Long Duration AR Exposure and the Potential for Physiological Effects

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ABSTRACT

With the U.S. Army pushing augmented reality (AR) as a solution to its distributed learning problem and other industries adapting its use in domains where there is a high demand for accelerated workforce reskilling, scalable transfer of tacit knowledge, or human error associated with fatal consequences, it is crucial to develop AR usage protocols that ensure its efficacy and safety. One area of particular concern is the safety of long duration AR exposure. Many studies have evaluated the adverse effects of virtual reality (VR) exposure and demonstrated that the severity of maladaptations is generally proportional to exposure duration. Will AR be the same? While much of the industry has assumed the adverse effects associated with AR are less problematic than VR exposure because the latter presents with much more overt symptoms, there is limited research in this area to date. This paper suggests a need exists to fully comprehend both the impact that AR has on the human perceptual experience and the physiological maladaptations that result from its use. A few basic recommendations for hardware specifications are also provided, which should assist with mitigating some of the known AR maladaptations by minimizing the discrepancy between how the human processes stimuli and how information is displayed within AR systems.

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THE HISTORY AND SIGNIFICANCE OF AUGMENTED REALITY

Augmented reality (AR)-based devices, for the most part, fall under the category of wearable technology. Looking at the consumer electronics market, the first significant effort in recent history to commercialize AR as a form of wearable technology was Google's Project Glass (Goldman, 2012). While the consensus in the industry is that this product was simply too early for commercial adoption, resulting in it being relegated to business-use only, it nonetheless showed that there was a desire present for wearable computing going forward (Brunner, 2018). Although the device may have failed in an economic sense, it still managed to revolutionize how AR was viewed by both the public and hardware manufacturers alike; with Google Glass proving that miniaturization of head worn display (HWD) technology can be cost-effective and paving the way for other companies to develop similar systems. Furthermore, the market clearly wanted something to live up to the potential that Google Glass presented, but with much higher fidelity and a more desirable form factor. Capitalizing on this desire, Microsoft (MS) has since released the development edition of the HoloLens, while Facebook and Apple are vying to get into the AR headset market in the near future. Comparatively, with much higher resolution, increased field-of-view, and better tracking, the latest generation of AR HWDs stand a much better chance of mass market adoption as compared to Google Glass.

While only recently reaching the point of commercialization, AR has a long history of military and industrial use cases due to its numerous potential benefits (Carmigniani et al., 2011). The U.S. military, having funded AR research since its initial conceptualization by Caudell and Mizzel (1992), led to the development of the first functional AR system by Rosenburg (1994). This system, named Virtual Fixtures, allowed for projection of sensory information onto a user's physical environment (Rosenberg, 1994). Following this, the work of Milgram and Kishino (1994) integrated AR into the spectrum of Mixed Reality (MR) with development of the virtuality continuum. After this initial proof-of-concept, many different proprietary AR systems were developed to support the needs of the military. More recent examples of AR applications for military use cases include Tactical Augmented Reality (TAR), the Synthetic Training Environment (STE), and the Augmented Reality Sandtable (ARES). While the TAR and STE involve HWDs designed for individual soldiers and ARES is designed to deliver squad-based tactical information in malleable environments, they share one crucial element; all three of these AR systems are designed to facilitate a training process that is more effective than their traditional counterparts (Morozov, 2019). Industrial use cases may not be as training oriented as those found in the military, instead focusing on entertainment, user experience, and operational support. Some of the most prominent and well-commercialized AR installments can be seen at Walt Disney World (Mine et al., 2012). Many of Disney's new attractions, such as the Na'vi River Journey in Pandora, have implemented projection-based AR (much like Rosenberg's Virtual Fixtures [1994]) that tracks animatronic characters and allows for more organic detail and movement in the hopes of avoiding the uncanny valley phenomenon.

Figure 1. An example of detail provided by projection in Na'vi River Journey (Sanders, 2019).

The military continues to be a major driving force behind AR development for training applications. To that end, the benefits of AR in training need to be well established and the early results are favorable. Research has suggested that

AR has the capability to provide faster knowledge acquisition, improved retention, increased trainee motivation and engagement, and a highly immersive, contextualized, and embodied learning experience (Chan et al., 2010; Lee, 2012). These benefits have been demonstrated in industrial and entertainment settings. For example, Hou and Wang (2012) demonstrated that memory-based assembly routines can be learned faster by using an AR-based model as compared to traditional 2D isometric drawings. Jung et al. (2016) compared content in a 2D museum setting to content displayed using AR-based 3D projection mappings of a physical environment and found there was an increase in recognition memory and accuracy of pattern location memory, greater self-reported spatial presence, and a substantial increase in user satisfaction regarding the training experience (2016). There has also been research on how AR can negatively impact a user from a cognitive perspective. For example, there is evidence that cueing within an AR environment can lead to attentional tunneling (McDonald, 2016), that users may develop a dependency on AR features and instructional components (Gavish et al., 2013), and that AR training may lead to an overall lack of skill transfer between simulated, AR-based tasks and the real tasks a user is being trained to perform (Vapenstad et al., 2017). While it is still unclear as to whether such findings are generalizable across different modes of AR, these studies are indicative of the types benefits and hurdles AR training may present (Diegmann, Schmidt-Kraepelin, van der Eynden, & Basten, 2015; Radu, 2014).

Over the last several years, the increased fidelity of the latest AR HWDs has been a driving-force behind their adoption (Vovk, Wild, Guest, & Kuula, 2018). Previously, development of both hardware and software relating to AR platforms was greatly limited by the technology. While this is still the case, many aspects – such as framerate and resolution – have now caught up to the minimum standard seen in related fields, such as virtual reality (VR). However, the news is not all positive; due to AR hardware capabilities now matching the standard for VR, many developers and hardware manufacturers assume that the underlying scientific principles for their application are also similar (Tsai et al., 2018). While there is certainly some overlap, there is a need to evaluate AR as a separate entity in order to develop AR-based design principles and usage protocols, and to characterize how much variation there truly is between AR and VR technologies, particularly with regard to their impact on users. One area of concern is the large gap in the literature surrounding what makes AR unique in terms of any potential physiological maladaptations imposed on the human body. There has been some limited research into this (c.f. Vovk, Wild, Guest, & Kuula, 2018), but for the most part it has been overshadowed by AR technology's market potential, resulting in design and usage principles taking a backseat to utility at the hardware development stage (Dunleavy, 2014).

PHYSIOLOGICAL MALADAPTATIONS IN AR

When discussing how AR impacts the body, there are two main aspects to consider: how the human body adapts to AR physiologically, and how it adapts cognitively. The primary focus of this paper is the former; by better understanding the physiological impact of AR, there is greater potential for use-cases, such as systems relating to training and education, to both improve training efficacy and prevent any physiological maladaptations from occurring. The limited evidence available suggests that AR systems pose the greatest burden on the oculomotor system, specifically visual discomfort/ fatigue, difficulty focusing, and headaches. Thus, with potential for AR exposure to be lengthy (on the order of hours), there is significant potential for high magnitude adverse physiological aftereffects. It is also necessary to understand the discourse surrounding the cognitive impact of AR, as there is always the potential for interaction between the two.

AR training simulations have the potential to provide a contextually rich, immersive environment within which learning objectives can be effectively met; however, limitations may exist regarding both the type and extent of physiological maladaptations one may experience in such an environment (Lee, 2012). At a basic level, this is caused by some degree of mismatch between the information visually displayed in the AR headset and the user's other senses. These maladaptations may arise depending on numerous factors, including inter-pupillary distance (IPD) mismatches, an artificially restricted field-of-view (FOV), a low framerate, or any lag-time between a user's movement and the updated spatial mapping of the displayed information within the headset (Fang et al., 2017). Several physiological maladaptations can result from a mismatch between any or all of these, including a shift in visual function, degraded proprioception, and ataxia. These perceptual limitations can significantly reduce the effectiveness of AR-based training programs if left unchecked (Fang et al., 2017), and, depending on the task for which a user is being trained, pose significant safety risks should the training experience degrade real-world performance post exposure.

Impact of Maladaptations on AR Use Cases

Within the training curriculum for Tactical Combat Casualty Care (TCCC), the U.S. Army has been pushing AR as a solution to its distributed learning problem. TCCC is the curriculum of choice for the U.S. Army in training its soldiers as Combat Lifesavers (CLS). This training program focuses on those potentially survivable injuries that occur most often on the battlefield, with the leading causes of preventable deaths being massive hemorrhage and tension pneumothorax (Bellamy, 1984; Butler, 1996; Champion et al., 2003 as cited in Kotwal et al., 2011). CLS provide care for these injuries while preventing further casualties and completing a unit's mission (National Association of Emergency Medical Technicians [NAEMT], 2018). Effective CLS training that transfers knowledge directly and accurately to the field is central to decreasing preventable combat casualty deaths.

Consider the potential safety risks that might arise from using an AR environment to train TCCC medical tasks. One such risk might stem from the use of medical manikins with AR overlays. For example, one of a CLS primary tasks is needle decompression. Needle decompression is a treatment for tension pneumothorax, involving precision placement of a needle into the chest cavity in order to relieve excess pressure. If physiological maladaptations occur while soldiers are undergoing AR training for this task, there is a possibility that negative training transfer will occur. For example, if a 3D model of a ribcage were shown as an AR overlay and it was not properly superimposed and aligned onto the physical manikin, maladaptation in hand-eye coordination could occur. The result of such negative training might be that soldiers have now learned to place the needle in an improper location, which could lead to a shift in the kinesthetic position sense and potential for improper medical treatment post-AR exposure. This loss in dexterity could compromise patient safety if the medical practitioner-in-training were to perform an actual needle decompression or other dexterous medical procedures soon after training, or trainee safety if the medical practitioner with degraded coordination drives or operates machinery soon after training.

Another example is the proper application of a Combat Application Tourniquet (CAT) to a massively hemorrhaging limb. CATs are designed to stop bleeding and stabilize patients until they can be transported to a more advanced medical facility. If a training scenario of this type were to take place using present-day AR hardware, such as the MS HoloLens, trainees could face numerous difficulties when transferring learned skills into real-world applications. For example, one potential maladaptation of training massive hemorrhage in the MS HoloLens, which stems from an issue with how depth planes are viewed in this HWD, might be to cause a differential of up to 6 cm to be present between the holographic CAT and real-world counterpart when performing a task immediately after exiting AR training scenarios. Depending on the location of the massive hemorrhage, this might result in CLS personnel placing the CAT onto the damaged limb incorrectly. In such instances, 6 cm could be the difference between life and death, as accidently placing the CAT over a joint would fail to stop hemorrhage, potentially resulting in the death of the soldier.

Thus, while AR technology has the potential to advance medical simulation training, there is a need to identify any physiological limitations that could compromise training effectiveness and patient/trainee safety. As a result of this risk, it is necessary to place emphasis on ensuring that any such maladaptations are mitigated to the best extent possible, which means that software design and usage protocols would ultimately be guided by human factors principles derived specifically for AR training applications. Additional research is necessary to fully comprehend how to develop a series of best-practice heuristics for AR design and usage protocols. A potential starting point is to explore known AR limitations and devise guidelines to address these gaps.

KNOWN AR LIMITATIONS AND GUIDELINES FOR MITIGATION

Framerate and Resolution

As touched on earlier, there are many limitations in both the software and hardware of AR systems. While many of these limitations also exist in VR, the way an AR system is impacted by them may be entirely different. Two limitations that the scientific community have extensively focused on – framerate and resolution – are prime examples of this. In VR-based systems, these factors have been found to be two of the most important when trying to predict the degree of cybersickness experienced by a user (Weech, Keeny, & Barnett-Cowan, 2019). In stationary AR systems, research suggests that framerate and FOV have a similar, yet less severe impact on cybersickness (Padmanaban et al., 2017). In terms of framerate, since AR HWD have simulated objects shown on a portion of the visual field, having augmented objects displayed at a lower framerate is less impactful than having a simulation that spans the entire visual field run at a lower framerate, as would be the case in VR. On the other hand, low framerates in AR will often be perceived as lag, with the augmented element visually lagging behind what's anticipated by the user. This can cause a spike in error, reducing overall training efficacy and user's performance (Padmanaban et al., 2017). In terms of resolution, while resolution is thought to impact a user's performance in an AR environment (e.g., by making lines clearer and improving input accuracy), there is no clear indication that low resolution in AR impacts cybersickness (Hanna et al., 2018), but low resolution could drive eye fatigue (Kim, Lim, Gu, & Park, 2017).

In order to mitigate any maladaptations that would occur as a result of framerate issues in AR HWDs, hardware needs to be capable of maintaining a minimum framerate of 90 frames-per-second (FPS). VR literature suggests that this is the point at which cybersickness symptoms show the most improvement (Zielinski, Rao, Sommer, & Kopper, 2015). Research also suggests, however, that – as long as FPS is maintained at or above 60 FPS – consistency is just as important of a factor (Weech, Kenny, & Barnett-Cowan, 2019). In other words, users experiencing an augmented environment where the framerate is inconsistent, even within that 60- to 90- FPS range, are expected to experience symptoms of cybersickness. While it is likely that having a higher, consistent framerate above 90 FPS (in the range of 144+ FPS, which is in-line with high-end desktop gaming displays) for AR and VR HWDs will be even more effective at reducing symptoms, it is not currently practical to test this assertion in a high-fidelity setting due to immature technology; neither the processing ability nor the displays in present-day AR HWDs are capable of meeting such high FPS requirements. Similarly, it is recommended that displays used in VR HWDs maintain a minimum of 60 pixels per degree (PPD) in order to mitigate maladaptations related to low resolution and subsequently visual acuity. Literature shows that visual acuity is negatively correlated with cybersickness; thus, display resolution of at least 60 PPD will serve to decrease eyestrain by improving visual acuity, which is an issue present in many of today's HWDs (Fidopiastis, Meyer, Fuhrman, & Rolland, 2003).

Depth Planes

There is also the potential for maladaptations to be present when differences exist between one's natural depth perception and the depth planes simulated by an AR HWD. Depending on the development engine used to create an AR application, users may be forced into viewing content at specific focal distances, which may or may not match what is natively supported by a particular HWD, resulting in depth perception beyond those planes being artificially calculated and rendered (Padmanaban et al., 2017). It is suggested that this process results in maladaptations in the form of eyestrain and, in particular, that it results from differences between one's natural saccadic eye movement and the eye movement that occurs at forced visual depth planes in an AR HWD (Fidopiastis, Rizzo, & Rolland, 2010). Being forced to focus on non-ideal depth planes (below 2 m, for instance) is also responsible for vergence-accommodation conflict. As presented depth planes approach optical infinity – which begins at approximately 6 m and is indicated by light rays being viewed as parallel by the eyes – it becomes exponentially more difficult for both AR and VR headsets (along with other near-eye displays) to replicate shifts in focus that accompany natural vison (Padmanaban et al., 2017). The MS HoloLens 2, however, will potentially be able to partially mitigate the vergence-accommodation conflict resulting from holograms being placed outside of the ideal 2 m to 5 m zone. The process it uses is called reprojection (specifically depth reprojection, in this case), which is expected to reduce visual artifacting by independently stabilizing projections based on their distance from the user. This process will, however, require more effort on the developer's end and subsequently be more taxing on the hardware.

Research suggests that AR HWDs will need to have between five and ten depth planes in order to minimize the maladaptations that result following prolonged AR exposure; currently, with the MS HoloLens 1 and Magic Leap HWDs having one and two depth planes respectively, neither are capable of achieving this. The MS HoloLens, due to having a single depth plane, results in users having approximately a 6 cm action-response difference between virtual elements projected in their environment and their real-world surroundings. Although untested, it is likely that the Magic Leap will have a similar problem, but to a lesser degree because of its multiple depth planes. This may not appear significant at first, but because such maladaptations have the potential to persist following long-duration AR exposure, there is potential for safety risks based on the tasks performed by a user, as mentioned earlier, for example, in the tension pneumothorax AR training use-case. By including support for additional depth planes in future AR HWDs, these maladaptations may be reduced to an acceptable level, such that the number of depth planes is negatively correlated with the degree of discrepancy between the user's visual system and their surrounding environment.

Field of View

Field-of-view (FOV) also has a significant impact on the optics of HWDs (Weech et al., 2018). Because humans have a horizontal FOV of ~200 degrees horizontal and ~140 degrees vertical, coupled with the fact that human-computer interaction principles dictate the need for an ideal 1:1 system of interaction, any system that constrains a user's FOV below that will undoubtedly result in some degree of perceptual issues being present (Lin et al., 2002). This is a double-edged sword, however, as a wide FOV, when coupled with display stutter or similar issues, actually causes higher cybersickness scores to be reported. While the precise FOV modern VR HWDs isn't always published information, users report that the Oculus Rift is ~94 degrees and HTC Vive is ~110 degrees. In VR, low FOV can also cause users to feel constrained, and correlates to cybersickness (Duzmanska, Strojny, & Strojny, 2018; Weech et al., 2018). In AR, however, research suggests the impact isn't as direct. Even though AR HWDs have a significantly smaller FOV than even the smallest VR HWD (e.g., MS HoloLens 1 has an FOV of 34 degrees), in AR virtual elements are overlaid onto reality instead of directly replacing them, which means any physical visual tunneling that occurs in AR may have a reduced maladaptive impact on users who can still view real world elements (Drascic, & Milgram, 1996).

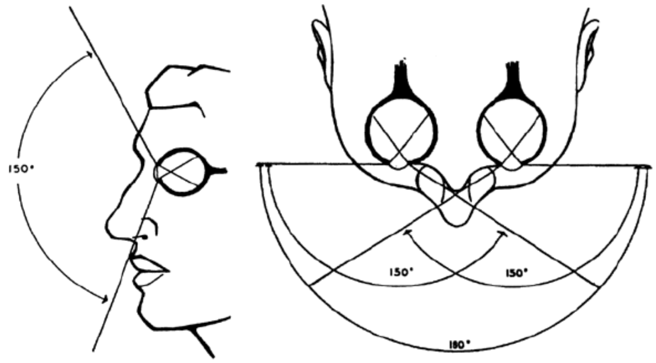

Figure 2. Approximate field-of-view of the human visual system (Mazuryk & Gervautz, 1999).

In accordance with the need to match display systems to a user's natural perception as closely as possible, the FOV supported by an AR HWD would ideally be approximately 200 degrees horizontal and 140 degrees vertical; this would account for the maximum possible range of both monocular and stereoscopic vision (Strasburger, Rentschler, & Juttner, 2011). Due to the maximum range of a single human eye being 150 degrees, and a 120 degree overlap existing between the two eyes at which stereoscopic vision occurs, today's AR HWDs, with an effective FOV of less than 50 degrees diagonal, are only capable of projecting across 22% of the human visual field in nominal conditions. Improving the FOV of AR HWD will allow augmented entities to be integrated into a user's peripheral vision, which is crucial for maintaining situation awareness (van Veen, Karjanto, & Terken, 2017) and plays a significant role in task performance (Baker et al., 2017). It is also important to note that there are two ways of increasing a HWD's FOV: moving the depth plane closer to the user or increasing the resolution of the display. Moving the depth plane within the frustrum will increase the FOV, but in doing so will also increase pixel size. Increasing the display's resolution is the only way to guarantee a FOV increase without a loss of visual acuity.

Interpupillary Distance

One recurring assertion in cybersickness literature is that females tend to be more susceptible than males, both in the context of traditional motion sickness and within virtual environments (Lentz & Collins, 1977; Stanney, Hale, Nahmens, & Kenedy, 2003). Recent research into cybersickness has discovered valuable links between cybersickness symptom presentation and interpupillary distance (Stanney, Fidopiastis, & Foster, 2020); while it has been known for some time that the single largest contributing factor to physiological motion sickness susceptibility is genetics, such that it accounts for approximately half of all variation in females (Reavley et al., 2006), the research of Stanney et al. (2020) found that mismatch between the IPD of female users and the ideal fit supported by HWDs may account for up to 42% of the preventable variation between the two genders. It was also determined that IPD difference continued to be the most influential variable when accounting for both severity and duration of cybersickness symptoms, such that females with a mismatched IPD presented with more severe symptoms and longer duration symptoms (Stanney et al., 2020). Designing AR HWDs (and VR HWDs) to allow users to adjust the IPD within a range of 50 to 77 mm may allow for 99% of the population – both males and females – to wear HWDs more comfortably and not have an IPD mismatch be a contributing factor to cybersickness-related maladaptations.

CONCLUSION

In order to meet the minimum standards needed for military and industry adoption of AR platforms, hardware and software developers alike need to be aware of how these systems perform in conjunction with the human perceptual process – with particular emphasis on the oculomotor system. Doing so should result in decreased maladaptation severity and a subsequent increase in both safety and performance. In other words, it is crucial that the industry undergo a paradigm shift from a techno-centric development process to one that is user-centric, based on the principles of user-centered design. One specific recommendation for how this paradigm shift may be achieved is by adjusting the applied definition of immersion from the work of Slater, Linakis, Usoh, and Kooper (1996), in which immersion was defined strictly as a measure of hardware fidelity, to that described in the work of Witmer and Singer (1998), in which immersion was defined as a user's response to a system. While literature does suggest that a combination of both theories is ideal for academic purposes (Diemer et al., 2015), the solutions currently sought by the AR industry are likely to be expedited by focusing on a user-centered design process. In time – as has been the case in other industries (i.e., aviation and spaceflight) – this will allow for the creation of standardized heuristics, which will help to simplify the management of maladaptations even further.

REFERENCES

Baker, N. A., Livengood, H., Nau, A. C., Owens, G., Chambers, A. J., Trout, J., & Cham, R. (2017). Effects of central and peripheral vision occlusion on motor performance during hand coordination tasks. *IISE Transactions on Occupational Ergonomics and Human Factors, 5*(3), 148-157.

Bellamy, R. F. (1984). The causes of death in conventional land warfare: implications for combat casualty care research. Military Medicine, 149(2):55-62.

Butler, F. K. Jr. (2017). Tactical Combat Casualty Care: Beginnings. Wilderness & Environmental Medicine, 28, S12-S17.

Brunner, G. (May 22, 2018). Why Google Glass failed, and what to expect next. *ExtremeTech*. Retrieved from https://www.extremetech.com/electronics/269215-why-google-glass-failed-and-what-to-expect-next.

Carmigniani, J., Furht, B., Anisetti, M., Ceravolo, P., & Ivkovic, M. (2011). Augmented reality technologies, systems and applications. *Multimedia Tools and Applications, 51*, 341-377.

Caudell, T. P., & Mizell, D. W. (1992). Augmented reality: An application of heads-up display technology to manual manufacturing processes. Paper presented in the *Proceedings of the Twenty-Fifth Hawaii International Conference on System Sciences.*

Chan, C. L., Ngai, E. K., Leung, P. K., & Wong, S. (2010). Effect of the adapted virtual reality cognitive training program among Chinese older adults with chronic schizophrenia: A pilot study. *International Journal of Geriatric Psychiatry, 25*(6), 643-649.

Champion, H. R., Bellamy, R. F., Roberts, C. P., Leppaniemi. A. (2003). A profile of combat injury. Journal of Trauma, 54(5) (suppl): S13-S19.

Diegmann, P., Schmidt-Kraepelin, M., van der Eynden, S., & Basten, D. (2015). Benefits of augmented reality in educational environment. *Proceedings of the 12th International Conference on Wirtschaftsinformatik*.

Diemer, J., Alpers, G. W., Peperkorn, H. M., & Muhlberger, A. (2015). The impact of perception and presence on emotional reactions: A review of research in virtual reality. *Frontiers in Psychology, 6*(26).

Drascic, D., & Milgram, P. (1996). Perceptual issues in augmented reality. *Proceedings of Stereoscopic and Virtual Reality Systems III, 2653*.

Dunleavy, M. (2014). Design principles for augmented reality learning. *TechTrends, 58*(1), 28-34.

Duzmanska, N., Strojny, P., & Strojny, A. (2018). Can simulator sickness be avoided? A review on temporal aspects of simulator sickness. *Frontiers in Psychology, 9*(2132).

Fang, W., Zheng, L., Deng, H., & Zhang, H. (2017). Real-time motion tracking for mobile augmented/virtual reality using adaptive visual-inertial fusion. *Sensors, 17*(5), 1037.

Fidopiastis, C. M., Meyer, C., Fuhrman, C. A., & Rolland, J. P. (2003). Quantitative assessment of visual acuity in projective head-mounted displays. *Proceedings of SPIE 5079, Helmet- and Head-Mounted Displays VIII: Technologies and Applications*.

Fidopiastis, C. M., Rizzo, A. A., & Rolland, J. P. (2010). User-centered virtual environment design for virtual rehabilitation. *Journal of NeuroEngineering and Rehabilitation, 7*(11).

Gavish, N., Guitierrez, T., Webel, S., Rodriguez, J., Peveri, M., Bockholt, U., & Tecchia, F. (2013). Evaluating virtual reality and augmented reality training for industrial maintenance and assembly tasks. *International Learning Environments*, *23*(6), 778-798.

Goldman, David (April 4, 2012). Google unveils 'Project Glass' virtual-reality glasses. *CNN: Money*. Retrieved https://money.cnn.com/2012/04/04/technology/google-project-glass/index.htm.

Hanna, M. G., Ahmed, I., Nine, J., Prajapati, S., & Pantanowitz, L. (2018). Augmented reality technology using Microsoft HoloLens in anatomic pathology. *Archives of Pathology & Laboratory Medicine*, *142*(5).

Hou, L., Wang, X., & Martijin, T. (2012). Using augmented reality to facilitate assembly: An experiment-based evaluation. *Proceedings of the 12th International Conference of Construction Applications of Virtual Reality.* International Telecommunications Union. (2019). Statistics: Individuals using the internet. Retrieved from https://www.itu.int/en/ITU-D/Statistics/Pages/stat/default.aspx

Jung, T., Dieck, C. T., Lee, H., & Chung, N. (2016). Effects of virtual reality and augmented reality on visitor experiences in museum. *Proceedings of the International Conference on Information and Communication Technologies in Tourism*.

Kim, D.J., Lim, C-Y., Gu, N., & Park, C.Y. (2017). Visual fatigue induced by viewing a tablet computer with a high-resolution display. *Korean Journal of Ophthalmology*, 31(5), 388–393.

Kotwal, R. S., Montgomery, H. R., Kotwal, B. M., Champion, H. R., Butler, F. K., Mabry, R. L., …Holcomb, J. B. (2011). Eliminating preventable death on the battlefield. Archives of Surgery, 146(12), 1350-1358. Doi: 10.1001/archsurg.2011.213.

Lee, K. (2012). Augmented reality in education and training. *TechTrends, 56*(2), 13-21.

Lentz, J. M., & Collins, W. E. (1977). *Motion sickness susceptibility and related behavioral characteristics in men and women*, Federal Aviation Administration, Report No. FAA-AM-76-14.

Mazuryk, T. & Gervautz, M. (1999). *Virtual reality – History, applications, technology, and future* [Unpublished thesis]. Institute of Computer Graphics, Vienna University of Technology.

McDonald, Z. (2016). *Augmented reality HUDs: Warning signs and drivers' situation awareness* [Unpublished thesis]. Rochester Institute of Technology.

Milgram, P., & Kishino, F. (1994). A taxonomy of mixed reality displays. *IEICE TRANSACTIONS on Information and Systems, 77*(12), 1321-1329.

Mine, M., Rose, D., Yang, B., van Baar, J., & Grundhofer, A. (2012). Projection-based augmented reality in Disney theme parks. *IEEE Computer, 45*, 32-40.

Morozov, M. (2019). *Augmented reality in military: AR can enhance warfare and training*. Jasoren. https://jasoren.com/augmented-reality-military/

Padmanaban, N., Konrad, R., Stramer, T., Cooper, E. A., & Wetzstein, G. (2017). Optimizing virtual reality for all users through gaze-contingent and adaptive focus displays. *Proceedings of the national Academy of Sciences of the United States of America, 114*(9), 2183-2188.

Radu, I. (2014). Augmented reality in education: A meta-review and cross-media analysis. *Personal and Ubiquitous Computing, 18*, 1533-1543.

Rosenberg, L. B. (1994). *The use of virtual fixtures as perceptual overlays to enhance operator performance in remote environments*. Wright-Patterson Air Force Base: Biodynamics and Biocommunications Division, Report No. AL/CF-TR-1994-0139.

Sanders, S. (2019). *Everything you need to know about Na'vi River Journey*. TouringPlans. https://touringplans.com/blog/2019/09/01/everything-you-need-to-know-about-navi-river-journey/

Slater, M., Linakis, V., Usoh, M., & Kooper, R. (1996). Immersion, presence and performance in virtual environments: An experiment with tri-dimensional chess. *VRST '96: Proceedings of the ACM Symposium on Virtual Reality Software and Technology*, 163-172.

Stanney, K. M., Fidopiastis, C., & Foster, L. (2020). Virtual reality is sexist: But it does not have to be. *Frontiers in Robotics and AI, 7*(4).

Stanney, K. M., Hale, K. S., Nahmens, I. & Kennedy, R. S. (2003). What to expect from immersive virtual environment exposure: Influences of gender, body mass index, and past experience. *Human Factors: The Journal of the Human Factors and Ergonomics Society, 45*(3), 504-520.

Strasburger, H., Rentschler, I., & Juttner, M. (2011). Peripheral vision and pattern recognition: A review. *Journal of Vision, 11*(5).

Reavley, C. M., Golding, J. F., Cherkas, L. F., Spector, T. D., & MacGregor, A. J. (2006). Genetic influences on motion sickness susceptibility in adult women: A classical twin study. *Aviation, Space, and Environmental Medicine, 77*(11), 1148-1152.

Tsai, C. F., Yeh, D. C., Huang, Y., Wu, Z., Cui, J., & Zheng, L. (2018). The effect of augmented reality and virtual reality on inducing anxiety for exposure therapy: A comparison using heart rate variability. *Journal of Healthcare Engineering*, *2018*, 6357351.

van Veen, T., Karjanto, J., & Terken, J. (2017). Situation awareness in automated vehicles through proximal peripheral light signals. *AutomotiveUI '17: Proceedings of the 9th International Conference on Automotive User Interface s and Interactive Vehicular Applications*, 287-292.

Vapenstad, C., Hofstad, E. F., Bo, L. E., Kuhry, E., Johnsen, G., Marvik, R., & Hernes, T. N. (2017). Lack of transfer of skills after virtual reality simulator training with haptic feedback. *Minimally Invasive Therapy & Allied Technologies, 26*(6), 346-354.

Vovk, A., Wild, F., Guest, W., & Kuula, T. (2018). Simulator sickness in augmented reality training using the Microsoft HoloLens. *Proceedings of the CHI Conference on Human Factors in Computing Systems*, 1-9.

Weech, S., Kenny, S., & Barnett-Cowan, M. (2019) Presence and cybersickness in virtual reality are negatively related: a review. *Frontiers in Psychology*, 10:158. doi: 10.3389/fpsyg.2019.00158.

Witmer, B. G., & Singer, M. J. (1998). Measuring presence in virtual environments: A presence questionnaire. *Presence, 7*(3), 225-240.

Zielinski, D. J., Rao, H. M., Sommer, M. A., & Kopper, R. (2015). Exploring the effects of image persistence in low frame rate virtual environments. *Proceedings of 2015 IEEE Virtual Reality (VR)*.