DOT/FAA/AM-21/31
Office of Aerospace Medicine
Washington, DC 20591

Extended Reality for Cabin Safety I: A Translational Study of Extended Reality Technology in Training and Research

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December 2021

Final Report

NOTICE

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Technical Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
DOT/FAA/AM-21/31		

4. Title and Subtitle Extended Reality for Cabin Safety I: A Translational Study of Extended Reality Technology in Training and Research	5. Report Date December 2021 6. Performing Organization Code
7. Author(s) Breeding L, Weed D, Beben M	8. Performing Organization Report No.
9. Performing Organization Name and Address FAA Civil Aerospace Medical Institute P.O. Box 25082 Oklahoma City, OK 73125	10. Work Unit No. (TRAIS) 11. Contract or Grant No.
12. Sponsoring Agency name and Address Office of Aerospace Medicine Federal Aviation Administration 800 Independence Ave., S.W. Washington, DC 20591	13. Type of Report and Period Covered 14. Sponsoring Agency Code

15. Supplemental Notes

16. Abstract

A translational study provides an informed approach to solving issues based on scientific research. This study provides background information on extended reality (XR) technology; discusses its use, value, and potential; and provides practical applications to solve certain issues based on the research. The Electronic Emergency Evacuation Aid for Aircraft Passengers evacuation simulation computer program is also evaluated for its use in aircraft cabin safety research. This study reviews several qualitative and quantitative findings to better understand the use of XR technology across an array of disciplines. Important considerations for implementing this tool are discussed, focusing on positive knowledge transfer and reduced cognitive load. These constructs are supported further by offering psychosocial and physiological considerations when implementing this technology in learning. Finally, an examination of integrating the technology into aviation training and research is presented along with identified gaps in the research for future investigation. In conclusion, XR is mature enough to conduct certain scientific studies, possesses the necessary elements for a positive transfer of knowledge in training by mitigating cognitive load factors, and addresses a large gap in current training methodologies by allowing participants to experience anomalous and dangerous scenarios without the associated physical harm. Data-driven implementation of XR technology in key areas of cabin safety research, emerging technology and trends, flight attendant training, and passenger education have the potential to assist the Federal Aviation Administration in the development of adequate tools and systems to advance its mission.

17. Key Words	18. Distribution Statement
Extended Reality, Aircraft Cabin Safety, Cabin Safety Research, Flight Attendant Training, Passenger Education, Emerging Technologies	Document is available to the public through the Internet: http://www.faa.gov/go/oamtechreports/ https://doi.org/10.21949/1524429

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	22	

Form DOT F 1700.7 (8-72) Reproduction of completed page authorized

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LIST OF FIGURES

LIST OF ACRONYMS

3D .... Three-dimensional
A-AR .... Active Augmented Reality
AR .... Augmented Reality
AQP .... Advanced Qualification Program
CFR .... Code of Federal Regulations
CVR .... Conventional Virtual Reality
ELEVAID .... Electronic Emergency Evacuation Aid for Aircraft Passengers
FAA .... Federal Aviation Administration
HMD .... Head-mounted Device
IVR .... Immersive Virtual Reality
LOSA .... Line Operations Safety Assessment
MR .... Mixed Reality
P-AR .... Passive Augmented Reality
PTSD .... Posttraumatic Stress Disorder
RPG .... Role-playing Game
SMS .... Safety Management System
VR .... Virtual Reality
XR .... Extended Reality

EXTENDED REALITY FOR CABIN SAFETY I: A TRANSLATIONAL STUDY OF EXTENDED REALITY TECHNOLOGY IN TRAINING AND RESEARCH

INTRODUCTION

The research in this report is sponsored by the Federal Aviation Administration (FAA) Aircraft Certification Service Policy and Innovation Division (AIR-600) as a request to review the virtual reality software product Electronic Emergency Evacuation Aid for Aircraft Passengers. The goal of this request is to understand if current research programs and practices can be augmented with extended reality technology to reduce the risks associated with human subject studies and live testing. The main outcomes of this study are to provide information for future aircraft cabin safety research activities, provide consultative services to stakeholders on the topic, and explore other extended reality research opportunities in related dimensions.

Technology now incorporates an array of approaches and aspects to supplement or replace reality, requiring new terminology to encompass the emerging developments. The current amalgam of reality-enhancing technology is referred to as extended reality (XR), which encompasses virtual reality (VR), augmented reality (AR), mixed reality (MR), and other immersive technologies that will be developed in this area (Marr, 2020). While much of the advancements in XR were made in the 2000s, forms of the technology have existed long before.

XR is a young technology with an old past. It has been imagined, written about, or implemented in some form since the late 19th and early 20th centuries (Baus & Bouchard, 2014; Forrest, 2018). The first tangible VR product came in the form of the stereoscope in 1838 (Forrest, 2018). Since that time, the technology has gradually improved both in terms of advancement and user experience. Researchers assert AR can be traced back in literature to as early as 1901 in a children's book, *The Master Key,* written by L. Frank Baum (Baus & Bouchard, 2014). In the story, the protagonist is presented with a pair of glasses that allows the wearer to see a superimposed demarcation on others' foreheads, which specified certain characteristics: good, wise, or cruel, among others (Baus & Bouchard, 2014). It would be several years later before the first tangible form of AR became available.

The First World War brought on a pressing need for an advanced solution. German warplanes were outfitted with an early AR device—an aiming reticle—as early as 1918 (Baus & Bouchard, 2014). This device would project the reticle onto a target through a glass device mounted in front of the pilot, which improved the pilot's shooting accuracy to hit targets while in flight (Baus & Bouchard, 2014). In 1929, the first immersive aircraft simulator with motion and sound provided pilots a safe alternative in acquiring or honing piloting skills while on the ground through an early form of VR (Forrest, 2018). Shortly after that, VR was recognized as a viable teaching methodology and entertainment experience.

Advancements in VR technology include the 1938 View-Master—a three-dimensional (3D) photo viewer; the 1960 Telesphere Mask—the first VR head-mounted hardware; the Sensorama in 1962, which simulated a motorcycle ride complemented with aromas and a vibrating seat; the 1977 Sayre Glove—the first wearable technology to interpret and convert finger movement into electrical signals; 1988's Virtual Interface Environment Workstation (V.I.E.W.) developed by the National Aeronautics and Space Administration in collaboration with VPL Research, Inc. for which users wore connected clothing, a glove, and a head-mounted display (HMD) to experience an AR environment (Forrest, 2018). Later advancements in the 1990s and 2000s include incorporating gamification and advancement in both technology and hardware (Forrest, 2018). In the 21st century, new products and advancements placed XR into a broader market.

From the mid-2000s to the present, the VR, AR, and MR market grew (and continues to grow significantly) to include advanced equipment, hardware, and applications (apps) produced by prominent companies such as Facebook, Google, HTC, Microsoft, and Samsung (Wirtz, 2021). Products such as the Apple iPhone have given expansive access and availability to integrate this technology into everyday life. One notable example of this access is that users can now superimpose products, like furniture, in a living space using a retailer's app before purchasing the product.

The level of growth, advancement, and maturity this technology has experienced poses questions about its use and application in a scientific or research setting. To that end, the FAA is examining emerging technologies, such as XR, to increase the protection and survival of human occupants in passenger-carrying aircraft. As such, this research is an extension of a request to better understand how and when to apply XR in research. The approach for this investigation is to first understand its history and current application. Then, examine an XR tool created for aircraft cabin evacuation for its use in a research setting. Finally, consider new and innovative ways to harvest the benefits of applying the technology to aviation safety. The potential outcomes for this investigation will stem from future expanded research into various aspects of aviation safety. Currently, there appears to be limited research concerning the use of XR technology in four critical areas, (1) aircraft cabin safety research; (2) use to supplement, integrate, or augment other emerging technologies; (3) flight attendant training and experiential learning modalities; and (4) passenger safety education. This literature review and translational study approach aims to reduce gaps and to drive more research, application, and implementation within the previously identified areas. A translational approach to examine XR technology is beneficial because it provides context and the current state of the technology, and it seeks ways to apply the technology to solve issues and problems in research and training through practical application. The benefit of this approach could inform data-based decision making in the development and application of XR technology for research and simulation. This also provides for advancing the literature, bridging gaps, and enhancing aviation safety standards and protocols. The goal of this translational study is to provide a discussion of the past, present, and future of XR by describing the technology; reviewing the market and presence of the technology; examining how it supplements training and enhances learning; integrating it into aviation training methodologies; leveraging the technology in cabin safety research; and exploring its future use, application, and effect.

DESCRIPTION OF THE TECHNOLOGY

XR technology exists in an array of modalities, including conventional virtual reality (CVR), immersive virtual reality (IVR), passive AR (P-AR), active AR (A-AR), and MR (Frederiksen et al., 2020). Each type of XR offers its version of a generated sense of reality in varying degrees. CVR is characteristically a simulation of a computer-generated environment viewed on a screen or monitor, which allows users to perform an array of tasks or actions (Frederiksen et al., 2020; Mirelman et al., 2016). Video games played on a computer or home entertainment system are an example of CVR. IVR, however, transforms the environment from a flat projection into a multidimensional experience that immerses the user in sound, motion, tactile feedback, and other stimuli through the use of special hardware such as an HMD and handheld controllers (Frederiksen et al., 2020; Mirelman et al., 2016; Pettijohn et al., 2019). An example of IVR is using special hardware, described later, to create a sense of being inside the CVR video game. P-

AR allows a user to be transported virtually to a location using cameras but limits interaction (D. Ferguson, personal communication, April 14, 2021). An example of P-AR is watching a surgery with several digital overlays around the surgeon that depict the patients' vitals and other information. A-AR differs from VR in that the live environment is augmented with computer-generated elements to comprise a comprehensive and sometimes immersive experience that incorporates both realities; screens, monitors, and headsets may be used (Baus & Bouchard, 2014; Pettijohn et al., 2019). An example of A-AR is a heads-up display found in select automobiles that projects critical information, such as speed, on the windshield. MR varies from the others in that a digitally superimposed element interacts in real-time with the environment (Versace et al., 2020). An example of MR would be using a special HMD to visualize temperature variations or emergency equipment statuses throughout the aircraft cabin. These technologies are being applied across various industries and organizations for training, entertainment, and development purposes.

XR technology is typically developed with the entertainment industry in mind; however, because of the beneficial properties and learning outcomes, this technology has been embraced by various training departments, including military, education, and health care (Baus & Bouchard, 2014; Magee, 2011). Training programs that use this technology rely on various modalities, including video games, to present lessons. Video games, or the semblance thereof, generally have not been favored as respectable media to convey lessons or foster learning (Bogost, 2010). However, video games are staking a respectable claim in human learning and development and are the subject of many studies on their effectiveness in such domains (Bogost, 2010). This journey to embrace the technology mimics that of the radio and television, then-new technologies in their own time, not only for its ability to communicate a message but also its ability to convey learning and development principles in an innovative way (Bogost, 2010). However, as with most technology, developers must also evolve and grow to maximize the use and benefits of the tool, including educational videogames (Bogost, 2010). A training program that incorporates this technology and is rooted in educational and developmental principles has many advantages.

Organizations realize the value and benefits of XR because of its affordability and portability and its capability to portray more realistic and immersive training scenarios that may otherwise be impossible or improbable to replicate (Baus & Bouchard, 2014; Youngblut, 1998). Institutions favor the use of such technology because it provides learners with an opportunity for hands-on learning instead of traditional modalities such as lectures or other passive-assimilative learning modalities (Youngblut, 1998). This is evident in industries that are explicitly using AR and MR to address skills gaps.

Given the risk of a significant fraction of the knowledgeable workforce retiring in a compact period and the onboarding of new employees, there is a risk of a break in and degradation of information transfer. XR technology helps bridge the skills gap by providing archived information which can be passed along to and shared among new cohorts (Versace et al., 2020). Senior employees can record or live stream processes and procedures for the new generation of workers to learn from and apply more safely and efficiently. This technology affords certain benefits that traditional training facilities and scenarios may not possess. Specifically, XR technology controls for prohibitive costs, safety hazards, limited capital, and other valuable and restricted resources (Youngblut, 1998).

MARKET AND PRESENCE

The market for and presence of the subject technology indicates growth over the coming decades. Surveying the commercial presence and availability of XR hardware and software yields many results, further suggesting that this technology is on an upward trajectory. As of 2019, this $11.52 billion global market is estimated to grow by over $76 billion by 2025 (Novicio, 2021). Novicio (2021) reports that the 2019 VR market share for commercial applications is 52.5% of the total composition. Some of the prominent brands in the market include Oculus, HTC, Sony, and HP, which produce a VR experience through their own commercially available headsets (Stein, 2021; Versace et al., 2020). The hardware varies in resolution and requirements. Some systems require a connection to a personal computer or gaming console; some only need a Wi-Fi connection for wireless HMDs, such as the Oculus Quest 2 (Stein, 2021). The hardware may need additional elements, such as logging in to a Facebook account before accessing any features or software, as seen in the Quest 2 (Stein, 2021). Low-tech solutions might only require a smartphone, such as Google Cardboard. Regardless of the hardware, advancements are only made better by the core element (i.e., software).

Design firms specializing in custom-built XR experiences, including Excyte, Groove Jones, and Iflexion, are changing how industries engage with and use this technology (Mangur, 2021). These firms custom design experiences leveraging XR technology among other advanced technology such as artificial intelligence and machine learning. These firms have portfolios that include some of the most recognizable brands, platforms, and companies that use the technology as a conduit to foster a deeper connection between an experience and its target demographic. The value in these developments is how industries are using this technology to connect with their employees, customers, and market.

SUPPLEMENTING LEARNING AND ENHANCING TRAINING

Understanding how this technology can supplement learning and enhance training may inspire new and innovative ways to deepen the learning experience. As technology increasingly proliferates in classrooms and training facilities, we must first evaluate the needs and goals of the desired training before exploring the nuanced aspects of design and delivery (Goss Lucas & Bernstein, 2014). When considering the use of technology in training, it is critical first to understand its effect on learning. Key areas are presented to gain a better perspective of implementing the subject technology into training.

Learning Overview and Efficacious Learning Modalities

During the learning process, it is crucial to provide limited information to assist in the memorization of material (Ormrod, 2016). This concept is measured by cognitive load, which describes the impact of varying amounts of information that the learner is tasked with memorizing (Ormrod, 2016). Cognitive load and learning are important factors to consider when selecting the training modality (Frederiksen et al., 2020).

In a recent study, researchers tasked participants with performing simulated laparoscopic surgery using CVR and IVR (Frederiksen et al., 2020). Laparoscopic surgery is a minimally invasive surgical procedure whereby medical instruments are inserted into a few small areas, generally in the abdominal wall, and guided by the surgeon from afar. In the IVR condition, participants were presented with the sights and sounds of a typical operating room (Frederiksen et al., 2020). However, Frederiksen et al. (2020) found that the cognitive load significantly increased in those trained via IVR because of the level of realism portrayed in the simulation, which featured extraneous background elements that distracted the participants during the procedure. The implication of this study reveals an attenuation of learning due to the high cognitive load associated with IVR (Frederiksen et al., 2020). Cognitive load is an essential factor to consider in the learning environment. Mitigating the effects of high cognitive load may be accomplished by various approaches to maximize positive knowledge transfer. For example, researchers concluded that learners exposed to relevant materials before IVR lessons perform tasks at a lower cognitive load than their counterparts (Meyer et al., 2019). Performance measurements should investigate validation of reduced cognitive load and positive knowledge transfer. AR may present another opportunity to reduce cognitive load.

Researchers found that participants who engaged in navigational tasks experienced a reduced cognitive load when using AR on a mobile device to navigate to a destination (Paskoff et al., 2015). In training or research circumstances where digital overlays can supplement the live environment, it may facilitate knowledge transfer and reduce cognitive load. Developers should consider the level of realism and its value in their overall training goals.

Companies are using XR technology in innovative ways to mitigate some of the limitations and restrictions that traditional methodologies may not have been able to alleviate. A closer examination of these benefits reveals that some employers use VR to train employees to respond to anomalies or emergencies that might otherwise be too dangerous, expensive, or difficult to replicate (Noguchi, 2019). For example, The Boeing Company uses the technology to train and reinforce skills among astronauts, and Verizon, the mobile retailer and service provider, uses the technology to train its employees to handle in-store robberies while at (simulated) gunpoint (Noguchi, 2019; Novicio, 2021). Employees who have personally experienced in-store armed robberies describe the level of realism in the simulation as palpable (Noguchi, 2019). The technology is also being used in clinical settings to facilitate comprehensive learning and address specific needs.

Research conducted by Comer (2016) on combat veterans living with posttraumatic stress disorder (PTSD) revealed significant findings in the value and use of virtual reality simulation of a battlefield and battle conditions. According to Comer, clinicians had previously relied on patients' memories to respond to imagined battle conditions because real-life exposure to such conditions, although very effective, was unsafe and impractical. However, with the introduction of VR, those suffering from the effects of combat-related PTSD are now able to experience realistic but simulated battlefield conditions, which has proven to be very effective in treatment (Comer, 2016). Considering the level of realism that can be portrayed in this technology, lesson design should be carefully thought out with training goals in mind. Further, training development should focus on specific methodologies of knowledge transfer.

Knowledge Transfer

In several health care studies, patients with limited mobility or mobility issues responded positively during the rehabilitation process when researchers incorporated VR into the therapy. Participants significantly improved their walking and stability performance while avoiding virtual obstacles (Cano Porras et al., 2018; Mirelman et al., 2016). Training managers and developers should consider a lesson design that incorporates a positive transfer of information. Positive transfer occurs when knowledge or performance in one area or task is subsequently used in another area or task, which can emphasize important lessons and tasks (Ormrod, 2016). It is also important to be critically aware of the possibility for negative transfer while using the technology.

A negative transfer occurs when a previously learned action or task hinders future learning (Ormrod, 2016). This may occur where there are dissimilarities in the generated environment versus the actual environment (Myers et al., 2018). In both the simulated and real-world conditions, these nuances should be thoroughly understood by the instructors and evaluators and should be part of the training conversation with the learner (Myers et al., 2018). These dissimilarities might occur in the fidelity of the simulation, such as mismatched noises, interactions, instruments, equipment, and other elements (Myers et al., 2018).

INTEGRATION INTO AVIATION TRAINING METHODOLOGIES

When considering integrating XR technology into flight attendant training, there are methodological nuances to consider. United States air carriers with flight attendant operations are required to follow specific training requirements per the relevant sections of the Code of Federal Regulations (CFR) 14, Parts 121 (2007) and 135 (2020); and 49 CFR Parts 172 (2011) and 1544 (2002), where applicable. This particular training is sometimes referred to as "traditional training" (Federal Aviation Administration [FAA], 2021a, para. 2). However, some airlines voluntarily participate in an alternative training methodology known as the Advanced Qualification Program (AQP), which must prove "an equivalent or better level of safety than traditional training" (FAA, 2021a, para. 2). Flight attendant AQP is, as of this writing, implemented at six U.S. airlines—four major and two regional (T. Phipps, personal communication, March 24, 2021). The philosophical approach to training and qualification in an AQP program is inherently innovative, and the posture of such a program encourages further innovation to attain higher levels of safety through constructs such as continuous improvement and trained-to-proficiency (FAA, 2021a). One such innovation may arguably be the use of the subject technology in cabin safety research and flight attendant training.

Flight Attendant Training Application

Flight attendant training lessons and scenarios could benefit by incorporating elements of interactivity to further reinforce learning with XR technology. Using this technology to test demonstrable proficiency and learning affords unique benefits and savings because training would not require heavy use of training devices or aircraft. Additionally, the ability to present rare or emergency scenarios during training may be beneficial in exposing novel situations that may have more extensive connections to Threat and Error Management performance. Understanding past performance during these incidents helps develop training scenarios to correct response behavior in future events, as exemplified in the following case study.

Fluorescent light ballasts installed throughout the aircraft cabin pose a relatively minimal hazard to occupants during a fire event (FAA, 2019). However, as the FAA (2019) notes, the incorrect handling of this kind of fire event can contribute to severe degradation in safe operations. A trans-Pacific flight experienced an in-cabin fluorescent light ballast fire shortly after takeoff. While the crew successfully resolved the issue, the pilot in command nearly executed an overweight landing. The FAA determined, in its investigation, the crew was unfamiliar with this type of issue and the minimal threat it posed, which could have resulted in a catastrophe if managed incorrectly. Therefore, exposing crews to such novel incidents during training could better prepare them for correctly handling these types of rare situations.

For airlines, particularly, it would behoove training managers to collect and evaluate training and proficiency data from multiple data streams within the safety management system (SMS) to understand any gaps. These identified gaps may be considered for future training. Of course, this does not supersede, alleviate, or negate any of the responsibilities outlined within 14 CFR Part 5 (2010) or any other applicable CFR requirements. Training and enterprise leadership must ensure all pertinent regulations and standards are met related to data evaluation and training. To ensure the effectiveness of the training, one should develop a testing methodology to measure against performance. Another valuable integration of the technology is in passenger education to improve cabin safety.

Passenger Education Application

Interactivity is a worthy construct to evaluate for its role in research and training. The interactive nature of the technology presents an opportunity for developers to foster and facilitate more profound connections with safety information, which may promote better learning capabilities. Passenger education is a component of the larger safety program and its overall mission to protect passengers during anomalies and emergencies in the commercial airline dimension. However, the challenge of passenger education includes a means to promote information retention (Chittaro, 2017). In a recent study of airline passenger safety briefings, participants were tested for their retention of the information presented in safety briefings via safety video and briefing cards, as well as a safety video with interactive controls (Chittaro, 2017). The interactivity component revealed greater retention of information among participants over time (Chittaro, 2017). Additional research of this construct revealed similar findings.

Beben et al. (2021) asked participants to review traditional forms of safety information currently found on aircraft—either a safety briefing card or a safety information video demonstration. In addition, participants performed the relevant safety actions using a Serious Game, which is a game designed for educational and applied learning purposes, rather than one designed solely for entertainment. The study findings revealed that participants in the Serious Game group retained the safety knowledge more accurately than those in the safety card or safety video groups in a post-test later in the day. Testing the effects of information retention for flight attendants and passengers is necessary for understanding its validity, reliability, and efficacy.

Testing Methodologies

The extant literature is rich with quantitative research and data related to integrating XR technology into training. Many conclusions can be made based on the empirical findings available, not least of which is that the technology is well measured quantitatively. Therefore, training managers, safety managers, and other concerned parties may devise simple testing methodologies to measure training effectiveness via XR modalities. Using a task list, such as the Flight Attendant Job Task List, could provide specific basic duties and responsibilities, which can be measured through observation after XR training is completed (FAA, 2021b). Although primarily used in pilot, aircraft maintenance, and ramp service domains, airlines have successfully implemented a version of the Line Operations Safety Assessments (LOSA) program to measure and manage these gaps through peer-to-peer nonpunitive observations (FAA, 2014). The LOSA program is part of an organization's larger data stream that safety managers can use to help determine the overall health of safety programs.

Limitations and Cautions

Before incorporating XR technology, one should carefully consider the need to introduce XR into training, the reason to incorporate this technology, and the desired outcomes by applying the technology. While the numerous documented lessons learned draw from experience relative to the subject technology, peripheral lessons can be gleaned from pilot simulator training, e-learning, and other training modalities used in the airline industry. This section discusses some of the more common themes that emerge from the literature, but it is not an exhaustive collection of all limitations and cautions that should be considered before implementing XR technology. Also, safety risk management assessments should be completed per the relevant provisions of 14 CFR Part 5 (2010) and the carrier's SMS policy before implementing changes or new programs.

Novelty

The novelty effect of this technology is worthy of consideration, and leadership in charge of training should conduct an in-depth examination of training needs and benefits before incorporating this technology. Leadership should strive to avoid assumptions about XR use based on first impressions and without proper diligence. Before implementing such technology, a representative population sample should be selected to validate constructs such as cognitive load, learning and knowledge transfer, and subsequent performance. The population sample should capture a diverse sampling representative of the larger population.

Studies have shown that certain risks are taken in simulation, which may not represent the individual's actual actions when faced with the same issue in real life. Trainers should interact with the learners to correct any risk-taking and to provide a sense of criticality and realism to the lesson. Importantly, real-world principles and other governing constructs are often understood and replicated in a virtual environment (Parsons et al., 2020). When participants are in a virtual world, they tend to respect the physical boundaries presented in the environment, such as walls and other obstructions (D. Ferguson, personal communication, April 14, 2021). Another consideration is inhibiting undesired responses to stimuli.

Promising research has indicated that subjects clinically diagnosed with insect phobias were able to successfully approach, interact with, and exterminate the target insects (cockroaches) unassisted after regimented exposure therapy for up to 12 months post-treatment (Baus & Bouchard, 2014). The implications of this study show that exposure to anomalous and emergency conditions may decrease an unwanted response in favor of a desired behavior or action.

Population and Privacy Considerations

One should also consider the feasibility of using the technology among all individuals in the target group. A thorough consideration of sociocultural, socioeconomic, and socioemotional constructs and the development team's own cognitive biases should be considered as these may have unintended effects on training development. Additionally, these should be mitigated in lesson design and development, accounting for the current population and future population needs, where possible. Studies have shown that e-learning methodologies can have prohibitive effects across multicultural environments because of relevancy, sensitivity, inclusion, and motivation (de Brito Neto et al., 2014).

Another consideration is the acceptability and desirability of the technology among generational cohorts with this specialized training type. Younger generational cohorts seemingly prefer XR technology to learn and demonstrate proficiency due to their comfortability and savviness with digital interfaces (Baghdasarin, 2020). These are important considerations when deciding to use this technology and assimilating the curricula to be used in conjunction with this technology.

Lastly, one of the obstacles XR technology must navigate, according to Marr (2020), is the protection of personal information. The technology collects various physiological data about its user, including attention, eye tracking, interaction, and emotions. While this information may be useful in certain cabin safety research and other types of scientific investigative processes, inappropriate use of this data collection must be controlled for before its integration into the field. Those using the technology should be explicitly aware of the data being tracked and for what purpose. Additionally, early research indicates similar issues manifested in the internet age also remain underlying threats to XR. Cyberbullying, deep fake misrepresentations, privacy concerns, and perceived addiction are all worthy issues, among others, to be addressed and controlled for as the technology continues to expand into new and novel areas, including research (Morvan et al., 2020). Beyond the psychosocial effects, physiological effects must also be considered.

Motion Sickness

During testing, it is important to consider logging any user issues with motion or simulator sickness. Interestingly, Pettijohn et al. (2019) and Curry et al. (2020) found that while no significant differences exist between still, synchronous, and asynchronous movement in IVR and AR, the durative effects of being in simulation tended to produce more symptoms consistent with motion or simulation sickness. Therefore, it is recommended to be cognizant of study or lesson duration and aggregate time in the simulation. This may work exceptionally well when incorporating mini-lessons such as firefighting or evacuation training (Lovreglio et al., 2020). Considering the robust application of the technology, research using this technology is ongoing, necessary, and beneficial.

CABIN SAFETY RESEARCH

These advancements pave the way for groundbreaking and state-of-the-science research in cabin safety. As presented herein, there exists an array of data supporting the beneficial training outcomes from XR technology. The subject technology provides experiences that are impossible or impractical in the real environment but are now possible for human experience in novel ways (Youngblut, 1998). Therefore, incorporating the technology into research areas related to cabin safety may be beneficial in understanding human factors in these novel events. In consideration of the impact to safer operations, cabin safety research would benefit from evaluating the use of such technology in conducting aircraft emergency evacuation research, testing and measuring visual and aural aid comprehension, studying behavioral responses to changing stimuli and environmental conditions, expanding the use of the subject technology in combination with and supplementing other emerging technology, supplementing flight attendant training and expanding knowledge transfer, and increasing passenger education. However, while the research is just beginning, it is important to understand any potential for immediate and/or lasting psychological effects of experiencing traumatic scenarios in XR.

Analyses of the effects of trauma and anxiety in virtual environments tend to be associated with positive outcomes in the clinical setting. Much of this work is seen in the treatment of PTSD as previously discussed and in therapies for social interaction in those living with autism, as those interactions can be an anxiety-producing experience (James et al., 2016). XR exposure therapy has also revealed significant improvements in those presenting symptoms of depression, schizophrenia, phobias, and other disorders (Parsons et al., 2020). A recent study revealed that separating the worlds of real-life and simulation can be difficult.

Parsons et al. (2020) reported that a recreation of Milgram's work in delivering perceived electrical shocks to another person has the same effect in the virtual environment. Participants exhibited similar if not the same degree and range of emotional and physical responses as in the 1960's study. This implication is important for the advancement of XR as a research tool because it demonstrates that deep-seated values, principles, and responses still manifest despite being cognitively aware of the difference in environments. A step forward in this research arose from a collaboration to improve cabin safety.

Evaluation of the Electronic Emergency Evacuation Aid for Aircraft Passenger Software

The Electronic Emergency Evacuation Aid for Aircraft Passengers (ELEVAID) VR software tool was developed by the University of Udine, Italy, as the result of a collaborative project with the FAA to explore the use of technology in cabin safety research. The tool is a CVR 3D aircraft cabin environment in which several factors may be manipulated to create numerous anomalous and emergency conditions. The tool permits users to either select an existing scenario or to create their scenario. The user can further define their own experience within certain parameters. Some of the available options include aircraft type (i.e., Boeing 777-300 and Airbus 320), phase of flight, type of damage, types of threats (e.g., fire, smoke), and passenger and crew considerations such as passenger load and flight crew incapacitation.

The cabin environment depicts the conditions selected, and the user is placed in the first-person point of view as a full-bodied avatar. The tool is a role-playing game (RPG), much like the common and widely available RPG games on various platforms. To interact with the scenario, users must input desired actions by using the computer mouse and keyboard to initiate avatar action. The mouse acts as visual and physical navigation while the "W" key moves the avatar in the direction in which the avatar is looking. The tool provides the user with options to respond or react in various ways (see Figure 1). Programmatic buttons appear on the screen, which the user may select to guide the avatar's actions. Some actions are futile, such as donning a life vest for a land evacuation. However, during a water evacuation, other passengers are observed wearing life vests and proceeding to exits (see Figure 2). The simulation also offers feedback when incorrect actions are selected. For example, during an A320 ground evacuation, the over-wing window exit was opened with fire outside. The avatar was depicted as being on fire, and the scenario ended with an educational reminder (see Figure 3).

Figure 1

Depiction of Selectable Action Buttons During Simulation in ELEVAID

Note. ELEVAID = Electronic Emergency Evacuation Aid for Aircraft Passengers

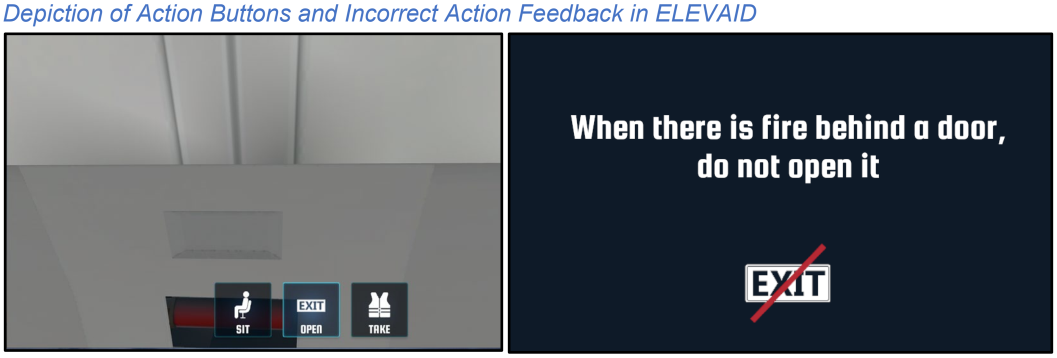
Figure 2

Depiction of Cabin Condition and Simulated Passenger Behavior in ELEVAID

Note. ELEVAID = Electronic Emergency Evacuation Aid for Aircraft Passengers

Figure 3

Depiction of Action Buttons and Incorrect Action Feedback in ELEVAID



Note. ELEVAID = Electronic Emergency Evacuation Aid for Aircraft Passengers

This tool may be best used for passenger education rather than research activities because additional considerations are needed in programming and interaction criteria to suit research activities. The programming should be revised to emphasize several critical elements gathered from actual findings in emergency evacuations. This advancement could provide a more comprehensive course of action in the spirit of passenger education. To address the gaps in XR translational research work, future endeavors should focus on four main areas: (1) cabin safety research; (2) use of XR within and among emerging technologies and trends; (3) flight attendant training; and (4) passenger education.

EXPLORATORY ANALYSES OF FUTURE USE, APPLICATION, AND RESEARCH

Understanding the progress and potential for this technology is key in finding new and innovative ways to incorporate it into research, training, and development. In early 2020, market watchers and spectators alike began to see the potential rapid expansion of both hardware and software in response to the large-scale quarantining and lockdowns associated with the coronavirus disease 2019 (COVID-19) pandemic (Novicio, 2021). Having the ability to connect and interact remotely with colleagues and teams, or for those craving respites, the technology provides a means to meet those desires. As XR technology matures, advancements in requirements are also changing. The future of the technology is already orientating to a more natural feel as hardware components such as controllers are being replaced by one's own hands (Wirtz, 2021). HMDs, such as the Oculus Quest 2, use tracking sensors on the unit to detect one's hands and movements, which are replicated digitally onscreen and allows interactivity with the digital environment.

As the technology advances, new products are entering the market rapidly. The latest addition to the suite of XR hardware is a bodysuit the user dons to feel even more immersed in the technology (Çöltekin et al., 2020). Wearing the suit replicates the experiences and sensations of being in the virtual environment and allows greater motion and movement tracking. Other possible advancements on the horizon include incorporating other senses, such as olfactory, into the experience for a more complete and comprehensive experience. The future of this technology has, thus far, exhibited very few limits to its growth and use.

Future Research

There appears to be a dearth of evidence addressing qualitative approaches to studying the effects of XR training in aviation. Future studies should consider investigating flight attendant training with XR technology through the various approaches in qualitative analyses to examine the various questions and nuances within each philosophical assumption (Creswell & Poth, 2018). Subsequent studies of the incorporation of XR should include a quantitative and qualitative approach to uncover a deeper understanding of the effect of this technology in research, education, and training. Quantitative analyses can be used to address differences in cabin configurations, comparative evacuation studies, sign and visual comprehension and effectiveness, and information retention. Qualitative analyses can be used to address users' experience in the virtual environment and conditions, which can uncover sociocultural and socioenvironmental differences where additional mitigation or context may be needed in future iterations. Research is also needed to understand the feasibility of large-scale multiuser simultaneous programming that allows for numerous connections across various locations. Practical application of the technology in future training and research has been recently amplified, focusing on reducing person-to-person contact during the COVID-19 global pandemic.

The future study of XR technology should evaluate current use and potential future application in emergencies simulated during flight attendant training. The data and information gathered from this study should then be used to develop a systematic approach to aircraft evacuations and other safety-related scientific studies for aircraft cabin safety initiatives and several trials in flight attendant emergency procedures training. The results of those studies can then be used to develop specific passenger education campaigns through various media and methodologies. Next, all findings could guide the creation of a study to understand evacuation behaviors and patterns. Incorporating other technologies, such as artificial intelligence, could increase and reinforce the desired outcomes in these emergency procedures. Flight attendants could have a more responsive and comprehensive training experience, and scientists could understand how certain threats cause specific behavioral reactions.

CONCLUSION

This translational study provides a history of XR technology from its infancy to practical application in modern issues. The in-depth examination of the technology characterized its growth from an entertainment device to one that has provided multiple benefits across an array of training and development dimensions. The technology is built around hands-on or experiential learning, one of the more compelling and advantageous learning modalities in education. Additionally, the proper safety of the technology allows for life-saving training scenarios not previously possible, practical, or ethical. Implementing this technology is already solving complex issues in the workplace and addressing skills and training gaps effectively. Therefore, its relative maturity makes it ready for inclusion and implementation in the aviation sector in aircraft cabin safety research, flight attendant training, and passenger education. Advanced software programs can deliver data far beyond traditional research observation and provide insights into human behavior not previously understood. Using specialized software with broad application and accessibility, such as ELEVAID, and the suite of Serious Games like it, this technology can provide unparalleled opportunities for passenger education in aircraft safety and emergencies. As the demand and market grow, XR technology will continually offer more diverse and novel opportunities to understand human behavior and performance. This valuable information will help the community better understand how to train to proficiency and increase the protection and survivability of human occupants in aircraft emergencies.

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