will be used, the Human Factors related to the different users involved, such as patients, healthcare professionals, and technical specialists. The third aspect, Envisioned Technology, provides a high level overview of the technology which is required to be able to investigate the research questions posed in section 1.3. Each of these aspects will be discussed separately in the following paragraphs.

Table 3 - Overview of Work Domain & Support analysis activities

Activity	**Goal**	**Domain**
WWW search	Find relevant projects/products	International projects/products on computer and/or virtual reality based cognitive rehabilitation.
Literature survey	Find relevant publications	Papers, projects, journals, conferences on: cognitive rehabilitation, virtual reality, motivation & games.
Document analyses	Assessment of: human factors, operational demands	Recommendations, rehabilitation protocols, statistics, ethics.
Interviews	Assessment of: human factors, operational demands, envisioned technology	Medical specialists, researchers.

The interviews, which were conducted with 5 professionals, were guided by the questionnaire listed in Appendix A. For each of the three aspects a number of questions had been devised beforehand. During the interview, depending on the background and/or answers provided by the interviewee, the appropriate questions were selected and asked. Furthermore the questionnaire served as a guide, meaning that ad-hoc questions were asked, for instance to follow up on remarks given by an interviewee.

2.2.1 Operational demands

During the WDS analysis insights were gained in the technological requirements for the different users which are involved. After a cognitive deficit has been identified by the therapist during a clinical assessment, the patient can practice the required skill autonomously and on a daily basis in his or her home environment. The patient's performance and progress is monitored by the therapist during subsequent clinical assessments, and the content of the exercises is adjusted according to individual patient needs. In order to stimulate adherence to the planned therapy, patient and therapists have to focus on the patient's motivation, self-efficacy and goal setting (Blanson Henkemans, 2009).

2.2.2 Human factors knowledge

As mentioned in section 1.2.3, the population targeted by this research consists of the elderly diagnosed with mild cognitive impairments. Also the typical ('healthy') aging process may already be accompanied by a decline of cognitive functions such as sensory function, speed of processing, working memory, language and social skills, motor skills, as well as the interrelationships between these processes (Park, Gutchess, Meader & Stine-Morrow, 2007, Fisk et al., 2009). Furthermore cognitive deficits caused by dementia may include impairments in praxis, organizational skills, attention and judgment (Gifford, & Jones, 2009).

The elderly population may not be very experienced with using a computer. Some individuals can overcome this with practice, while others can not or do not want to engage with computers altogether due to personality traits (Blanson Henkemans, 2009). Regardless of their physical and cognitive capabilities and skills some people seem to have an emotional barrier which prevents them from engaging with computers.

Besides diversity in physical and cognitive skills among the elderly, another relevant variation may be in the language spoken by the elderly. In Switzerland for instance, there are four national languages (German, French, Italian and Rumantsch). In the Netherlands there are two national languages (Dutch and Frisian). Enabling the entire targeted population to receive cognitive rehabilitation implies that the technology must be (easily) localizable into any of these languages.

Although ideally technology is designed to be universally accessible, this may not be possible given the wide variety of cognitive and physical skills within the targeted population. A tradeoff had to be found between the envisioned technology and the part of the targeted population who are able to use the technology. This is why the targeted population has been defined as 'elderly diagnosed with mild cognitive impairments, but still capable of independent living'. As an example, elderly who are (partially) blind or have arthritis are assumed to not belong to the targeted population.

2.3 Requirements baseline

This section provides an overview of the requirements baseline which emerged as a result of the work domain and support analysis which has been detailed in the previous sections. In the next sections the core functions of the envisioned technology will be listed, and their accompanying claims which can be used to experimentally validate or invalidate them. Section 2.3.2 contains three example scenarios which aided with envisioning how the core functions would translate into real-world situations.

2.3.1 Core functions and claims

This section identifies the core functions of the system. They are related to the assessment and training of cognitive skills, while nurturing a motivated learner. These core functions have been translated into features of the system, which have been implemented in system prototype as will be described in chapter 3. These features can have positive and negative effects, which have been expressed in the accompanying claims.

Table 4 - Core functions of the system, and claims on their positive and negative outcomes

Core Functions	**Software features**	**Claims**
Assessment of one or more cognitive skills	For patients: • Provision of assessment environment, • Automated recording of performance metrics. For therapists: • Support for evaluation of recorded performance metrics, • Support for adjusting the content of the assessment.	+Computer based assessment allows evaluation of (at least) the same performance metrics as the conventional paper based assessment (No. 1).
Training of one or more cognitive skills	For patients: • Provision of training environment, • Automated recording of performance metrics recording, • Enable monitoring of current skill level. For therapists: • Support for evaluation of recorded performance metrics, • Support for adjusting the content of the training exercise.	+ Most patients can engage with the exercises autonomously and in a home environment (No. 2). - Due to the variability in physical and mental skills it is difficult to provide computer based training with which all the patients can engage (No. 3). +Training with the provided exercises increases the task performance (No. 4).
Promote patient motivation and adherence.	For patients: • Incorporate targeted cognitive skill in an affective game design, based on high level design heuristics ("assist me, challenge me, emote me"). • Favor physically active and reality based interaction mechanisms over traditional sedentary and mouse/keyboard based mechanisms • Incorporate affective game engine, which enables virtual assistant characters to have appropriate affective expressions.	+Because of the applied affective game design mechanisms, patients are more motivated to engage with the training (No. 5). -Due to individual differences in the origin of motivation, it is difficult to design a game that motivates every member of the targeted population (No. 6). +Reality based and physically active interaction is more engaging and motivating than sedentary, computer mouse and keyboard based interaction (No. 7). +Patients are motivated to engage with the training exercises because of the affective feedback provided by in-game virtual assistants (No. 8).

Note that the core functions and associated claims from Table 4 are independent of the type of cognitive skills that have to be rehabilitated. This means that these core functions and claims are identical when creating virtual reality and game-based rehabilitation for e.g. short term memory or visuo-spatial skills. Before any claims about a system's functioning can be experimentally verified or falsified, the targeted cognitive skill(s) must be further specified and expanded into game design features. Only then can the claims from Table 4 be associated with experimentally verifiable or falsifiable hypotheses. This will be further elaborated on in section 3.4 of this document, which discusses the hypotheses resulting from the system prototype.

2.3.2 Use case scenarios

A number of scenarios have been devised to aid with envisioning how the core functions and claims translate to a real-world context. They can describe the environment in which the system will be used, and the actors who will be using the system, their goals and objectives, and possibly the sequences of actions and events involved with reaching them (Go, & Carroll, 2004, cited in Blanson Henkemans, 2009). Three scenarios have been created, which cover all possible uses of the system. Within these three scenarios two actors can be identified: Alexander, a 60 year old male who has been diagnosed with mild cognitive impairments, and Christel, a 34 year old cognitive therapist who is working with Alexander on the rehabilitation of his lost cognitive skills.

2.3.2.1 Scenario 1: unsupervised rehabilitation exercises, carried out in a home environment

When becoming of age, Alexander has been diagnosed with specific cognitive impairments. It is unclear if these impairments are caused by the typical aging process, or by dementia. He consults with his therapist Christel, who designed appropriate exercise content with an accompanying training schedule to restore his cognitive functioning to the level where it used to be when he was younger.

Regardless of his lack of experience with computer use, Alexander can engage with the provided training environment while (alone) at home, in front of the television or computer screen. This requires physical activity, as he must stand or sit in front of the TV screen and move his body and arms to interact with the training environment. The training environment is assisting him in different ways, for instance by providing clear and simple goals. The training environment is also challenging him in different ways, for instance by continuously adapting the difficulty level to match his skills. During a training session, when he is doing well a virtual assistant avatar appears on the screen to commend him with his accomplishments, as well as to challenge him by announcing that he is ready for an increased difficulty. Similarly when he feels that he is not doing well a virtual assistant appears which supports him to not give up and to continue practicing. At any time Alexander can query the training software about his current skill level, which allows him to monitor his own progress. During his training sessions the training environment has automatically recorded performance metrics, which can be analyzed by Christel during his next visit. These help Christel to monitor Alexander’s progress through the training schedule, and to decide whether she needs to adjust the training content whenever it is too easy or too hard for him.

2.3.2.2 Scenario 2: supervised skill assessment, carried out in a clinical environment

When becoming of age, Alexander has been diagnosed with specific cognitive impairments. It is unclear if these impairments are caused by the typical aging process, or by dementia. He consults with his therapist Christel, who designed appropriate exercise content with an accompanying training schedule to restore his cognitive functioning to the level where it used to be when he was younger.

After practicing autonomously for a number of weeks, Alexander reports to Christel for the next scheduled therapeutic session. As Christel is interested in monitoring his progress, she starts by investigating the performance metrics which the system has automatically recorded of Alexander's training sessions. They show her that he has been keeping to the training schedule that they agreed upon, and that the content of the provided exercises still is a good match for his skill level. To get an idea about how Alexander's current skill level compares to the averages from his peers (either healthy or with a similar medical condition), she wants to administer a standardized assessment. The assessment that Christel uses is computer based, and made to resemble a traditional 'paper based' assessment as closely as possible so that she can use data collected during prior studies conducted by other researchers. The system allows Christel to change the assessment's content to match to the previous study of which she would like to use the results for comparison.

Regardless of his lack of experience with computer use, Alexander can engage with the provided assessment environment. This requires him to sit down behind a desk and use a computer keyboard or mouse to submit simple choice-responses. This computer based assessment environment automatically records Alexander's performance metrics, and aids Christel with processing this data into meaningful representations which help her with deciding on the appropriate course of action for Alexander's continued treatment.

3 The System Prototype

This chapter provides a step by step overview of the System Prototype (see Figure 3) that was created to be able to experimentally verify the claims that were made in section 2.3.1. The first step was to decide on a cognitive exercise which traditionally is used for assessment and training of a cognitive skill, and which also is suitable for use in a virtual reality based game environment. Section 3.2 will outline how affective computing principles have been applied to design a game which explicitly targets some motivational variables. Since this research project is internationally oriented, the envisioned system was required to be able to deal with the different languages being spoken by the targeted population, as discussed in section 1.2. Section 3.3 describes all the software components which have been created, how and by whom they are supposed to be used, and provides a brief overview of their underlying implementation.

3.1 The mental rotation task in virtual reality

To investigate the research questions posed in section 1.3, a choice had to be made for a cognitive skill which could be targeted by a rehabilitation process. Furthermore it had to be possible to both train the cognitive skill using one or more exercises, and to assess the skill level in order to monitor the rehabilitation progress. The specific formulation of the research question has led to the identification of a number of selection criteria, which guided the process of finding a suitable cognitive skill and training and assessment tasks. These requirements are:

- The addressed cognitive skill must be one that is commonly subjective to decline due to neurodegenerative diseases or the healthy aging process,

- Conventional therapeutic exercises used must be suitable for adaptation to a virtual reality based computer game,

- Conventional therapeutic exercises must be repetitive in nature.

Several publications have been found during the literature study that offer an overview of cognitive functions commonly targeted by rehabilitation (Cicerone et al., 2000, Cicerone et al., 2005, Cappa et al., 2005). They are attention, visuo-spatial reasoning, motor planning and execution skills, language and communication skills, memory, executive functioning and problem solving and visual recognition. Feedback from medical and clinical specialists obtained during the interviews at the ETH Zurich confirmed their need to be addressed through therapy.

Spreen and Strauss have published (2006) a compendium of neuropsychological tests. For each of the cognitive functions listed in the previous paragraph they have identified a number of tests which assess the level of functioning. For example visuo-spatial memory can be assessed clinically using the Benton Visual Retention test, by briefly presenting visual designs followed by a recall or recognition task after a varying amount of time. Attention can be assessed with the Visual Search and Attention Test, which requires the participant to identify a letter or symbol which matches a previously given target. Adapting such tests to virtual reality based training or assessment environments may not necessarily provide benefits related to effectiveness and efficiency, when compared to other possible test formats. Since such tests could also be implemented using multimedia based applications, adapting them to virtual reality does not seem to provide any prominent advantages.

One cognitive domain which is particularly suitable for training and assessment using virtual reality is with the human visuo-spatial ability (Rizzo, et al., 1998). Shepard and Metzler have described (1971) a method to study visuo-spatial skills by investigating the mental rotation of three dimensional objects, as shown in Figure 5. The experiment that they conducted was designed to measure the time required by subjects to determine the identity of a shape as a function of the angular difference between two portrayed three dimensional shapes. They found that the time required for identification of the shape linearly increases with the difference in angular rotations. A subsequent study noted (Bethell-Fox, & Shepard, 1988) that the number of separate pieces which construct each of the two presented patterns also influence the time required for encoding, mentally rotating, and comparison of unfamiliar stimuli. The traditionally used assessment to measure mental rotation ability lacks the precision needed for thorough understanding of this human ability (Rizzo et al., 1998). The use of virtual reality for the assessment and training of visuo-spatial skills allows for better standardization of stimulus presentation, as well as quantification of stimuli characteristics.

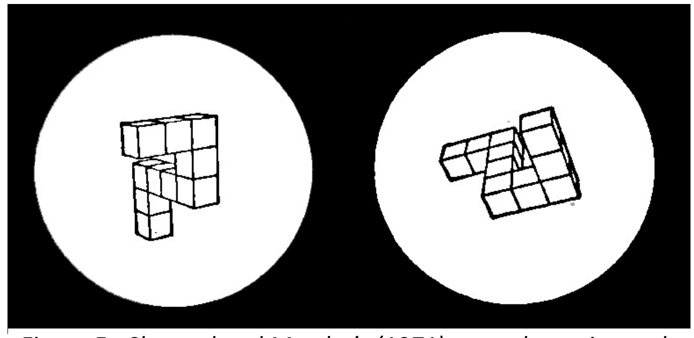


Figure 5 - Shepard and Metzler's (1971) mental rotation task: are these two shapes the same?

The ability to mentally rotate a shape is required in everyday situations. For example planning a route to the supermarket, navigating the supermarket to find groceries, and travelling back to your home are three distinct activities which require the visuo-spatial ability. Visuo-spatial abilities are an important variable in the differential diagnosis of dementia, caused by for instance Alzheimer's disease (Marusan, Kulistak, & Zara, 2006). There is evidence that the mental rotation process is at least partially guided by motor processes (Wiederbauer, Schmid, & Jansen-Osmann, 2007, Wexler, Kosslyn, & Berthoz, 1998). Previous studies have reported a correlation between the physical ability to perform manual rotation and the ability to perform mental rotation. This evidence suggests that there may be transfer effects between the mental and manual rotation skills.

These particular characteristics made the mental rotation task a suitable candidate for use in this project. It meets the selection criteria stated in the beginning of this section, and can be used in an experiment or study to investigate patient motivation.

3.2 Affective computing based cognitive rehabilitation

One of the opportunities for using virtual reality to support cognitive rehabilitation which was mentioned in section 2.1.2, is to apply principles from computer games to make the rehabilitation exercises more engaging. This section will discuss how principles from affective gaming have been applied in order to fulfill that opportunity. The following sections will discuss how high level affective game design principles have been applied to explicitly target motivational variables. Section 3.2.2 outlines how the Human Computer Interaction has been designed to be both enabling to the targeted population, and to promote enjoyment by creating a more physically active gaming experience. Section 3.2.3 concludes with an overview of how an in-game virtual assistant provides supportive feedback, based on an inferred emotional state of the player.

3.2.1 High level affective game design

A number of motivational variables have been identified from the list provided by Bostan (2009), which had to be targeted by affective game design. These motivational variables have been listed in Table 5. It is assumed that these variables are not of equal importance for the motivation of every single individual. Some of these motivational variables have been chosen because they appeared to be the most likely candidates for being appreciated by people, regardless of their personality type. For instance, it is safe to assume that very few people will be motivated to engage with a task if its goals are not defined or if they are not offered any feedback on their progress towards these goals. Other motivational variables, such as concentration and social interaction, have been chosen because they allow other cognitive functions to be addressed in the game based rehabilitation. In this way not only visuo-spatial abilities can be trained, but also attention, and skills required for social interaction.

Table 5 - Motivational variables to be targeted explicitly by the game design

Motivational variable	Abbreviation
Concentration	[Co]
Clear goals	[Cg]
Feedback	[Fb]
Challenge	[Ch]
Advancement	[Ad]
Curiosity	[Cu]
Social interaction	[Si]

The high level design heuristics for affective game design proposed by Gilleade and Allanson (2005) have served as a starting point for creating motivating exercises based on the mental rotation task. For each of the three heuristics “assist me, challenge me, emote me”, first a list of possible game elements was created. Then, this list was prioritized based on perceived importance and the resources available during the time of the project. For instance, creating an animated virtual therapist avatar was one game element that was given low priority because of the time required to engineer it versus the time available for this project. Simulating the avatar allowed a basic version of a ‘virtual assistant’ to be incorporated in the project, while limiting the amount of effort required to create a fully animated one. During a training session, a virtual avatar is displayed with still photos showing a therapist that provides textual messages to the patient. In a similar way the items on the list of possible game design elements were altered or removed, until the list as shown in Table 6 remained.

Table 6 - The affective game design elements, and their relevance to motivational variables from Table 3

Challenge me	Assist me	Emote me
Adapt game difficulty based on skill level of player [Co][Ch][Ad]	Provide multimodal feedback on task goals and performance [Cg][Fb]	Adapt game difficulty based on inferred affective state of player [Co][Ch][Ad]
Multiple high score tables to show a variety of player achievements [Ad][Fb][Cu]	Provide supportive feedback when performance is low, and when performance is high [Fb][Si]	Use of auditory effects to influence mood and emotion [Fb]
Multiple game modes: [Co][Ch][Ad][Cu]	Provide peripheral visual cues which offer additional depth cues	Use of in-game music to influence mood and emotion [Co]

• Regular • Time limited • Max 1 incorrect answer • Max 3 incorrect answers	[Fb]
Award achievement medals to the player [Ad][Fb]	Provide motion parallax as a visual cues, which offer additional depth cues [Fb]
	The player can ask for help with a trial for a limited number of times, possibly with a score penalty [Fb]

Game design criteria which challenge the player include an adaptive game difficulty, based on the skill level of the player. If a game is too easy or too hard then the players may get demotivated, so ideally the difficulty should adapt itself to the skill of the player. Furthermore the game can be played in a number of different modes, for which different strategies may lead to the best possible result. An example is the 'sudden death' mode which continues indefinitely as long as the player keeps providing correct answers, and the 'time limited' mode in which an incorrect answer may be provided in pursuit of the most correct answers provided within a predefined time limit. For each of the available game modes the player's performance is recorded in a high-score table, and different achievement medals are awarded based on the player's efforts to engage with the game. For instance, a 'perfectionist' medal could be awarded if the player completes the 'Normal' game mode flawlessly. Or alternatively, an 'adherence' medal could be awarded if the player adheres to a regular training schedule, as provided by his or her cognitive therapist and part of his or her rehabilitation program.

Game design criteria which assist the player include multimodal feedback on the goals of each of the game's tasks, as well as the player's performance. Furthermore affective feedback is provided by an in-game virtual assistant, based on the player's inferred emotional state (see section 3.2.3). During the game there are additional visual cues about the object's shape provided. These cues include peripheral visual cues, as well as motion parallax which is achieved by physically moving in front of the TV (using a head tracking mechanism based on the Nintendo Wii remote, see section 3.2.2). Lastly if the player has trouble with a given trial, he or she can ask for help and will be presented with additional hints or visual cues which may help with the task at hand.

Game design criteria which influence the player's include an adaptive difficulty based on the player's inferred emotional state. Furthermore sound effects and background music are used to provide performance related feedback, and influence the player's mood and emotions. For instance, different sound effects are played back when the player provides a correct or an incorrect answer. It has been reported (Thompson, Schellenberg & Husain, 2001) that listening to music can have an effect on arousal, mood as well as increase the performance on a particular cognitive task. However the underlying mechanisms of which musical compositions influence particular effects on arousal and emotion are not very well understood yet (Juslin, & Vastfjall, 2008) which makes it difficult to predict which particular music will induce which particular emotion. Furthermore, according to Dollinger (1993) several researchers noted a correlation between particular personality traits and musical preferences, with for instance extraversion being positively related to high arousal music (such as jazz) and excitement seeking being related to another (such as hard rock). For these reasons the game must support the in-game playback of players' own music (digitized in the industry-standard MP3 format) so that they can select the music which elicits the appropriate emotional and affective responses.

3.2.2 Human Computer Interaction for the elderly population

The Human Computer Interaction had to be designed in such a way that it enables its primary user group, the elderly population (see section 1.2.3), to use it autonomously. To cater for this requirement, a number of design elements have been taken into consideration. First of all the graphic design was carried out with the typical visual impairments of the aging population in mind. All buttons and texts exposed in the graphic user interface are large in size, and multimodal feedback in the form of size animation, color animation and haptic feedback (a vibrating input device, see the next paragraph) are provided when the player moves the mouse cursor over a button which can be pressed. Peripheral visual cues are also used explicitly which may help with completing the task successfully, prompting the player to either train his peripheral vision. Alternatively, as Cicerone et al. proposed (2000) the player can practice with compensatory mechanisms for the degraded peripheral vision by explicitly moving his or her own head to look at the visual cues. Other design elements taken into account include multimodal feedback about performance, as the player is informed about correct or incorrect responses by a text display, by graphic animation and by sound. And lastly, to allow the software to be used in a home environment, it had to provide on-screen instructions which introduce the respective training modes and their respective goals.

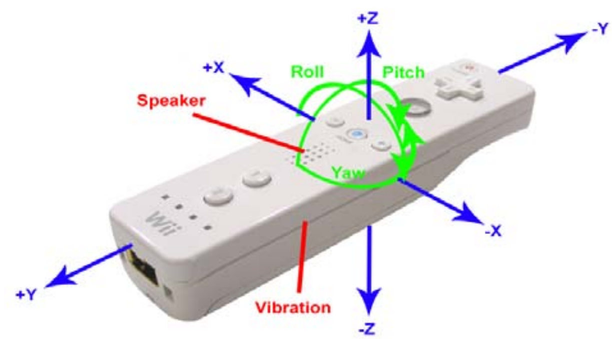


Figure 6 - Input sensors and output actuators of the Nintendo Wii Remote

Another relevant design element is related to selecting appropriate input devices and mechanisms. Nakatsu, Rauterberg and Vorderer noted (2005) that in order to increase the enjoyment of playing computer games, they need to be designed so that they promote a more active experience instead of the conventionally passive one. Other studies conducted by Mark, Rhodes, Warburon and Bredin (2008) and Bianchi-Berthouze, Woong-Kim, and Patel (2007) reached a similar conclusion, noting that besides increased motivation a more active experience also seemed to promote adherence. An active experience is primarily based on sufficient motor behavior involved in user actions. The advent of gaming consoles such as the Sony Playstation and the Nintendo Wii, came a diversity in the available input devices such as controllers such as the Nintendo Wii Remote (Figure 6). Although many of these controllers allow for a more active gaming experience, not all of them seem to be suitable for the targeted population. For instance, in a previous study done at the Sensory Motor System lab, which designed therapeutic virtual environments to be used by the elderly, Buss (2009) describes the use of a combination of a Sony Playstation gamepad in combination with a Dance Dance Revolution floor mat for interacting with the virtual environment. The gamepad consists of two joysticks and more than 12 buttons which must be operated by both hands. The floor mat must be operated by stepping on one of four areas in order to execute an action. During a clinical trial some elderly were unable (or did not want) to learn how to operate these input devices. To be able to reason about what other input devices and mechanisms may be more intuitively usable, Jacob et al. proposed (2008) the notion of Reality Based Interaction as an approach to designing interaction. In essence the idea is to make computer interaction more like interacting with the real world. This interaction style draws its strength by building upon the player's knowledge of the real world (e.g. physics, proprioception, surrounding environment) to a much greater extent than before. Therefore it seems to suggest that gamepads which allow the player to interact by making gestures (such as waving your arm, or pointing at the screen) are more intuitive to use. The same holds for controlling movement in the virtual environment by movement in the real world. This has lead to the selection of the Nintendo Wii Remote as the main input mechanism for the software that was created in this project, because it allows gesture based input as well as haptic and auditory output. Alternatively, the conventional computer keyboard (using only the two SHIFT keys) and mouse can be used as input devices. Another design decision was to employ a proprietary headtracking method based on a Nintendo Wii Remote used in conjunction with modified infra-red LED safety glasses, an idea pioneered by Lee (2008). This setup allows the software to track the player's head position and orientation, and update the representation of the virtual environment accordingly (presenting the player with an additional depth cue of motion parallax, which may aid with the Mental Rotation Task at hand). Figure 7 shows an overview of the primary Human Computer Interaction devices that have been chosen. Not shown are the alternative devices, the computer mouse and keyboard, which can be used if a player prefers to.

Figure 7 - The HCI devices used in this project: pointing (top left), head tracking (top right), and TV screen (bottom)

3.2.3 Affective feedback through a virtual assistant

Kenny, Parsons, Gratch and Rizzo noted (2008) a growing need for technology which can dynamically interact with the elderly population to gather information, monitor their health care, provide information or act as companions. Artificially intelligent virtual characters may utilize multi-modal input in order to reason about the human in the real environment, and respond to them in a manner which may have a powerful effect on them or their living situation. The future work proposed by them includes virtual assistants to therapists or clinicians, which provide affective responses in the form of verbal and non-verbal output. These virtual assistants may be used by the therapists to get information about the daily activities of the patient, or to find out about any specific issues which may be present.

The presented research builds upon these conclusions by incorporating an in-game virtual assistant character, which assists the player by providing supportive feedback at appropriate times (see Figure 8). This could for instance involve providing supportive feedback if the player is performing poorly, while providing more challenging feedback when player performance is high. This required the development of an affective game engine as proposed by Hudlicka (2009), which requires the fulfillment of three core requirements. The first core requirement involves the creation of a shared emotion knowledge base containing a representation of player's , and game

Figure 8 - An in-game virtual assistant offering supportive feedback to the player.

character's, possible affective states and their triggers. For many games, simple 'black-box' models which do not attempt to represent the underlying affective mechanisms are sufficient. The second core requirement involves the creation of an affective user model of players, which is based on the shared emotion knowledge base and used to track the player's behavior in the game and sense specific triggers (from the available Human Computer Interaction devices) which lead to manifestations of, or transition between the possible affective states. This process involves that for each input device semantic primitives must be specified which can be used to detect emotions or transitions between affective states (Hudlicka, 2008). Semantic primitives can be defined which aid with recognition of facial expressions, posture, speech, or more basic primitives which monitor the player's controller inputs (Hudlicka, 2008). A third core requirement involves the modeling of game characters' emotions, the ability for virtual avatars to develop and express their emotions.

To implement the in-game assistant which provides feedback at appropriate times, the first two core requirements for an affective game engine were implemented. Figure 9 shows an overview of how the first two core requirements have been implemented. A number of emotional states have been identified based on how players of a game based on the Mental Rotation Task may feel about their performance. From a neutral state a well performing player will first enter a pleased state, and if the good performance continues he or she will eventually become pleased. However if the good performance still continues, the player will eventually get bored with the game and lose interest. If a player in a neutral state performs poorly, he or she will first get disappointed and eventually insecure. If the poor performance continues the player will eventually lose interest because the game is too difficult. If the player becomes disinterested, either because the game is too difficult or too hard, then the possible courses of action in the therapeutic program could for instance be for the therapist to alter the game profile (provide easier or more difficult stimuli, see section 3.3.1.2) or alternatively, look for other exercises that are better matched to the skills or preferences of that particular person. Figure 9 also describes how the player's behavior is monitored through the Nintendo Wii Remote, and how the choices made are used to infer intrinsic emotional states and their transitions: the answers provided contribute to the intrinsic pleasantness, which can be interpreted in terms of the needs for achievement and advancement.

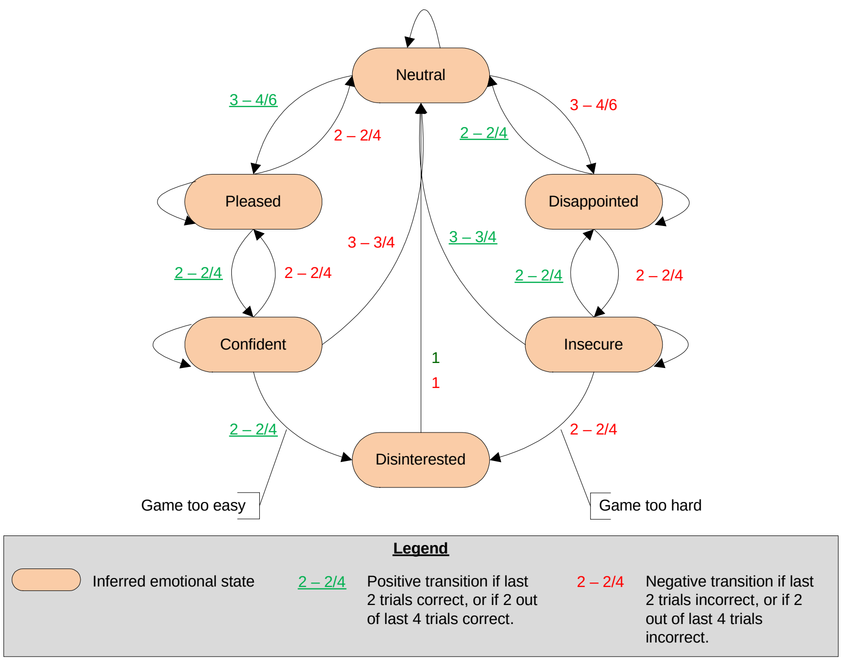


Figure 9 - Emotion knowledge base and the transitions triggered by semantic primitives for the input controller

One category of 'special case' situations had to be taken into consideration for the transitions between emotional states, in which the inferred emotional states could theoretically go from "confident" to "insecure" in just 6 trials, which may not be very realistic except if the player is diagnosed with e.g. bipolar disorder and its associated rapid mood swings (DSM-IV, 1994). To prevent this from happening, the inference algorithm can only execute a second transition between emotions after a predefined “waiting period” after the first transition was executed.

During a game when a transition between two emotional states is detected, a virtual assistant will be shown on screen providing textual feedback which is appropriate for that particular emotional state, as shown in Figure 9. Lewthwaite and Wulf provided evidence (2009) that providing additional social comparative (normative) feedback increases both motivation and learning of motor skills, when compared providing only feedback about task performance after each trial (veridical feedback). This effect may also be present when applied in the context of cognitive training or rehabilitation. Whether the feedback ‘You did better than 10% of your peers’ is perceived as motivating may be dependent on their personality types, which psychological and psychogenic needs drive their behavior (see section 2.1.3), and any cognitive deficits they may have. Therefore in the current implementation of the supporting software, providing social comparative feedback will not be provided. Table 7 lists the example feedback which has been chosen for each of the emotional states (this can be changed by the therapist, see section 3.3.2). These example texts have been created based on the idea that if player performance is poor, then the message must be conveyed that as long as the player keeps practicing, he or she is doing well. If the player performance is high, then the feedback acknowledges this but also adopts a more challenging tone to motivate the player.

Table 7 - Example feedback provided by the virtual assistant

Inferred emotional state	**Feedback provided**
Neutral	Good work. Keep at it!
Pleased	Great job! Let’s try to make this a bit more challenging.
Confident	Excellent work! You’ve obviously gotten the hang of this.
Disappointed	You are doing well. Please continue trying!
Insecure	You are doing well. Please take your time and look carefully, before answering.
Disinterested	Perhaps the game difficulty has been set too low.
Disinterested	Perhaps the game difficulty has been set too high.

3.3 The creation and usage of the system prototype

This section provides an overview of the software which has been created to fulfill the requirements as described in the previous sections. The envisioned system in Figure 2 shows the different software components, who their typical users are, and in which context they are used. The training and assessment component is described in section 3.3.3, and represents the only component which is used by patients themselves. The stimulus editor is described in section 3.3.1, and is used by therapists to design the appropriate stimuli which are used in the training and assessment component. The training editor is described in section 3.3.2, and is used by scientists or engineers to adjust properties of the training and assessment component, such as the language used in the Graphic User Interface (GUI). Section 3.3.5 will provide a brief overview of how these software components have been implemented, and which tools have been used in the process.

3.3.1 The Mental Rotation Stimulus Editor GUI

Bethell-Fox and Shepard noted (1988) that one of the effects of practice with particular stimuli of the Mental Rotation Task was that the response time became partially independent of the complexity of those stimuli. Some of their test subjects seemed to switch from a piecewise mental representation of the shape if it is unfamiliar, to a representation as a whole when it is familiar. This suggests that when a shape is learned, the strategy for the solving task is adapted from performing the mental rotation, to memory retrieval from the learned shape. With continued practice of these subjects, instead of mental rotation, the speed of their memory access was trained. This effect may be countered by ensuring that the shapes used in any computer (or paper) based version of the Mental Rotation Task are unique and non-repetitive. Although this may be more relevant to computer based training programs than it is for assessment programs, no evidence has been found in the surveyed literature that prior studies have taken this into account (e.g. Rizzo et al., 1998, Samsudin, & Ismail, 2004, Marusan, Kulistak & Zara, 2006). This prompted the idea to investigate the automated generation of stimuli for use in this project.

The initial approach was to investigate an algorithmic approach to generate stimuli, without the intervention of a therapist. The results of this investigation are presented in section 3.3.1.1. When this did not seem to provide useful results under all circumstances the choice was made to implement semi-automatic generation of stimuli, which gives the therapist the ability to control stimulus complexity and to generate training and assessment profiles based on previously created templates. Section 3.3.1.2 describes the stimulus editor which was implemented and how it can be used for semi-automatic generation of stimulus profiles.

3.3.1.1 Stochastic L-System based evolution of Mental Rotation Task stimuli

Lindenmayer Systems, or L-System for short, is a theory which has been developed to investigate plant development (Prusinkiewicz & Lindenmayer, 1990). An L-System consists of a language definition which contains the grammar for all basic elements of complex objects. This language definition is combined with a set of production rules, which are used to rewrite any given sentence. A particular example such a rewrite process is the Koch construction, which creates self-similar snowflake curves (Figure 10). In this example there is one starting symbol, the initiator, and one production rule, the generator. Subsequent rewrites operate on the initiator shape, and replace each side of the shape with the generator shape. Figure 10 shows the result of the first four rewrite steps.

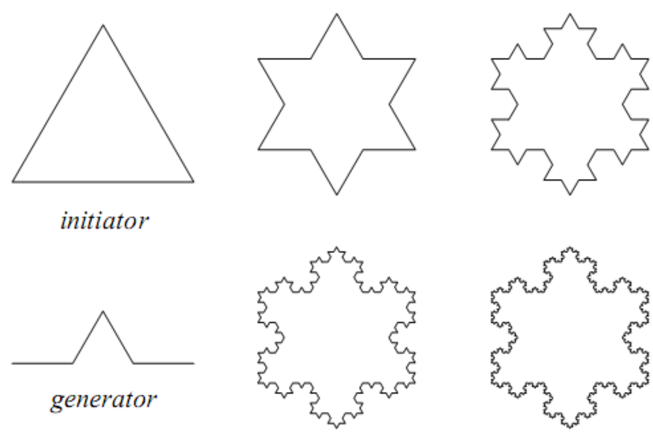


Figure 10 - Koch construction of a snowflake curve (Prusinkiewicz & Lindenmayer, 1990)

In order to model more complicated objects such as plants, a more sophisticated grammar and accompanying interpretation of L-Systems is needed. In these cases the grammar consists of human-readable characters, and the notion of 'turtle interpretation' has been introduced (Prusinkiewicz & Lindenmayer, 1990) to allow more complicated objects to be described. The basic idea is that each symbol defined by the grammar has an effect on the current state of the turtle. Figure 11 shows a two-dimensional example of such an L-System, where the character F moves the turtle one step forward (and draws a line), while the symbols + and – rotate the turtle 90 degrees counterclockwise and clockwise, respectively.

The definition of L-Systems provided in Figure 11 does not allow the description of trees which contain branches. To achieve this two new symbols must be introduced to the grammar. If a left bracket '[' is encountered in a string then the turtle interpreter pushes the turtle's current state on a stack. Each subsequent symbol (F, + or -) is interpreted as shown in Figure 11, until a right bracket ']' is encountered. The turtle interpreter then pops a state from the stack, and uses that state for subsequent interpretations of the string. Figure 12 shows an example of such a bracketed string representation of a tree with branches.

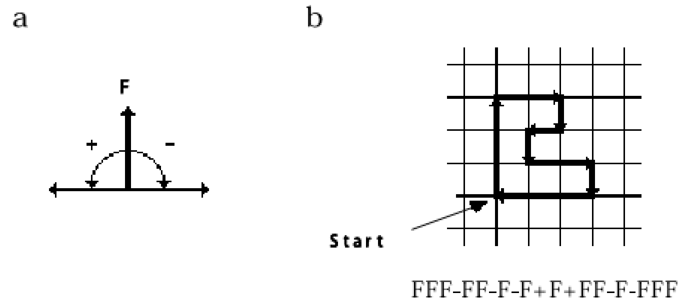


Figure 11 - (a) turtle interpretation of symbols F, + and -. (b) Interpretation of a string (Prusinkiewicz & Lindenmayer, 1990)

Figure 12 - Bracketed string representation of a tree with branches (Prusinkiewicz & Lindenmayer, 1990)

The L-Systems described so far in this section are deterministic in nature, as each time that the systems are evaluated they will result in an identical object. To counter this effect the production rules can be applied stochastically, resulting in a variation of both geometric properties (such as stem lengths, variations in heading, or branching angles) and the resulting topology. A stochastic L-System is described by the ordered quadruplet $G_{\pi} = <V, \omega, P, \pi>$ (Prusinkiewicz & Lindenmayer, 1990), with V denoting the alphabet, ω the axiom or starting shape, and a set of production rules P. The probability distribution function $\pi : P \rightarrow (0,1]$ maps the set of production rules into the set of production probabilities, resulting in one of the possible production rules to be chosen for the current rewrite step.

Figure 13 shows an example of a stochastic L-System that is capable of generating two dimensional stimuli for the mental rotation task. The stochastic L-System is adapted in order to gain more control over the generated geometry and topology. Instead of a parallel rewrite of all symbols contained in the string, this system only rewrites a turtle head symbol ('f'). This limits the geometric changes induced by a single rewrite step, and allows for the individual length of stems and branches to be limited by controlling the maximum number of rewrite steps per symbol instance. Figure 14 shows some objects which could be produced by this L-System. In general, the probabilities chosen for p2, p3 and p4 influence the resulting shape. The maximum length of stems and branches, and the maximum depth in the hierarchy at which a branch can occur have not been considered in this example. Extending this L-System from two to three dimensions requires two additional grammatic symbols ('ad' and 'ae'), to account for the two additional rotations caused by the extension into third dimension. For precise control of the direction in which branches occur, additional symbols could be added (for instance, '[b' to branch in the direction of the positive x-axis, '[c' to branch in the direction of the negative x-axis, '[d'

$G_{\pi} = <V, \omega, P, \pi>$		Grammar and probabilities
V :	f a ab ac [ ]	• f = turtle head
ω :	a f	• a = step forward
P_{grow} :	$f \xrightarrow{p1} a\ f$	• ab = step forward and rotate 90° cw
	$f \xrightarrow{p2} ab\ f$	• ac = step forward and rotate 90° ccw
	$f \xrightarrow{p3} ac\ f$	• p1 + p2 + p3 = 1
P_{branch} :	$f \xrightarrow{p4} [\ a\ f\ ]\ f$	• p4 + p5 = 1
	$f \xrightarrow{p5} f$	

Figure 13 - Example of an adapted stochastic L-System which generates 2-D Mental Rotation Stimuli

to branch in the direction of the negative z-axis, and '[e' to branch in the direction of the positive z-axis. Branches in the direction of the positive and negative y axis do not occur).

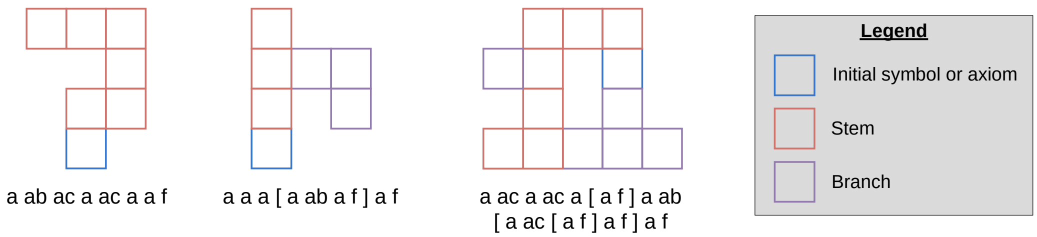


Figure 14 - Possible objects with the adapted stochastic L-System of Figure 13

The adapted stochastic L-System as described in the previous paragraphs has been implemented, and was able to generate random 3 dimensional shapes which may be useful for the Mental Rotation Task. After manual specification of the parameters which determine stem and branch length and probabilities, and a seed value for a pseudo-random number generator, the algorithm could generate an indefinite amount of shapes according to those properties. However upon inspection of the generated shapes, it became obvious that not all shapes generated by the algorithm were actually useful in a Mental Rotation Task. At least three types of problems with the algorithm have been identified:

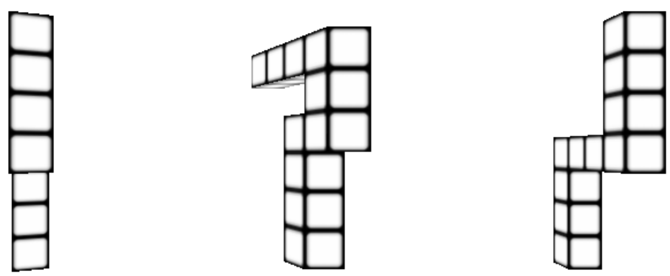


Figure 15 - The left shape is ambiguous, as it might be identical to any of the two other objects.

- Problem 1: it is possible for the L-System to generate geometry which overlaps the same space. This can happen in 3D and 2D, for instance in Figure 14 in the rightmost shape one of the branches is already touching the axiom. It is likely that one of the subsequent rewrite steps will generate new geometry which overlaps previous geometry. This problem could be solved by extending the algorithm with a constraint which is applied before new geometry is added, so that all spaces next to and in front of new geometry must be empty.

- Problem 2: the left object in Figure 15 shows an example of how the L-System can generate shapes which have visual ambiguities for the human observer. Due to the object's shape and its orientation, it is difficult to perceive if the left shape is equal to the center or the right shape. The generation of such ambiguous shapes could possibly be prevented by extending the algorithm with a constraint that disallows shape orientations which result in perceptual ambiguities. However such an extension may be non-trivial to engineer.

- Problem 3: the right object in Figure 15 shows an example of how the L-System can generate shapes which have another kind of ambiguities for the human observer. As noted in section 3.1, the stimulus pairs for the Mental Rotation Task can either be identical, or mirrored. However, if the right object in Figure 15 is mirrored in any of the three possible planes, the resulting shape is identical to the non-mirrored shape. The generation of such shapes could possibly be prevented by extending the algorithm with a constraint which determines if a mirrored and possibly rotated shape equals its non-mirrored counterpart. However such an extension may be non-trivial to engineer.

To allow continuation of this project in light of the problems described above, a slightly different approach to generate Mental Rotation Task stimuli by using L-Systems was chosen. Since the bracketed string representation of Mental Rotation Task stimuli turned out to be very flexible, as it offers precise control over the stimulus shape. The alternative approach was to create a GUI which makes it possible to manually define one or more 'template' shapes, and then generate a number of variations (angular difference, mirrored or not) based on these template shapes. The results of this approach are described in the following section.

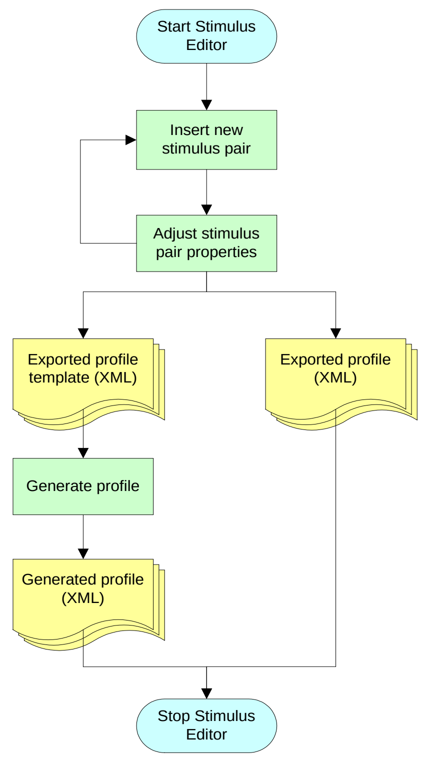


Figure 16 - Flow diagram for using the Mental Rotation Task Stimulus Editor

3.3.1.2 A semi-automated Mental Rotation Task Stimulus Editor

This section describes the Mental Rotation Task Stimulus Editor (MRTSE) which was created, based on the bracketed string representation of three dimensional shapes which was introduced in the previous section. The MRTSE can be used to create a set of stimuli for use in the assessment and training modes of the software, as described in section 3.3.3. Alternatively it can be used to generate a set of stimuli based on a previously created set of template stimuli. Figure 16 shows the flow diagram associated with the MRTSE. When this editor is started, a main screen is shown as depicted in Figure 18. In this main screen a list of stimuli and their properties are visible (top left), information is shown about the GUI element currently under the mouse cursor (top right), and a preview of the currently selected stimulus pair is shown (bottom). When a new stimulus is inserted in the list, its complexity parameters can be manually adjusted by selecting the stimulus from the list. Table 8 lists each of the complexity related parameters, their possible values, and their meaning. If one of these parameters is adjusted, the stimulus preview in the lower part of the screen is updated instantaneously.

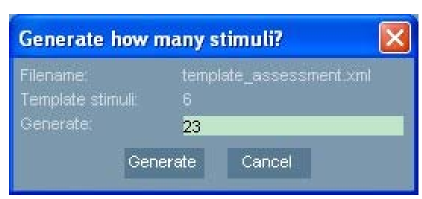


Figure 17 - Semi-automatic randomization of any number of stimuli based on templates.

A list of stimuli can be exported to either a stimulus profile which is used in the assessment and training modes of the software, or to a template profile. Both profiles are human readable XML files. A template profile can be used to generate a profile containing many variations on most of the complexity parameters (all but the Difficulty Index and the Symbolic Representation). After a desired number of stimuli has been entered (see Figure 17), a randomization process will take place for the specified amount of times. During this process a random stimulus template will be selected from the template, and most of its complexity parameters (excluding the difficulty index and symbolic representation) will be randomized. The resulting stimuli will be exported to a profile which can be used in the assessment and training modes of the software. An alternative randomization process involves applying quantized angular rotations (0, 20, 40, 60, 80, 100, 120, 140 and 160 degrees) for all three degrees of freedom. Although these implementations do not prevent some of the problems described in the previous section from arising, it does offer the therapist more precise control over the stimulus difficulty by allowing What You See Is What You Get (WYSIWYG) editing, and the ability to review the stimuli which end up in the training and assessment parts of the program.

Table 8 - Editable parameters which influence the complexity of a stimulus pair

Complexity parameter	Possible values	Description
Source yaw	[0,360]	Yaw of the source shape
Source pitch	[0,360]	Pitch of the source shape
Source roll	[0,360]	Roll of the source shape
Target yaw	[0,360]	Yaw of the target shape
Target pitch	[0,360]	Pitch of the target shape
Target roll	[0,360]	Roll of the target shape
Target mirrored X	Yes/No	If 'Yes' the target shape is mirrored in the X plane
Target mirrored Z	Yes/No	If 'Yes' the target shape is mirrored in the Z plane
Difficulty index	[0, 4.294.967.295]	Index of difficulty assigned to this shape
Symbolic representation	V : a ab ac ad ae [b [c [d [e]	Bracketed string representation as introduced in section 3.3.1.1

As described in the previous paragraph, one of the complexity parameters of a stimulus is a difficulty index. This numerical value is chosen by the therapist, and a measure for the perceptual and cognitive effort required to correctly identify the stimulus. A therapist is free to define virtually as many levels of difficulty as required. If the software is used in Affective Training Mode (see section 3.3.3), the difficulty will be automatically adjusted according to which stimuli are in the selected stimulus profile (see next section).

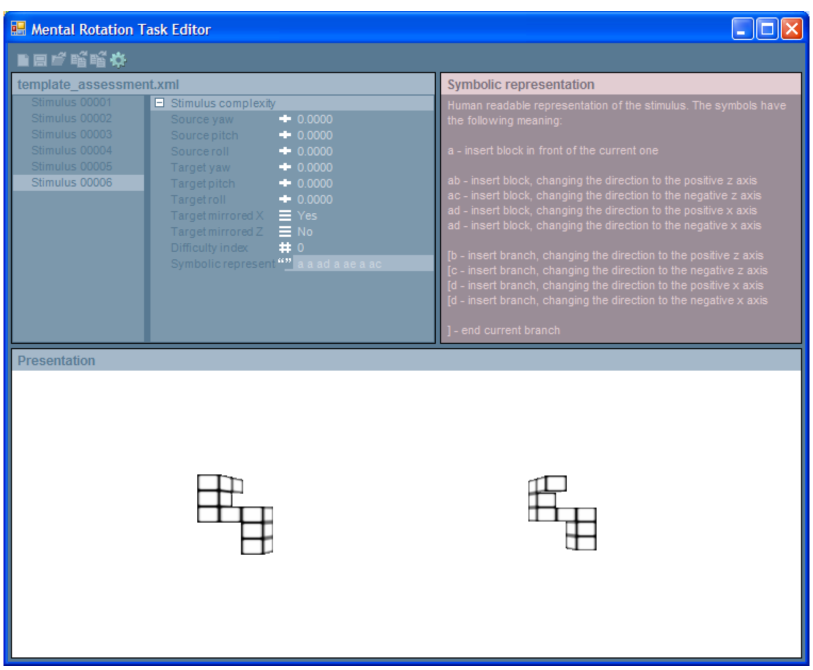


Figure 18 - The main screen of the Mental Rotation Task Stimulus Editor

The Mental Rotation Task Stimulus Editor GUI consists of a single screen as shown in Figure 18. The three main visible areas are the stimulus property area showing the adjustable properties (top left, blue background), an information area showing details of whatever GUI element is located under the mouse cursor (top right, red background), and a preview area displaying the selected stimulus (bottom, white background).

3.3.2 The Mental Rotation Training Editor GUI

The Mental Rotation Training Editor, as shown in Figure 19, allows an engineer to configure many properties of the assessment and training games. Table 9 provides some selected examples of these properties. For each of the game modes that were implemented aspects such as the size and animation of buttons can be changed, as well as visual properties such as size and distance of the stimulus pairs which are presented on the screen. Normally these settings do not have to be adjusted. However if for instance the assessment and training software must be localized, then the training editor can be used to select which language (XML) file should be used. When the adjustments are finished, the settings are exported to a binary file, which in turn is read by the assessment and training software. Note that many more parameters are available than have been discussed in this section, and that the main window of the training editor contains an information panel that shows a description of the parameter which is currently under the mouse cursor.

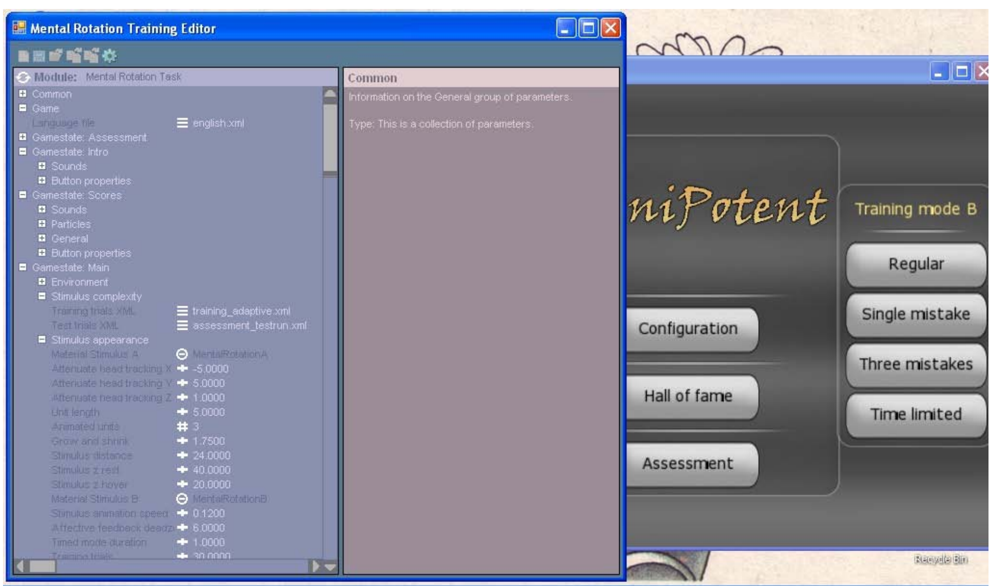


Figure 19 – The Mental Rotation Training Editor windows

Figure 19 show the two windows of the Mental Rotation Training Editor. The leftmost window enables the inspection of properties which influence the content and behavior of the training and assessment exercises and (some of) the GUI’s aesthetics. Within this window the two main visible areas are the property area which shows the adjustable properties (left, blue background), an information area showing details of whatever GUI element is located under the mouse cursor (top right, red background). The rightmost window shows a WYSIWYG and interactive preview of the training and assessment environments.

Table 9 - An overview of some selected parameters which can be adjusted with the Game Editor

Parameter group	**Parameter name(s)**	**Description**
Game	Language file	A language file is an XML file which contains all language dependent content that is used in the assessment and training software. By default the language is English, but custom language files can easily be created using a text editor.
Assessment/Stimulus Environment	Camera position, Camera projection type	Positions the camera, which determines the perspective on the virtual environment and the presented stimuli. Chooses between perspective and orthographic projection, which influence how the shape is presented on the screen.
Assessment/Button properties	Button width, Button height, Button zoom	Width of all buttons in this game mode. Height of all buttons in this game mode. If a mouse is over a button, then its width and height are scaled according to this numerical factor.
Assessment/Stimulus complexity	Stimulus definitions, Practice stimulus definitions	Specifies which XML file with stimulus definitions should be used in this mode. Specifies which XML file with stimulus definitions should be used for practicing before the actual assessment.
Assessment/Stimulus appearance	Unit length, Background color	Determines the size of individual geometric blocks which make up the stimuli. This determines the background color of the screen, in those areas not occluded by stimuli
Assessment/Sounds	Mouse over button, Button press, Exit program	Specifies which sound effect (an mp3 file) gets played. Specifies which sound effect (an mp3 file) gets played. Specifies which sound effect (an mp3 file) gets played
Main/Stimulus appearance	Animated units, stimulus distance, stimulus z rest, stimulus z hover, timed mode duration, feedback deadzone, training trials, show answer	Influences the animation at the start and end of a stimulus presentation. Determines the horizontal distance between the two stimuli Determines the default z-coordinate (depth) of a stimuli Reduces the depth of a stimulus if the mouse cursor is over it Determines the duration of a time-limited training mode (e.g. 1 minute) Determines how much turns must be in between affective feedback presented to the player Determines how many trials must be completed in the (normal) training mode Determines the duration in seconds of the animation played after an answer has been submitted, which shows if the two stimuli are identical or not

3.3.3 The Mental Rotation assessment and training GUI

Figure 203.2 shows a flow diagram which describes all the possible pathways which a patient who is using the created software (such as in scenario 1 in section 2.3.2) will follow. Distinctions have been made between completing a training session that was designed according to conventional computer based testing (Training Mode A, orange), a training session that was designed using affective gaming principles (Training Mode B), and an assessment session that was designed according to conventional modes (e.g. Samsudin & Ismail, 2004, Marusan, Kulistak & Zara, 2006) of.computer based testing . The rectangular boxes in Figure 20 identify the different screens which are part of the software, and a screenshot of each of them is shown in Figures 22 to 30. The remainder of this section will discuss the flow diagram for each of the software's modes in more detail.

When the player selects Training mode A from the main menu screen, he will first be shown a screen with the virtual assistant who provides instructions for the mode as shown in Figure 22. These instructions briefly introduce the goal of the Mental Rotation Task, and subsequently explain how many trials must be completed in this mode (this can be specified by the therapist using the 'training editor', see section 3.3.2). This training mode is based on a conventional computer based Mental Rotation Task (e.g. Samsudin & Ismail, 2004, Marusan, Kulistak & Zara, 2006) and can be played by using either the computer mouse or the computer keyboard (using both shift keys to indicate whether the shapes are identical or different) as shown in Figure 23. Upon completion of the number of trials as specified by the therapist, the player is informed that the Training mode has ended through the screen as shown in Figure 24. The performance measures as detailed in section 3.3.4 are automatically exported to an XML file for future processing, and the software returns to the main menu screen.

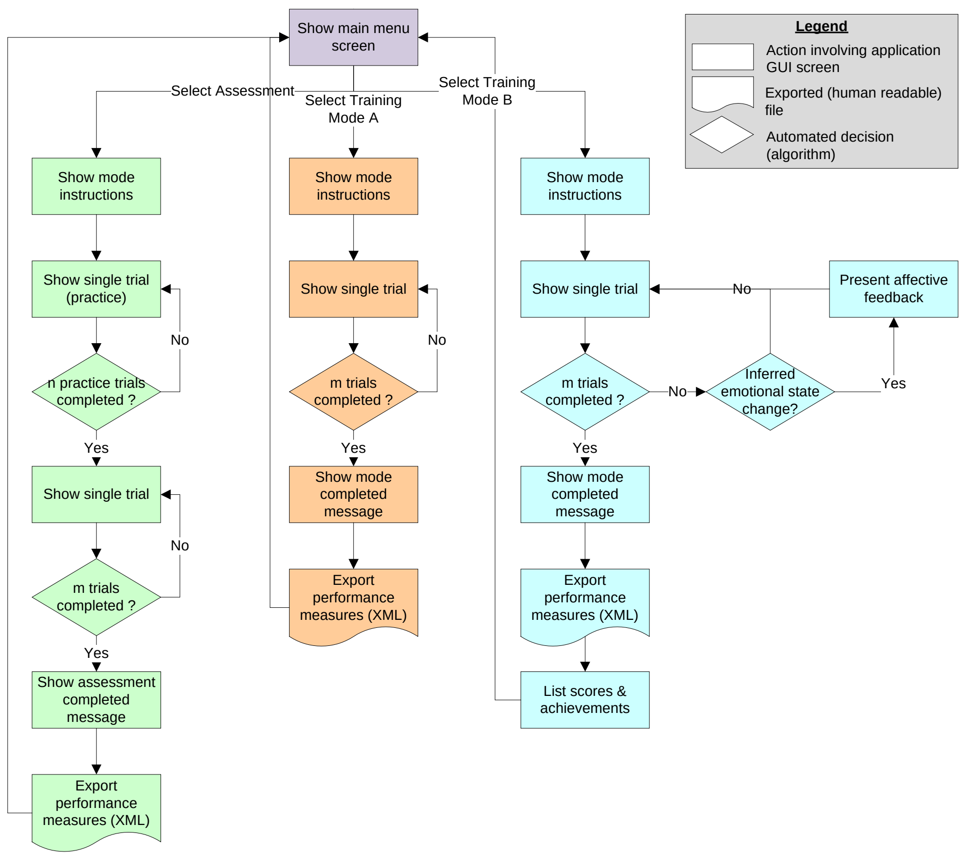


Figure 20 - Flow diagram for a single training or assessment session

When the player selects one of the four modes from the Training mode B category (regular, time limited, max one incorrect answer, max 3 incorrect answers, as described in section 3.2.1) as shown in the main menu screen (see Figure 21), he will be shown a screen with the virtual assistant who provides instructions that are specific to the chosen game mode, as shown in Figure 22. All game modes from the Training mode B category are based on affective game design, and can be operated using the Nintendo Wii Remote for gesture based input and tactile output, and the infra red LED safety glasses for headtracking (as described in section 3.2.2). The player can choose to stand in an open area in front of the TV screen, or to sit down in a chair positioned in front of the TV screen. If the player is uncomfortable using the Nintendo Wii Remote, he can alternatively use the computer mouse or keyboard to operate these training modes. The player is presented with a single trial, as shown in Figure 23. The player can physically move his head to “see around” the presented 3D shapes, while due to the motion parallax effect of the textured tunnel surrounding the shapes, additional visual cues are presented to his peripheral vision. If the player points the input controller at one of the two shapes, the shape will be brought closer to the player as it appears to be hovering in front of the TV screen, as shown in Figure 27). After the player has provided his response to the trial, he will be provided with both visual as well as auditory feedback about the identity of the shapes and the correctness of his response, see Figure 26. This figure also shows how the buttons are animated both in color and in size when the mouse cursor is positioned over them. When this happens, the input controller will rumble briefly. This is one example how the software provides multimodal feedback is provided through color and shape animation, sound and tactile feedback. Section 3.2 introduced how a partial affective game engine has been implemented which enables an in-game virtual assistant to provide affective feedback, based on the inferred emotional state of the player. An example of such feedback is shown in Figure 18. Upon completion of the number of trials as specified by the therapist, the player is informed that the Training mode has ended through the screen as shown in Figure 14. The performance measures as detailed in section 3.3.4 are automatically exported to an XML file for future processing, and the player is presented with an overview of his personal high scores and awarded achievement medals, see Figure 29. When the player is done with investigating his achievements, the software returns to the main menu screen.

The last mode to be discussed is the Assessment mode. Like the other modes it can be accessed from the main menu screen. The assessment mode is nearly identical to the Training Mode A, and thus also based on a conventional computer based Mental Rotation Task (e.g. Samsudin & Ismail, 2004, Marusan, Kulistak & Zara, 2006). The differences are that in the assessment mode, prior to the assessment itself the player is introduced to a practice round during which he is presented with a predefined number of practice stimuli (again specified by the therapist using the ‘training editor’, see section 3.3.2). The remainder of this mode is functionally and graphically identical to the Training Mode A previously described in this section.

Figure 21 - Show main menu screen

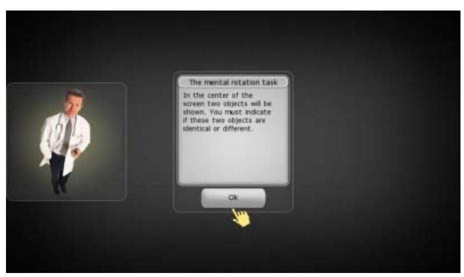


Figure 22 - Show mode instructions (all modes)

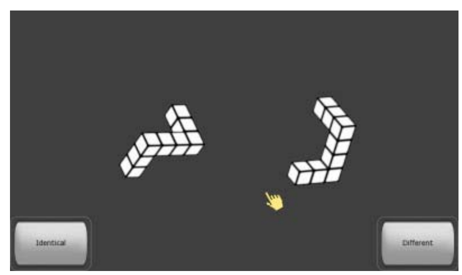


Figure 23 - Show single trial (modes Assessment and Training A)

Figure 24 - Show mode completed message (all modes)

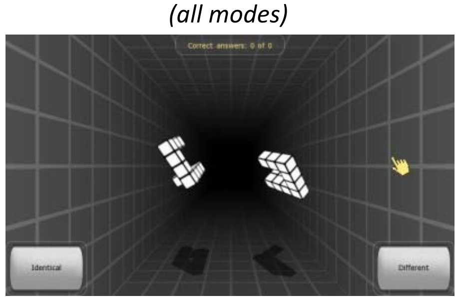


Figure 25 - Show single trial (mode Training B)

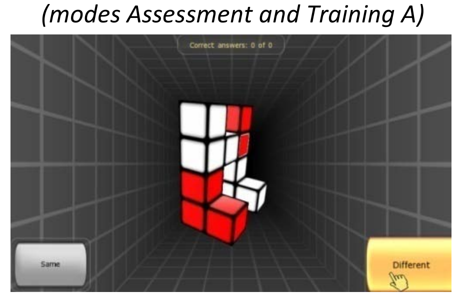


Figure 26 - Show single trial – response feedback (mode Training B)

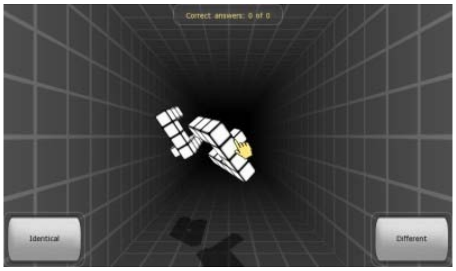


Figure 27 - Show single trial – help with trial (mode Training B)

Figure 28 - Present affective feedback (mode Training B)

Figure 29 - List scores and achievements (mode Training B)

3.3.4 Automated recording of performance metrics

To facilitate an analysis of the player's visuo-spatial skills, the performance related data as shown in Table 10 are recorded automatically by the game. Such an analysis could determine which stimulus' complexity parameters (stimulus difficulty, see section 3.3.1 and angular difference) have the most influence on the player's mental rotation ability. All data is written into two text files with different but standardized formats (XML and comma separated values) to increase the possibility that a statistical analysis program can read them and work with the data.

Table 10 - Performance related data to be recorded by the program

Data field	Description	Example
Trial number	Number of the trial	*1*
Response correct	Indicates if the user response was correct	*Yes*
Response time	Indicates the time it took the user to respond to the trial	*1.9024*
Stimulus description	Human readable representation of the stimulus	*a a a ab a a a ac a a a ad a a a*
Stimulus difficulty	Therapist-assigned difficulty level of the stimulus	*2*
Mirrored target X	Indicates if the target stimulus is mirrored or identical to the source stimulus	*No*
Mirrored target Z	Indicates if the target stimulus is mirrored or identical to the source stimulus	*Yes*
Source yaw	Degrees of rotation of source stimulus	*0*
Source pitch	Degrees of rotation of source stimulus	*20*
Source roll	Degrees of rotation of source stimulus	*40*
Target yaw	Degrees of rotation of target stimulus	*20*
Target pitch	Degrees of rotation of target stimulus	*40*
Target roll	Degrees of rotation of target stimulus	*60*

3.3.5 Components used to create the system prototype

This section provides a brief description of the tools and the open source components which have been used as a basis for creating the required proprietary software. Figure 30 shows an overview of the existing open and closed source components which provided a basis for implementing the training and assessment, stimulus editor and training editor components. Section 3.3.5.1 will briefly introduce the reused software components, while section 3.3.5.2 will discuss the software components which have been developed in the course of this thesis project.

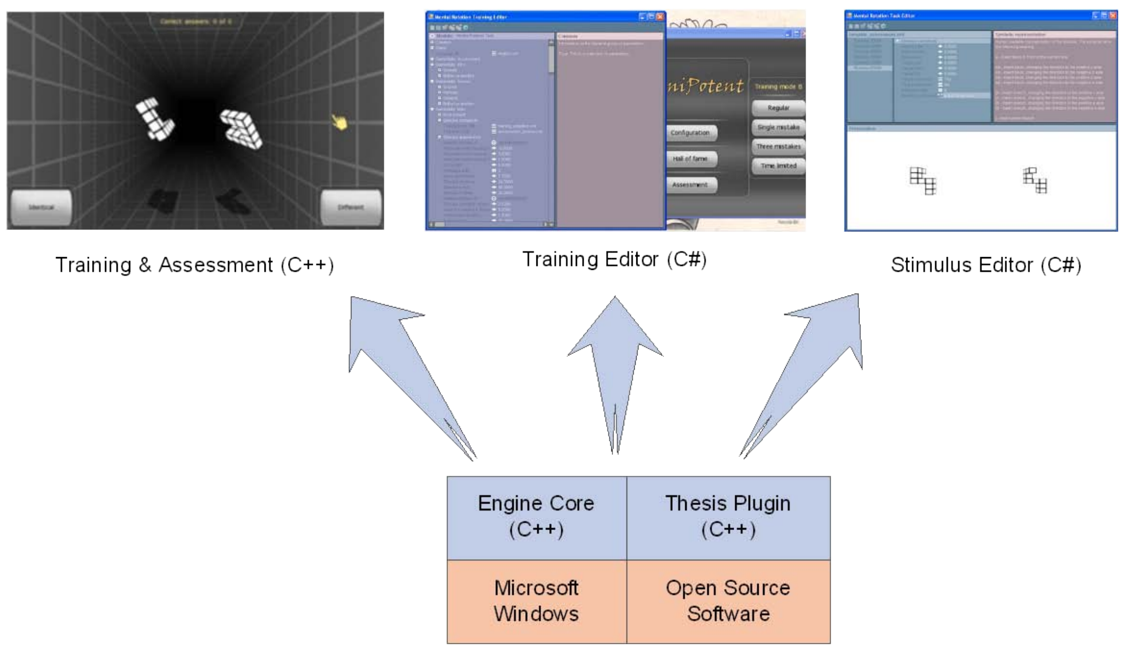


Figure 30 - An overview of existing and developed software components

3.3.5.1 Reused existing software components

Open Graphics Rendering Engine (OGRE)[3] is a cross platform open source C++ programming library which provides extensive functionality and features for hardware accelerated display of 3D graphics. It has been in development for over 10 years and is currently at version 1.7.1. Among its features are support for scene graph management, script based material definitions, script based screen compositing to achieve for instance image post processing effects, skeletal animation for virtual characters, support for OpenGL and DirectX based graphics hardware and much more.

Object-Oriented Input System (OIS)[4] is a cross platform open source C++ programming library which provides functionality to handle input from computer mice, keyboards, joysticks, gamepads and so on.

WiiYourself[5] is an open-source C++ programming library for the Microsoft Windows platform which provides functionality to handle input from, and output to Nintendo Wii related peripherals. For instance, with this library it is possible to use the Nintendo Wii Remote as an input device, as well as use its integrated haptic and auditory feedback devices to provide cues to the player.

TinyXML[6] is an open-source C++ programming library for the Microsoft Windows platform which provides functionality to read and write human readable files in the XML format.

[3] http://www.ogre3d.org

[4] http://www.sourceforge.net/projects/wgois

[5] http://wiiyourself.gl.tter.org

[6] http://www.grinninglizard.com/tinyxml

FMOD[7] is a closed-source and proprietary cross platform C++ library and toolkit for the creation and playback of audio. A non-commercial license is available which allows software not intended for commercial distribution to use FMOD for free.

3.3.5.2 Custom software components

This section briefly introduces the software components which have been developed during the course of this thesis project. The goal of this introduction is to provide a high level understanding of the object-oriented code created to support the requirements as described in the previous sections, and not to provide a detailed technical description of all the components which have been developed.

The Engine Core Component

The Engine Core component provides interface and implementation classes which have been designed around two main functions. Figure 31 provides a high level overview of the most important interface and implementation classes. The first main function of these classes is to be able to render interactive virtual environments to one or more attached computer screens. The IModule and IModuleImpl interfaces perform this task. This is split into two interfaces to allow the different implementation classes to be provided in another component (see the next section). The second main function around which the interface and implementation classes from the Engine Core component have been

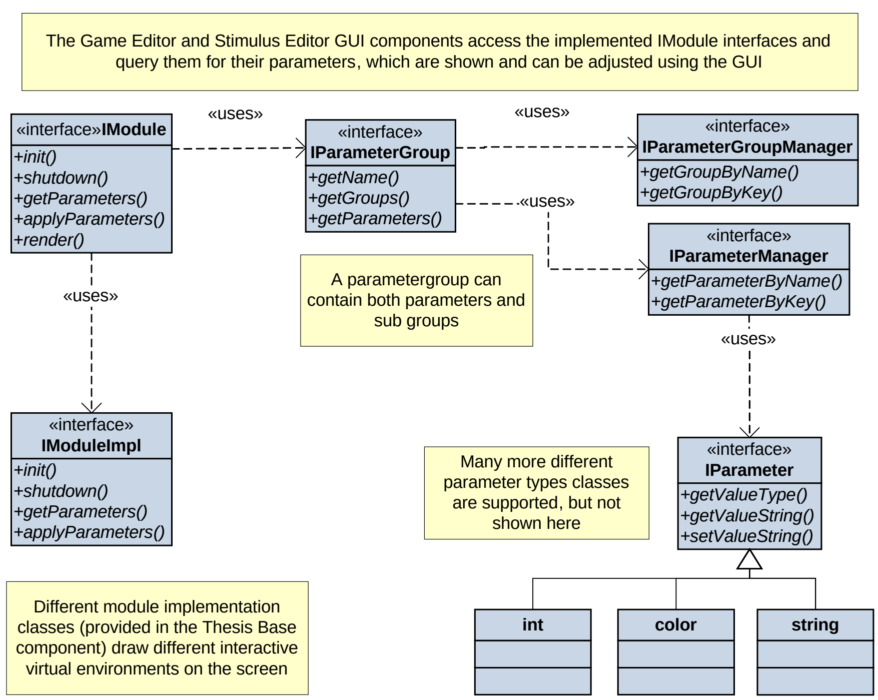


Figure 31 - High level overview of the Engine Core component

[7] http://www.fmod.org

designed, is to allow the implemented Modules to expose parameters of different types (such as int, float, color, strings), ordered in a parameter group hierarchy. Other components can query any given IModule interface for its parameters, and for instance provide a GUI to adjust them.

Thesis Base component

The Thesis Base component, as shown in Figure 32, provide interface and implementation classes for the Mental Rotation Task assessment and training, and stimulus and game editing, as previously discussed. The MentalRotationGame implementation class is responsible for rendering all interactive virtual environments for conventional computer based training, affective game based training, and assessment of the Mental Rotation Task. This class uses a GameManager helper class to aid with management of the different game states, each of which implements a specific part as shown in Figures 22 to 30. According to Valente, Conci and Feijo (2005) such a hierarchical approach to game state management is robust and leads to more manageable state transitions, and a less complicated implementation than with the conventional approach of not using an object oriented state hierarchy but by assigning numeric identifiers to track the current game states.
The StateAffectiveTraining game state uses an interface to deal with the tracking of emotional states, and their transitions, as described in section 3.2.3. It provides methods to query how long (for how many trials) the current emotional state has been active, and to send notifications for game events in order to determine if a transition between two emotional two states occurs.
The TrialHelper class implements all functionality which is required for loading and saving sets of Mental Rotation Task stimuli. These stimuli are stored in XML files. During a training or assessment session this class can also suggest which stimulus to use in the next trial, depending on the current training mode, a preferred level of difficulty, and which stimuli have been used in previous trials. Two other important classes, MentalRotationTurtle and TurtleToMesh have been omitted from this diagram. They provide straightforward implementations of the turtle algorithm described in section 3.3.1.1, and an algorithm to convert the resulting turtle instructions into three dimensional geometry subsequently displayed in the virtual environment.

The three GUI components

This section briefly introduces the three GUI components which have been developed during this project. Since these components mostly exist of straightforward GUI elements, no diagrams have been provided for the interface and implementation classes. These classes mostly mirror the interface classes as provided in the Engine Core component: there is a class which is responsible for displaying information about a module after querying its IModule interface, and similarly a class for displaying parameter groups and their parameters and values, after querying the IParameterGroup and IParameter interfaces respectively.
A notable distinction between the GUI components is that the Training and Assessment GUI has been implemented in C++. This was required to maximize the computational and rendering performance. The Stimulus and Game Editor GUIs have been implemented in a higher language (C#) because from the author’s prior professional experience as a software engineer it became clear that designing and implementing GUIs with the .NET framework can be done more

easily and quickly than when using C++.

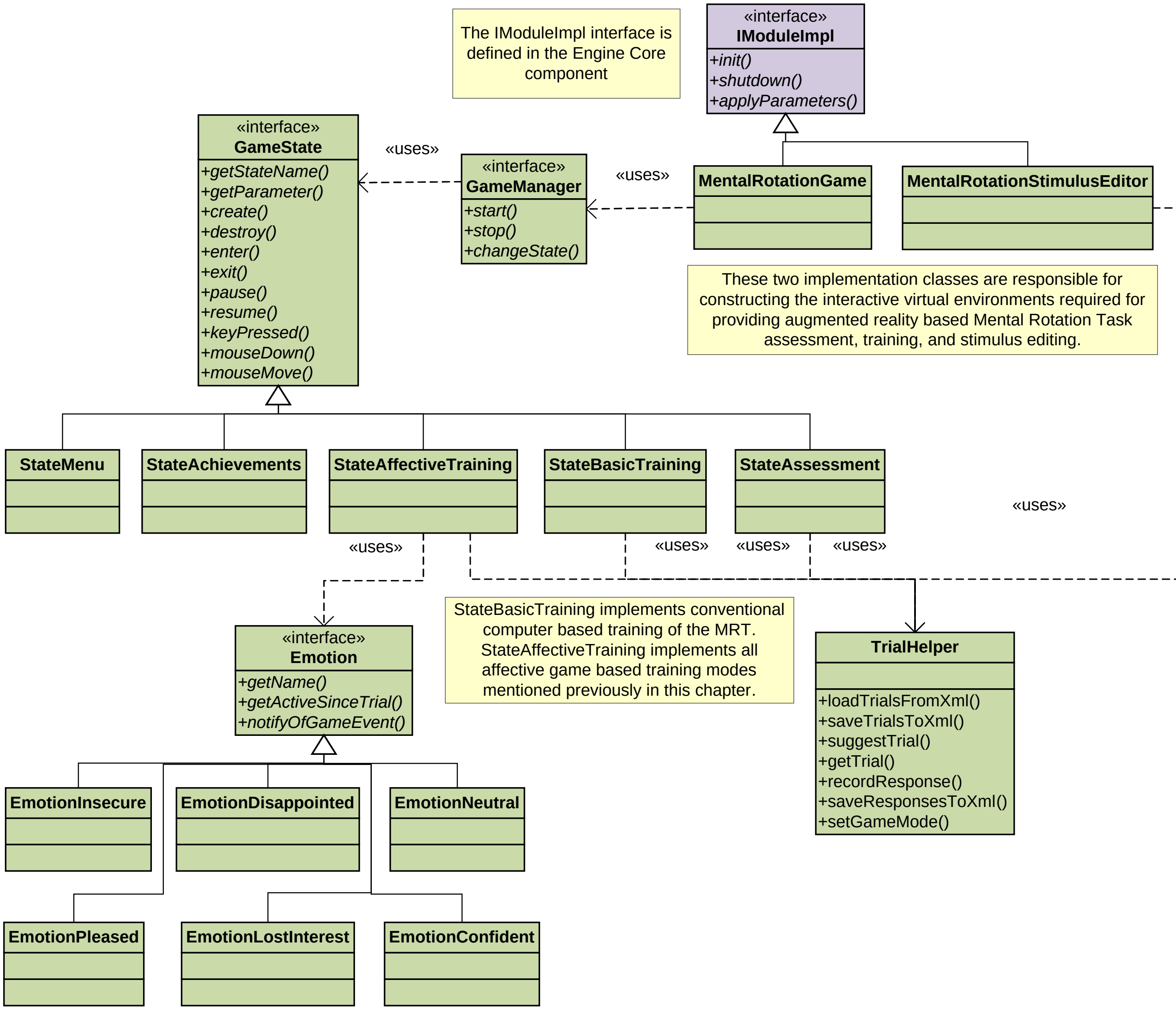


Figure 32 - High level overview of the Thesis Base component

3.4 Using the prototype to investigate claims

This section introduces the hypotheses which have been tested in a pilot study at the Delft University of Technology. The claims about the system's core functions that were part of the requirements baseline were listed in Table 4 in section 2.3.1. Based on these claims, two main hypotheses were derived, as shown in Table 11 (hypotheses H1 and H2).

Table 11 - Experimentally verifiable hypotheses and claims, supported by the prototype

	Hypothesis description	Claim number
H1	Rehabilitation exercises that are designed using principles of affective gaming increase the motivation to engage with the exercise in the elderly population.	No. 5, No. 6, No.8

H1.1	Incorporating high scores as a game design element contributes to increasing motivation and willingness to engage.	
H1.2	Incorporating achievement medals as a game design element contributes to increasing motivation and willingness to engage.	
H1.3	Incorporating adaptive difficulty as a game design element contributes to increasing motivation and willingness to engage.	
H1.4	Incorporating different game modes as a game design element contributes to increasing motivation and willingness to engage.	
H1.5	Incorporating virtual characters providing affective feedback as a game design element contributes to increasing motivation and willingness to engage.	
H2	Rehabilitation exercises utilizing reality based interaction increase the motivation to engage with the exercise in the elderly population.	No. 2, No. 3, No. 7
H2.1	Rehabilitation exercises utilizing (head) tracking increase the motivation to engage with the exercise in the elderly population.	
H2.2	Rehabilitation exercises utilizing gesture based interaction increase the motivation to engage with the exercise in the elderly population.	

Table 11 shows how the 2 main hypotheses are related to the claims posed in Table 4 in section 2.3.1. These two hypotheses are generic and independent of the type of cognitive skill that is to be rehabilitated. When the decision was made to target visuo-spatial skills in this research and an accompanying affective game based design had been created, the main hypotheses could be decomposed into sub-hypotheses. Each of these sub-hypotheses investigates a specific characteristic of the affective-gaming based design which has been applied.

4 Evaluation of system prototype and proposed experiment

Chapter 2 has shown how the Situated Cognitive Engineering (SCE) method has been applied to conduct a Work Domain and Support analysis, and how that has lead to a Requirements Baseline for virtual reality based neurocognitive rehabilitation. Chapter 3 then showed how a system prototype has been created which implements some of these requirements and can be used to experimentally verify the associated claims. This chapter provides a discussion of the remaining steps from the SCE method applied to the medical domain, as it is shown in Figure 3. Section 4.2 discusses the medical ethics that are related to the created prototype. Section 4.3 provides an overview of the initial experimental study which was proposed. Section 4.3 discusses the results of an expert evaluation of the system and the study design, and the subsequent refinements made to the system prototype.

4.1 Proposed randomized controlled experiment

As noted in section 1.2, the goal of this project was to develop the hypotheses, methodology, and prototype system to enable the SMS lab to conduct a clinical experiment which investigates patient motivation in virtual reality based neurocognitive rehabilitation (see Figure 1). This involved the design of an experiment to investigate the hypotheses from section 1.3. Appendices G and H provide the details for the experiment which was initially proposed to the ETH Zürich. This section will present a brief overview of the goal and the methodology of the proposed experiment. Prior to submitting a project proposal to the ethics committee of the ETH Zürich, the proposed experiment was reviewed by experts (researchers and medical specialists) associated with the Sensory-Motor Systems Lab at the ETH Zürich.

The aim of the proposed experiment was to investigate the two main hypotheses outlined in section 1.3. A randomized controlled design was applied to the experiment. The participants would be divided randomly into two equally sized groups, with the experimental variable being 'received affective gaming based training' (group 2) versus 'received conventional computer based training' (group 1, control). Each participant is subjected to one experimental session of minimum 45 and maximum 60 minutes (see Table 12). Each session starts with a brief introduction to the content of the session by a responsible researcher. The remainder of the session consists of a questionnaire (asking about the participant background, see section h) of Appendix G), a task training round using a computer based version of the Mental Rotation Task (MRT), another questionnaire (asking about motivational feedback, see section h) of appendix G) and a performance assessment round using a computer based version of the MRT.

Table 12 - The initially proposed experimental protocol

	Duration (minutes)	Group 1 (n=26, control)	Group 2 (n=26)
Introduction	5		
Questionnaire 1	5		
Training round	22	MRT: Standard mode	MRT:Affective mode
Questionnaire 2	5		
Assessment round	8	MRT: Standard mode	MRT: Standard mode

During the training rounds, two computer based versions of the MRT will be used: standard mode and affective mode. The assessment mode is similar to a conventional computer based version of the MRT, and can be operated with either a computer keyboard or a computer mouse.

The hypotheses posed in Table 1 would be investigated by conducting a statistical analysis of the collected data. The cumulative data collected in the questionnaires will provide measurements to investigate Hypothesis 1. Hypothesis 2 will be investigated by performing an unpaired two sample t-test (power = 0.80, $\alpha = 0.05$, for an expected large effect size) on the Response Time (RT) and Response Correctness (RC) as recorded by the software (see Table 10) in section 3.3.4.

4.2 Medical ethics

This section discusses the ethical issues involved with the system as envisioned in Figure 2, and its uses as described in the scenarios in section 2.3.2.. In 1964 the World Medical Association[8] drafted a first version of a policy on the ethical principles for medical research involving human participants. This 'declaration of Helsinki' states that it is the responsibility of all researchers involved in medical research to protect the life, health, privacy and dignity of a human subject. This can be achieved through the assessment of predictable risks and burdens in comparison with foreseeable benefits to the human subjects, their family or caregivers and society as a whole. Furthermore this is applicable to both situations when testing medicine- or eHealth-based interventions (Blanson-Henkemans, 2009).

In their compilation report on ICT and ageing Kubitschke et al. (2009) provide a detailed overview of the ethical issues involved. The various functionalities or design features of the system prototype may be accompanied by a range of ethical issues. This section only provides a brief introduction to those issues which are related to the functionalities and design features present in the developed system prototype.

When applying 'remote care' some ethical issues related to remote medical consultation and treatment are invoked. Although a medical doctor is responsible for the therapeutic program, in practice most of the patient's interactions with professionals are with nurses rather than doctors. A frequent arrangement is a nurse led triage, in which the nurse administers a standardized treatment protocol and reports feedback about the patient's progress to the doctor. Under these circumstances two ethical issues often arise. They involved difficulties because of the physical distance between the nurse and the patient, and difficulties because the requirements of the response protocols they must adhere to. Both ethical issues are related to the rehabilitation software developed in this research. The difficulty caused by the physical distance may be somewhat mitigated by requiring the patient to report to the clinic or hospital periodically (if the geographic distance between the patient and health care professional permits it). Alternatively the technology can be extended with additional modalities for communication (such as video and voice). The second ethical issue can possibly be mitigated if the response protocol (e.g. which therapeutic exercises to administer next when assessment shows that certain progress milestones have been met) is well defined. In that case a virtual assistant can administer the response after the responsible medical personnel has been informed and approved the next course of action.

With regards to 'monitoring and surveillance' other ethical issues may arise. The 'principle of informed consent' requires that the purpose of a (possibly ICT-based) treatment program must be made transparent to the patient.

[8] http://www.wma.net/en/30publications/10policies/b3/index.html

However this may be a challenge when the patient's capacity to engage with information is restricted, as can be the case with elderly people diagnosed with dementia. Furthermore all gathered information must serve a clearly specified purpose, and is directly related to the needs that are being addressed. Another issue may be related to the management of such gathered information and data, as (inter)national security and privacy rules may be applicable to the storage and transmission of the data, as well as to which non-medical personnel are allowed access to it.

With regards to 'automation' there are some ethical issues which manifest themselves when technology is used in a home environment in support of independent living. Assistive technology aims to help with conducting activities of daily life. Prolonged support may cause a dependence on the technology as well as a loss of existing skills or capabilities. Surrogate technology replaces interactions with a human caregiver altogether, and may lead to social exclusion and dehumanization. The prototype rehabilitation software developed in this research is mostly surrogate in nature, and mitigates the associated risks by only automating the repetitive administration of exercises while still requiring periodic and face-to-face interaction with a therapist. Castelnuovo, Lo Priore, Liccione, and Cioffi have identified the issue of 'unknown effectiveness' of automated intervention- until computerized rehabilitation protocols have been validated patients may be better off with conventional treatment. This can be a confounding issue given how many evidence based recommendations can be made for such conventional treatments, as noted in section 2.1.1.1. One ethical issue involving game-based rehabilitation may be particularly relevant to this research: as noted by various researchers (e.g. Stanney, 1995, Picard, 2000, Coyle, Doherty, Matthews, & Sharry, 2007) computer games may lead to addiction. This may particularly be the case if they are explicitly designed to be engaging and motivating. This risk can be mitigated by taking into consideration time constraints for allowing or denying the patient access to the game, as defined by the therapist.

Coyle, Doherty, Matthews, and Sharry (2007) provide general guidelines how rehabilitation technology can be designed and engineered that help with meeting ethical requirements in the medical domain. It should be based on accepted theoretical models of mental health care, and designed in full collaboration with domain experts or professionals. Furthermore it should be designed to integrate with existing working methods, and be used by clients under guidance of a therapist. Prior to use in a clinical settings the reliability and usability of the technology should be verified, as well as its therapeutic validity. And finally ethical clearance must be provided by an independent committee prior to the start of all proposed studies.

4.3 Expert evaluation and refinements

During the course of the implementation phase of this research, on three separate occasions domain experts have been presented with the system prototype in various stages of development, along with a draft design of an experiment that investigated the hypotheses from section 1.3. The domain experts involved two (cognitive) psychologists, three researchers involved with basic research of human computer interaction and neuropsychological rehabilitation, and a technical director and co-founder of company that provides commercial products for virtual rehabilitation to an international market. The feedback from these domain experts was used to improve the system prototype and the experimental design, which will be described in the remainder of this section. T

The feedback that was provided can be divided in three categories, according to that the remarks relate to: the ergonomics of the software and hardware user interfaces, the stimuli used for the training and assessment sessions, and the experimental protocol. The following paragraphs each will discuss the feedback one of these categories.

With regards to the ergonomics of the hardware and software user interfaces, the following feedback was received. First of all one expert expressed some concerns that, in the GUI screens as shown in Figures 22 to 40, the buttons were too small. While using the training or assessment software some participants may not be able to use the pointing device to keep the cursor over the buttons stable enough to also be able to press a key on the pointing device to select the button. Fortunately the developed system turned out to be flexible enough for a significant part of the GUI to be changed. This can be achieved without any required changes to the program's implementation code, by modifying one of the script files which contains the definitions for the button sizes, locations, colors and so on. Figure 21 and Figure 23 show the relative sizes of the buttons, after this particular comment was processed. The buttons in the training and assessment games are larger than the buttons in the menu screen, and Figure 23 shows how the button size is animated when the cursor is over the button. This may help the participants to deal with the buttons being too small (note that in section 3.3.3 it was also mentioned that the training and assessment game can be played without the pointing device, by pressing two keys which indicate a response on a computer keyboard).

Another concern about the GUI which was expressed was about how the 3D shapes were projected onto the 2D screen surface. The projection mechanism used can result in a distortion of the shape. In the literature two such mechanisms were found: perspective (e.g. Rizzo, Buckwalter, & Neumann, 1998) and orthographic (e.g. Jordan, Heinze, Michael, & Lutz, 2002) projection. Although the perspective projection mechanism may distort the 3D shape in the process of projecting it on to a 2D screen, that same mechanism provides an ecologically valid depth cue: that of the parallel lines (perpendicular to the screen plane) which converge towards the center of the screen with increasing distance. Initially the perspective projection mechanism was implemented in both the training and the assessment modes of the software. However after one expert expressed concerns about how it may result in confusion, the software was changed so that the 'Mental Rotation Task - Game Editor GUI' (see section 3.3.2) can be used to indicate which of the projection mechanisms should be used.

One expert expressed a concern about the way that the 3D shapes are animated if the software is used in the training mode. Each of the stimuli will be animated on a block-by-block basis, as indicated in Figure 33. Being able to see the shape form in such a way may provide the patient additional cues about the structure of the shape. However the feedback provided by a single expert indicated he found this confusing instead of assisting. Following this feedback the software was changed so that the 'Mental Rotation Task - Game Editor GUI' (see section 3.3.2) can be used to alter the properties of this animation, or to turn it off altogether.

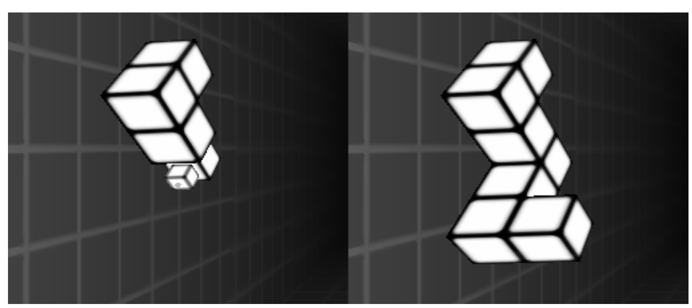


Figure 33 - Two frames from an animated stimulus during training mode

The last remark made about the ergonomics of the hardware and software user interfaces was related to the head-tracking mechanism which was used. After expressing initial concerns about the ergonomics and usability of head-tracking mechanisms in general, one expert indicated that he believed that this project's implementation could be very useful for creating virtual environments in general. This interaction mechanism could allow software to have some knowledge about where the user's attention is directed. This could be used for the creation of avatars (such as virtual assistants) in the virtual environment, which respond to the user's attention. For instance, an avatar could make eye contact or walk towards the user regardless of his or her position, or it could verbally remind the user to pay attention to what is happening on the screen if his or her attention is dwindling.

With regards to the stimuli of the training and assessment sessions, the following feedback was received. One expert considered the stimuli which were shown during a demonstration too complicated for the target audience. At that time the simplest shape that was used in the software, was identical to the shape in the original work of Shepard and Metzler (1971). Given the variation in cognitive skills in the targeted audience (elderly with varying gradations of dementia, each of which may have different effects on particular cognitive skills) it may not be possible to design one set of stimuli which is suitable for that entire group. Following this feedback, for subsequent use of the prototype software the 'Mental Rotation Task – Stimulus Editor GUI' (see section 3.3.1) can be used to design a wider range of stimuli. Ideally the stimuli should be designed in close cooperation with a therapist or cognitive psychologist.

With regards to the experimental protocol, the following feedback was received. One expert noted that in his experience, patients diagnosed with mild to severe Alzheimer's disease do not seem to be willing to spend more than a few minutes of their attention on questionnaires. This may particularly be an issue if they are required to complete a questionnaire after more than half an hour of engaging with computer based training, such as with this prototype system. This may pose conflicting requirements: Brinkman (2009) suggested using multiple questions with different wordings to acquire a single piece of information, in order to minimize the chance of the participant providing a wrong or partial answer because of a lack of understanding of the question. However this can rapidly increase the number of questions in a questionnaire, as for 10 dimensions or variables you would need anywhere from 40 up to 100 questions. This may especially be a complicating factor for the population that may not possess the mental skills to interpret the questions, for instance due to a decline in language skills. Another expert suggested that it is possible to design the virtual environments in such a way that questions are 'woven in' intermittently. It may even be possible to reduce the number of explicit questions by carefully designing the virtual environment. As an example related to this research, instead of asking in the questionnaire if the participant "enjoys a game more if different game modes are available", the software could automatically analyze which of the available game modes was played and how often, which also may provide an indication of player preference. Following this feedback the protocol and questionnaires have been redesigned to be as short as possible, while still providing enough information to be conclusive about the hypotheses under investigation.

Two other remarks provided by experts during the evaluative sessions, were related to the physical capabilities of thee participants. The demonstration of the training and assessment software showed a player who was standing in front of a TV screen. It was noted that if elderly participants have to stand in front of the TV screen and be physically active, they may become fatigued and as a result their postural stability may decline. Elderly people who have to deal with the consequences of stroke, or advanced Alzheimer's disease, may also be subject to such postural instabilities. Following this feedback the protocol was adjusted in several ways. First of all the criteria for participant inclusion were adjusted to include the requirement that prospective participants should be capable of standing or walking for about 20 minutes, allowing one or two breaks of a couple of minutes. Furthermore, in the case of physical fatigue, the experimental setup would allow the participant to conduct all sessions either standing up or while seated, with the ability to switch between the two during a session.

5 Evaluation of hypotheses and system prototype in a pilot study

This chapter provides a detailed overview of the final steps which completed one iteration of the Situated Cognitive Engineering (SCE) method introduced in section 1.6. Within this research project, the goal of the 'user experience' step was to conduct a pilot study which investigated the hypotheses noted in section 1.3. Most of the hypotheses were derived from the main research question "How can virtual reality- and game-based rehabilitation exercises be designed to be more motivating for the elderly population?". Table 1 lists all of the hypotheses which were investigated during the pilot study. The method used during this pilot study is described in section 5.1. The analysis of the results and their bearings on the hypotheses will be discussed in section 5.2. A secondary goal of the pilot study was to evaluate if the targeted population would be able to use the system prototype. If they would not be able to use it, feedback would be solicited in order to improve the prototype. The results of this secondary goal will also be discussed in section 5.3.

5.1 Method

5.1.1 Design

The pilot study used a within-participants design in which each participant completed two rounds of computer-based mental rotation tasks. One of the rounds utilized affective gaming techniques and reality-based interaction, while the other round did not. Participants were asked to fill in questionnaires at the beginning of the study session and after each round. As part of these questionnaires, participants self-rated their motivation to play training computer games. During both rounds the used computer program recorded task related performance metrics, which consisted of stimulus pair number, response time, response correctness, and angular differences.

5.1.2 Participants

Nine American participants (5 female, 4 male) were recruited from within the network of family and friends to take part in the pilot study. All participants met the following inclusion criteria:

- They were between 55 and 80 years old
- They were able to think clearly and were capable of independent living
- They were able to move their arms freely
- They were able to see a computer screen clearly from a few feet away
- They were native American English speakers

All participants gave their informed consent at the beginning of the session.

5.1.3 Materials

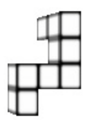
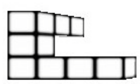
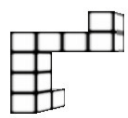
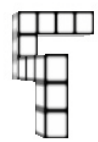
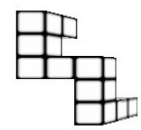
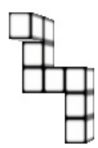
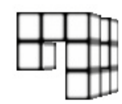
The stimuli used during the two rounds of the mental rotation task were created with the 'Mental Rotation Stimulus

Editor GUI' (see section 3.3.1). A set of assessment and training stimuli has been created with difficulty indices assigned according to the following properties:

1. The number of blocks of a shape
2. The number of heading changes of a shape
3. The number of branches of a shape (note: adding even a single branch, consisting of a single block, may already be too difficult to correctly identify for all but the most skilled people)

Examples of resulting stimuli have been provided in Table 13. During the affective gaming based training session, the difficulty of the used stimulus pairs was matched with the participant's performance and affective state. Although each participant was exposed to the same set of possible stimuli, the actual stimuli used during the training session varied per participant. During the computer-based assessment session each participant was exposed to the same series of stimuli.

Table 13 - Example stimuli for the Assessment (A) and Training (T) modes, and their Difficulty Indices

Mode	D.I. 1	D.I. 2	D.I. 3	D.I. 4	D.I. 5	D.I. 6	D.I. 7
A							
T							

Three questionnaires were used during the pilot study. All of the questionnaires, as well as the text in the software, were written in American English. The texts avoided any domain-specific or overly technical terminology, and were verified by a native English speaking man-machine interaction research scientist. Each questionnaire concluded with an open question which enabled the participant to provide additional remarks.

The first questionnaire (see Appendix E) contained questions about the participants' use of electronic equipment (such as televisions, digital cameras, and personal computers) and whether the participants played any board or card games. Furthermore, it asked whether the participants would be interested in playing computer games for mental skills training, and what they would expect from such games.

The second questionnaire (see Appendix F) contained two sections. The questions in the first section asked about the participant's experience with the affective computing round that had just been completed. These questions included queries about their enjoyment of the experience, their satisfaction with their performance, and whether they could understand and easily learn the game controls. The questions in the second section asked about how much the affective gaming elements (section 3.2.1) contributed to their enjoyment and willingness to continue using the training software. These questions were set up as a four point Likert scale ('strongly disagree' to 'strongly agree'), with a fifth option indicating 'no opinion' or 'can not say'.

The third questionnaire (see Appendix G) also contained two sections. The first section was similar to the first section in the second questionnaire, and asked about the participant's experience with the just-completed round of tasks. The second section asked about the participant's interest and motivation in playing computer games to train mental skills, now that they had tried training and assessment games. These questions were set up as a four point Likert scale ('strongly disagree' to 'strongly agree'), with a fifth option indicating 'no opinion' or 'can not say'.

5.1.4 Apparatus

A personal computer with a 19 inch monitor running custom software was used to present the mental rotation tasks. The software could be run in two operating modes (affective gaming and normal), each with its own corresponding hardware configuration.

During the affective gaming mode, participants interacted with the computer using reality-based interaction devices. The devices used were a Nintendo Wii remote as a pointing device, and a head-tracking device which allowed the objects on the computer monitor to appear three dimensional. Figure 34 shows the prototype system being used in a simulated living room environment.

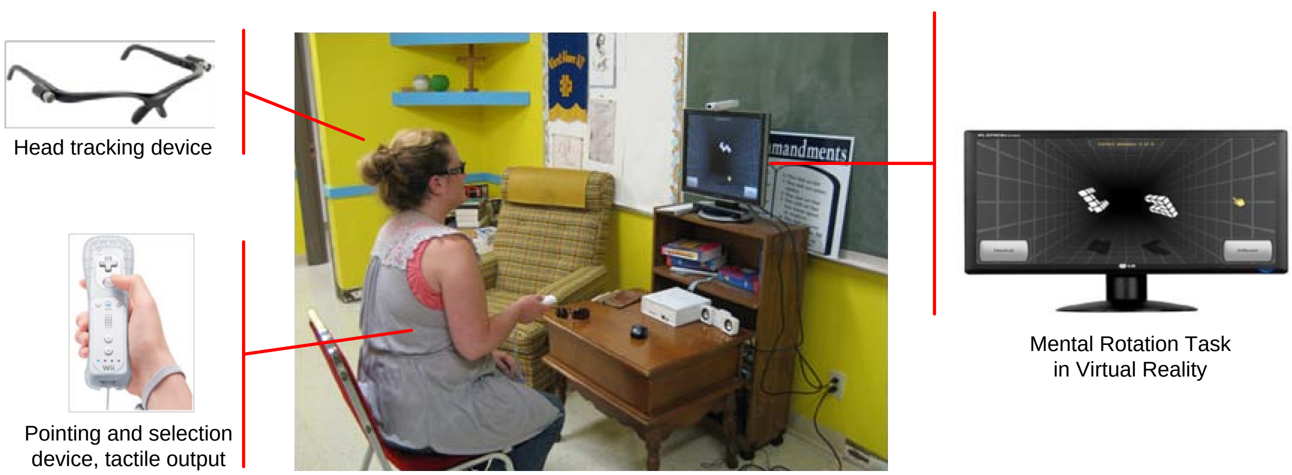


Figure 34 – The prototype system in a simulated living room environment

The Nintendo Wii pointing device was set up as indicated in the Nintendo Wii operation manual[9]: the sensor bar was placed below the monitor, and the participant's chair was located about 120 cm in front of the sensor bar and in a direct line of sight. Participants gave their answers to the mental rotation task questions by pointing at the appropriate button on the monitor with the pointing device.

The head-tracking device consisted of the frame of a pair of glasses with attached infrared lights which pointed forwards. The infrared light was picked up by a second Nintendo Wii remote which was attached to the top of the computer monitor. The computer software converted the light detections into head movement data, and altered the

[9] http://www.nintendo.com/consumer/manuals/index.jsp

on-screen image accordingly to produce a three-dimensional effect. The head-tracking device had identical operational constraints to the pointing device, namely that the glasses and Wii remote be separated by at least 120 cm.

During the normal mode, the pointing device and head-tracking device were not used, in order to simulate the experience of a standard mental rotation task assessment. The chair was repositioned to be close to the monitor as in a standard office arrangement. The participants were allowed to choose between using the computer keyboard or mouse for inputting their answers. Both the keyboard and the mouse were located on a small desk in front of the computer monitor. The two mouse buttons and two of the keyboard keys were color coded as a visual reminder, with green for “shapes similar” and red for “shapes different” answers.

The participants were handed the information sheet from Appendix B prior to the experimental session, and were informed of the start and end times of their sessions well before the day they took place.

5.1.5 Procedure

The protocol was tested on two family members prior to the pilot study, in order to ensure the suitability of the protocol and the software. The data collected during these test runs is not considered as part of the study results, and is therefore not included in the statistical analysis.

Each participant completed the pilot study session individually, and each session lasted approximately a half hour. The exact protocol followed by the experimenter can be found in Appendix C.

At the beginning of the session, the participant was introduced to the study and its purpose, reminded of their right to withdraw from the study at any time, and given the opportunity to ask questions. The participant was then asked to sign a consent form (see Appendix D) prior to continuing. The first task was to fill in the first questionnaire (Appendix E), which contained questions about general computer use, interest in games, and motivation to engage with rehabilitation games.

The participant was then asked to train for the mental rotation task, using the affective-gaming mode with reality-based input, for five minutes. The used computer program recorded task related performance metrics, which consisted of stimulus pair number, response time, response correctness, and angular differences. Afterwards, the participant filled in the second questionnaire (Appendix F), which contained questions about how motivating they found the training round.

Next, the participant completed the second, assessment round of mental rotation tasks, using the normal mode without reality-based input. This round also lasted for five minutes. The used computer program recorded task related performance metrics, which consisted of stimulus pair number, response time, response correctness, and angular differences. After the round, the participant filled in the last questionnaire (Appendix G), which contained questions about how motivating the participant found the assessment round.

Lastly, the participant was debriefed on the experiment and given the opportunity to ask questions. Each participant was also given a small gift in appreciation of their time.

5.2 Results

5.2.1 Response coding

The second and third questionnaire which use a four point Likert scale ('strongly disagree', 'disagree', 'agree', 'strongly agree'), with a fifth category for omitted or not applicable responses. The categories from the Likert scale were intended to be assigned a numerical value on a scale (e.g. between 1 and 4) for further processing. It turned out that this can not be done, because it would assume that the attributed numeric distance between two adjacent categories are always equal. However this may differ on an individual basis: where one person attributes the value 1 to the category 'disagree' and 2 to the category 'agree', for another person these numbers may be for instance 1 and 3.

To allow the results to be used in a subsequent statistical test, they had to be recoded into a continuous scale. The categories 'strongly disagree' and 'disagree' were assigned the numerical value 0 and labeled 'disagree'. Categories 'agree' and 'strongly agree' were assigned the numerical value 1 and labeled 'agree'. Blank responses and responses marked "Not Applicable" are disregarded.

5.2.2 Questionnaire 1

The educational background of the participants is given in Table 14.

Table 14 - Educational background of participants

	Advanced Degree	**Bachelor Degree**	**University (Incomplete)**	**High School**	**High School (Incomplete)**
Number of participants	3	2	2	2	0

All participants used a TV and telephone on a regular basis. The majority of participants also used a mobile phone (8), digital camera (6), personal computer (6), and radio (5) regularly. Only two regularly used a game console.

A majority of the participants regularly played puzzle games (6) and knowledge games (such as Trivial Pursuit) (5). Only a few regularly played strategy games (2) and skill games (such as Mikado) (2). Two participants reported that they did not play games.

Seven participants reported using computers every day, while the remaining two participants reported never using a computer.

A majority of the participants reported using a computer to write documents (8), send and receive e-mail (7), look up information (6), play computer games (5), and manage photo collections (5). None of the participants used the computer to chat.

Six participants reported wanting to play computer games. Of the three participants who disagreed, two reported never playing games. Four participants reported wanting to play training games on the computer daily, while three (33%) wanted to play training games weekly. One participant was interested in playing computer training games occasionally, and one participant was not interested in ever playing training games.

A majority of the participants wanted computer training games to be challenging, easy to use (9), fun (8), and understandable (8). Three of the participants wanted computer training games to be easy, while three other participants wanted them to be difficult.

5.2.3 Questionnaire 2

Table 15 shows the descriptive statistics for the responses to Questionnaire 2. Some trends in responses can be seen from the table. All participants enjoyed the training round (Q2.1) and think that their performance would improve with practice (Q2.3). Furthermore each of them noticed the adaptive game difficulty (Q2.8), stated that they would like to play again to increase their high score (Q2.14), and that they want to be encouraged during an exercise (Q2.17).

The responses to several questions showed a tendency to one end of the dichotomous scale. Eight participants learned the game controls easily (Q2.5), want the difficulty of the exercises to adapt to their skills (Q2.16), and are interested in physically active virtual reality games (Q2.19). Eight participants did not think that the game was always too easy (Q2.7), and seven participants did not think that the game was always too hard (Q2.6).

Table 15 - Results of Questionnaire 2

	N	Mean	Std. Deviation	Variance
Q2.1-Enjoyed playing the game	9	1.00	.000	.000
Q2.2-Satisfied with performance	8	.25	.463	.214
Q2.3-Thinks performance would improve with practice	9	1.00	.000	.000
Q2.4-Understood the game controls	9	.78	.441	.194
Q2.5-Learned game controls easily	9	.89	.333	.111
Q2.6-Found game always too difficult	9	.22	.441	.194
Q2.7-Found game always too easy	9	.11	.333	.111
Q2.8-Noticed adaptive game difficulty	8	1.00	.000	.000
Q2.9-Motivated by score	9	.67	.500	.250
Q2.10-Motivated by challenge	9	.56	.527	.278
Q2.11-Motivated by encouragement	9	.44	.527	.278
Q2.12-Motivated by ease of use	9	.56	.527	.278
Q2.13-Motivated by head-tracking	6	.50	.548	.300
Q2.14-Wants to play to increase score	9	1.00	.000	.000
Q2.15-Wants to play to win medals	8	.75	.463	.214
Q2.16-Wants adaptive game difficulty	9	.89	.333	.111
Q2.17-Wants encouragement	9	1.00	.000	.000
Q2.18-Wants movement-based gaming	8	.75	.463	.214
Q2.19-Wants 3-D gaming	8	.88	.354	.125

Q2.20-Interested in new game mode	9	.33	.500	.250
Q2.21-Interested in multiple game modes	8	.75	.463	.214

5.2.4 Questionnaire 3

Table 16 shows the descriptive statistics for the responses to Questionnaire 3. Some trends in responses can be seen from the table. All participants enjoyed the assessment round (Q3.1), think that their performance would improve with practice (Q3.3), and found the game controls easy to learn (Q3.5). All participants did not think that the game was always too easy (Q3.7), and seven participants did not think that the game was always too hard (Q3.6).

Table 16 - Results of Questionnaire 3

	N	Mean	Std. Deviation	Variance
Q3.1-Enjoyed playing the game	9	1.00	.000	.000
Q3.2-Satisfied with performance	5	.80	.447	.200
Q3.3-Thinks performance would improve with practice	9	1.00	.000	.000
Q3.4-Understood the game controls	9	.89	.333	.111
Q3.5-Learned game controls easily	9	1.00	.000	.000
Q3.6-Found game always too difficult	9	.22	.441	.194
Q3.7-Found game always too easy	9	.00	.000	.000
Q3.8-Motivated by score	6	.50	.548	.300
Q3.9-Motivated by challenge	9	.78	.441	.194
Q3.10-Motivated by encouragement	7	.29	.488	.238
Q3.11-Motivated by ease of use	9	.67	.500	.250
Q3.12-Increased motivation to play computer games	9	.44	.527	.278
Q3.13-Enjoyed first game more than second	9	.33	.500	.250

5.2.5 Evaluating hypotheses

This section will evaluate the hypotheses from section 1.3 by investigating the statistical significance of selected responses from questionnaire 2. In most cases a binomial test has been used to determine statistical significance (see Appendix H for a list of all obtained results), warranted by the dichotomous scale to which these responses have been coded (see section 5.2.1). Figure 35 shows boxplots for the coded responses which are relevant to the hypotheses. In the figure it can be seen that all the provided responses to some questions (e.g. Q2.8 and Q2.14) are identical. The figure also shows that some responses were automatically classified as outliers (e.g. with Q2.16 and Q2.19) by the statistical analysis software used (SPSS 17.0). It did not seem possible to influence this behavior.

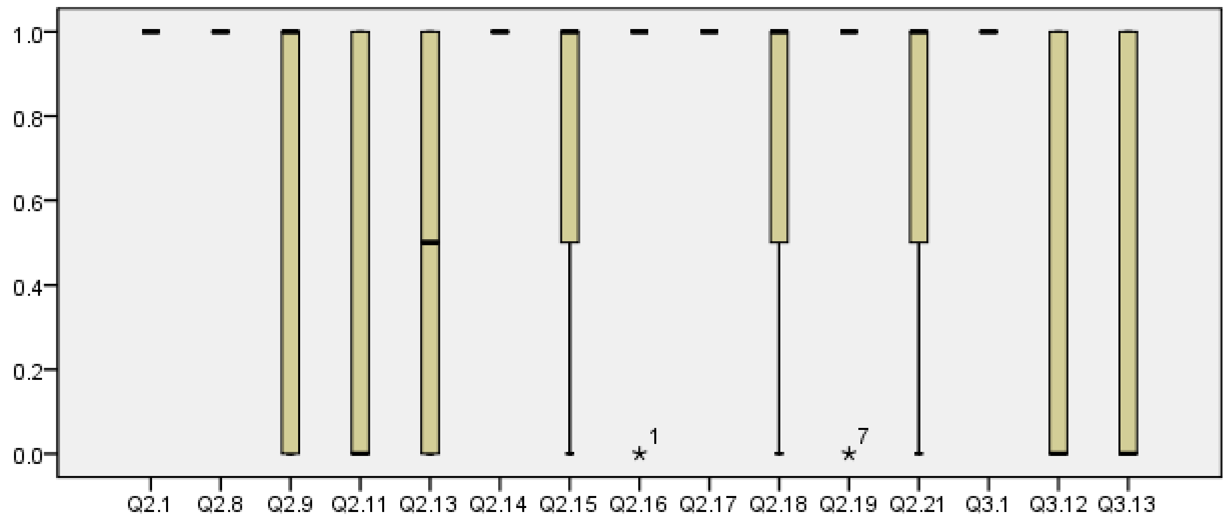


Figure 35 – Descriptive statistics after coding of the responses

Hypothesis 1 : Rehabilitation exercises that are designed using principles of affective gaming increase the motivation to engage with exercise in the elderly population

Both the second and third questionnaires asked the participant whether they enjoyed the respective round (training or assessment, Q2.1 and Q3.1). All participants reportedly enjoyed these rounds, given the mean of 1 for the responses to these questions (see Table 15 and Table 16). According to the statistical analysis software that was used (SPSS 17.0) these two means can not be compared using an one sample t-test because the standard deviations for both of them are zero.

In the third questionnaire, participants were asked to indicate whether they enjoyed the affective gaming round more than the normal round (Q3.13) and if their motivation to engage with exercises had increased since the start of the session (Q3.12). A binomial test with test proportion 0.50 did not yield any significant results. Although all participants enjoyed the affective training mode, it can not be concluded if their motivation to engage with exercises was increased because principles of affective gaming were used to design the exercise. Possibly the responses from more participants are needed before any significant results can be observed.

Several principles of affective gaming were explored in isolation in hypotheses 1.1 through 1.5, detailed in the sections below. These results show that the individual affective gaming principles were helpful in motivating the participants to interact with the game.

Hypothesis 1.1 : Incorporating high scores as a game design element contributes to increasing motivation and willingness to engage

In the second questionnaire, participants were asked to indicate whether they found the scores motivating (Q2.9) and whether they would want to play the game again in order to improve their score (Q2.14). A binomial test with test proportion 0.50 did yield significant results for Q2.14 ($p<0.004$), implying that participants wanted to play the game again to increase their high score. However the results for Q2.9 (which asked if participants were motivated by high scores) were not significant. These results partially support the hypothesis that high scores contribute to an increase in and willingness to engage.

Hypothesis 1.2 : Incorporating achievement medals as a game design element contributes to increasing motivation and willingness to engage

In the second questionnaire, participants were asked whether they would want to play the game again in order to win more achievement medals (Q2.15). A binomial test with test proportion 0.50 did not yield significant results in support of this hypothesis. Possibly the responses from more participants are needed before any significant results can be observed.

Hypothesis 1.3 : Incorporating adaptive difficulty as a game design element contributes to increasing motivation and willingness to engage

In the second questionnaire, participants were asked whether they noticed that the game difficulty adapted to their abilities (Q2.8) and whether they would want adaptive difficulty in other training games (Q2.16). A binomial test with test proportion 0.50 yielded significant results in support of this hypothesis, $p<0.008$ for Q2.8 and $p<0.039$ for Q2.16. Participants seem to notice adaptive difficulty when present in an exercise, and request adaptive difficulty in future exercises.

Hypothesis 1.4 : Incorporating different game modes as a game design element contributes to increasing motivation and willingness to engage

In the second questionnaire, participants were asked whether they would like extra game modes in the computer training game (Q2.21). A binomial test with test proportion 0.50 did not yield significant results in support of this hypothesis. Possibly the responses from more participants are needed before any significant results can be observed.

Hypothesis 1.5 : Incorporating virtual characters providing affective feedback as a game design element contributes to increasing motivation and willingness to engage

In the second questionnaire, participants were asked whether they were motivated by the messages of encouragement given by the virtual character in the game (Q2.11) and whether they would like encouraging messages in future training games (Q2.17). A binomial test with test proportion 0.50 yielded some significant results in support of this hypothesis (Q2.17, $p<0.004$). Although the feedback from the virtual character in the game did not seem to have an effect on participant motivation, all participants indicated that they are motivated by incorporating encouraging messages in future training games. The results partially support the hypotheses that affective feedback contributes to motivation and willingness to engage.

Hypothesis 2 : Rehabilitation exercises utilizing reality-based interaction increase the motivation to engage with exercise in the elderly population

This hypothesis was not tested directly, but has rather been split into two sub hypotheses, 2.1 and 2.2, detailed below. The results from the sub hypotheses support the idea that reality-based interaction devices increase motivation.

Hypothesis 2.1 : Rehabilitation exercises utilizing (head) tracking increase the motivation to engage with exercise in the elderly population

In the second questionnaire, participants were asked to indicate whether they were motivated by the head-tracking capabilities of the game (Q2.13), and whether they would like to have similar 3-D capabilities in future training games (Q2.19). A binomial test with test proportion 0.50 did not yield any significant results in support of this hypothesis, however it is likely that with more participants the results will be significant (currently the results for Q2.17 had a $p<0.070$).

The participants were split as to whether the current implementation of head tracking was motivational, with one third agreeing, one third disagreeing, and one third not having an opinion. A confounding factor may be that for the first few participants the head-tracking mechanism used in the prototype system did not work properly. Despite this, most of the participants requested head tracking in future games. These results partially support the hypothesis that the use of (head) tracking is motivating the elderly population.

Hypothesis 2.2 : Rehabilitation exercises utilizing gesture based interaction increase the motivation to engage with exercise in the elderly population

In the second questionnaire, participants were asked to indicate whether they wanted gesture based interaction devices (such as the Nintendo Wii remote pointer) in future games (Q2. 18). Although the majority (6) of participants requested gesture- and movement-based interaction in exercises, these results are not statistically significant. Therefore the results related to hypothesis 2.2 are inconclusive.

5.3 Discussion of results

The results obtained in the pilot study that was conducted can be interpreted in the context of the main research question as noted in section 1.3 and the accompanying theoretic background that was described in chapter 2.1. Rizzo and Kim (2005) concluded that gaming factors can be used to increase the patient's motivation when engaging with rehabilitation exercises. The system prototype that was created shows how affective gaming (Hudlicka, 2008, 2009) can be used to design games which explicitly target motivational variables. Bostan (2009) provided a framework for mapping these variables to psychological and psychogenic needs, and goal driven behavior. This framework allowed player motivation to be explicitly taken into account when designing the system prototype. One participant stated that he was so immersed in the training game that he had lost all sense of time. In his perception the allocated 5 minutes for the training game had passed 'with the blink of an eye'. This kind of immersion and enjoyment may be an instance of Csikszentmihalyi's 'Flow' state (see section section 2.1.3). He also stated that he was motivated to continue playing, which according to Paras and Bizzacchi (2005) are two key components which increase the effectiveness of game-based learning.

Rizzo and Kim (2005) also concluded that a challenge of virtual reality based neurocognitive rehabilitation is to design the interaction with input and output devices as well as GUIs in such a way that they are intuitively usable by the elderly population. Other studies concluded that physically active gaming increased the player's adherence and affective attitude (Mark, Ryan, Warburton, & Bredin, 2008), and an additional incentive to engage with healthy behavior (IJsselstein, Nap, de Kort, & Poels, 2007). Therefore the system prototype that was created deployed a Reality Based Interaction (Jacob et al., 2008) approach, favoring embodied and physically active interaction techniques over traditional sedentary techniques. The results from the pilot study support the hypotheses that RBI techniques increase the motivation to engage with the rehabilitation exercises.

The requirements baseline which was described in section 2.3 contained two use case scenarios which exemplified the system's features and core functions. Scenario 1 involved a patient engaging with rehabilitation exercises, carried out in a home environment. In the pilot study the participants had to complete a round of computer-based training for the mental rotation task, for which the content was prepared by the researcher. During this round the researcher stepped away from the participant, and restrained from any interaction unless solicited. All participants were able to autonomously complete the training, while the recorded results seem to indicate that their motivation was supported by how the prototype system functioned. From this it can be concluded that the prototype system can support the execution of scenario 1. Scenario 2 involved a patient's supervised assessment of cognitive skill, carried out in a clinical environment. In the pilot study the participants had to complete a round of computer-based assessment for the mental rotation task, for which the content was also prepared by the researcher. Almost all participants were able to complete the assessment, while their performance metrics were recorded in a format that is accessible to commonly used data analysis software (such as Excel, SPSS). From this it can be concluded that the prototype system can also support the execution of scenario 2.

The research which was conducted as described in the previous chapters was not entirely void of problems. One problematic factor was the variety of cognitive skills in the targeted audience. Dementia due to the typical aging process or neurodegenerative diseases can manifest itself quite differently within individuals. Similarly there is a variety of physical capabilities, as well as computer literacy in the targeted population. Because of this variety a number of questions arise: should the training exercise target a single cognitive skill or multiple ones, and which ones should that be? Which input and output device(s) match the physical skills of the targeted population? These questions must be addressed prior to the design and engineering phase, in order to ensure that the expectations are met afterwards. However particular care should be taken that this does not lead to the exclusion of access to rehabilitation for a subset of the clinical population.

Even though eight of the nine participants wore glasses, in only one case did the glasses interfere with the head-tracking device. For two participants, the head-tracking device did not work properly. This was likely caused by an incorrect positioning of the chair in front of the computer screen. Even though instructions were provided to the participants to be seated in the chair which was placed at an appropriate distance in front of the computer screen (see section 5.1.4), upon seeing the computer mouse and keyboard (which were used for the assessment part of the session) they assumed that they would need to use them for the training session as well, and subsequently moved the chair forward. Other participants remarked that they had trouble reading the texts on the computer screen, and thus had to move the chair forward. Having a computer screen that is smaller than the operational guidelines for which the system prototype was designed, and having a single apparatus for both the 'affective training' and 'assessment' sections, thus interfered with the correct functioning of both the head-tracking and subsequently also the pointing device. This also influenced the quality of the stimuli in the training session: without a degree of freedom which provided motion parallax, some of the stimulus pairs were perceptually ambiguous and therefore the correct answer was difficult or even impossible to deduce. This would not have been an issue if the head-tracking mechanism was working properly.

One of the first participants was observed to have difficulties with using the pointing device to select a button widget of the GUI. She did not seem to have any problems with using the pointing device to position the cursor over the button widget, but whenever she pressed a button on the pointing device to select the button widget, her arm and hand were not stable enough to keep the cursor positioned over the button widget on the screen. After the participant's session was over, the 'Mental Rotation Training Editor GUI' (section 3.3.2) was used to increase the button widget sizes to 150%. None of the subsequent participants reported experiencing any similar problems.

One participant found using a computer mouse during the assessment section very confusing. She was using the mouse with her left hand and pushing the right mouse button to select a button on the screen. Despite the researcher repeating the instructions to use the left mouse button, she did not want to finish the assessment session. When the session was over, however, she indicated that she was still very motivated to continue with the training or assessment game. Prior to the start of the next participant's session, the left mouse button was marked with colored adhesive tape to provide a perceptually distinctive clue as to which mouse button should be used. The keys on the computer keyboard had already been marked with red and green colored adhesive tape.

6 Discussion of research project

The sections of this chapter present the recommendations for future work which can be made based on the results from this project. Section 6.1 presents brief conclusions which can be drawn from the entire project. Section 6.2 discusses the recommendations which can be made for the experimental study that has been prepared at the SMS lab of the ETH Zürich and the University of Zürich. The final section of this chapter, section 6.3, presents recommendations for future work on the same topics.

6.1 Conclusion

This research project started with the identification of two inter-related problems with regards to virtual reality based neurocognitive rehabilitation. The first problem was that rehabilitation exercises are not designed to be motivating for the patient. Furthermore supporting the cognitive rehabilitation process can be a time consuming and repetitive process, for patient, therapist, or caregiver. The second problem was that virtual reality based neurocognitive rehabilitation targeted at the elderly population often suffered from usability issues.

This project researched how virtual reality- and game-based cognitive rehabilitation exercises can be designed to be more motivating for the elderly population. Two main hypotheses have been formulated, used to investigate the claims about core functions of a prototype system that has been designed and built. Although responses from more participants are needed in order for the results to be conclusive, the data partially supports the hypothesis that designing exercises based on principles of affective gaming and reality based interaction, both are perceived as motivating by the targeted audience. The prototype system which has been created has shown to be usable for future experimental investigations of these hypothesis, with a few adaptations as discussed in the next section.

6.2 Recommendations for the experiment prepared at the ETH Zürich

This section provides an overview of the recommendations which can be made to the researchers at the SMS lab of the ETH Zürich, who will conduct the randomized controlled experiment which has been prepared.
This experiment is described in Appendix I which contains the 2nd version of the application form for the ethics committee of the ETH Zürich, after the first one received tentative approval. The recommendations in this section can be divided into roughly two categories. They can be related to the system prototype (both hardware and software) or the experimental protocol.

Figure 36 - The ideal hardware setup for the 'affective training' mode

The recommendations related to the technological aspect are as follows. First of all the stimuli used in the assessment and training modes of the prototype software should be designed in cooperation with a therapist to match the skills

of the targeted population. This may be more important when the targeted population consists of people diagnosed with varying degrees of cognitive deficits. By using the 'Mental Rotation Stimulus Editor GUI' as noted in section 3.3.1, stimulus profiles can be created with stimulus complexities that match the targeted population's skills. The second recommendation is related to the technological setup during the experiment.
Given the confusion of participants during the pilot study, it is recommended that any future experiments use two separate installations for the training and assessment phases of the session. One installation is specifically for conducting the 'affective training mode' based section of the experiment, and involves a large television screen with the participant standing or sitting in front of it (holding the pointing device and wearing the head-tracking device) as shown in Figure 36. The second installation is specifically for conducting both the 'conventional training mode' and the 'assessment mode' sections of the experiment. This involves a standard multimedia desktop PC, with all the buttons from the keyboard and mouse that are required for interacting with the virtual environment marked in clear colors (see section 3.3.1.2).
The third and final recommendation that is related to the technology involves the language used in the 'Mental Rotation Training and Assessment GUI' (section 3.3.3) and all information (such as questionnaires) that is provided to the participants of the experiment. Initially the GUI and all questionnaires have been provided in the English language, but these should be translated into the language that is natively spoken by the participants. The targeted population may not be fluent (enough) with the English language, which may be a confounding factor that influences the quality of the results gathered during the study.

With respect to the experimental protocol the following recommendation can be made. Initially the protocol was set up so that a participant is subjected to a single session of 45 to 60 minutes. However this may be too physically and mentally demanding for the targeted population. This may be mitigated by increasing the number of sessions for each participant, while shortening the time. This has an additional benefit: repeated exposure to the training environment may have a larger effect on the resulting task performance (measured during the assessment session). These training effects may not be as measurable during the initially proposed 'single session' design. Furthermore such a within participants design also decrease the required sample sizes, which can be beneficial to the study if the number of participants which can be recruited is limited (such as is the case with people diagnosed with Alzheimer's Disease). The categories used on the Likert scale in questionnaires 2 and 3 should be extended with a numerical value, so that this value is presented to the participant when filling in the questionnaire. This enables the responses to be interpreted as being on a continuous and homogenous scale, preventing the problem with the analysis of results as described in section 5.2.

The last recommendation is related to the limited generalizing capabilities of the results which will be collected during the experiment (which uses healthy participants). Given the influences which aging as well as the presence of cognitive deficits can have on an individual's sources of motivation, it is recommended that the experiment is repeated in a clinical setting, with participants who have been diagnosed with (mild) cognitive impairments.

6.3 Recommendations for future work

The pilot study marked the first full-scale trial with the software and hardware setup, and several points should be noted for future research in this area. Most of these recommendations are related to improvements to the 'affective gaming' design, with some others related to gathering data from large quantities of players or the generalizing qualities of the results from statistical analysis of the data collected during the experiments described in this document.

Hudlicka noted (2008) that the emotion knowledge base could be effective without being 'ecologically valid'. The model of emotions and the various transitions between them is not based on principles of cognitive psychology. An ecologically valid emotion knowledge base could be researched and validated, which may not only be relevant in the context of the mental rotation task, but in a more general context of "emotion in games".
The mechanism by which emotional states from the player are inferred could also be extended. More sensory modalities could be added which provide additional physiological measurements which can be used to more successfully infer or detect emotional states and any transitions between them. Such measurements could include facial recognition using computer vision, speech recognition, and posture recognition. Note that none of these sensors has to be held by the player. Wearable computing applications may provide additional sensors that provide physiological measures that may indicate emotional states, such as Galvanic Skin Response, Heart rate, Electromyogram and so on. Such an improved mechanism for inferring emotional states would also require validation.
The last recommendation that is related to 'affective gaming' and is worth noting, is that the virtual assistant (which is simulated in the prototype system, see section 3.2.3) could be made more human-like by creating an animated and expressive virtual avatar. Having such an avatar capable of different non-verbal communications such as facial expressions, gestures, postural stance, as well as the ability to provide verbal feedback may allow another dimension to the cognitive skills which can be trained and assessed with the technology: that of social skills.

Another recommendation for future work involves the potential of the provided technology to act as a standardized training and assessment tool for the mental rotation task (since no such tool is publicly available). To support this the usability of the GUI used by the therapist's could be evaluated, to investigate if it supports all the tasks that they may want to use it for. Furthermore if the technology is extended with a centralized, anonymous and online repository of assessment results, then the collective results may provide insights in the collective skill level of the population. The technology would need to be extended with a client-server mechanism for reporting back the results of assessments, as well as functionality for aiding the health care professionals with data collection, extraction, analysis and visual representation of these results.

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Appendix A – Work Domain Support Analysis interview protocol & questionnaire

The time limit for the interview is 60 minutes. The following list identifies the different phases of the interview:

- [<5 minutes] Briefly introduce myself, my academic background/ research interests
- [5 minutes] Ask question 1 and 2, to get an indication about the interviewee's background, and attitude towards ICT in general
- [5 minutes] Briefly introduce my thesis assignment and 3-step approach:
    - To perform a Work Domain and Support analysis (WDS) consisting of interviews such as these, and information gathered during my literature research
    - To construct baseline requirements by devising scenarios and use cases for the software, its core functions and verifiable claims about its functioning
    - Perform iterative refinement of these baseline requirements:
        a. By conducting (one round of) expert reviews of these baseline requirements
        b. By building a prototype based on some core functions and claims, and evaluating it in a clinical environment
- [45 minutes] Ask questions from the 3 themes 'operational demands, human factors, envisioned technology', spending max 15 minutes per theme.
- [45 minutes] **Or alternatively**, the themes used during the interview may be dependent on the interviewee's background (for instance it may not be very useful to ask detailed technical questions to a clinician)

Interview questions

To help decide which questions to ask during an interview, all of the following questions are prioritized according to their subjectively perceived importance. During an interview questions with priority 3 will be asked first, and questions with a lower priority will be asked only if there is time left after asking all the questions with a higher priority.

#	Theme	Question
1.	**General**	Could you briefly introduce yourself and your occupation or daily role?
2.		Before we start, do you think that computer programs can become an integral part of clinical cognitive rehabilitation? Why or why not?
3.		Can you explain the main steps that are performed in providing cognitive rehabilitation therapy?
4.	**Operational demands**	How is conventional rehabilitation of cognitive skills done in general: one to one, or in a group setting? What are the reasons for using a group setting? What are the reasons for using a one to one setting?
5.		During conventional rehabilitation, which kind of performance measurements are used to measure mental functioning or monitoring progress of the rehabilitation?
6.		Do the conventional assessment mechanisms for cognitive skills offer enough fidelity to assess specific cognitive skills or functions?
7.		Does conventional rehabilitation of cognitive skills involve giving the patient exercises that can be practiced by him or her self, possibly in a home environment? If not, why not?
8.		Do you think clinicians could do with one rehabilitation exercise (such as the V-Store) targeting higher level functioning only, or do you see a need for exercise programs targeted at various basic cognitive skills as well as higher cognitive functions
9.		Should a vr program focus on rehabilitation only, or also provide means to conduct an assessment ?
10.	**Human Factors: Cognitive Task Load**	Which tasks could a computer perform (beyond presenting a virtual environment to the user) that would give the clinicians more time to perform other therapeutic activities?
11.	**Human Factors: Situation awareness and sense making**	Are there standards as to the content of a therapy (based on an evaluation of a patients progress) or is the therapeutic approach individualized, based on the

		patient's individual situation? Do the therapeutic approaches differ per clinician (and per institute) or are they all supposed to have the same approach under the identical circumstances?
12.	**Human Factors: Diversity of cognitive capacities**	Which cognitive skills do you think are important to be addressed during rehabilitation? Is this the same for each patient?
13.		Do you think patients (or healthy individuals) would benefit from playing mentally stimulating games with each other, or participate in other leisure activities that are mentally or physically engaging with friends or family members?
14.	**Human Factors: Diversity of motor skills**	Technology can be designed so that it is usable by individuals with a huge variance in both cognitive capacities as well as (fine) motor skills. However this may come at a certain price. Would you prefer the technology to be designed in support of 'universal access for all', or are you in favor of technology to support only a limited majority of the population (for example 80%-20%), while keeping development and operational cost down and allowing more diverse therapeutic content?
15.	**Human Factors: Trust and emotion**	What makes validation of a therapeutic approach so difficult? What would you consider the most important factor that determines if a therapeutic approach can be validated or not?
16.		Are there motivational issues that arise during the therapy? Do you think patients could or should be motivated more to participate or engage with the therapeutic exercises?
17.		During a therapeutic session, are patient emotions such as frustration (at his or her performance of a certain task) avoided, or is the patient supported in overcoming these emotions and continuing to engage with the task at hand?
18.	**Human Factors: Collaboration**	Would you delegate task administration responsibilities to a computer program, if the program would keep you 'in the loop' (at all times informed about the patient's progress and any abnormalities that may occur)?
19.		Telerehabilitation involves the remote monitoring and administration of some therapeutic exercises (not the entire therapy). Under the remote guidance of a clinician a patient could perform relevant exercises in a home environment. Do you think this could be of benefit to you or your organisation?
20.		Would you accept if the training or performance on (sub)tasks was monitored by the computer, and it would make suggestions to the clinician on the administration of specific training programs, based on these performance scores?
21.	**Envisioned technology**	What are the differences between home based and clinical based versions of the envisioned technology?
22.		What are the different ways in which a patient can engage with the technology (desktop pc, console, online/offline, mobile phone and so on)
23.		What kind of data on the patients performance or ongoing therapy should be recorded and stored? Where should it be stored (online/offline)? Would this data have to be shared among clinicians or professionals (across institutions)?
24.		[In both Switzerland as well as in the Netherlands] not everybody may understand a shared, common language ('High German' or 'Algemeen Beschaafd Nederlands') due to regional or local dialects spoken. How will the technology deal with these people? Through regionalization of the therapeutic content (extra effort), or through exclusion from use of the system (extra effort due to conventional therapy)?
25.	**General**	Do you have anything to add about what you would want the technology to be able to do, or the requirements it should be able to fulfill?

Appendix B – Participant information sheet

Thank you for your interest in participating in my research study. This sheet explains the purpose of the study and what you will be asked to do if you choose to participate.

Purpose of the Study

I am investigating whether computer training can help to prevent the loss of mental skills associated with the aging process. As part of this research, I want to determine whether the computer training equipment is practical to use, and whether the training game is enjoyable to play.

I am conducting this study for my master's degree in human-computer interaction. This is an international research project, with work being done in the United States, Switzerland, and the Netherlands.

Procedure

I am inviting a number of volunteers like you to participate in the study. The session will last for about 20 minutes.

During the session, you will first be asked a few background information questions, such as your age and how much experience you have with using computers. These answers are needed for statistical purposes and will be kept confidential.

After the background questions, you will be asked to practice playing a computer game. In the game, you will be shown two objects on a computer screen, and you will need to decide whether the objects are the same or not. The game will last for about 10 minutes.

Once the game is finished, you will be asked to answer some questions about what you liked (or not!) about the game.

You will then be asked to play the game again for about 5 minutes. This time, your score will be recorded. I will use this score, together with the answers that you gave to the questions, to help improve the training system.

Schedule

You can participate in the study at any time from June 18th to June 23rd.

Eligibility

To participate in the study, you should be:

- between 55 and 80 years old
- able to think clearly and be capable of independent living
- able to move your arms freely
- able to see a computer screen clearly from a few feet away

In addition, you should not be taking any medication that affects your mental state, such as sleeping pills, anti-depressents, or memory pills.

Risks and Rewards

This study poses little to no risk to your personal health.

You will be helping scientists and engineers to improve the effectiveness of assessment and treatment methods for cognitive skill decline. Participants will also receive a small gift as a token of appreciation for volunteering their time.

Right of Withdrawal

As a participant, you have the right to withdraw from the study at any time without consequences. You do not need to give a reason.

Privacy and Data Protection

Your original answers and scores will be treated confidentially. They will be stored securely, and will only be accessible to the study researchers. Published versions of the research will use only anonymized versions of the answers and scores.

To participate, please contact:

Sherry Fain

Lead researcher:

Sacha Panic

31 Lake Forest Hills
Shreveport, LA 71109
United States

Koningsplein 37
2611 XD Delft, Netherlands
(+31) 15-212-7360

Appendix C - Experimental protocol

Introduction & Informed Consent

Thank you for taking the time to participate in this experiment. At my university, I am studying whether computer training can help to prevent the loss of mental skills that occurs as people age. Today you will be helping me to investigate whether the computer training program is enjoyable to use. If the training is enjoyable, then other studies will be conducted to see if the training is effective.

During the session today, I will ask you to play a computer game and answer some questions. In total, this will take about 20 minutes of your time.

Before we begin, I need to inform you that you have the right to leave at any time. You also have the right to request that your data be returned to you. Your data will be kept strictly confidential, and I will remove any identifying references to you when I write up my report. After this study is completed, all recorded data will be destroyed.

Do you have any questions so far? If not, then I would like to ask you to please read and sign this consent form.

[HAND OUT CONSENT FORM]

Questionnaire 1

[COLLECT CONSENT FORM]

Thank you. Next, I would like to ask you to complete the first questionnaire.

[HAND OUT QUESTIONNAIRE 1]

Please let me know if anything is unclear.

Play training mode

[COLLECT QUESTIONNAIRE 1]

Thank you. Next, I would like you to try the training game. You can use these devices:

[SHOW GLASSES AND WII REMOTE]

You place the safety glasses on your head like this:

[SHOW PLACEMENT OF GLASSES]

And you hold the controller like this:

[SHOW USING THE CONTROLLER]

By pointing the controller at the screen, you can control the position of the yellow hand image. If the hand is positioned over a grey button, the button will turn yellow and vibrate briefly. When that happens, it means that you can press the button on the screen by pressing the round A button on the controller, like this:

[SHOW PRESSING BUTTON]

Do you have any questions so far?

OK. In the game, you will be asked to say whether two shapes are the same or different. Shapes are the same when you can rotate one to match the other. Be careful though: a mirror image of the shape is not the same! There are no passing or failing scores, so just do your best.

Are you ready to give it a try? Great!

[START TRAINING IN 5 MINUTE TIMED MODE]

Questionnaire 2

Well done! Now I would like you to fill in a few more questions, about what you thought of the game. Okay?

[HAND OUT QUESTIONNAIRE 2]

Play assessment mode

[COLLECT QUESTIONNAIRE 2]

Thank you. I would now like you to play the game again, but without the glasses and the controller. Instead, you can use the mouse to give your responses. The mouse will control the yellow hand image on the screen. When the hand is over the button of your choice, press the left mouse button to activate it.

[DEMONSTRATE MOUSE]

Do you have any questions before we start? I will be recording the score this time. Are you ready?

[START ASSESSMENT MODE]

Questionnaire 3

That was great! We’re almost done. I just need you to answer a few more questions, about how you liked this version of the game.

[HAND OUT QUESTIONNAIRE 3]

Debrief

[COLLECT QUESTIONNAIRE 3]

Thank you. What did you think of the experiment? Do you have any further questions? Then I would like to thank you again for participating. Please accept this small gift as thanks.

Appendix D – Participant consent form

PARTICIPANT CONSENT FORM

This form should be signed before you take part in the study.

Student researcher's name: A.S. Panic (a.s.panic-1@student.tudelft.nl)

Summary of study:

I am investigating whether computer training can help to prevent the loss of mental skills associated with the aging process. As part of this research, I want to determine whether the computer training equipment is practical to use, and whether the training game is enjoyable to play.
I am conducting this study for my master's degree in human-computer interaction. This is an international research project, with work being done in the United States, Switzerland, and the Netherlands.
I am inviting a number of volunteers like you to participate in the study. The session will last for about 20 minutes. For half of the session you will be playing a computer based training game, and for the other half you will be answering questionnaires.
You will be helping scientists and engineers to improve the effectiveness of assessment and treatment methods for cognitive skill decline. You will also receive a small gift as a token of appreciation for volunteering your time.

This study poses little to no risk to your personal health.

Statement of informed consent:

The student researcher named above has briefed me to my satisfaction on the research for which I have volunteered. I understand what is required of me when I consent to participate in this project. I understand that I have the right to withdraw from the research at any point and to have the data returned to me if requested. I understand that my rights to anonymity and confidentiality will be respected.

I consent to participate in this study. Date: June 19th, 2010

Signature________________________ Name(Block letters) ________________________

Appendix E – Questionnaire 1

Questionnaire 1 **Participant # ____**

Please answer the questions below by clearly marking the checkbox next to the appropriate answer. Mark only one answer unless otherwise instructed.

Example:

Did you sign a consent form and hand it in to the researcher present at the experiment?	■ Yes ☐ No

If you wish to change your answer, then mark the new answer and draw a circle around it. Please provide answers to all of the following questions:

What is your gender?	☐ Male ☐ Female
What is the highest level of education that you have completed?	☐ University, master's or PhD ☐ University, bachelor's ☐ Some university ☐ High school ☐ Did not complete high school
What kind of equipment do you use regularly? Please mark all that apply.	☐ TV ☐ Radio ☐ Telephone ☐ Mobile phone ☐ Digital photo camera ☐ Personal computer ☐ Video game console
What kind of games do you like to play? Please mark all that apply.	☐ Strategy games (bridge, chess) ☐ Skill games (Jenga, Mikado) ☐ Knowledge games (Trivial Pursuit, Scrabble) ☐ Thinking games (Sudoku, crossword puzzles) ☐ Other ☐ I don't play games
Would you like to play these games on the computer?	☐ Yes ☐ No
How often do you use a computer?	☐ Every day

	☐ A few times a week ☐ Once a week or less ☐ I don't use a computer

If you use a computer, what do you use it for? Please mark all that apply.	☐ Looking up information (recipes, weather) ☐ Playing games ☐ Typing and printing letters ☐ Sending and reading email ☐ Managing and printing my photos ☐ Chatting ☐ Other
Would you be interested in playing computer games which train your mental skills? If so, how often?	☐ Yes, daily ☐ Yes, weekly ☐ Yes, but only occasionally ☐ No
What do you expect from computer games which train your mental skills? Please mark all that apply.	☐ They should be fun ☐ They should be challenging ☐ They should be easy in difficulty ☐ They should be hard in difficulty ☐ They should be easy to understand ☐ They should be easy to use

Thank you for the time you took to complete this questionnaire. Should you have any further remarks about this questionnaire or the experiment so far, please note them in the section below. If you don't have any remarks, then please hand in this form to the researcher present at the experiment.

Your additional remarks:

Appendix F – Questionnaire 2

Questionnaire 2 **Participant # ______**

Please answer these questions about the game that you just played. Answer by clearly marking the checkbox next to the appropriate answer. Mark only one answer unless otherwise instructed.

Example:

	Strongly disagree	**Disagree**	**Agree**	**Strongly agree**	**No opinion or can't say**
On a sunny day, the color of the sky is blue.	☐	☐	☐	■	☐

If you wish to change your answer, then mark the new answer and draw a circle around it. Please provide answers to all of the following questions:

		Strongly disagree	**Disagree**	**Agree**	**Strongly agree**	**No opinion or can't say**
1	I enjoyed playing the game.	☐	☐	☐	☐	☐
2	I am satisfied with how I did.	☐	☐	☐	☐	☐
3	I think my performance would improve if I played the game more often.	☐	☐	☐	☐	☐
4	I could understand the game controls.	☐	☐	☐	☐	☐
5	The game controls were easy to learn.	☐	☐	☐	☐	☐
6	The game was always too difficult.	☐	☐	☐	☐	☐
7	The game was always too easy.	☐	☐	☐	☐	☐
8	The game difficulty changed while I was playing.	☐	☐	☐	☐	☐

9	I wanted to continue playing because I could see my score.	☐	☐	☐	☐	☐
10	I wanted to continue playing because the game was challenging but not frustrating.	☐	☐	☐	☐	☐

11	I wanted to continue playing because of the encouraging messages in the game.	☐	☐	☐	☐	☐
12	I wanted to continue playing because the controls were easy to use.	☐	☐	☐	☐	☐
13	I wanted to continue playing because of the head-tracking glasses.	☐	☐	☐	☐	☐
14	I would like to play a game to increase my score.	☐	☐	☐	☐	☐
15	I would like to play a game to win new achievement medals.	☐	☐	☐	☐	☐
16	I would like to play a game that modifies its difficulty to suit my abilities.	☐	☐	☐	☐	☐
17	I would like to play a game that encourages me to continue playing.	☐	☐	☐	☐	☐
18	I would like to play a game that lets me control it by moving in front of the screen.	☐	☐	☐	☐	☐
19	I would like to play a game that lets me see depth in the display.	☐	☐	☐	☐	☐

For the next questions, assume that the game had a new mode which ended the first time that you made a mistake. Your score would be the number of correct answers before the game ended.

		Strongly disagree	**Disagree**	**Agree**	**Strongly agree**	**No opinion or can't say**
20	I would like to play the game with the new game mode.	☐	☐	☐	☐	☐
21	I would like to play a game that has several different modes.	☐	☐	☐	☐	☐

Thank you for the time you took to complete this questionnaire. Should you have any further remarks about this questionnaire or the experiment so far, please note them in the section below. If you don't have any remarks, then please hand in this form to the researcher.

Your additional remarks:

Appendix G – Questionnaire 3

Questionnaire 3 **Participant # ______**

Please answer these questions about the game that you just played. Answer by clearly marking the checkbox next to the appropriate answer. Mark only one answer unless otherwise instructed.

Example:

	Strongly disagree	Disagree	Agree	Strongly agree	No opinion or can't say
Louisiana summers are hot.	☐	☐	☐	■	☐

If you wish to change your answer, then mark the new answer and draw a circle around it. Please provide answers to all of the following questions:

		Strongly disagree	Disagree	Agree	Strongly agree	No opinion or can't say
1	I enjoyed playing the game.	☐	☐	☐	☐	☐
2	I am satisfied with how I did.	☐	☐	☐	☐	☐
3	I think my performance would improve if I played the game more often.	☐	☐	☐	☐	☐
4	I could understand the game controls.	☐	☐	☐	☐	☐
5	The game controls were easy to learn.	☐	☐	☐	☐	☐
6	The game was always too difficult.	☐	☐	☐	☐	☐
7	The game was always too easy.	☐	☐	☐	☐	☐

8	I wanted to continue playing because I could see my score.	☐	☐	☐	☐	☐
9	I wanted to continue playing because the game was challenging but not frustrating.	☐	☐	☐	☐	☐
10	I wanted to continue playing because of the encouraging messages in the	☐	☐	☐	☐	☐

	game.					
11	I wanted to continue playing because the controls were easy to use.	☐	☐	☐	☐	☐
12	I am more motivated to play computer games now than I was this morning.	☐	☐	☐	☐	☐
13	I enjoyed the first game more than the second.	☐	☐	☐	☐	☐

Thank you for the time you took to complete this questionnaire. Should you have any further remarks about this questionnaire or the experiment so far, please note them in the section below. If you don't have any remarks, then please hand in this form to the researcher.

Your additional remarks:

Appendix H – Results of data analysis

The responses from questionnaires 2 and 3 have been coded into a dichotomous scale, with 0 labeled as 'Disagree' and 1 labeled as 'Agree'. Then the binomial test is used to investigate the significance of the observed proportions of responses, with the null hypotheses being that the two categories are equally likely to occur. The binomial test used a test proportion of 0.50.

		Category	N	Observed Prop.	Test Prop.	Exact Sig. (2-tailed)
Q2.1-Enjoyed playing the game	Group 1	1 (Agree)	9	1.00	.50	.004
	Total		9	1.00		
Q2.2-Satisfied with performance	Group 1	0 (Disagree)	6	.75	.50	.289
	Group 2	1 (Agree)	2	.25		
	Total		8	1.00		
Q2.3-Thinks performance would improve with practice	Group 1	1 (Agree)	9	1.00	.50	.004
	Total		9	1.00		
Q2.4-Understood the game controls	Group 1	1 (Agree)	7	.78	.50	.180
	Group 2	0 (Disagree)	2	.22		
	Total		9	1.00		
Q2.5-Learned game controls easily	Group 1	1 (Agree)	8	.89	.50	.039
	Group 2	0 (Disagree)	1	.11		
	Total		9	1.00		
Q2.6-Found game always too difficult	Group 1	0 (Disagree)	7	.78	.50	.180
	Group 2	1 (Agree)	2	.22		
	Total		9	1.00		
Q2.7-Found game always too easy	Group 1	0 (Disagree)	8	.89	.50	.039
	Group 2	1 (Agree)	1	.11		
	Total		9	1.00		
Q2.8-Noticed adaptive game difficulty	Group 1	1 (Agree)	8	1.00	.50	.008
	Total		8	1.00		
Q2.9-Motivated by score	Group 1	0 (Disagree)	3	.33	.50	.508
	Group 2	1 (Agree)	6	.67		
	Total		9	1.00		
Q2.10-Motivated by challenge	Group 1	0 (Disagree)	4	.44	.50	1.000
	Group 2	1 (Agree)	5	.56		
	Total		9	1.00		
Q2.11-Motivated by encouragement	Group 1	0 (Disagree)	5	.56	.50	1.000
	Group 2	1 (Agree)	4	.44		
	Total		9	1.00		
Q2.12-Motivated by ease of use	Group 1	0 (Disagree)	4	.44	.50	1.000
	Group 2	1 (Agree)	5	.56		
	Total		9	1.00		
Q2.13-Motivated by head-tracking	Group 1	1 (Agree)	3	.50	.50	1.000
	Group 2	0 (Disagree)	3	.50		

	Total		6	1.00		
Q2.14-Wants to play to increase score	Group 1	1 (Agree)	9	1.00	.50	.004
	Total		9	1.00		
Q2.15-Wants to play to win medals	Group 1	0 (Disagree)	2	.25	.50	.289
	Group 2	1 (Agree)	6	.75		
	Total		8	1.00		
Q2.16-Wants adaptive game difficulty	Group 1	0 (Disagree)	1	.11	.50	.039
	Group 2	1 (Agree)	8	.89		
	Total		9	1.00		
Q2.17-Wants encouragement	Group 1	1 (Agree)	9	1.00	.50	.004
	Total		9	1.00		
Q2.18-Wants movement-based gaming	Group 1	1 (Agree)	6	.75	.50	.289
	Group 2	0 (Disagree)	2	.25		
	Total		8	1.00		
Q2.19-Wants 3-D gaming	Group 1	1 (Agree)	7	.88	.50	.070
	Group 2	0 (Disagree)	1	.13		
	Total		8	1.00		
Q2.20-Interested in new game mode	Group 1	0 (Disagree)	6	.67	.50	.508
	Group 2	1 (Agree)	3	.33		
	Total		9	1.00		
Q2.21-Interested in multiple game modes	Group 1	1 (Agree)	6	.75	.50	.289
	Group 2	0 (Disagree)	2	.25		
	Total		8	1.00		
Q3.1-Enjoyed playing the game	Group 1	1 (Agree)	9	1.00	.50	.004
	Total		9	1.00		
Q3.2-Satisfied with performance	Group 1	0 (Disagree)	1	.20	.50	.375
	Group 2	1 (Agree)	4	.80		
	Total		5	1.00		
Q3.3-Thinks performance would improve with practice	Group 1	1 (Agree)	9	1.00	.50	.004
	Total		9	1.00		
Q3.4-Understood the game controls	Group 1	0 (Disagree)	1	.11	.50	.039
	Group 2	1 (Agree)	8	.89		
	Total		9	1.00		
Q3.5-Learned game controls easily	Group 1	1 (Agree)	9	1.00	.50	.004
	Total		9	1.00		
Q3.6-Found game always too difficult	Group 1	0 (Disagree)	7	.78	.50	.180
	Group 2	1 (Agree)	2	.22		
	Total		9	1.00		
Q3.7-Found game always too easy	Group 1	0 (Disagree)	9	1.00	.50	.004
	Total		9	1.00		
Q3.8-Motivated by score	Group 1	0 (Disagree)	3	.50	.50	1.000
	Group 2	1 (Agree)	3	.50		
	Total		6	1.00		
Q3.9-Motivated by challenge	Group 1	1 (Agree)	7	.78	.50	.180
	Group 2	0 (Disagree)	2	.22		

	Total		9	1.00		
Q3.10-Motivated by encouragement	Group 1	0 (Disagree)	5	.71	.50	.453
	Group 2	1 (Agree)	2	.29		
	Total		7	1.00		
Q3.11-Motivated by ease of use	Group 1	0 (Disagree)	3	.33	.50	.508
	Group 2	1 (Agree)	6	.67		
	Total		9	1.00		
Q3.12-Increased motivation to play computer games	Group 1	0 (Disagree)	5	.56	.50	1.000
	Group 2	1 (Agree)	4	.44		
	Total		9	1.00		
Q3.13-Enjoyed first game more than second	Group 1	0 (Disagree)	6	.67	.50	.508
	Group 2	1 (Agree)	3	.33		
	Total		9	1.00		

Appendix I – Application form for the Research Ethics Committee of the ETH Zürich

Application Form to the Research Ethics Committee of ETH Zurich

To be submitted to: ETH Zurich, Ethics Commission, Office of Research, HG E 32.2, 8092 Zürich

A. General Information

Project Title

Investigating the effects of affective game design on player motivation and task performance

Principle investigator

Name	Address of institute	E-Mail address	Phone number
Prof. Dr. Ing. Robert Riener	TAN E 4, Tannenstrasse 1	riener@mavt.ethz.ch	0446326679

Involved collaborators

Name	Address of institute	Email address	Phone number
Dr. Peter Wolf	TAN E 6.2, Tannenstrasse 1	Peter.Wolf@mavt.ethz.ch	0446327109
B. Buss	TAN B 6.1, Tannenstrasse 1	Bernhard.Buss@mavt.ethz.ch	0446325917
A.S. Panic	TAN B 6.2, Tannenstrasse 1	Sasa.Panic@mavt.ethz.ch	

Number of participants	***Duration of the study***	***Type of project***
Minimum: 52	Begin:April 22nd, 2010	☐ Research Project
Maximum:57	End:July 7th, 2010	■ (Master Thesis)

Signature of principle investigator:

Date: Signature:

B. Scientific Information

All scientific information shall be submitted on the following numbered appendixes:

Appendix 1: Abstract

Although some knowledge exists about the preferences for types of games and entertainment of the elderly, little is known about which particular aspects of game design have a positive effect on engagement and motivation. Affective games take the player's emotional state into account, and adjust their content accordingly. The aim of this study is to investigate if virtual reality based exercises for neurocognitive rehabilitation can be made more motivating and more effective by using affective gaming design principles. Initially the targeted population consists of healthy elderly people. A clinical followup study will be targeted at elderly people who have been diagnosed with dementia caused by for instance Alzheimer's Disease.

The experimental protocol involves a minimum of 52 participants randomly divided into two equally sized groups, and consists of a single session during which the participants are required to use virtual reality based training and assessment on the Mental Rotation Task, which is a commonly used clinical instrument for the assessment of cognitive skills. Performance related data will be collected automatically and anonymously, which will be complemented by two brief questionnaires which have to be completed by the participants.

Appendix 2: Project

a) Background literature survey

An analysis of the strengths, weaknesses, opportunities and threats of virtual reality based neurocognitive rehabilitation (Rizzo and Kim, 2005) summarized the main issues which will be investigated in the study proposed in this document. Two noted strength are that gaming factors can be used to enhance the patient's motivation during the exercises, and that self-guided exploration and independent practice is made possible. Two noted weaknesses are termed as 'the interface challenge', and are related to the methods and devices of interaction and presentation that are used. The results from the study proposed in this document provide precise insights into how to design and implement virtual reality based neurocognitive rehabilitation programs which capitalize on these two strengths, while mitigating these two weaknesses.

The first aim of this study is to find out whether the elderly find affect-adaptive game based rehabilitation scenarios more engaging and motivating than more rigid rehabilitation scenarios. Haier et al noted (2009) that playing computer games based on visuo-spatial tasks can lead to structural and functional changes in the brains of adolescent girls. Flores et al noted (2008) that more studies are needed to find out which specific design criteria of games promote motivation in elderly users, while at the same time rehabilitating impaired cognitive skills. Bostan noted (2009) that what people perceive as motivating factors may be related to their personality traits (e.g. whether they are competitive, achievers, socializers and so on). Although some knowledge exists about the preferences for types of games and entertainment of elderly people (Gamberini, 2006 and Flores et al, 2008), little is known about which particular aspects of game design have a positive effect on engagement and motivation. The affective state of a player has a significant role in these and other aspects of user experience. This implies that in order for games to be

continuously perceived as engaging and motivating, they must monitor and adapt to the affective state of the player. Hudlicka calls this 'Affective gaming' (Hudlicka, 2009), and Gilleade and colleagues have identified three high level design heuristics for such affect-adaptive games: assist me, challenge me, and emote me (Gilleade et al, 2005).
The second aim of this study is to find out whether an interaction design which focuses on more natural and embodied interaction, promotes acceptance by the elderly population. Fisk et al noted (2004) that in research of the use of virtual reality for cognitive rehabilitation of elderly users, in more than 50% of the cases the reported problems are related to the usability of interaction devices. Although much of these problems can be circumvented by offering training, the preferred solution is to prevent these problems by improving the design of the used technology. Human computer interaction devices which allow more natural and embodied interaction can be picked up and used intuitively and more easily by the targeted elderly population (Gamberini et al, 2006).

b) Project overview

During the course of the project two studies will be conducted. The first study, outlined in this proposal, investigates the aforementioned research questions with healthy elderly participants. A second and separate follow-up study will repeat the experiment with elderly who have been diagnosed with mild cognitive impairments. The combined findings of these two studies will help to improve the design of virtual reality based training scenarios. Such improvements may lead to an increase in motivation of the healthy as well as the clinical elderly population and their capability and willingness to engage with computer game based training scenarios.

Although there is some information available on which types of games elderly people prefer, data on which specific aspects of game design are motivating to this targeted group does not seem to be available (Gamberini, 2006 and Flores et al, 2008). The target group addressed in this project consists of elderly people who may or may not be diagnosed with dementia resulting from Alzheimer's Disease. Within the related 'Cognimat' project, the selection criteria for recruiting participants has been defined as an age between 55 and 80 (Buss, 2009).

The results from this study are relevant for both clinicians and researchers who consider using virtual reality and game technology for training of cognitive skills of the elderly. These results will provide evidence about the effects of virtual reality and affective gaming based training on the rate of learning as well as the player motivation. Furthermore, the results from this study are relevant for society in general, as they provide insights into which affective game design criteria promote engagement and motivation in elderly players. These new insights may increase the effectiveness and enjoyment of virtual reality based training scenarios. Finally, this study may provide new insights into which type of human computer interaction devices are accepted by the elderly population. In the study outlined in this proposal the targeted population consists of healthy elderly.

c) Goals of the project

The aim of this study is to investigate the following hypotheses:

H1 Rehabilitation exercises that are designed using principles of affective gaming increase the motivation to engage with the exercise in the elderly population.

H2 Rehabilitation exercises that are designed using principles of affective gaming result in a better task performance.

A secondary aim of this study is to investigate the rate of acceptance of human computer interaction devices which allow naturalistic (gesture based) interaction techniques.

The results from this study can be useful for other studies done at the SMS Lab. The *Multimodal Immersive Motion rehabilitation with Interactive Cognitive Systems (MIMICS)* project investigates physiological measures which can be used to control presence, attention and motivation within virtual reality based rehabilitation scenarios. The results of the study proposed in this document help to evaluate the evidence for psychological measures that can be used in the design of virtual reality based rehabilitation scenarios, to promote patient motivation and adherence.
The results of the study proposed in this document are also related to the *Cognimat* project which is currently being formed to investigate virtual reality based neurocognitive rehabilitation of Alzheimer's disease.

d) Research plan

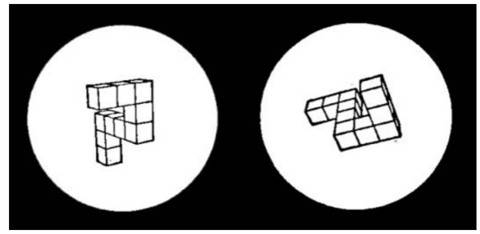

Figure 44 The Mental Rotation Task: are these objects the same?

In this study, different game design criteria will be applied to try to make a cognitive task training scenario more exciting and challenging to the learner. The Mental Rotation Task is a standardized assessment of cognitive skills (Shepard and Metzler, 1971). However the game design criteria are chosen based on their general applicability to other cognitive tasks. According to Gilleade (2005), the affective design criteria (see Table 12) can be grouped according to what they aim to influence: Level of challenge, level of assistance, and player mood.

Table 13 The affective game design criteria evaluated in this study

Challenging	**Assisting**	**Mood enhancing**
Adapt game difficulty based on skill level of player	Provide multimodal feedback on task goals and performance	Adapt game difficulty based on inferred affective state of player
Multiple high score tables to show a variety of player achievements	Provide supportive feedback when performance is low, and when performance is high	Use of affective auditory effects to influence mood and emotion
Multiple game modes: Normal Time limited 'Sudden death' Max 3 incorrect answers	Provide peripheral visual cues which offer additional depth cues	Use of in-game music to influence mood and emotion
Add a secondary task to the game	The player can ask for help with a trial for a limited number of times, possibly with a score penalty	
Variable payoff mechanisms		
Award achievement medals to the player		

To facilitate this investigation, a proprietary computer based version of the Mental Rotation Task has been created. Figure gives an overview of the computer devices that are used. A TV is used to present the task to the player. The player is standing or sitting in front of the TV and interacts with the system by using a Nintendo Wii remote in his or her hand. This device acts as a pointing and selection device, and also allows auditory and tactile feedback to be presented to the player. The player also interacts with the system by wearing infra red LED eye glasses, which allow the system to track the player's head position and orientation.

Figure 45 An overview of the technology to which participants of this study are directly exposed: the Nintendo Wii remote, infra red LED eye glasses and a flatscreen TV.

e) Research method

A randomized controlled design is applied; The participants are divided randomly into two equally sized groups. Each participant is subjected to one experimental session of 60 minutes (see Table 14). Each session starts with a brief introduction to the content of the session by a responsible researcher. The remainder of the session consists of a questionnaire (asking about the participant background, see section h) on the next page), a task training round using a computer based version of the Mental Rotation Task (MRT), another questionnaire (asking about motivational feedback, see section h) on the next page) and a performance assessment round using a computer based version of the MRT.

Table 14 The experimental protocol used in this study

	Duration (minutes)	**Group 1 (n=26, control)**	**Group 2 (n=26)**
Introduction	5		
Questionnaire 1	5		
Training round	22	MRT: Standard mode	MRT:Affective mode
Questionnaire 2	5		
Assessment round	8	MRT: Standard mode	MRT: Standard mode

During the training and assessment rounds, two computer based versions of the MRT will be used: standard mode and affective mode. These two versions are described as follows:

- *Standard mode*: this presents the participant with an augmented reality based version of a traditional computer based MRT. In this mode the participant stands in an open area in front of the TV screen, and is wearing the infra red eye glasses and holding the Wii Remote. 30 MRT trials are presented using augmented reality techniques, causing them to appear to the participant as interactive holographic illusions in front of the TV. Using augmented reality offers the participant an additional visual cue (motion parallax) over a traditional computer based version. The participant responds to each trial by using a handheld pointing and selection device to acquire and select one of two virtual buttons on the TV screen. Each session records performance data (response time and response correctness) on 30 trials.

- *Affective mode*: this mode is based on the standard mode, but presents the participant with a game that has been designed to engage and motivate the participant, as well as to have therapeutic effects. Each session records performance data (response time and response correctness) on all trials.

Prior to the start of the training and assessment rounds, the participants are presented with three practice stimuli which allow them to get used to the task and its supporting human computer interaction devices.

During each session data will be recorded which is related to the participant's performance and/or motivation. To complement the two questionnaires (see section h), during the training and assessment rounds performance data will be recorded automatically by the proprietary software. For each of the trials the data fields as shown in table 3 will be recorded. The recorded data is only accessible to the project collaborators. Subsequent analysis of this data will provide answers to the hypotheses that were listed in section c "goals of the project".

Neither the proprietary software nor the questionnaires record the participant's name. The participant consent form (see appendix 7) however does record the participant's name. To safeguard the participant's anonymity, one project collaborator will be responsible for collecting consent forms and planning the date and time of the session, while another collaborator will be responsible for conducting the actual session and collecting the associated data. After the study has been completed, all recorded data will be erased and/or destroyed.

Table 3 The performance related data fields which are recorded automatically by the proprietary software

Data field	Description	Example
Trial number	Number of the trial	*1*
Response correct	Indicates if the user response was correct	*Yes*
Response time	Indicates the time it took the user to respond to the trial	*1.9024*
Stimulus description	Human readable representation of the stimulus	*a a a ab a a a ac a a a ad a a a*
Stimulus difficulty	Assigned difficulty level of the stimulus	*2*
Mirrored target X	Indicates if the target stimulus is mirrored or identical to the source stimulus	*No*
Mirrored target Z	Indicates if the target stimulus is mirrored or identical to the source stimulus	*Yes*
Source yaw	Degrees of rotation of source stimulus	*0*
Source pitch	Degrees of rotation of source stimulus	*20*
Source roll	Degrees of rotation of source stimulus	*40*
Target yaw	Degrees of rotation of target stimulus	*20*
Target pitch	Degrees of rotation of target stimulus	*40*
Target roll	Degrees of rotation of target stimulus	*60*

f) Analysis of data and expected results

The hypotheses posed in section c will be investigated by conducting a statistical analysis of the collected data. The cumulative data collected in the questionnaires will provide measurements to investigate Hypothesis 1. Hypothesis 2 will be investigated by performing an unpaired two sample t-test (power = 0.80, $\alpha = 0.05$, for an expected large effect size) on the Response Time (RT) and Response Correctness (RC) as recorded by the software (see table 3 in section e).

We expect that a majority of participants will be motivated to engage with the affective gaming based rehabilitation exercises (H1), and that such rehabilitation exercises result in a better task performance (H2). We also expect that the rate of acceptance of human computer interaction devices which allow naturalistic interactions is higher than in previously conducted experiments at the lab (Buss, 2009).

g) Time frame

Participant acquisition will start after obtaining approval from the Ethics Committee, and will last for one month. As an example the participant acquisition could be conducted from April 22nd 2010 to May 26th 2010.

The experiment itself will be conducted after the participant acquisition has been completed. Assuming that three sessions can take place on a single day, the experiment will run for about one month. As an example this could be from June 3rd 2010 to July 7th 2010.

h) Questionnaires/surveys

Interacting with computers (for the first time) can be a tiring experience to the elderly population. Therefore it has been decided to keep the amount of questions as limited as possible. For the same reason all the questions used require the participant to select one or more answers, or to mark his answer on a Likert scale. Please refer to Appendix 7 for an overview of the questions asked in the questionnaires. In the first questionnaire, 11 answers are provided by marking appropriate checkboxes, and in the second questionnaire the 25 answers are marked on a 5 point Likert scale.

i) Language dependant component

Due to time constraints it has been decided by the project members to implement this initial study in the English language. This applies to all the questionnaires used, as well as the graphical user interface (GUI) of the proprietary software which has been created. However it has been anticipated that there may not be many people from the targeted group who are fluent (enough) in the English language, so it is possible to translate all the questionnaires as well as the proprietary software to any other language.

Appendix 3: Expected risks and according precautionary measures

This section details the few risks involved with the technical setup used in the experiment. The setup as detailed in Figure requires the participant to physically move in an open area in front of a TV. This area should be made free of all physical objects which could cause the patient to fall and injure themselves. To prevent postural instabilities from participants during the experiment, they are allowed to take breaks between the different phases of a session or during the training phase (see table 2). Alternatively the participants can complete the session while sitting down on a chair in front of the TV, instead of standing up. The responsible researcher present at the experiment can remind the participant that he or she can take a small break if necessary. To minimize this risk the participant can be asked to sit down on a couch or chair that is placed in front of the TV, while still being able to interact with the virtual environment by moving his or her head and upper body.
Since the used human computer interaction devices recognize gestures made by the arm that holds the device, a risk is that the participants hit their arms into physical objects while performing the gestures. As stated before, to limit the chance of personal injury all physical objects must be removed from the area in front of the TV. Furthermore the interaction with the game is designed in such a way that it does not require the participant to (wildly) wave their arms around, but is limited to pointing, selecting and dragging of virtual objects on the screen.
During a typical experimental session the responsible is in the same room as the participant. Once the session is started the responsible researcher acts as a passive observer. The responsible researcher and the student observer are not exposed to any risks for physical injury.

Appendix 4: Principle investigator

j) Curriculum vitae of principle investigator Prof. Dr. –Ing. Robert Riener:

- Since June 2006 Associate Professor for Sensory-Motor Systems at ETH Zurich (Department of Mechanical Engineering and Process Engineering) and University of Zürich (University Hospital Balgrist, Medical Faculty).
- August 2005 Call to a full professorship on Biomechanics and Movement Science, University of Karlsruhe: declined
- May 2003 – May 2006 Assistant Professor for Rehabilitation Engineering at ETH Zurich (Dept. Information Technology and Electrical Engineering) and University Zürich (University Hospital Balgrist, Medical Faculty).
- Guest Lecturer at TU Munich, Germany, and University Koblenz-Landau, Germany
- January 2003 Habilitation in *"Biomechatronics"* at the Faculty of Electrical Engineering and Information Technology, Technical University (TU) Munich.
  Thesis title: "Technology of Multimodal Virtual Reality in Medicine".
- March 2002 Offer of an assistant professorship at Iowa State University (Dept. of Health and Human Performance): declined
- March 1999 – April 2003 Research Associate at the Institute of Automatic Control Engineering (Prof. G. Schmidt) and coordinator of the Biomedical Engineering Group, TU Munich

- Jan. 1998 – Feb. 1999 Postdoctoral work at the Centro di Bioingegneria (Prof. A. Pedotti), Politecnico di Milano
- May 1997 Dissertation at the TU Munich.
  Thesis title: „Neurophysiological and biomechanical modelling for the development of neuroprostheses“ ("summa cum laudae")
- July 1993 – Dec. 1997 Research Assistant at the Institute of Automatic Control Engineering (Prof. G. Schmidt), TU Munich, Germany
- Sept. 1992 – April 1993 Diploma thesis at the University of Maryland, USA
  Scholarship: Prof. Erich Müller Stiftung
- Nov. 1988 – April 1993 Study of Mechanical Engineering, TU Munich, Germany, Major: Aerospace

k) Publication list of principle investigator (of the past 5 years)

- Staubli, P., Nef, T., Klamroth, V., Riener, R. (2009) Effects of intensive arm training with the rehabilitation robot ARMin II in chronic stroke: Four single-cases. *Journal of NeuroEngineering and Rehabilitation*. Submitted
- Nef, T., Kiefer, G., Mueller, R., Riener, R. (2009) Effects of arm training with the robotic device ARMin I in chronic stroke: Three single cases, *Neurodegenerative Diseases*, in press.
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Appendix 5: Participants

l) Exact number of participants

With the results collected during the assessment phase of the experimental session (see Table) the quantitative effects of the type of task training (Normal vs. Affective) on task performance can be measured. The number of participants required to measure an expected large effect size is 52 (Based on an independent two-sample t-test, with power = .80, alpha=.05)

The results collected during the 2nd questionnaire phase of the experimental session (see Table) provide qualitative feedback on game design criteria which are perceived as engaging and motivating.

m) Selection and exclusion criteria

Participants are selected for inclusion (by the project collaborators) if they meet the following criteria:

- Age: 55-80.
- Must be able to stand and/or walk for about 20 minutes, allowing one or two breaks of 2-3 minutes.
- No history of motion sickness.
- No physical disabilities.
- No medical condition.
- Little to no computer gaming history.
- No medicine usage that would alter cognitive capabilities (e.g. learning, perception, memory, visuo-spatial abilities).
- Vision corrected to standard.
- Basic understanding of spoken and written English.

n) Recruitment of participants

Participants will be recruited by project collaborators both internally at, and externally from the ETH. Internal recruitment is initiated by word of mouth and email communication. External volunteers will be recruited through an advertisement campaign through the office of Corporate Communications at the ETH.

Appendix 6: Information sheet for participants[10]

Study title: Investigating the effects of affective game design on player motivation and task performance

a) Goal of the study

This study aims to investigate how computer game based training can be designed, so that it increases the motivation to engage with the training as well as the practicability of the used interaction devices. This knowledge may ultimately help to design computer based training scenarios which may help with preventing degradation of mental skills, due to either the normal aging process in healthy elderly people, or symptoms such as Alzheimer's Disease.

b) Research procedure

We invite a number of volunteers like you to come to our lab for less than one hour. During that time you will first be asked to complete a questionnaire which asks you about your background information. This will take about 5 minutes. Thereafter you will be required to play a computer game which trains you to perform a basic task. In this computer game you are presented with two objects on a TV screen, after which you must decide if these objects are the same or not. This task training will last for about 22 minutes. Thereafter, we ask you to fill out a questionnaire regarding the experiences you had during your training with the computer game. This will take about 5 minutes. Finally, you are expected to once again play the computer game for about 8 minutes, during which your performance is recorded. Based on your answers and your performance data we expect to define design criteria of enjoyable therapeutic computer games.

c) Schedule

You will be invited to come to our lab and participate in the study in the period from May 3rd to June 7th.

d) Conditions to be met for participation in the study

- Your age must be between 55 and 80.
- You must be able bodied and capable of independent living.
- Your need to have an average to good mental health for people from your age, and not suffer from any severe impairment.
- You must have no history of postural instabilities, so you can stand in front of a TV to play a computer game.

[10] Information sheet for participants - version 2, February 2nd 2010

- You must have no history of motion sickness, such as car sickness.
- Your vision must be standard, or corrected to standard by wearing glasses or contact lenses.
- You must not be using any medicine that would influence the conditions mentioned above. If you are using medicine, please consult with your Doctor to find out if you can still be admitted.

e) Advantages and disadvantages for participants / Risks

There are very few risks for your personal health involved with your participation. We will take precautions to make sure that you cannot injure yourself while standing in front of a TV and playing the game. If your physical fitness limits you from standing in front of a TV, you can also sit down to prevent you from falling and hurting yourself.
Participating in this experiment has at least one advantage for you. You have the opportunity to help scientists and engineers to improve existing computer based training methods for mental skills. In the future this knowledge may help to improve the effectiveness of treatment methods for for instance Alzheimer's Disease.

f) Source of funding

This project will be conducted using resources already available at the ETH SMS Lab, with financial support from the IDEA league, a focused network of leading European universities of science and technology.

g) Compensation/Reimbursement

As a compensation for your time and efforts, we will offer you CHF 50,- per hour of volunteered time.

h) Right of withdrawal

As a participant, you have the right to withdraw from the study at any time without needing to specify any reasons nor facing negative consequences.

i) Data protection

The obtained data will be stored safely and reported in an anonymous form. Only the responsible investigators and/or the members of the ethical committee have access to the original data under strict confidentiality.

j) Insurance coverage

Possible damages to your health, which are directly related to the study and are demonstrably the fault of ETH Zurich, are covered by the general liability insurance of ETH Zurich (insurance policy no. 100.001 of the Swiss Mobiliar insurance company). However, beyond the before mentioned, the health insurance and the accident insurance (e.g. for the way to or back from the study location) is in the responsibility of the participant.

k) Contact person(s)

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0446325917

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Appendix 7: Consent Form [11]

Please read this form carefully.
Please ask the investigator or the contact person if you have any questions.

Study title: Investigating the effects of affective game design on player motivation and task performance

Study location: M3 Lab, Meeting room
ML.F.55
Sonneggstrasse 3
8092 Zürich

Principal Investigator's Name and First Name: Prof. Dr. –Ing. Robert Riener

Participant's Name and First Name: …………………………………………………………………………

Participant:

I participate in this study on a voluntary basis and can withdraw from the study at any time without giving reasons and without any negative consequences.
I have been informed orally and in writing about the aims and the procedures of the study, the advantages and disadvantages as well as potential risks.
I have read the written information for the volunteers. My questions related to the study participation have been answered satisfactorily. I have been given a copy of the information for the volunteers and the consent form.
I was given sufficient time to make a decision about participating in the study.
With my signature I certify that I fulfill the requirements for the study participation mentioned in the information for the volunteers.
I have been informed that possible damages to my health which are directly related to the study and are demonstrably the fault of ETH Zurich, are covered by the general liability insurance of ETH Zurich (insurance policy no. 100.001 of the Swiss Mobiliar insurance company). However, beyond the before mentioned, my health- and/or accident insurance (e.g. for the way to or back from the study location) will apply.
I agree that the responsible investigators and/or the members of the ethical committee have access to the original data under strict confidentiality.
I am aware that during the study I have to comply with the requirements and limitations described in the information for the volunteers. In my own health interest the investigators can, without mutual consent, exclude me from the study.

I will inform the investigators about my medical treatments and medication (prescribed by medical doctors or self-purchased).

Location, date . . . .   Signature volunteer . . . .

[11] Consent form version 1, February 2nd 2010

Location, date . . . .   Signature investigator . . . .

Appendix 7: Questionnaires to be completed during a session

General introduction

During this experiment data is collected by using our Mental Rotation Task training and assessment software, and by completing two questionnaires. Completing each of the questionnaires will take about 5 minutes of your time.
All the data will be collected by the researcher present at the experiment. To respect your privacy all recorded data is stored anonymously and separately from the consent form that you signed. After analysis of the data and completion of our study, all recorded data will be destroyed.
If at any time during the experiment you have any questions, please ask them to the researcher that is present. Thank you for taking the time to participate in this experiment.

Questionnaire 1[12]

The purpose of this questionnaire is to obtain insights into your affinity with computers and computer games. Please answer the questions below by clearly marking the checkbox next to the appropriate answer. Mark only one answer unless otherwise instructed.

EXAMPLE QUESTION: Did you sign a consent form and hand it in to the researcher present at the experiment?	■ Yes ☐ No

If you wish to change your answer, then mark the new answer and draw a circle around it. Please provide answers to all of the following questions:

1) What is your gender?	☐ Male ☐ Female
2) What is your highest educational attainment?	☐ University, master's or PhD ☐ University, bachelor's ☐ Secondary education ☐ Other ☐ I have not received any formal education
3) What kind of equipment do you use regularly? Please mark all that apply.	☐ TV ☐ Radio ☐ Telephone

[12] Questionnaire 1, version 4, March 23rd 2010

	☐ Mobile phone ☐ Digital photo camera ☐ Personal computer ☐ Video game console
4) What kind of games do you like to play? Please mark all that apply.	☐ Strategy games (bridge, chess) ☐ Skill games (Mikado) ☐ Knowledge games (Trivial Pursuit, Scrabble) ☐ Thinking games (Sudoku, crossword puzzles) ☐ Other ☐ I don't play games
5) Would you like to play such games on the computer?	☐ Yes ☐ No
6) Would you like to play games on the computer by yourself?	☐ Yes ☐ No
7) Would you like playing games on the computer, with people who are located elsewhere?	☐ Yes ☐ No
8) How often do you use a computer?	☐ About once a week ☐ A few times a week ☐ Every day ☐ I don't use a computer
9) If you use a computer, what do you use it for? Please mark all that apply.	☐ Looking up information (eg. recipes)on websites ☐ Playing games ☐ Typing and printing letters ☐ Sending and reading email ☐ Managing and printing my photos ☐ Chatting ☐ Other
10) Would you be interested in playing computer games which train your mental skills?	☐ Yes ☐ No
11) What do you expect from computer games which train your mental skills? Please mark all that apply.	☐ They should be fun ☐ They should be challenging ☐ They should be easy in difficulty ☐ They should be hard in difficulty

	☐ They should be easy to understand ☐ They should be easy to use ☐ They should be playable with others (cooperative) ☐ They should be playable with others (competitive) ☐ They should be playable alone ☐ They should allow me to engage in social activities

Thank you for the time you took to complete this questionnaire. Should you have any further remarks about this questionnaire or the experiment so far, please note them in the section below. If you don't have any remarks, then please hand in this form to the researcher present at the experiment.

Your additional remarks:

General introduction

During this experiment data is collected by using our Mental Rotation Task training and assessment software, and by completing two questionnaires. Completing each of the questionnaires will take about 5 minutes of your time.
All the data will be collected by the researcher present at the experiment. To respect your privacy all recorded data is stored anonymously and separately from the consent form that you signed. After analysis of the data and completion of our study, all recorded data will be destroyed.
If at any time during the experiment you have any questions, please ask them to the researcher that is present. Thank you for taking the time to participate in this experiment.

Questionnaire 2[13]

The purpose of this questionnaire is to obtain insights in how much you enjoyed using our computer based training for the Mental Rotation Task, and which specific elements of the program contributed to your enjoyment the most. Please answer the questions below by clearly marking the checkbox next to the appropriate answer. Mark only one answer unless otherwise instructed.

	Strongly disagree		**Neither agree nor disagree**		**Strongly agree**
EXAMPLE QUESTION: On a sunny day, the color of the sky is blue.	☐	☐	☐	☐	■

If you wish to change the your answer, then mark the new answer and draw a circle around it
Please provide answers to all of the following questions:

	Strongly disagree		**Neither agree nor disagree**		**Strongly agree**
1) I found the training round to be enjoyable.	☐	☐	☐	☐	☐
2) I like it when games are easy for me to play.	☐	☐	☐	☐	☐
3) I would play this game again to improve my high score.	☐	☐	☐	☐	☐
4) Being able to play the game in different	☐	☐	☐	☐	☐

[13] Questionnaire 2, version 4, March 23rd 2010

modes makes me want to play it again.					
5) I like that there are different medals to be earned by playing the game.	☐	☐	☐	☐	☐
6) I like that there are secondary tasks to be completed in the game.	☐	☐	☐	☐	☐
7) I like the supportive feedback provided by the game.	☐	☐	☐	☐	☐
8) I like it that the game allows me to check incorrect answers.	☐	☐	☐	☐	☐
9) I like the use of sound effects.	☐	☐	☐	☐	☐
10) I like the use of music.	☐	☐	☐	☐	☐
11) I think the game was too difficult.	☐	☐	☐	☐	☐
12) I think the controls were easy to learn.	☐	☐	☐	☐	☐
13) I am satisfied with my performance.	☐	☐	☐	☐	☐
14) I would be interested in playing more games which aim to improve everyday life.	☐	☐	☐	☐	☐
15) I think that more training would improve my performance.	☐	☐	☐	☐	☐

Thank you for the time you took to complete this questionnaire. Should you have any further remarks about this questionnaire or the experiment so far, please note them in the section below. If you don’t have any remarks, then please hand in this form to the researcher present at the experiment.

Your additional remarks:

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