A Review Investigating Applications of Augmented Reality in Skill-based Training and Simulation.

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Abstract: - Augmented reality (AR) technology has the potential to extend beyond its predominant use in medicine, particularly in investigating motor learning for skill-based tasks. However, research on head-mounted AR displays (HMD-AR) for motor pattern learning remains limited, especially in tactical applications. This study conducts a scoping review to compare AR technologies with existing methods for complex tasks like aim training. Among 21 reviewed articles, only one explored motor pattern learning with HMD-AR, highlighting a significant gap. Findings emphasize the need for further research on HMD-AR's role in developing complex motor skills for tactical populations.

Key-Words: - Augmented Reality, Head-mounted Display, Skill-based Training, Tactical, Reality-based Technology, Simulation, Magic Leap, Hololens.

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1 Introduction

In modern society, technology plays a vital role in daily life, impacting our choices, activities, and productivity. New and emerging technologies benefit professionals in almost every field imaginable. Specifically, sectors like medicine, business, education, fitness, and the military are all heavily influenced by technology. Among these advancements, augmented reality (AR) provides an unmatched experience to the end-user through capabilities like gamification; enhancing learning, training, and skill development to allow an end-user to refine their abilities in a controlled, adaptable, and immersive environment [1]. To fully grasp the capabilities and reach of AR, it is worthwhile exploring what this technology is, what it can do, the potential applications, and best practice for future use in research.

1.1 An Introduction to Augmented Reality

Augmented reality (AR) is a reality-based technology within the broader categorization of extended reality (XR) that allows the seamless integration of virtual objects into the end-user's real-world field-of-view (FOV) [2]. Wearable AR devices with gaming capabilities became commercially available to the public as early as 2016 [3]. Although the original Google Glass Explorer Edition was released in 2013, the intent of this device was as a mixed reality (MR) device for personal use, primarily functioning as a voice-activated personal assistant that supported basic functions like taking photos, sending messages, and other rudimentary functions that may benefit other populations and the broad general public [4]. Current iterations of MR devices excel in integrated and immersive business intents like hosting virtual meetings or observational support and metrics presentations for teams that are geographically dispersed [5]. Historically, MR has been muddled into the definition of AR, leading to confusion in the current literature. Thus, for the sake of a definitive and separate classification, MR and AR are not the same. In the context of providing a use-based definition, MR is primarily intended and most commonly used for business utility, whereas AR should be categorized as intended for field-specific learning, training, and activity. Notable AR devices such as the Magic Leap 1 and Microsoft HoloLens, both feature head-mounted displays (HMDs), enabling users to interact with virtual objects in their FOV through specific hand movements or gestures, thereby providing freedom of motion [6]. AR devices with HMD capabilities (HMD-AR) such as those produced by Magic Leap and Microsoft have significantly impacted various industries by offering new methods for training, education, and experiential learning of complex motor tasks [6,7,8]. Recent advancements have seen new iterations of AR technology from Magic Leap and Microsoft, with Meta also entering the market with its own AR device, the Orion AR glasses, which is tentatively set to release in 2025 [6,9]. Researchers have explored a wide range of applications regarding HMD AR technology spanning various fields and populations, with vast success in fields like education and medicine [7, 10]. Prominent uses include educational and practicum-based activities, particularly in medical education for teaching anatomy and facilitating guided surgical practice or rehearsal of skill-based activities [11,12,13,14]. These devices offer a method for managing critical resources such as personnel, time, and designated space, with minimal equipment setup and pre-built scenarios that can be easily repeated.

From a broader perspective, three inherent qualities make AR devices attractive for implementation in fields like medicine and education: 1) the ability to visually perceive the local environment without obstruction from integrated virtual objects, 2) hands-free interaction or usage of specially designed implements to engage with virtual objects, and 3) minimal setup requirements for training, events, or test protocols. Given these attributes, AR holds unique potential for application in various fields that it has yet to penetrate. This paper focuses on one such field—tactical human performance—where AR technology could significantly influence the enhancement of lethality and situational readiness among Soldiers.

1.2 Practical Simulation

In all professions, hands-on training and practice are what define expertise in any given field. Practice in the form of hands-on training, builds skillsets through repetition. In hospital-based and military medicine, providers in their given environments have access to Simulation Mannequins (SimMan) paired with a computerized medical application run from a centralized computer console which allows for repetitive scenarios to enhance skill-based training [15]. Similar to this, practice within a virtualized simulation environment for the goal of replicating real-world scenarios functions equivalently to practicing repetitions in controlled settings [16]. AR provides exactly this, a controllable and adaptable simulation environment, but with an added benefit of a time-efficient reset for task repeatability and lowered costs for required equipment in some circumstances [17]. Based on the development of a specially designed computer-based application using such a platform as Unity or Unreal Engine, end-user's should be able to use AR to optimize skill-based learning particular to field-specific needs [18]. Although providing AR technology as a new method of training may be unique and entertaining for some time, this has its limits, specifically in reference to compliance and enjoyment of the modality by the end-user. To overcome these foreseeable challenges, gamification of an AR-based modality has the ability to catapult the end-user experience into a new echelon of novelty in engagement and sustainability.

1.3 Gamification

Gamification, defined as the addition of game-based elements to specific tasks within a protocol, is a critical additive component for use with simulation technologies for optimizing skill-based learning during training [19]. Entertaining users through interactive engagement or competition, continuation of participation is encouraged. By providing an enjoyable experience paired with measurable performance markers and systematic rewards based on performance, it can be hypothesized that increases in compliance would be seen with a simulation training method using aspects of gamification [20,21].

Funding and employing gamified approaches to training would be a wise decision for large organizations in areas related to military, human performance, motor learning, or rehabilitation. Currently, approaches toward using AR in the tactical setting have limited guidance yet to be extrapolated from other areas due to current iterations of reality-based technology being a relatively new option for training and learning. Therefore, this paper aims to provide insights on relevant applications using HMD-AR devices for skill-based training which can both directly and indirectly benefit organizations like the US Army in designing specialized training approaches specific to improving Soldier lethality and situational readiness.

1.4 Memory and Motor Learning

Soldiers must make effective and quick decision calls when under pressure. Thus, due to the inherent uncertainty and dynamic situational elements found in high-risk situations, it is important for Soldiers to practice and simulate certain skills to commit a designated response to memory [22,23]. To memorize a skill like aiming and firing a weapon, end-users must practice the motor pattern through hands-on training. The best way to train a skill is by practicing it directly.

Other approaches may also involve fixed or random practice formats. However, in the current literature it is well documented that random practice schedules provide a more effective motor learning environment versus that of a blocked, or fixed, practice schedule [24]. The randomization aspect of learning specific motor patterns can also be implemented for variable intent. For example, when training a skill such as aiming and interacting with virtual objects, the location where the object appears can be randomized, creating a focus on reaction time and replicating real-world training events and scenarios. This would result in a random but repeatable and measurable experience for each attempt.

2 Background on Current Technology

AR devices are capable of providing the end-user with an experience that few other technologies can match equivalently, both in the relative and absolute sense. This emanates from a more technical perspective relevant to components and design. In the following sections, all current known AR devices will be discussed, and valid competitive technology will be comparatively assessed. However, all technologies discussed in this paper will be relevant to visually immersive technologies.

2.1 Augmented Reality Devices

HMD-AR technology is capable of providing a unique experience due to the specific technical capabilities based on the components. Currently, at the writing of this paper, there are actively well over 35 different devices classified as AR technology available on the market for consumer purchase. However, some of these devices are not true HMD-AR technology, and instead should fall under the classification of MR. This is based on a variety of standard functions and features that are either present or absent unique to each device.

A full list of all current technologies marketed as an AR device is provided below in Table 1. Furthermore, Table 1 is intended to reclassify any marketed devices from AR to MR if they do not fit all specific listed criteria.

Table 1.
List of all marketed virtualized AR-based visual-interactive devices or applications.

Device Name	Manufacturing Company	Bluetooth Capable (✓/×)	Hands Free (✓/×)	Gaming Capable (✓/×)	HMD (✓/×)	Stand Alone (✓/×)
Magic Leap 2	Magic Leap	✓	✓	✓	✓	✓
HoloLens 2	Microsoft	✓	✓	✓	✓	✓
Everysight Raptor	Everysight	✓	×	×	✓	✓
RealWear HMT-1Z1	RealWear	✓	✓	×	×	✓
MAD Gaze Vader	MAD Gaze	✓	✓	×	✓	✓
Shadow Creator Halomini	Shadow Creator	✓	✓	×	✓	✓
Asus AirVision M1	Asus	×	×	×	✓	×
Brilliant Labs Frame	Brilliant Labs	×	✓	×	✓	✓
DigiLens Argo	DigiLens	✓	✓	×	✓	✓
Viture Pro	Viture	✓	✓	×	×	✓
TCL RayNeo X2	TCL	×	✓	×	✓	×
Viture One Lite	Viture	✓	×	×	✓	×
RealWear Navigator Z1	RealWear	✓	✓	×	×	✓
Xiaomi Mijia	Xiaomi	✓	✓	×	✓	✓
Nubia Neovision Glass	Nubia	×	✓	×	✓	×
Rokid Max	Rokid	×	✓	×	✓	×
Spacetop	Sightful	✓	×	×	✓	×
Campfire Headset	Campfire	×	✓	×	✓	✓
INMO Air2	INMO	✓	✓	×	✓	✓
TCL NXTWear S	TCL	×	✓	×	✓	×
RealWear Navigator 520	RealWear	✓	✓	×	×	✓
Razor MR Glasses	ThirdEye	×	✓	×	✓	×
Viture One	Viture	✓	×	×	✓	×
Huawei Vision Glass	Huawei	✓	×	×	✓	×
TQSKY T1	TQSKY	×	✓	×	✓	×
Dream Glass Flow	DreamWorld	✓	✓	×	✓	✓
Vuzix Shield	Vuzix	✓	✓	×	×	✓
INMO Air	INMO	✓	✓	×	✓	✓
MAD Gaze Wave	MAD Gaze	×	✓	×	✓	×
Rokid Air Pro	Rokid	×	✓	×	✓	×
NuEyes Pro 3e	NuEyes	×	×	×	✓	×
Dream Glass Lead Pro/Plus	DreamWorld	✓	✓	×	✓	✓
Cosmo Vision	Cosmo Cntd.	✓	×	×	✓	✓
RealWear Navigator 500	RealWear	✓	✓	×	×	✓
Holoswim 2/2 Pro	Guangli	×	✓	×	✓	✓
Rokid Air	Rokid	×	✓	×	✓	×
Tilt Five	Tilt Five	✓	×	✓	✓	×
Iristick.G2	Iristick	×	×	×	✓	×
Lenovo ThinkReality A3	Lenovo	×	✓	×	✓	×
XYZ Atom	XYZ Reality	✓	✓	×	✓	✓
Engo 1	Engo Eyewear	✓	×	×	✓	✓
TCL NXTWear G	TCL	×	✓	×	✓	×

Using Table 1, the devices are assessed based on five criteria involving both components and features: 1) Does it support Bluetooth capabilities, 2) Can the device be used in a hands free format, 3) Does it support interactive gaming and game design, 4) Does it feature an HMD with a physical binocular or monocular glass visor, and 5) is it a stand alone device or does it require constant connection to an external device to support specific functions.

With the aforementioned criteria, many of the devices found in Table 1 can be actively eliminated for not meeting all of the specified criteria. Each criteria plays a role in suggesting optimal equipment specifications for providing a new standard to HMD-AR simulated training. Bluetooth capability is important to allow for customizability in pairing external devices or implements to be connected for specific training modalities involving such skills as aim training or fine motor control practice. A correct hands-free format is represented by that of the observed capabilities provided by the Magic Leap device line, where the device is capable of recognizing end-user hand movements and gestures to interact with the virtualized objects overlayed into the real-world view [25]; however, this is further extrapolated to also allow for training-specific implements or external devices to be used once paired via Bluetooth connection [26]. The support of gaming capabilities and game design is a critical customization capacity that allows investigators and end-users to use platforms like Unity or Unreal Engine to design games and applications to be played on the HMD-AR device [27]. Of all criteria, one of the most important aspects to cover for a reality-based technology like AR is the presence of an HMD, or the display visor that the end-user views the augmented world through. Finally, for convenience and functionality in variable environments, a device must be a standalone AR device; meaning it is able to function without relying upon constant connection to another external device.

Not all devices categorized as AR devices meet these criteria, some examples of eliminated devices and their supporting reasoning are provided. Devices like those from the companies RealWear or Vuzix, do not feature an AR glass display visor and are intended for supportive vision capacities and remote monitoring [28,29]. Other companies like Guangli or Engo provide their technology to support swimmers and cyclists respectively to track session-specific performance data. Parallel to this, devices like those produced by DreamWorld were eliminated due to having a limited preset gaming capacity while requiring constant wired connection to an external console or device that runs the game. Thus, after applying the unique technical requirements to assess all available options, only two technologies remain to be classified as HMD-AR devices. Specifically, of the approximately 42 devices found marketed as AR technology, the Magic Leap and Microsoft HoloLens device lines were found to be the only two applicable HMD-AR devices, meaning that less than five percent of marketed AR technologies are currently equipped to operate at a higher standard to fit the needs of scientific literature. All specifications for the Magic Leap and Microsoft devices are summarized below in Table 2.

Table 2
All AR-based devices that meet all given criteria.

Device Name	Manufacturing Company	Bluetooth (✓/×)	Hands Free (✓/×)	Gaming Capable (✓/×)	HMD (✓/×)	Standalone (✓/×)	Cost ($ USD)	Initial Release Year
Augmented Reality Devices								
Magic Leap 2	Magic Leap	✓	✓	✓	✓	✓	$3,299	2018
HoloLens 2	Microsoft	✓	✓	✓	✓	✓	$3500	2016

2.2 Other Comparable Technology

Few technologies can equivalently be compared to an HMD-AR device, in terms of functionality and features. Technology, for accurate comparison must be “visual interactive” by nature, meaning there must be a visual component either using a wearable headset, a screen/projector, or television; and the end-user must be able to interact with objects during participation.

Under these constraints, virtual reality (VR) headsets are at the forefront of the few selections on equivalent technology. A comparative visual is provided in Fig. 1 to see that AR and VR headsets on the surface only differ in one way: that AR provides the capacity to see the local environment, which is a major safety advantage for the end-user.

Fig. 1: Images of AR and VR headsets.

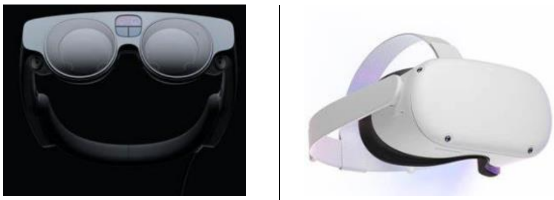


Fig. 1a: Magic Leap 2 AR Headset. Fig. 1b: Meta Quest VR Headset.

For the intent of this paper, handheld mobile AR devices for modalities like Pokémon GO are not comparable to HMD AR devices due to the requirement of a cellular device for both visualization and on-screen interaction [6]. Even if future advancements allow for the cellular device to be made wearable with a customizable HMD capacity whereby the user is allowed to see the visible environment, limitations still exist based on the reliance of the allowable view of the camera from the cellular device. Thus, there are not many devices that are effectively comparable to HMD-AR technology.

2.3 Laser Shot Simulation Technology

Although most technologies outside of reality-based technology cannot compete equivalently with AR in terms of features and performance capabilities, there is one technology that does provide a reasonable visual interactive simulation experience to the end-user. Specifically, the Laser Shot tactical simulation system, which relies on a fixed screen and a Bluetooth connected weapon system [30]. With the fixed screen requirement, systems like the Laser Shot system require a dedicated space allocated for execution of testing or assessment modalities. An example visual of a target during a practice test, the high-precision camera that captures laser-hit interactions, and the Bluetooth weapon device with an electronic laser attachment can be seen below in Fig. 2.

Fig. 2: Image of the Weapon System and visuals for the Laser Shot Simulation Technology.

This Laser Shot system, and any that integrates a specialized training modality will require complex prerequisites. In relation to this particular technology, the end-user must have prior knowledge of, or be willing to learn other skills, such as how to zero a weapon. As seen in Fig. 2., without this knowledge some shots, despite aiming in a supported position at the target, will be off until modifications are made to allow for a properly zeroed, accurate, shot. Furthermore, with each shot taken, instantaneous interaction with the target occurs on-screen as captured by the high-precision camera that reads and records laser contacts with the on-screen targets. Therefore, simulation technologies like the Laser Shot system provide a simulated experience of shooting on a range which allows practice without the excessive requirement of allocated resources like expending bullets, resetting paper shooting targets, or acquiring time and space on a range; making a technology such as this the current gold standard for cost-effective training modalities involving skills like aim training within the tactical setting.

3 Methods

A review of the current literature was conducted and confined to studies published in English language peer-reviewed journals found through searching PubMed and IEEE Explore. Articles were first assessed for applicability based on title, abstract, and then the full article.

This scoping review addressed two general questions of: 1) 'What areas or fields is the current research primarily within while using an HMD-AR device used to conduct skill-based training?' and 2) 'Is there any existing literature using HMD-AR for motor skills training or simulation?'

3.1 Inclusion Criteria

Studies must meet the following criteria: (a) involve investigations with hands-on tasks involving training field-specific skillsets; and (b) employ the use of an HMD-AR device, specifically either the Magic Leap or HoloLens AR devices.

3.2 Exclusion Criteria

All found articles were first assessed for removal of duplicate articles. No duplicate articles were found, thus, all found articles were reviewed for quality and applicability, first by title, then by abstract, and finally, if applicable, by reviewing the full article. Upon further investigation, if an article covered a topic of business or education, or did not contain discussion in some format on skill-based training or learning, it was also excluded. Concurrently, fully robotic investigations were removed, but robotic-assisted interventions were included as long as the participants were required to complete a motor task.

3.3 Search Strategy

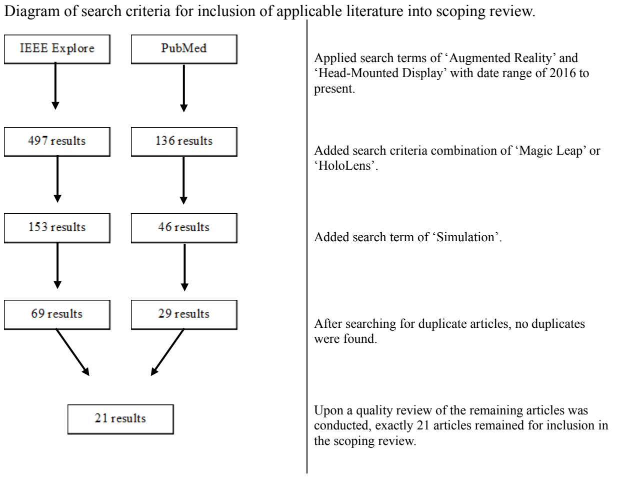
The literature search strategy was conducted using the following databases: PubMed and IEEE Explore. An important factor to consider for elimination of irrelevant publications is time in the form of an applicable date range applied for the projected search criteria. This is due to the initial inception of what is appropriately categorized as HMD-AR technology in the context of this paper being at the earliest produced and on the market in 2016. Thus, the searchable date ranges for applicable publications are set from 2016 to the present.

Following the application of the applicable date range, relevant articles were found by first applying the required search terms. Once the final search terms were applied, the studies were reviewed for inclusion into the scoping review.

3.3.1 Search Terms and Quality Review

Two specific terms of 'Head-Mounted Display' and 'Augmented Reality' are required as the focus of this paper is to discuss HMD-AR technology. An addition of a search term criteria of either 'Magic Leap' or 'HoloLens' was added to ensure applicability to the applicable system lines as shown previously in Table 2. A final search term of 'Simulation' was added as hands-on practice, or simulation, modalities are required for skills-based training. The full step-by-step search process is visualized below in Table 3.

Table 3
Diagram of search criteria for inclusion of applicable literature into scoping review.



The combination of these search terms, shown in Table 3, allowed for narrowed search results specific to the intended HMD-AR devices and the intended use of HMD-AR technology on skills-based training and simulation.

Following the full search criteria applied to both PubMed and IEEE explore, a quality review was performed by the investigators and only 21 articles were found to be applicable to the intent of this scoping review.

4 Results

4.1 Search Results

Following the retrieval of approximately 98 search results between both PubMed and IEEE Explore databases, a quality review was conducted by the investigators. Exactly 21 full text articles were found to be applicable with the intent of this scoping review. Below in Table 4 is a full breakdown of all approved applicable studies.

Table 4
All included articles following quality review.

Title of Article	Authors	Publication Year
Towards Wearable Augmented Reality in Healthcare: A Comparative Survey and Analysis of Head-Mounted Displays.	Baashar et al.	2023
Microsoft HoloLens 2 in Medical and Healthcare Context: State of the Art and Future Prospects.	Palumbo	2022
Validity of HoloLens Augmented Reality Head Mounted Display for Measuring Gait Parameters in Healthy Adults and Children with Cerebral Palsy.	Guinet et al.	2021
Utility of optical see-through head mounted displays in augmented reality-assisted surgery: A systematic review.	Birlo et al.	2022
Head-Mounted Display-Based Augmented Reality for Image-Guided Media Delivery to the Heart: A Preliminary Investigation of Perceptual Accuracy.	Doughty and Ghugre	2022
Ultrasound in augmented reality: a mixed-methods evaluation of head-mounted displays in image-guided interventions.	Rüger et al.	2020
Feasibility of using a low-cost head-mounted augmented reality device in the operating room.	Kubben and Sinlae	2019
Effectiveness of the HoloLens mixed-reality headset in minimally invasive surgery: a simulation-based feasibility study.	Janabi et al.	2020
Assessing the Effect of Augmented Reality on Procedural Outcomes During Ultrasound-Guided Vascular Access.	Saruwatari et al.	2023
Augmenting Image-Guided Procedures through In Situ Visualization of 3D Ultrasound via a Head-Mounted Display.	Haxthausen et al.	2023
HoloLens-Based Vascular Localization System: Precision Evaluation Study With a Three-Dimensional Printed Model.	Jiang et al.	2020
Augmented reality in computer-assisted interventions based on patient-specific 3D printed reference.	Moreta-Martinez et al.	2018
Integrated Quantitative Evaluation of Spatial Cognition and Motor Function with HoloLens Mixed Reality.	Tada et al.	2024
Validation of an Augmented Reality Based Functional Method to Determine and Render the Hip Rotation Centre During Total Hip Arthroplasty.	Neuville et al.	2024
Robot-Assisted Augmented Reality (AR)-Guided Surgical Navigation for Periacetabular Osteotomy.	Ding et al.	2024
Mixed Reality Surgical Navigation System; Positional Accuracy Based on Food and Drug Administration Standard.	Morley et al.	2024
Augmented Reality-Based Rehabilitation of Gait Impairments: Case Report.	Held et al.	2020
Utilization of facial fat grafting augmented reality guidance system in facial soft tissue defect reconstruction.	Liu et al.	2024
Software Framework for Customized Augmented Reality Headsets in Medicine.	Cutulo et al.	2019
Performance Evaluation of Mixed Reality Display for Guidance During Transcatheter Cardiac Mapping and Ablation.	Southworth et al.	2020
Augmented Reality-Based Trajectory Feedback Does Not Improve Aiming in Dart-Throwing.	Ueyama and Harada	2023

Articles were removed based on a variety of reasons, including but not limited to the following criteria: 1) focus on MR, VR, or mobile AR devices and applications, 2) focus on telehealth, communications, or Metaverse, 3) focus on calibration, theoretical design, or other non-related topics specific to the devices and 4) failure to fully cover HMD-AR technology as an intervention or supportive technology.

4.2 Summary of Findings

Within the applicable literature, 17 of the 21 (81%) found articles were used specific to the medical field, investigating surgical or procedural practice, or exploring applicability to medical interventions. In the study by Baashar et al., a review of the current literature on the feasibility of using HMD technology in the surgical setting was conducted and found that HMD-AR technology, specifically the Microsoft HoloLens has potential benefit in supporting various surgical procedures and even medical training [31]. Some articles came to similar conclusions on the utility of HMD-AR technology as a facilitating element in various medical specialties, across various procedures, and medical education for learning improvements [32,33,34,35,36,37,38,39,40]. Whereas other studies investigated such constraints surrounding accuracy, precision, and even time-to-completion for a given surgical simulation task using HMD-AR technology [41,42,43,44]. Uniquely, in a study by Saruwatari et al., HMD-AR technology was found to not only demonstrate procedural efficiency and accuracy but also showed preferred usability in surveyed feedback obtained from study participants [45]. Ding et al. provided robot-assisted HMD-AR interventions that assessed accuracy of guided approaches during periacetabular osteotomy to investigate improving surgical accuracy and safety [46]. Moreover, Morley et al. found that HMD-AR technology performance capabilities exceeded positional tracking accuracy set by FDA standards placing the foundation for HMD-AR technology as a clinical support resource [47]. Therefore, the overall consensus seems to conclude that HMD-AR technology bears high potential for future applications on improvements in the field of medicine and translatable efforts towards skill-based training.

Of the remaining articles, three (14%) investigated rehabilitation methodologies or interventions. Findings by Guinet et al. showed the utility of HMD-AR technology in assessing gait in patients with cerebral palsy [48]. In the study by Tada et al., motor function capabilities were assessed showing the feasibility of HMD-AR technology in quantitative evaluation within rehabilitation tasks [49]. Held et al. investigated real-time feedback and improvements in gait performance, showing that the HMD-AR system held capabilities of uniquely providing biofeedback to the end-user [50]. These articles showed that motor function and motor learning capabilities can be assessed at a fundamental level of movement.

Finally, only one article (5%) by Ueyama and Harada, looked into motor skills training in an aim-related skill, specifically dart throwing [51]. This article was actually deemed to hold the highest relevance in terms of skill transferability to the tactical field covering the use of AR to train a particular fine motor skill with an aiming component.

Thus, it can be said that the field of medicine dominates the current applicable literature relative to HMD-AR utilization. Concurrently, it can also be said that there exists no literature at the writing of this paper whereby HMD-AR is used to assess performance-focused skill-based training in the tactical setting. However, there is a singular study by Ueyama and Harada that does delve into HMD-AR for skill-based training, which should be a foundation for future research.

5 Discussion

Although the study by Ueyama and Harada, which assessed a novel AR-based feedback system for dart throwing intended within the context of motor learning, did not show improvements while using the trajectory-guided AR-based application; it did lay the foundation providing direction for future research applications within motor learning and showcased HMD-AR technology as a skill-based performance tool [51]. Specifically, in the creation of cost-effective assessment modalities for field-specific training and rehabilitation, devices such as HMD-AR technology allow for high levels of customizability. Permitting the creation of specialized applications through Unity or other platforms whereby investigators can create augmented environments to meet the demands of their intended research [27].

5.1 HMD-AR Tactical Applications

The Laser Shot screen-based system functions similar to HMD-AR technology, however, it still holds one key drawback when compared with HMD-AR technology. Specifically, HMD-AR devices AR can be used anywhere with minimal setup, whereas the Laser Shot technology requires dedicated space, a particular laboratory-style setup, and due to the projector and screen-based elements require optimal indoor lighting conditions. HMD-AR technology only requires the AR device itself and optional implements depending on application-based intents, making it unparalleled in simulation technologies. Concurrently, it has been found that HMD-AR systems can function in variable lighting environments with minimal interference to the display of the virtualized objects [38]. Thus, the variability of utility in terms of location and minimized parts required places HMD-AR technology in a favorable position to provide at a minimum a replicable experience to what the Laser Shot technology can provide to an end-user.

Combining the intent and utility provided by aspects found within both HMD-AR technology, like that shown in the article by Ueyama and Harada, and the Laser Shot technology; future research within the area of tactical human performance is recommended to focus on skill-based training within applications built for HMD-AR technology in conjunction with external implements for such intents like that of aim training technology on particular weapon systems.

Providing gamified experiences using an HMD-AR technology could catapult weapon system training to a new level for organizations like the Army and allow for a cost-effective, mobile, engaging, and practical means to improving and maintaining aspects of Soldier lethality and readiness depending upon the designed application.

6 Conclusion

HMD-AR technology is a new technology, still less than a decade old. The utility and capabilities are still to be fully explored within the current literature. The benefits of HMD-AR are predominantly experienced by those in the field of medicine. However, despite insights into skill-based training applications still being limited within the current literature; there are strides towards investigating applications of HMD-AR in these areas. Furthermore, there exists no active literature in the field of tactical human performance on using HMD-AR technology to train specific skills or abilities, making this paper a novel investigation to address a gap in the literature. Overall, HMD-AR technology bears a highly customizable and unmatched approach toward capabilities relevant to conducting skill-based training, but further research is required to explore benefits and drawbacks to this technology.

References:

[1] Asari, M. K. S. M., Suaib, N. M., Abd Razak, M. H., Ahmad, M. A., & Shaleh, N. M. Empowering Skill-Based Learning with Augmented Reality and Virtual Reality: A Case Study. *IEEE International Symposium on Consumer Technology (ISCT)*, 2024, (pp. 225-229).

[2] Iop, A., El-Hajj, V. G., Gharios, M., de Giorgio, A., Monetti, F. M., Edström, E., ... & Romero, M. Extended reality in neurosurgical education: a systematic review. *Sensors*, 22(16), 2022, 6067.

[3] Siriborvornratanakul, T. Through the realities of augmented reality. *HCI International 2019–Late Breaking Papers: 21st HCI International Conference*, 21, 2022, (pp. 253-264).

[4] Rao, S. U., Ranganath, S., Ashwin, T. S., & Reddy, G. R. M. A Google glass based real-time scene analysis for the visually impaired. *IEEE Access*, *9*, 2021, pp. 166351-166369.

[5] Felden, C., & Wenzel, L. Google Glass as industry 4.0 technology. *Zeszyty Naukowe. Organizacja i Zarządzanie/Politechnika Śląska*, 2017.

[6] Davis E., Patel R. H., Graves B. S., Sawhney V., Gupta M., Pandya A. S. A Novel Framework for Analysis of Lower Limb Movements: Integration of Augmented Reality and Sensor-based Systems. *Sports Injr Med* 6: 183, 2022.

[7] Caruso, T. J., Hess, O., Roy, K., Wang, E., Rodriguez, S., Palivathukal, C., & Haber, N. Integrated eye tracking on Magic Leap One during augmented reality medical simulation: a technical report. *BMJ simulation & technology enhanced learning*, *7*(5), 2021, 431.

[8] Hardeman, L. E. S., Geerse, D. J., Hoogendoorn, E. M., Nonnekes, J., & Roerdink, M. Remotely prescribed and monitored home-based gait-and-balance therapeutic exergaming using augmented reality (AR) glasses: Protocol for a clinical feasibility study in people with Parkinson's disease. *Pilot and Feasibility Studies*, *10*(1), 54, 2024.

[9] Orion AI glasses: The future of AR glasses technology., Meta, 2024. https://about.meta.com/realitylabs/orion

[10] Hanfati, K., Sukaridhoto, S., Rante, H., Budiarti, R. P. N., & Nadatien, I. Application of mixed reality and artificial intelligence to assist medical students in learning injection technique. *Bali Medical Journal*, *12*(3), 2023, pp. 3363-3369.

[11] Barteit, S., Lanfermann, L., Bärnighausen, T., Neuhann, F., & Beiersmann, C. Augmented, Mixed, and Virtual Reality-Based Head-Mounted Devices for Medical Education: Systematic Review. *JMIR serious games*, *9*(3), 2021, e29080.

[12] Huang, T. K., Yang, C. H., Hsieh, Y. H., Wang, J. C., & Hung, C. C. Augmented reality (AR) and virtual reality (VR) applied in dentistry. *The Kaohsiung journal of medical sciences*, *34*(4), 2018, pp. 243–248.

[13] Mandal, P., & Ambade, R. Surgery Training and Simulation Using Virtual and Augmented Reality for Knee Arthroplasty. *Cureus*, *14*(9), 2022, e28823.

[14] Sinou, N., Sinou, N., & Filippou, D. Virtual Reality and Augmented Reality in Anatomy Education During COVID-19 Pandemic. *Cureus*, *15*(2), 2023, e35170.

[15] Laerdal Medical. Simulation Mannequin Portfolio. *SimMan Portfolio*. https://laerdal.com/us/information/simman-portfolio/

[16] Xie, B., Liu, H., Alghofaili, R., Zhang, Y., Jiang, Y., Lobo, F. D., ... & Yu, L. F. A review on virtual reality skill training applications. *Frontiers in Virtual Reality*, 2, 2021, 645153.

[17] Cross, J., Boag-Hodgson, C., Ryley, T., Mavin, T. J., & Potter, L. E. Using extended reality in flight simulators: a literature review. *IEEE transactions on visualization and computer graphics*, 29(9), 2022, pp. 3961-3975.

[18] Tusher, H. M., Mallam, S., & Nazir, S. A systematic review of virtual reality features for skill training. *Technology, Knowledge and Learning*, *29*(2), 2024, 843-878.

[19] Cascella, M., Cascella, A., Monaco, F., & Shariff, M. N. Envisioning gamification in anesthesia, pain management, and critical care: basic principles, integration of artificial intelligence, and simulation strategies. *Journal of anesthesia, analgesia and critical care*, *3*(1), 33, 2023.

[20] Saric, K., Redd, C., Varnfield, M., O'Dwyer, J., & Karunanithi, M. Increasing health care adherence through gamification, video feedback, and real-world rewards. *International Conference of the IEEE Engineering in Medicine and Biology Society,* 2018, pp. 1584-1587.

[21] Tosto-Mancuso, J., Tabacof, L., Herrera, J. E., Breyman, E., Dewil, S., Cortes, M., ... & Putrino, D. Gamified neurorehabilitation

strategies for post-stroke motor recovery: challenges and advantages. *Current Neurology and Neuroscience Reports*, *22*(3), 2022, pp. 183-195

[22] Reale, C., Salwei, M. E., Militello, L. G., Weinger, M. B., Burden, A., Sushereba, C., ... & Anders, S. Decision-making during high-risk events: a systematic literature review. *Journal of cognitive engineering and decision making*, *17*(2), 2023, pp. 188-212.

[23] Tornero-Aguilera, J. F., Stergiou, M., Rubio-Zarapuz, A., Martín-Rodríguez, A., Massuça, L. M., & Clemente-Suárez, V. J. Optimising combat readiness: Practical strategies for integrating physiological and psychological resilience in soldier training. In *Healthcare* (Vol. 12, No. 12, 2024, pp. 1160).

[24] Lage, G. M., Ugrinowitsch, H., Apolinário-Souza, T., Vieira, M. M., Albuquerque, M. R., & Benda, R. N. Repetition and variation in motor practice: A review of neural correlates. *Neuroscience and biobehavioral reviews*, *57*, 2015, pp. 132–141.

[25] Yang, L., Chen, J. A., & Zhu, W. Dynamic hand gesture recognition based on a leap motion controller and two-layer bidirectional recurrent neural network. *Sensors*, *20*(7), 2020, pp. 2106.

[26] Meli, L., Pacchierotti, C., Salvietti, G., Chinello, F., Maisto, M., De Luca, A., & Prattichizzo, D. Combining wearable finger haptics and augmented reality: User evaluation using an external camera and the microsoft hololens. *IEEE Robotics and Automation Letters*, *3*(4), 2018, pp. 4297-4304.

[27] Arthur, E., Sullivan, D. J., & Gardias, P. M. *Augmented reality as a means of improving efficiency and immersion of human-swarm interaction*, Doctoral dissertation - Worcester Polytechnic Institute, 2020.

[28] Sharma, A., Wu, L., Bloom, S., Stanga, P., RaviChandran, N., Ting, D. S., ... & Rezaei, K. A. RWC update: artificial intelligence and smart eyewearables for healthy longevity; choroidal hemangioma widefield optical coherence tomography. *Ophthalmic Surgery, Lasers and Imaging Retina*, *54*(2), 2023, pp. 74-77.

[29] Limoli, P. G., Morales, M. U., Costanzo, P., Limoli, C., & Reich, K. Augmented Reality Eyewear (ARE) for Home-Based Vision Training after Biofeedback Rehabilitation of Eccentric Viewing. *Optometry & Visual Performance*, *5*(1), 2017.

[30] Laser Shot - specialized training simulations. *Laser Shot Simulations*. https://lasershot.com/, 2025.

[31] Baashar, Y., Alkawsi, G., Wan Ahmad, W. N., Alomari, M. A., Alhussian, H., & Tiong, S. K. Towards Wearable Augmented Reality in Healthcare: A Comparative Survey and Analysis of Head-Mounted Displays. *International journal of environmental research and public health*, *20*(5), 2023, pp. 3940.

[32] Palumbo A. Microsoft HoloLens 2 in Medical and Healthcare Context: State of the Art and Future Prospects. *Sensors (Basel, Switzerland)*, *22*(20), 2022, pp. 7709.

[33] Birlo, M., Edwards, P. J. E., Clarkson, M., & Stoyanov, D. Utility of optical see-through head mounted displays in augmented reality-assisted surgery: A systematic review. *Medical image analysis*, *77*, 2022, pp. 102361.

[34] Rüger, C., Feufel, M. A., Moosburner, S., Özbek, C., Pratschke, J., & Sauer, I. M. Ultrasound in augmented reality: a mixed-methods evaluation of head-mounted displays in image-guided interventions. *International journal of computer assisted radiology and surgery*, *15*(11), 2020, pp. 1895–1905.

[35] Kubben, P. L., & Sinlae, R. S. N. Feasibility of using a low-cost head-mounted augmented reality device in the operating room. *Surgical neurology international*, *10*, 26, 2019.

[36] Al Janabi, H. F., Aydin, A., Palaneer, S., Macchione, N., Al-Jabir, A., Khan, M. S., Dasgupta, P., & Ahmed, K. Effectiveness of the HoloLens mixed-reality headset in minimally invasive surgery: a simulation-based feasibility study. *Surgical endoscopy*, *34*(3), 2020, pp. 1143–1149.

[37] von Haxthausen, F., Rüger, C., Sieren, M. M., Kloeckner, R., & Ernst, F. Augmenting Image-Guided Procedures through In Situ Visualization of 3D Ultrasound via a Head-Mounted Display. *Sensors (Basel, Switzerland)*, *23*(4), 2023, pp. 2168.

[38] Jiang, T., Yu, D., Wang, Y., Zan, T., Wang, S., & Li, Q. HoloLens-Based Vascular Localization System: Precision Evaluation Study With a Three-Dimensional Printed Model. *Journal of medical Internet research*, *22*(4), 2020, e16852.

[39] Moreta-Martinez, R., García-Mato, D., García-Sevilla, M., Pérez-Mañanes, R., Calvo-Haro, J., & Pascau, J. Augmented reality in computer-assisted interventions based on patient-specific

3D printed reference. *Healthcare technology letters*, *5*(5), 2018, pp. 162–166.
[40] Neuville, Q., Frantz, T., Van Gestel, F., Janssen, B., Vandemeulebroucke, J., Duerinck, J., & Scheerlinck, T. Validation of an Augmented Reality Based Functional Method to Determine and Render the Hip Rotation Centre During Total Hip Arthroplasty. *The international journal of medical robotics + computer assisted surgery: MRCAS*, *20*(6), 2024, e70011.
[41] Doughty, M., & Ghugre, N. R. Head-Mounted Display-Based Augmented Reality for Image-Guided Media Delivery to the Heart: A Preliminary Investigation of Perceptual Accuracy. *Journal of imaging*, *8*(2), 33, 2022.
[42] Liu, K., Chen, S., Wang, X., Ma, Z., & Shen, S. G. F. Utilization of facial fat grafting augmented reality guidance system in facial soft tissue defect reconstruction. *Head & face medicine*, *20*(1), 51, 2024.
[43] Cutolo, F., Fida, B., Cattari, N., & Ferrari, V., Software Framework for Customized Augmented Reality Headsets in Medicine, *in IEEE Access*, vol. 8, 2019, pp. 706-720.
[44] Southworth, M.K., Silva, J.N.A., Blume, W.M., Van Hare, G.F, Dalal, A.S., & Silva, J.R., Performance Evaluation of Mixed Reality Display for Guidance During Transcatheter Cardiac Mapping and Ablation, *IEEE Journal of Translational Engineering in Health and Medicine*, vol. 8, 2020, pp. 1-10.
[45] Saruwatari, M. S., Nguyen, T. N., Talari, H. F., Matisoff, A. J., Sharma, K. V., Donoho, K. G., Basu, S., Dwivedi, P., Bost, J. E., & Shekhar, R. Assessing the Effect of Augmented Reality on Procedural Outcomes During Ultrasound-Guided Vascular Access. *Ultrasound in medicine & biology*, *49*(11), 2023, pp. 2346–2353.
[46] Ding, H., Sun, W., & Zheng, G. Robot-Assisted Augmented Reality (AR)-Guided Surgical Navigation for Periacetabular Osteotomy. *Sensors*, *24*(14), 2024, pp. 4754.
[47]
[48] Guinet, A. L., Bouyer, G., Otmane, S., & Desailly, E. Validity of Hololens Augmented Reality Head Mounted Display for Measuring Gait Parameters in Healthy Adults and Children with Cerebral Palsy. *Sensors*, *21*(8), 2021, pp. 2697.
[49] Tada, K., Sorimachi, Y., Kutsuzawa, K., Owaki, D., & Hayashibe, M. Integrated Quantitative Evaluation of Spatial Cognition and Motor Function with HoloLens Mixed Reality. *Sensors*, *24*(2), 2024, pp. 528.
[50] Held, J. P. O., Yu, K., Pyles, C., Veerbeek, J. M., Bork, F., Heining, S. M., Navab, N., & Luft, A. R. Augmented Reality-Based Rehabilitation of Gait Impairments: Case Report. *JMIR mHealth and uHealth*, *8*(5), 2020, e17804.
[51] Ueyama, Y., and Harada, M., Augmented Reality-Based Trajectory Feedback Does Not Improve Aiming in Dart-Throwing, *IEEE Access*, vol. 11, 2023, pp. 64738-64744.

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The content of the article was fully conceptualized by Edward Davis and Valentina Saracino. All other authors equally contributed in the present to review the article and provide feedback on crafting the final product to be published, and at all stages of the scoping review, from the formulation of the problem to the final findings, all authors equivalently contributed to the final product presented in this article.

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