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AGILE DEVELOPMENT OF A VIRTUAL REALITY COGNITIVE ASSESSMENT

S T Koenig[4], D Krch[2,3], N Chiaravalloti[2,3], J Lengenfelder[2,3], O Nikelshpur[2,3], B S Lange[1], J DeLuca[2,3], A A Rizzo[1]

[1]USC Institute for Creative Technologies, 12015 E Waterfront Drive, Playa Vista, CA 90094, USA

[2]Kessler Foundation Research Center, 1199 Pleasant Valley Way, West Orange, NJ 07052, USA

[3]Department of Physical Medicine and Rehabilitation, University of Dentistry and Medicine of New Jersey, 90 Bergen Street, Newark, NJ 07103, USA

4 Katana Simulations UG, 15 Pruefeninger Strasse, 93049 Regensburg, Germany

koenig@katanasim.com

Abstract: In recent years user-centered design, participatory design and agile development have seen much popularity in the field of software development. More specifically, applying these methods to user groups with cognitive and motor disabilities has been the topic of numerous publications. However, neuropsychological assessment and training require special consideration to include therapists and brain-injured patients into the development cycle. Application goals, development tools and communication between all stakeholders are interdependent and outlined in a framework that promotes elements of agile development. The framework is introduced by example of a virtual reality cognitive assessment for patients with traumatic brain injuries. The assessment has seen a total of 20 iterations over the course of nine months including changes in task content, task difficulty, user interaction and data collection. The framework and development of the cognitive assessment are discussed.

Keywords: Virtual Reality, Cognitive Assessment, Agile Development, Neuropsychology

Introduction

Virtual reality (VR) applications have been successfully applied in a wide range of clinical scenarios (Koenig, 2012; Riva, 2005; Rizzo et al., 2010; Rose, Brooks, & Rizzo, 2005). Their strengths and capabilities have been described numerous times (Rizzo & Kim, 2005; Rizzo, Schultheis, Kerns, & Mateer, 2004). One of the main weaknesses of virtual environments, their immature engineering process (Rizzo & Kim, 2005), has seen much improvement by two recent advances in software development. Continuous innovations in computer technologies and the availability of new software development methods have contributed to VR applications becoming more accessible to researchers and clinicians. Especially the rise of computer games and game engines has spurred a vast growth of the number of development tools available to researchers (Siwek, 2007; Trenholme & Smith, 2008). With such tools the rapid development of virtual environments and clinical tasks can be achieved (Koenig et al. 2011, Koenig, 2012).

Agile software development (Beck et al., 2001; Cohen, Lindvall, & Costa, 2003) and techniques such as participatory design (Astell et al., 2009; Bruno & Muzzupappa, 2010), co-design (Dewsbury et al., 2006; Francis, Balbo & Firth, 2009; Freudenthal, Stüdeli, Lamata & Samset, 2010) and user-centered design (Fidopiastis, Rizzo & Rolland, 2010) have been successfully applied towards the creation of VR and health care applications.

An agile development method can best be established by continuous communication between software developers, clinicians and patients. By iteratively adapting the application requirements to user feedback and needs, the development process remains flexible throughout the application’s lifecycle. Working software should be put into the hands of users as early as possible during development while minimizing the time needed to write documentation or make elaborate plans for the software’s future iterations (Beck et al., 2001).

In line with agile development, a multitude of design methodologies has been published recently that give the user a central role in the development process. User-centered design places its focus on defining requirements and building software that is relevant to the users and their problems. For example, Gabbard, Hix and Swan II (1999) distinguish a behavioral and constructional domain when developing virtual environments. User interaction and the user's view of the developed system are represented by the behavioral domain. Due to the immersive and possibly multimodal nature of virtual environments the authors provide guidelines and protocols for usability testing and heuristic evaluation of virtual environment characteristics.

Most participatory approaches focus on the inclusion and communication with patients and caregivers throughout the development cycle. For example, Astell and colleagues (2009) describe such method for the design of computer-based support systems with dementia patients and their caregivers. They depict the communication process and the special considerations that are required when working with a user population with cognitive impairments. The authors name their approach user-centered in nature and describe how the user is actually involved in the design and evaluation process. This is a situation where the distinction between different methodologies becomes vague and methods and their respective names overlap.

Participatory design and also co-design have often been described as actively involving the user in the design and development process of a product or system instead of just adapting the outcome to the user's needs. This can be achieved by exploring the user's habits and problems, discovering solutions together and iteratively prototyping solutions with the user until an appropriate solution to the user's problems has been achieved. Spinuzzi (2005) lays out the details of such methodology, its limitations and how it can be evaluated. A systematic co-design approach for designing technologies for users with autism spectrum disorder is described by Francis, Balbo and Firth (2009). In a structured evaluation by a panel of seven autism experts a set of guidelines has been identified that addresses the use of design techniques and co-design management when working with individuals with autism spectrum disorders.

Fidopiastis (2006) and Fidopiastis, Rizzo and Rolland (2010) describe a user-centered design approach by benchmarking immersive technologies before using them for cognitive rehabilitation application. This approach is aiming to increase validity of virtual reality assessments. The authors base their user-centered practices on the ISO13407 guidelines which have since then be revised by ISO9241-210:2010 "Human-centered design for interactive systems". These standards again put heavy emphasize on understanding and involving the user throughout the iterative development cycle.

All of the described development methods highlight the importance of including the user into the development process, both at the design and testing stages. Each existing publication focuses on specific application areas or user group such as patients with dementia (Astell et al., 2009), autism spectrum disorder (Francis et al., 2009) amputees (Cole, 2006) or cognitive rehabilitation in general (Fidopiastis et al., 2010). It becomes apparent that each clinical domain poses its own unique challenges for the development process, especially with regards to the patients' ability to partake in the design and evaluation process as outlined by traditional user-centered and participatory design guidelines. Francis and colleagues (2009) particularly highlight this discrepancy by contrasting symptoms of autism spectrum disorders with the requirements for contributing to the participatory design process. The authors conclude that the co-design method can be much more difficult with users with autism spectrum disorders. Though, the selection of appropriate methods and tools that empower the users during the design process can greatly facilitate the designer – user interaction.

It is the purpose of this paper to outline methods and challenges for user-centered design in the domain of neuropsychological rehabilitation. The development of VR applications for neuropsychological training and assessment requires additional design factors to be considered. The overview in the following chapters provides details of such factors and their influence on development, testing and communication between involved stakeholders. An example for applying such framework to a VR assessment for patients with traumatic brain injuries is presented and discussed.

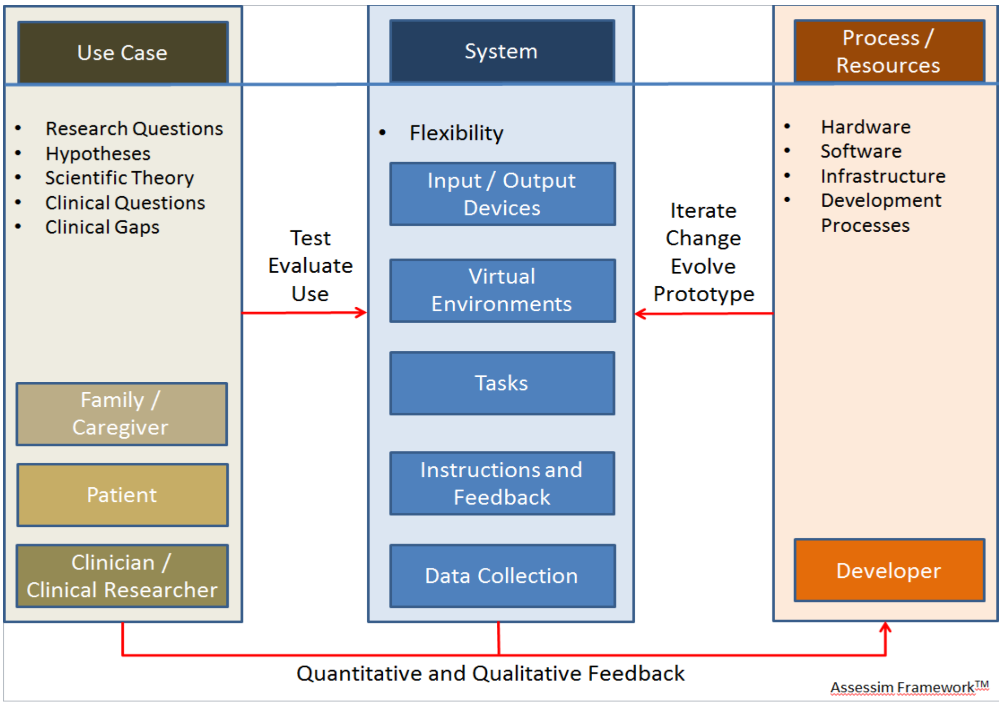
Methodology

Virtual reality technology comes with a well-known set of strengths and limitations (Rizzo & Kim, 2005). Widely available development tools such as game engines and 3D modeling applications lay the foundation for effective workflows to build interactive virtual environments within days instead of months (Koenig, 2012). However, the availability of such development tools does not automatically provide a standardized way of creating applications that solve existing clinical problems. As previously outlined, user-centered and participatory design provides guidelines for user involvement, but the integration of these guidelines into the actual development process – from project inception to finished product – is left to the developer. This leads to the question of how design, development workflow and user integration can effectively be combined to create applications that provide value in the context of cognitive rehabilitation. The following framework provides an outline of such workflow in the context of a virtual reality cognitive assessment.

An initial exploration of research questions, scientific inquiries, clinical questions or clinical gaps can motivate the design and development of an application that addresses an identified problem or opportunity. A developer then chooses the appropriate tools and resources to build a virtual reality system that solves the identified problem. However, a virtual reality system potentially consists of a large number of components that include software and hardware elements. Choices for each component have to be made based on the input from several user groups. This is where a communication challenge starts to emerge which is not accounted for in traditional user-centered or participatory design methods. Depending on the purpose of the developed application, a large number of user groups can be involved in the development of such a virtual reality system. For example, a system might primarily be designed for several members of the clinical team who need to administer the application to a patient. More use cases emerge when cognitive assessment and training scenarios are considered that range from one-off usage at a clinic to long-term exposure beyond the scope of inpatient and outpatient rehabilitation. Moreover, communication with individual user groups can be asymmetric such that input from certain user groups is purposely restricted or prioritized over other groups. Exemplarily, patients' knowledge about a neuropsychological assessment sometimes has to be minimized and limited to usability feedback while clinicians can be more directly involved in the design process. In each case individual user groups can either give direct input on design decisions or indirectly provide usage data to inform design choices for different system components.

With such a wide range of scenarios, it becomes apparent that the development process involves numerous decisions with many unknown variables and outcomes. Figure one lists several system components that can potentially be integrated in order to build a complete virtual reality system.

Figure 1. Development framework for systems of virtual reality training and assessment. Source: authors



During the course of system development each component needs to be flexible. The amount of choices available for each component complicates the planning of system specifications prior to the development effort. Hence, agile development methods minimize the initial planning process and produce a simple working prototype based on early input from relevant user groups. Subsequent design decisions can address system components in an

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iterative fashion while allowing the overall design of the system to remain flexible. This flexibility pays off when system components need to be changed or replaced due to user feedback and once the system's outcome data is analyzed for its validity and reliability. Ideally, each iteration provides new insights and feedback that can guide design and development decisions of future iterations. With short iteration times (e.g. 2-4 weeks) and a strong focus on collecting user feedback, the chances of successfully finishing a project increase substantially. A large body of evidence suggests that agile development can lead to higher project completion rates, especially in complex scenarios where many aspects of design and development are unknown at the outset of the project (Larman, 2004, pp. 63 – 108).

System Description

Assessim Office is a virtual reality cognitive assessment developed in collaboration with the University of Southern California Institute for Creative Technologies and the Neuropsychology and Neuroscience Laboratory (NNL) of the Kessler Foundation Research Center. The application is based on the Assessim Framework and provides a range of realistic tasks for the assessment of cognitive abilities. The aim of the application is to assess cognitive functions, specifically executive functions, in a complex functional environment. The combination of several tasks of different priorities (e.g. rule-based decision task, reaction time task, divided attention task) is expected to simulate challenging scenarios which are similar to the demands that are placed on the cognitive system in a real-world work setting. It is predicted that such ecologically relevant task scenario is more sensitive to cognitive deficits of brain-injured individuals and can predict cognitive performance in real-world settings accurately.

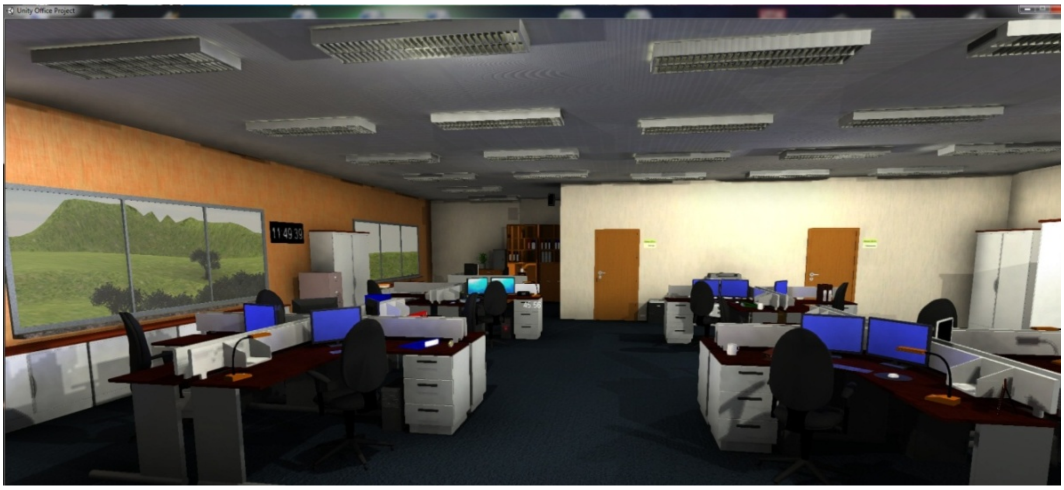
Project Members and Communication

The development of the described framework and its extension for Assessim Office was completed by one virtual reality developer with clinical background. The clinical research team at the NNL consisted of two research scientists, one postdoctoral fellow, three research assistants and several additional staff members. Design decisions were discussed between the virtual reality developer, the research scientists and postdoctoral fellow at the NNL. Direct communication between the developer and the research team consisted of email conversations and Skype calls during which one research scientist was the point of contact for the NNL. Brain-injured patients were only involved in user tests once the initial task design and development were finished. Assessim Office was designed to be a cognitive assessment administered to brain-injured patients with traumatic brain injury. Hence, the early task design was not driven by patient input or user feedback, but rather by scientific theories of human cognition. The researchers at NNL acted as proxies for the patients (Francis et al., 2009) by providing input about the appropriateness of individual system components. A first prototype of Assessim Office was installed on a desktop PC at NNL during an early project meeting. Subsequent updates to the application were exchanged through the filesharing platform Dropbox.

Prototyping

Initial prototypes of the Assessim Framework and Assessim Office were developed over the course of three months. The framework was developed with the game engine Unity and contained a simple event system to trigger object interactions, audio and visual cues. Further, the saving of text files to the local hard drive was implemented. The office environment for Assessim Office (Figure 2) was created with Google SketchUp as outlined by Koenig and colleagues (2011). Before the first prototype was installed at NNL, a menu system and a practice trial similar to the actual assessment session were developed. The total development time for these prototypes was approximately 100 hours, most of which were spent for modeling the virtual environment. The office scene was chosen for its functional relevance, work-related context and relevance for additional projects.

Figure 2. Virtual office environment rendered in the Unity game engine.



Each of the system components consisted of a minimally viable solution which is based on lean methods as described by Ries (2011). The goal of the initial prototype was to deliver a simple functional virtual environment to the researchers at NNL. Without any knowledge of how such system can be adapted to the needs of a clinic, research laboratory and patient population, any implementation of features or task content is uncertain and can potentially change several times throughout the development process. The first prototype consisted of mouse and keyboard input, because it was natively supported by the game engine Unity. Output through a standard 24-inch LCD monitor and plug-and-play stereo desktop speakers was chosen due to simplicity, availability and the non-spatial nature of the planned cognitive tasks. The virtual office environment and several simple reaction time and decision tasks (i.e. reply to email, respond to ringing phone, make decision about email offer) were implemented for an unrelated experiment. This implementation was based on a simple trigger system which enables the developer to attach a C# single script to any object within the virtual environment in order to make the object interactive (e.g. turn a monitor on and off). Instructions about tasks or user input were not included, because tasks and input schemes were expected to change over time. Data collection capability was recognized as a fundamental feature needed for any clinical trial and was supported through saving and loading text files from the PC's local hard drive. The exact content and structure of the saved files was still undetermined.

Iteration

During December 2011 and December 2012 a total of 22 iterations were developed and tested. On average, the application received an update every 13 days. Average response time between user feedback or design decisions and their implementation in the next update is estimated to be approximately three days. Average development time for each update is estimated to be approximately five hours. Estimations are based on time stamps of file updates and email conversations between developer and point of contact at NNL. However, time estimations are approximated due to developer commitments in several parallel projects. Initial iterations were focused on changes to the task content and user instructions.

Starting after the sixth iteration user testing was extended beyond two research scientists at NNL. Each subsequent update was first screened by the research scientists and later tested with one to two staff members. Each user was encouraged to provide verbal feedback about all system components. A total of seven staff members were tested throughout the development process, three of whom were repeatedly exposed to the application. During these early iterations adjustments to task content, task instructions, audio feedback and user interaction were made.

The ninth iteration added a divided attention task during which the user has to turn a projector on whenever it overheats. The locations of the projector and projector remote control require the user to turn their attention away from their virtual desk on which all other tasks are positioned. This task was also intended to increase overall difficulty of the virtual assessment in order to avoid ceiling effects. Further, user interaction with a joystick was added. It was expected that the navigation through the virtual office was made more intuitive by the use of a joystick. However, early feedback by researchers and several staff members confirmed that using a computer mouse was more efficient and intuitive for interacting with items within the virtual environment.

Iterations nine to thirteen were focused on updates to each of the cognitive tasks. Frequency and timings of phone rings, email responses and decision-making tasks were adjusted to provide an adequate challenge for healthy users. Task events were timed to overlap so that the user had to make decisions on which task to prioritize. Most development time was spent on testing the exact timings of the tasks.

During the thirteenth iteration a major change to the cognitive tasks was implemented. During discussions between developer and researchers it became apparent that the combination of cognitive tasks did provide an adequate pacing but did not measure the underlying cognitive construct that it was expected to measure (i.e. executive functions). Too many reaction time tasks that did not require decision-making or inhibition of false responses were implemented. Within eight hours of development several tasks were removed and a new task was added to the system. This change was made possible by the flexibility of the development process which only required the scripting of the new task within the task component of the outlined system (Figure 1). Answering phone calls was completely removed from the assessment and phone rings were now solely used as distractions. Printing documents was also removed as a standalone task and integrated into the decision-making task. The complexity of the rule-based decision making task was increased to balance the overall difficulty of the assessment. The user now had to evaluate incoming email offers based on several criteria and accept or decline them. Further, based on a different criterion the user had to print the incoming offer and place the printed document at a predefined location. The interference of criteria for both tasks was intended to assess the user's ability for inhibition of dominant responses. A new virtual character was added to the scene to plausibly explain the printing of incoming offers.

During the following iterations minor changes to data saving, instructions and difficulty to the newly implemented task were made. Again, most of the development time was spent on balancing and testing task difficulty. During iteration 19 and 20 the application was first pilot-tested with brain-injured patients. Also, iteration 20 addressed feedback of staff members experiencing dizziness during conducted test trials. Environmental factors and user interaction were discussed with the developer and the rotation speed of the virtual camera was reduced to prevent sudden viewpoint changes. User feedback suggested that the camera moved too fast while the user was getting accustomed to the input scheme during practice trials. Instead of testing several rotation speeds separately a speed control was implemented that allowed the research scientists to change camera rotation speed while the application was running in order to find the optimal setting for users to be comfortable.

After the application was used as an outcome measure for several clinical trials, no major changes to the software were made to avoid jeopardizing the validity and reliability of the collected data. Consequently, iterations 21 and 22 were focused on bug fixing and performance optimization instead of changes to task content.

Future iterations are expected to address bugs and critical feedback once the clinical trials have been finished. Further changes are anticipated once all patients have been tested and validity and reliability analyses have been applied to cognitive task outcome measures. The system's task and data collection components can then be adapted to improve the tasks' validity and clinical value as a cognitive assessment.

***Figure 3**. Extended office environment rendered in the Unity game engine*

Summary

The Assessim Office cognitive assessment has undergone extensive iterative design and testing. During the course of 22 iterations four out of the system's five components have been modified and improved considerably. The system is currently being tested as an outcome measure for three clinical trials at the NNL of the Kessler Foundation Research Center. Four research assistants were trained with the application and are currently administering it to brain-injured individuals. Patients with traumatic brain injury and multiple sclerosis are providing valuable feedback by using the application in conjunction with standardized neuropsychological measures of attention, memory and executive functions. Throughout the design and development process the system remained simple and flexible so that changes for each individual component were easily implemented without affecting other components. Future iterations are expected to further improve the system's psychometric properties and test different options for input, output and data collection. Motion controllers (e.g. Microsoft Kinect, Leap), Head-Mounted Displays and visual data representations (e.g. after action reviews) are planned for future implementation.

Conclusion

Assessim Office is a cognitive assessment that has been designed and developed as part of a framework based on agile and user-centered design. The system is targeted at two user-groups – brain-injured patients and clinicians. Such complex user relationship (e.g. clinicians assessing patients) requires combinations of user-centered and participatory design. Clinical researchers at the Kessler Foundation Research Center were actively participating in the design and testing of the application. Brain-injured patients were only included in user testing after a total of 20 iterations and approximately six months of development. Design and user testing were asymmetric for both user groups because of the evaluative nature of the system and scientific grounding of the task content. The design and development processes were based on elements of agile methods. A wide range of changes to each of the system's components were made within only few hours of development. A working prototype was tested shortly after the beginning of the project. Due to the large amount of potential choices for each of the system components, no detailed plan for the finished system was made at the project outset. Instead, incremental changes to individual system components (e.g. input device, task frequency) were implemented and tested rapidly. Assessim Office is currently being used as outcome measure in three clinical trials. Based on patient feedback and results of validity analyses the system's components will likely undergo further iterations.

An extension of the current system is being developed by replacing the virtual environment with a larger office building. The building provides a more complex layout in order to assess the user's navigation ability. Additionally, a large number of interactive virtual characters are added to simulate a realistic, distractive work environment for cognitive assessment (Figure 3). Due to the flexible system architecture such extension only requires a change in art assets and the adaption of the cognitive tasks to the new environment. All other system components remain identical. Consequently, the described framework allows the developer to deploy a large number of cognitive assessments, each customized to a specific environment which is relevant to the assessed patients and users. This approach extends the context-sensitive clinical framework as described by Koenig (2012).

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