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Review of VR Technical Specification Requirements for a Procedural Training Task

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Abstract

Many aviation education and training programs are expanding their learning materials to include virtual learning environments (VLEs) that utilize virtual reality (VR) technology. While developing training materials and the VLE, an understanding of technical specification requirements is needed to inform stakeholders who need to choose a headset for a given training scenario. As part of a larger initiative to compare the usability of multiple VR headsets for implementation into procedural training, a review of the extant literature was conducted to identify technical specifications of VR head-mounted displays, followed by a pilot test of a head-mounted display (HMD) comparison methodology that considers VR HMD technical specifications ("tech specs") and usability aspects. This report identifies key technical specifications for VR HMDs which can be used as a guideline as technology changes. Further research and collaboration are anticipated to elaborate on the technical specifications to recommend for aviation training initiatives.

Keywords: virtual reality, virtual training, head-mounted displays

Introduction

Since the early 20th century, aviation has used immersive simulation technologies for training. Many institutions of higher education and technical training have adopted similar technologies to efficiently and effectively train professionals in a variety of industries (Buttussi & Chittaro, 2017; Lewis & Livingston, 2018; Narciso et al., 2021). In aviation education and training, flight simulation training devices (FSTDs) and other technologies range in terms of fidelity and immersion from part-task trainers to simulators that emulate the live-task environment to high-fidelity full-flight simulators. In comparison to FSTDs, virtual environments (VEs) can be developed with comparatively inexpensive, yet very realistic, hardware and software.

Many institutions of aviation education and training develop VEs for virtual reality (VR) as well as other forms of extended reality technology ([XR]; Birdsong et al., 2023; Cross et al.; 2023; Hight et al., 2021; Torrence & Dressel, 2022). The term XR encompasses a range of levels of immersion and realism, including augmented reality (AR), mixed reality (MR), and VR head-mounted displays (HMDs). XR technologies are adaptable to a variety of training scenarios and the broad range indicates a shift in expectations when it comes to fidelity, capability, and application of the technologies. Training and collaborating in VEs can increase skill and knowledge acquisition (Jensen & Konradsen, 2018). However, educators and trainers must also consider the development and implementation of the technology for training purposes: Is it accessible? Is it easily transported? Does the hardware meet the needs of the training objective? Are there technical limitations?

Statement of the Problem

Researchers and practitioners lack a comparison of XR technologies in a training environment using objective and subjective data, even though the performance and capabilities of XR technologies have rapidly evolved in the past five years. (Cross et al.; 2023; Torrence & Dressel, 2022). The consumer space witnessed a rise in consumer XR enterprises (e.g., Vive, Oculus), translating to increased demand in the military, industry, and commercial environments. Developers such as Varjo, XTAL, and JVC created MR and VR HMDs that feature photorealistic visual fidelity, naturally blended virtual and real elements, high-density LEDs, and lenses that adjust to the wearer’s pupils for optimal image quality. The field of view, refresh rate, resolution, and other performance aspects of XR hardware and software components are

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prioritized for training in the military and industrial sectors. However, choosing the incorrect technology may negatively impact training as opposed to enhancing it if the technical specifications of the hardware and software do not align with the aviation training requirements and learning outcomes.

Purpose of the Research

The goal of this project was to pilot test an HMD comparison methodology that considers VR HMD technical specifications ("tech specs") and usability aspects (user design principles, user experience, etc.). Although the foundation of the methodology included tech specs relevant to aviation learning and training using AR, MR, and VR HMDs, the scope of this report focuses on the tech specs of four models of VR HMDs; the usability results are published separately (Fussell, 2023). The project team chose several tech specs to evaluate a VR HMD for aviation training based on the relevant literature (Ahn et al., 2022; Chan et al., 2022; Franzluebbers & Johnsen, 2018; Nam & Choi, 2023; Yulius et al, 2021; see also Fussell, 2023). The team noted similarities and key differences between the different technologies to inform this report, create the HMD comparison methodology, and provide a foundation for expanded and replicated research. The project sponsor charged that the research must apply to changing technologies and be generalizable to similar use cases.

Technical Specifications and Assessments Overview

The team evaluated and compared the HTC Vive Pro, Meta ("Oculus") Quest 2, Valve Index, and Varjo Aero VR HMDs. We chose these HMDs because they include a variety of technical differences in hardware and software. Additionally, the cost, availability, and age of the HMDs vary, representing legacy headsets that may be more prolific in academic institutions as well as cutting-edge technology being acquired by corporate and military entities.

Since the goal of the larger pilot study was to compare VR HMDs along specific characteristics and attributes to support procedural and dynamic training and operations, the first consideration was the technical specifications of the HMDs. There are several HMDs available for purchase; however, they are not all created equal. Consumer headsets for entertainment have different hardware and software requirements from those used in a professional environment. The components associated with the HMDs also differ as companies focus on different aspects to enhance technology. While some companies may focus on affordability and access for the general population, others focus on advancing technology in various ways. The team reviewed the literature for common, objective measures of HMDs in terms of hardware, software, and technical specifications that can enhance or detract from a user's experience. After discussion with the project team, the following features were identified for review:

- *Cost*, to ensure reasonable comparisons among available HMDs to the general public.
- *Weight*, which can impact the ergonomics of the HMD design.
- *Visual display screen and lens types*, for comparison context of the visual displays.
- *Visual display field of view* (FOV), which refers to how much of the virtual world is seen by the user at once.
- *Visual display resolution*, as higher amounts of pixel display yield sharper, clearer, more detailed images.
- *Visual display pixel density* per degree and inch, which can be used to compare display sharpness and clarity.
- *Optical adjustments* for interpupillary distance (IPD), which allows the user to adjust the lens and headset for optimal image quality and comfort.

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- *Refresh rate*, which refers to how many frames per second the VR HMD can produce, as a refresh rate below 90 frames per second may induce symptoms of simulator sickness.

When considered overall, the tech specs of an HMD can impact the level of *immersion* and *presence* experienced by the user. Immersion is the extent to which a display (e.g., the HMD) can deliver an extensive surrounding of visual illusion; immersion is a term used to describe the technology (Brade et al., 2017). In contrast, presence is the perceived sense of being in the VE based on the processing of stimuli; as such, it is a term more applicable to the user. Based on these definitions, Brade et al. (2017) state that "perceived presence is therefore influenced by the level of immersion in different virtual environments" (p. 77).

Table 1 details the relevant technical specifications of the HMDs. Notably, the technical components of the HMD may increase or become enhanced as cost increases: The less expensive Oculus Quest 2 has a lower FOV, resolution, and pixel density per inch than the more expensive options. However, the cost may be more affordable for the general user looking for entertainment value as opposed to top-of-the-line training equipment. The design of the VR HMD, in terms of weight distribution, adjustments for comfort, and overall weight will also impact the user's experience if they cannot adjust the HMD to optimally fit their head. It is important to consider these trade-offs when choosing a VR HMD for aviation training. Table 1 also summarizes the findings of the review, broken apart by assessment overall scores and relevant, individual items.

Oculus Quest 2 Summary

The Oculus Quest 2 has the lowest price and overall weight, can be used wirelessly, and is heavily marketed and produced by the parent company Meta, making it a popular consumer option for entertainment or environments where multiple HMDs are required. The HMD also has fewer fit customization abilities, three preset lens distance positions, and the lowest FOV, which balances with a respectable resolution and pixel density. Combined with less fit customization, the wearer may experience reduced immersion and presence due to the technical specifications, causing them to view the VE as a series of images more so than an environment they are a part of (Fussell, 2023).

HTC Vive Pro Summary

Consumers in education, training, and entertainment environments also favor the HTC Vive Pro as a popular HMD. The HMD has a high resolution, pixel display, refresh rate, and a higher FOV than the Oculus. Although the IPD of the headset is adjusted by the user, it is the heaviest of the HMDs reviewed. The Vive offers a higher sense of presence and immersion in the VE and may cause some users to forget about the physical (real-world) objects that surround them but are not a part of the VE (i.e., a desk; Fussell, 2023).

Valve Index Summary

The Valve Index has the lowest pixel density and resolution of the HMDs under review, with a pixel density similar to the Oculus, a variable refresh rate, and a FOV similar to the Vive. Users rate the HMD highly/positively in terms of presence, immersion, and realism (Fussell, 2023), which suggests that tech specs play an important role in how user interact with virtual objects and the environment.

Varjo Aero Summary

The Varjo Aero is a professional-grade HMD designed for industry and advanced VR users as opposed to casual consumer use. Designed for working and training environments for experienced users, the HMD is the most expensive of the reviewed HMDs, has a high FOV, and boasts the highest visual resolution and density. Notably, Varjo advertises its HMDs as professional grade, “highest-immersion virtual and mixed reality products and services for advanced VR users” (Varjo, 2023) The headset has three points of fit in the band, active cooling for the face, and automatic motor-driven pupil calibration. In a comparative usability study, participants rated the Varjo lowest and had responses related to presence as well as positive comments regarding FOV, immersion, realism, visuals, and eye calibration (Fussell, 2023).

Table 1

Relevant Technical Specifications of the HMDs

HMD Consideration	**Meta (Oculus) Quest 2**	**HTC Vive Pro**	**Valve Index**	**Varjo Aero**
				
Cost	$300	$800	$1,000	$2,000
Weight	503g	850g	809g	717g
Visual display: screen	1 LCD Panel	Dual RGB low persistence LCD	Dual LCD, canted lens design	Dual Mini LED LCD
Visual display: lens	Fresnel dual stack lenses	Fresnel dual stack lenses	Fresnel dual stack lenses	Aspheric
Visual display: FOV	89 degrees	Up to 120 degrees	130 degrees; 108 degrees horizontal, 104 degrees vertical	115 degrees horizontal / 134 degrees diagonal (@ 12mm eye relief)
Visual display: resolution	1832x1920 pixels per eye	2448x2448 pixels per eye	1440x1600 pixels per eye	2880x2720 pixels per eye
Visual display: pixel density per degree, per inch	18.88x18.69 PPD, 538 PPI	24.93x25.37 PPD, 950 PPI	14.84x13.19 PPD, 598 PPI	35 PPD, the panel is 5.46”, 73 PPI
Refresh rate	90 Hz (wireless)/120 Hz (tethered)	120 Hz	80/90/120/144 Hz	90 Hz

Implications and Future Research

Among the HMDs reviewed, the choice of a VR HMD to aid instruction will likely be influenced by the training task; conducting a study with hypothesis testing to determine the extent of this influence is warranted. For procedural tasks, such as training on a pre-flight checklist or similar procedure, a highly realistic and immersive environment may not be needed, as the learner should be able to translate the actions learned to complete a task between virtual and real-world environments. Researchers need to further investigate the impact of immersion and presence on learning, skill acquisition, and mastery (Brade et al., 2017). With a higher sense of immersion comes a higher sense of engagement with a task and each action completed. A higher sense of presence may be linked to a heightened feeling of physical sense, engagement, and ecological validity (i.e., how real, or believable the VE and virtual content are) (Brade et al., 2017). This observation is notable because a higher sense of physical space, engagement, and ecological validity may result in users rating the usability of the system and general enjoyment more highly (Brade et al., 2017; Fussell, 2023).

Although this study provided interesting information regarding the technical specifications of the HMD when implemented for training, researchers need to conduct more thorough research on the impact of the tech specs and their correlation to training efficiencies. The following characteristics were identified as having some relevance when choosing a VR HMD for training.

- *Refresh rate* refers to how many frames per second the VR HMD can produce; the faster the refresh rate is for any VR HMD, the more fluid the experience in the VE is.
- *Field of view* refers to how much of the virtual world the user can see at once in terms of width, height, and depth.

- *Resolution* is the number of pixels that can be displayed by the HMD, usually shown as width x height.

In general, users of VR HMDs gave low scores related to simulator sickness (Fussell, 2023), indicating that the resolution, pixel density, and refresh rate were met or exceeded expectations for the tire change procedure. Users had conflicting views on the clarity, realism, and immersion of the experience for each HMD; however, these differences may be attributed to personal differences such as HMD fit, IPD, etc. Further research to understand how an HMD's technical specifications, requirements, and design impact training is needed. Additional research can explore how the refresh rate and FOV impact presence and immersion, cyber sickness, and cognitive load, thereby impacting knowledge and skill acquisition, recall, retention, and even mastery.

This project focused on identifying the technical specifications needed to enhance aviation training in a virtual environment. Institutions that wish to integrate VR into curriculum and training programs can directly apply the results, especially in an aviation training environment. This study was one component of a pilot study to identify the design and technical features of VR HMDs that impact user experience while completing a procedural task (see also Fussell, 2023). The project team identified the characteristics from a review of the literature and chose them for their commonality across headsets made by different manufacturers for different audiences (e.g., casual consumer or professional) and different use cases (e.g., entertainment or training). Further research on how tech specs impact learning, recall, and retention of a task learned in a VE with larger sample sizes, as well as using VR HMDs for different types of learning (i.e., factual, conceptual, procedural, and transfer) is recommended. This research will further support the expansion of aviation training to leverage the training affordances that come with incorporating VR technologies into aviation education.

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