Choosing virtual and augmented reality hardware for virtual rehabilitation: process and considerations

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ABSTRACT

Virtual and Augmented Reality hardware has become much more affordable in the past three years, largely due to the availability of affordable sensors and smartphone displays as well as financial investments and buy-in through the entertainment industry. Many new consumer devices are becoming available to researchers, clinicians and software developers. With so many options available, planning a Virtual Rehabilitation project and selecting appropriate hardware components can be a challenge. This paper presents a stepwise selection process for Virtual and Augmented Reality hardware. The process is described through an example project and clinical and technical implications of each hardware choice are discussed.

1. INTRODUCTION

Recent advances in Virtual Reality (VR) and Augmented Reality (AR) technology have provided a tremendous boost to the field of Virtual Rehabilitation. There have been two main drivers that have contributed to the recent surge in VR/AR popularity and increased awareness in these technologies: availability of affordable VR/AR hardware and availability of software development tools. Both of these factors also have a large impact on Virtual Rehabilitation applications.

1.1 Availability of affordable VR/AR hardware

Largely driven by the entertainment industry, prices for VR/AR head-mounted displays (HMDs) and tracking devices have become more affordable and accessible for consumers. Instead of spending tens of thousands of dollars for sophisticated HMDs and motion platforms, researchers, clinicians and educators can now purchase immersive VR/AR systems for under USD2000. Tracking solutions such as motion platforms, head-, hand- and body-tracking as well as a wide range of display methods have become available since the first Oculus Rift Prototype was released in March 2013 (Oculus, 2012).

1.2 Availability of software development tools

Game and simulation engines are a key component for VR/AR content development. These engines give developers the tools to create interactive software applications and integrate VR/AR hardware. The trend for game and simulation engines has gone from expensive, closed systems to free access for everyone. Unity Technologies was the first company to start giving its engine away for free to individuals and small companies in 2009 (Unity Technologies, 2016). Over the past year, CryEngine (Crytek GmbH, 2016) and Unreal Engine (Epic Games, 2016) followed a similar path and are now providing free licenses to their game engines. Other companies like Amazon (Amazon Lumberyard; Amazon Web Services, 2016) are joining the market with new free game engines, giving developers even more choices for software development.

Moreover, all major game engine providers have started to work with VR/AR hardware manufacturers to seamlessly integrate HMD-support and VR/AR user input into their products. Similarly, many companies releasing VR/AR hardware have started to provide integrations and example projects for the most popular game engines. This completely negates one of the main barriers to VR/AR adoption: a lack of platform compatibility between hardware and software components (Rizzo & Kim, 2005).

As a consequence, researchers, students and hobbyists can more easily become proficient in game and simulation development and even develop applications for fully immersive VR/AR systems. Game development courses at schools, universities and online learning platforms are becoming increasingly popular. Companies and researchers wishing to join the Virtual Rehabilitation field have a growing pool of skilled developers at their disposal. Developing VR/AR systems has transitioned from an expensive, narrow field of work to a growing industry that is open for anyone to join and start developing for free.

Taken together, both driving forces have had a large impact on VR/AR in general and the Virtual Rehabilitation field specifically. Researchers, clinicians, educators and developers have more hardware and development options available to them than ever before. However, with many new products and paradigms entering the market, a lack of standards, guidelines or prior experience with choosing and applying these new technologies can negatively impact Virtual Rehabilitation projects.

This paper aims to provide guidance for selecting VR/AR hardware and software by describing a stepwise process (Fig. 1) that can be applied to Virtual Rehabilitation projects. The process includes 1. Considerations for User Groups, 2. Deployment Platforms, 3. Choice of Content Delivery and 4. Choice of User Interaction. Each step of the process will be described through an example of a Virtual Rehabilitation project. The example project is a realistic simulation of a classroom which serves as an attention training and assessment. Available VR/AR hardware options and the implications of each option on clinical use and the end user are presented. The project used in this example has been ongoing for several years, however, this paper assumes the perspective of today's VR/AR market and discusses choices that are available as of Q1 2016.

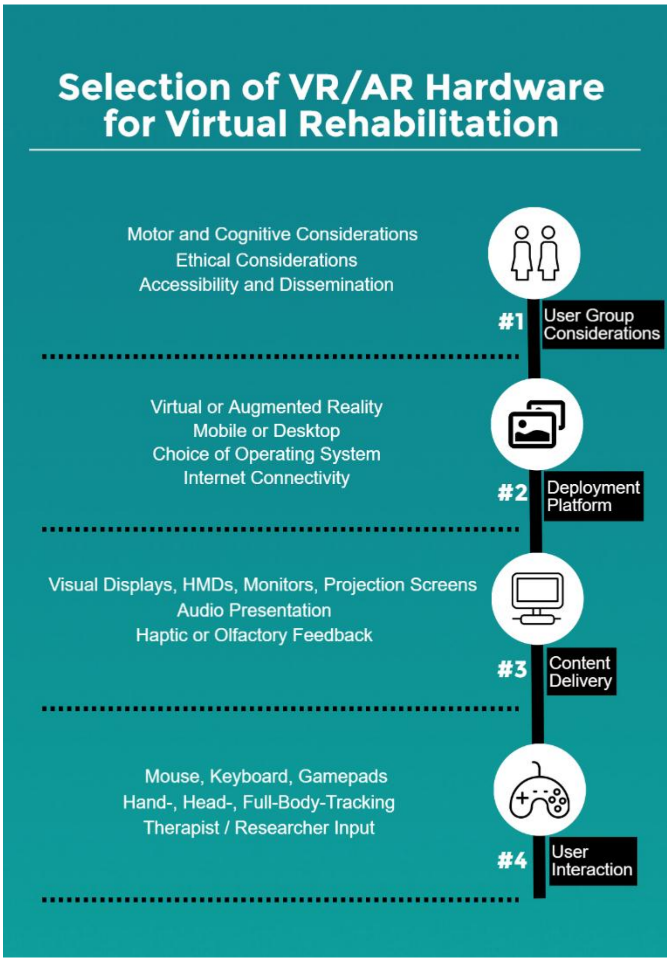


Figure 1. *Selection process for VR/AR hardware.*

These steps are presented in an order that puts steps which are more selective at the start. However, it can be necessary to re-evaluate previous steps if a desired mode of content delivery or user interaction is not supported by the chosen platform. Such cases will be mentioned in the example project.

2. DECISION PROCESS FOR SELECTING VR/AR HARDWARE FOR VIRTUAL REHABILITATION

The Virtual Classroom project (Figure 2; Klingsieck et al., 2015) aims to simulate an interactive classroom environment with students, teacher, distractions and learning content. The user is placed at a student's desk within the virtual environment and asked to monitor a task at the blackboard. Distractions are presented to challenge the user's sustained, focused and divided attention while the student has to respond to stimuli presented at the blackboard or by the teacher. The application is designed to be broadly used in research, education and clinical assessment and training. Depending on the intended use, the outlined decision process can vary considerably. The following stepwise process will focus on the training and assessment of attentional deficits in clinical use cases.

Lehrer stellt Frage an die Klasse.

Figure 2. *Virtual Classroom scenario.*

2.1 Considerations for User Groups

Considering the needs of a user group or examining a clinical gap are fundamental steps in the planning and design of a Virtual Rehabilitation application. These considerations are essential for making any follow-up decision in steps two to four by choosing VR/AR technology that takes into account motor and cognitive deficits, accessibility and ethical principles when working with the relevant user groups.

Virtual Rehabilitation applications often are built for two user groups, patients and therapists / researchers / educators. This project targets school or university students and the therapists who are conducting the attention assessment or training. It seems reasonable to expect students to be at least familiar with computers, entertainment technology or occasionally even VR/AR hardware. Moreover, motor deficits, fatigue or other health conditions that limit the project's hardware selection seem unlikely unless comorbid conditions are expected. Ethical considerations are limited to a standard risk of simulator sickness when using immersive VR/AR systems. Consequently, no hardware or deployment options need to be ruled out based on the student user group.

No additional hardware has been excluded for this project as long as each device does not interfere with patient safety and allows the therapist / researcher / educator to directly interact with the virtual scenario in real-time. This aspect will be discussed when deciding on user interactions (step 4).

This first evaluation step ensures that projects and applications are not driven by the existence of exciting new technology, but rather with a focus on the clinical need. Eliminating hardware choices through user needs and limitations can involve very broad decisions that can be further refined in the upcoming steps. If, for example, the user group was a patient population with severe physical or cognitive limitations, and system use was limited to bedside treatment, deployment platform, content delivery and user input would be vastly different from this described example application.

2.2 Choice of Deployment Platform

This decision influences most of the remaining choices in the process, as it determines which hardware, operating system and overall complexity the project will adopt. Deployment largely depends on where the system will be used. If the aim is to use the classroom in a lab setting, a Windows desktop PC is a viable choice. If the classroom focuses on clinical usage in private practices, a mobile solution with hardware such as the Samsung GearVR (Samsung Corporation, 2016) and a smartphone seem more appropriate to provide portability and easy access. The availability of internet access in the target environment can also play a large role in choosing system components.

Most major game engines (e.g. Unity, Unreal Engine, CryEngine & Lumberyard) allow developers to deploy their software to multiple platforms without making major changes to the project. For most Virtual Rehabilitation projects and applications, the free license of CryEngine has to be excluded as a development option, as it excludes simulations and serious games. Further, CryEngine does not support deployment to mobile platforms. The remaining engines support deployment to Android, iOS and Windows, all of which seem valid choices for the Virtual Classroom project. Mac OS or Linux are not supported by most HMDs and have to be ruled out as target operating systems.

For this particular project, two additional factors play a deciding role for the deployment platform that is chosen.

Firstly, attention assessments rely on highly accurate measurements of response timings. All available deployment options should undergo additional testing to guarantee that the latency between user input, response time measurement and a reaction on the system's display is within acceptable limits.

Secondly, a simulation of over 20 animated characters requires substantial rendering capabilities. It has to be tested whether a modern smartphone can actually run an application with such complex graphics. Performance optimization and character rendering solutions are essential for deciding for or against mobile deployment, but these topics are beyond the scope of this paper.

This second decision step does provide several paths to follow for this project, but mobile and desktop deployment as well as VR and AR remain viable options. The following steps can narrow our choice of VR/AR hardware down further.

2.3 Choice of Content Delivery

Content delivery entails the presentation of visual, audio, tactile or even olfactory stimuli. Only visual and audio stimuli are relevant for this example project.

Visual stimuli presentation for the Virtual Classroom project can be achieved through monitors, HMDs or projection screens. It is essential for this project to allow the student user to freely look around the classroom. Distractions can occur in any part of the classroom and encourage the user to focus their attention on events away from the blackboard. The main goal of this application is to quantify attention and inattention. If the user looks at the blackboard and fails to respond to a relevant cue, an error is recorded. If the user is distracted and looks away from the blackboard while missing a cue, this event also captures inattention, but is a qualitatively different type of error.

Looking around the classroom can be achieved by three means: placing displays all around the user (e.g. CAVE environment), utilizing head-tracking or implementing virtual head movement. Multiple screens or CAVE environments require a complex hardware installation and are mostly prohibitive in cost and space requirements. Virtual head movement does not require actual movement by the user and is controlled via mouse, keyboard or other input devices. In light of affordable HMDs which include head-tracking, an HMD was chosen as the preferred option for head-tracking in this example project.

Mobile versus desktop deployment was already discussed in the previous section and the selection of HMD will obviously be impacted by the choice that was initially made with regard to the deployment platform. The main considerations for choosing mobile or Windows-based HMDs should be comfort, display quality, latency, integration in game engines, integrated tracking systems, price and availability of other compatible hardware such as handheld controllers. Market availability of existing HMDs may play an important role for products that have not been released as consumer versions yet and are only available as development kits. Development kits may change over time and new hardware and drivers may not be compatible with previous versions. This can negatively impact the development process and project timelines.

Comfort should be tested based on the intended maximum length of a session with the intended application. Features like padding material, total weight, weight distribution and cable-management should be considered. The weight and comfort of the newer HMDs such as the Oculus Rift or HTC Vive (HTC Corporation, 2016) was considered reasonable for use in the Virtual Classroom, because the scenarios run for no longer than one hour. Some smartphone-based HMDs require the user to hold the HMD with their hands or interact with the phone via buttons on the HMD. Such interactions were avoided for the Virtual Classroom as they interfere with the natural position of students sitting at a classroom desk.

An interesting potential option is the use of AR hardware to superimpose students, teacher and blackboard onto a real room. However, the use of this method is not suitable for a highly specific context such as the Virtual Classroom. An AR system would limit the use of the Virtual Classroom to real-world rooms that are spacious enough and contain believable furniture to support the simulation of a Virtual Classroom. In addition, the rendering of seated, fully-animated characters in unpredictable real-world spaces is a large technical challenge. Consequently, AR devices like the Microsoft HoloLens (Microsoft Corporation, 2016) and Meta2 (Meta Company, 2016) have not been chosen for the development of the application.

Consideration of the above criteria leave devices such as the Oculus Rift, HTC Vive, Razer OSVR Development Kit (Razer Inc, 2016), Samsung GearVR, Google Cardboard (if used with plastic headmount) and Wearality Sky (when attached to hat and not handheld; Wearality Corporation, 2015) as potential hardware for displaying visual stimuli of the Virtual Classroom.

Auditory information is a key element of the Virtual Classroom for delivering distractions to the user. The spatial location of each audio cue is vital for systematically testing the user’s spatial attention. Modern game engines usually support the spatial presentation of audio sources. Thus, auditory content delivery needs to support spatial audio. While some HMDs already have headphones included that support spatial audio, external headphones can usually be added to a VR/AR system without any problem.

2.4 Choice of User Interaction

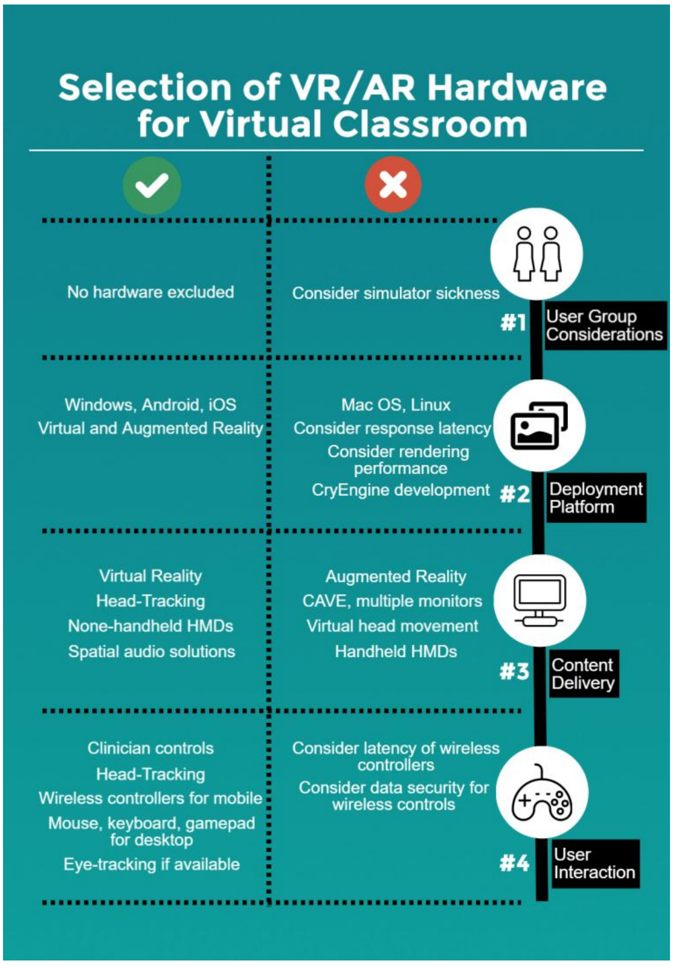
Recording user responses is vital for any cognitive assessment. The Virtual Classroom requires the user to respond to stimuli on the blackboard and to respond to input from the teacher.

If deployed as a mobile HMD, user input can be implemented through Bluetooth gamepads, keyboards or similar controllers. Speech recognition on Android or iOS are also valid options. In either case, latency variability needs to be taken into account when measuring response timings, as Bluetooth connections and voice recognition both add a slight delay to the response of the user. Desktop deployment provides more user input options, because many wired controllers, mice and keyboards with low input latencies are available. Desktop deployment also adds more options for writing, hand- and tool-tracking (i.e. pen) that can be used as a naturalistic response mechanism for the student user or as a detection method for fidgeting and motor activity. Such devices include writing tablets from companies like Wacom (Wacom, 2016) and hand-tracking devices such as the Leap Motion (Leap Motion Inc, 2016).

Head-direction, as measured through head-tracking, can also be used as a means of user input. Facing other students can reliably be detected and used to start distracting animations. Head-direction is also an important variable for determining whether the user was looking at the blackboard when task-related stimuli were presented and potentially omitted by the user. The downside to using head-direction as an approximation for gaze-direction is that it is unknown what exactly the user was looking at or even whether the user’s eyes were closed. Eye-trackers are not commonly integrated in HMDs yet, but several companies (e.g. Tobii AB, 2015; Fove Inc., 2016) are working on advancing foveated rendering, which requires eye-tracking to adaptively change the resolution of the displayed image based on the user’s gaze-target.

Lastly, the clinician’s, researcher’s or educator’s interaction with the system need to be considered. It is assumed that this user group requires a visual display of what the student user is experiencing in real-time. On a desktop VR system, the PC’s monitor will usually display the point-of-view of the HMD. For mobile systems, the smartphone’s display can be streamed to a TV via devices like Google Chromecast (Google Inc, 2016). Alternatively, Bluetooth or WifiDirect can be used to stream data from the smartphone to a second device that serves as the clinician’s / researcher’s / educator’s interface and live feed of the application. Further, it needs to be decided whether the clinician / researcher / educator requires direct control over the application or whether the scenario is fully automated. For the Virtual Classroom these controls can include triggering distractions or changing the parameters of the primary task on the blackboard. It has to be noted that in some clinical or military environments the communication via Bluetooth or WifiDirect are prohibited and thus, mobile deployment or communication between multiple devices have to be ruled out as possible hardware choices. This limitation does not apply to the Virtual Classroom when used in a therapist’s office or lab setting.

The choices presented in the previous steps are summarized in Figure 3.



Selection of VR/AR Hardware for Virtual Classroom

	✓	✗
#1 User Group Considerations	No hardware excluded	Consider simulator sickness
#2 Deployment Platform	Windows, Android, iOS Virtual and Augmented Reality	Mac OS, Linux Consider response latency Consider rendering performance CryEngine development
#3 Content Delivery	Virtual Reality Head-Tracking None-handheld HMDs Spatial audio solutions	Augmented Reality CAVE, multiple monitors Virtual head movement Handheld HMDs
#4 User Interaction	Clinician controls Head-Tracking Wireless controllers for mobile Mouse, keyboard, gamepad for desktop Eye-tracking if available	Consider latency of wireless controllers Consider data security for wireless controls

Figure 3. *Hardware selection process for the Virtual Classroom.*

3. CONCLUSION

The example of the Virtual Classroom application can be applied successfully to different use cases with various user populations, even after excluding many technologies and VR/AR devices. Applying the selection process to this example project, two main configuration scenarios emerged for clinical and research use. When space and mobility are of less concern, a Windows desktop system with current HMDs such as the Oculus Rift and HTC Vive seems optimal. The clinician, researcher or educator can interact with the application through a normal PC monitor and use mouse and keyboard to change assessment and training scenarios. For improved mobility and flexibility, smartphone-based HMDs such as the Samsung GearVR are the preferred choice. The clinician, researcher or educator can monitor and interact with the application through a wireless connection of a separate tablet or laptop.

The Virtual Classroom is currently being used in three research trials. One trial investigates the influence of seating position during a simulated math class on student attention and retention of presented material. A second trial is testing the effect of a neurofeedback training in the Virtual Classroom on children diagnosed with ADHD. Lastly, the Virtual Classroom is utilized as a training for teacher trainees to provide hands-on scenarios for diagnosing disorders such as ADHD or dyslexia (Klingsieck et al., 2015). The Virtual Classroom of the first two trials presents the user with a student's perspective and the last trial puts the user in the perspective of a teacher who can observe the classroom and interact with students. The first two trials leverage the Oculus Rift and a Windows PC and the last trial aims to make the Virtual Classroom accessible to a wide range of Windows-based laptops and desktop PCs.

The described selection process was devised to assist researchers to make decisions about hardware and software for use in Virtual Rehabilitation applications. Obviously, just as rehabilitation is not one size fits all, these solutions are not one size fits all. VR and AR applications can improve rehabilitation by offering flexible, tailored tools that can provide multimodal feedback, quantitative measurement and user engagement. It is important to consider the technical aspects and how decisions about hardware and software will ultimately have an impact on the final product in this fast-paced market of VR and AR technologies.

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