Human Factors Considerations in the Development of Extended Reality (XR) Training Systems

Victoria Cutler[1], Caitlin Moore[1], David Taylor[1], Beata-Noemi Balint[1], Rhys Hunt[2] & Mayowa Olonilua

[1]QinetiQ Ltd, UK, [2]Defence Science and Technology Laboratory, UK

SUMMARY

This research identified the Human Factors (HF) considerations associated with using Extended Reality (XR) systems for military training, by applying the UK Ministry of Defence (MOD) Early Human Factors Analysis (EHFA) methodology. Fifty-five HF considerations were identified, addressing user characteristics, equipment design, and organisational processes. Specific actions were recommended to address the identified HF considerations and support effective use of XR in training delivery.

KEYWORDS

Extended Reality, Training, Military

Introduction

Military training carries with it inherent risks from reflecting battlefield hazards, and can require access to expensive specialist equipment and large numbers of supporting personnel (Knerr, 2007; Alexander, Brunyé, Sidman and Weil, 2005). With the increasing availability and maturity of consumer-ready Head-Mounted Displays (HMDs), Extended Reality (XR)[1] training systems have the potential to address these challenges – by simulating the battlefield environment and specialist military equipment, and reducing the numbers of supporting personnel required (Knerr, 2007; Alexander et al, 2005). These potential benefits of using XR systems in military training will only be realised if the integration of the user in the system design is effective. Stone (2012) highlighted the importance of learning human-centred lessons from early implementation of Virtual Reality (VR) to ensure that future training systems are effective and meet the needs of both the trainees and instructors.

Previous work has identified Human Factors (HF) issues which influenced the effectiveness of military training delivery in XR. For instance, Vine, Harris, Bird, Wilson and de Burgh (2021) identified that effectiveness will depend on the validity and fidelity of the tool, motivation to use VR, difficulties in training the task in the real world, type of skill being trained, and desired learning outcomes. Palfrey, Taylor and Govan (2021) highlighted the importance of user and system considerations such as usability, cybersickness, and headset design when implementing a XR solution for flight training. Similarly, a study comparing a VR computer game to its desktop

[1] In the context of this research, XR is an umbrella term used to encompass all elements of VR, Augmented Reality (AR), and Mixed Reality (MR) systems. As a minimum, XR training systems include a headset that is used to present visual stimuli to the trainee, a means of making control inputs, and a software system that runs the training scenario; although a wider range of sensor, feedback, and tracking systems may be integrated in the system.

equivalent found that a lack of familiarity with the system and poor usability can increase cognitive load and reduce the ability of users to engage in team competencies (Balint, Dudfield and Stevens, 2022). However, no study was identified that collated HF considerations associated with using XR for military training to support teams in the development and implementation of XR based training solutions. As such, the primary aim of this research, undertaken as part of the DELTA[1] project, was to identify the HF considerations associated with using XR for military training, and develop guidance to mitigate any risks that were identified.

The scope of the research included all elements of XR systems, all training types, and all personnel who would interact with the XR system – including instructors, trainees and support personnel. However, the specific topic of Cybersickness was excluded. Cybersickness is a type of motion sickness that is caused by a disagreement between the visual and bodily senses of motion (Bos, Lawson, Allsop, Rigato and Secci, 2021). Cybersickness was excluded from the scope to avoid duplication of effort as NATO (2021) had recently published a paper on ‘Guidelines for Mitigating Cybersickness in Virtual Reality Systems’.

Approach

The research applied the UK MOD Early Human Factors Analysis (EHFA) approach (MOD, 2016). EHFA is typically used in the early stages of technology acquisition to identify the HF considerations that need to be taken into account during procurement, prioritise those considerations, and develop mitigations to address them. HF considerations include Risks, Assumptions, Issues, Dependencies and Opportunities (RAIDO). The EHFA process consists of five stages (MOD, 2016) and is shown in Figure 1.

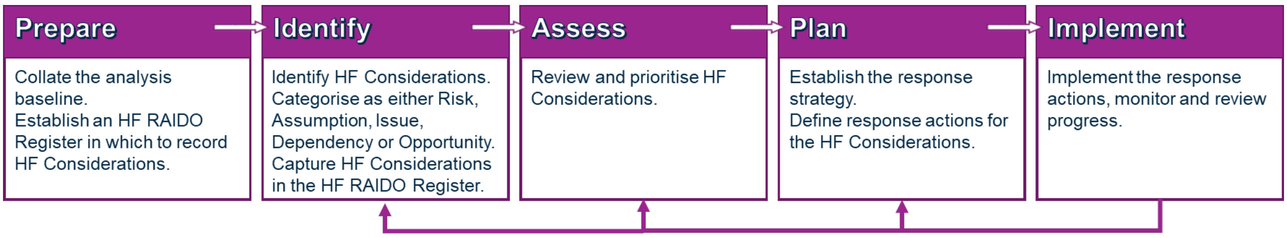

Figure 1: EHFA Process

During the **Prepare** stage, the analysis baseline was established, which included identifying documents related to the use of XR in military training and conducting interviews with Subject Matter Experts (SME) in both XR and in military training. Seventeen documents were reviewed, primarily comprising of research outputs related to the use of XR in military training, but also included guidance materials and policy documents. Six semi-structured interviews were carried out with people from UK MOD (2 interviewees) and Industry (4 interviewees) who were involved in the management, procurement and design of XR systems. The interviews and documents included examples of first-hand experience of using XR systems for military training. The questions asked were based on prompts outlined in the EHFA Methodology Guide (MOD, 2016) and covered issues

[1] The Defence Science and Technology Laboratory (DSTL) have established the Developing Education Learning and Training Advances (DELTA) project to identify, develop and test innovative approaches to accelerate and enhance learning, training, education, development and preparation of military personnel.

of personnel, training, human factors engineering, system safety, and social and organisational issues. Also, during the prepare stage an HF RAIDO Register was established based on the UK MOD RAIDO Register Template.

At the start of the **Identify** stage, two HF specialists and one XR researcher reviewed the EHFA analysis baseline, including the documents and interview transcripts. As the documents and interviews were reviewed, potential HF considerations were noted. The potential HF considerations were subsequently reviewed in a collaborative workshop involving HF and XR specialists to produce a draft set of HF considerations which were captured in the HF RAIDO Register.

The draft HF considerations were reviewed and prioritised during the **Assess** phase, by first rating their probability and impact (using a low/medium/high scale), and then combining these ratings to produce a probability-impact score. The definitions of probability and impact were taken from the EHFA Methodology Guide (MOD, 2016). The probability and impact ratings were agreed between the specialists who took part in the identification workshop, and representatives of the user community.

During the **Plan** stage, response plans and associated actions were developed for each HF consideration. This process began by selecting a response strategy for each HF consideration – to either take action to address the consideration or accept it. For all considerations where the response strategy was to take action, a detailed set of actions were prepared to mitigate the negative consequences and maximise the positive impact of the XR technology.

The final stage of the EHFA – **Implement** – will involve taking the actions described in the response plans. However, implementation of the response plans will be undertaken outside of the scope of the current study.

Findings

Fifty-five HF considerations were identified through the EHFA. The HF considerations were categorised as either a Risk, Issue, Assumption, Dependency or Opportunity. The majority of considerations were risks, with 44 being identified, there were also three assumptions, three dependencies and five opportunities. No issues were identified – although this was a facet of the definition used – as no specific XR system was being examined none of the risks were certain to occur.

The HF considerations covered a broad range of topics including equipment design, the number of personnel required to work with the system, the attributes of users, safety considerations, and the social and organisational impact of XR systems. Each HF consideration was mapped against the topic areas in the UK MOD structure of five Human Factors Integration (HFI) Domain, and the number of considerations associated with each domain is shown in Table 1. The numbers in Table 1 add up to more than the total number of considerations, as some considerations related to more than one HFI domain.

Table 1: HF considerations by type and HFI domain

HFI domain	Risks	Assumptions	Dependencies	Opportunities
Personnel	5	0	0	0
Training	4	2	3	3
Human factors engineering	30	1	0	2

System safety and health hazards	11	0	0	0
Social and organisational	5	0	0	1

HF Considerations

The highest priority risks, which were rated high for both probability and impact were:

- Potential for the benefits of XR technology to be overestimated due to its **novelty**, leading to XR being used in situations in which it is not suitable and/or does not benefit training.
- Difficulty in representing **non-verbal cues** during team training, resulting in insufficient transfer of these skills to live scenarios. Non-verbal cues include representing the trainees' non-verbal cues in the simulated environment, and the non-verbal cues of Non-Playable Characters (NPC) within the scenario.
- Achieving an adequate level of **presence and immersion** when training in XR. If trainees lack an adequate sense of presence and immersion, then there is a risk that the training will be ineffective. However, there is a lack of understanding of the required level of presence and immersion for effective training, and the factors that contribute to presence and immersion are not fully understood in the research literature. Presence and immersion are separate considerations, but were grouped in the EHFA as the same shortfalls in research and literature apply to both.
- **Negative training**, when behaviours in XR differ from those used in real scenarios, could lead to ineffective performance when skills are used in real life. Negative training can occur because of limitations of synthetic training, such as the inability to accurately represent a task, using the wrong model, or implementing a shortened version of the process.
- Adoption of a suitable **instructor-student ratio** for the training delivery. The role of the instructor in XR training is still being developed, and will vary depending on the tasks being trained and the nature of the XR simulation. If the instructor-student ratio is ineffective, it will impact on instructor workload and the quality of training delivered.
- Accommodation of users who wear **glasses and/or have other visual conditions**. There is a risk that some people may not be able to use XR training, if they possess visual conditions that are not accommodated by the XR headset.
- Accommodation of users with a very large or small **Inter-Pupillary Distance (IPD)**. Where it is not possible to adjust the XR headset to the IPD of the user, there is a risk of poor visual clarity and in some cases, personnel may not be able to use the system.
- Having an adequate number of appropriately skilled **personnel to support the system**. The support requirements for XR systems used in military training are still being understood. The number of support personnel, and the skills required by those personnel will depend on the technology used and the tasks being trained. A lack of adequate support personnel could result in the XR system being unavailable when required.

The highest priority opportunities (also rated high for both probability and impact) were associated with:

- Data captured by the XR system being used to improve **training feedback**. XR provides the ability to capture a large quantity of data automatically, and make that data available to support the process of delivering feedback to trainees on completion of their training. Effective training feedback can be powerful in supporting trainee performance, and so exploitation of the data captured provides an opportunity to enhance military training.

- **Biometric data** captured by the XR system being used to improve training delivery. The capabilities of XR systems enable new forms of data to be captured including biometric data such as eye movements, facial tracking and body tracking. Biometric data could provide insights that can be used to improve training delivery, feedback and content.

In line with the EHFA methodology, assumptions and dependencies were not assigned a probability-impact score, but their qualitative impact is described in the HF RAIDO Register

Response plans

During stage four of the EHFA process, response plans were generated to mitigate the risks and exploit the opportunities offered by XR. The response plans were grouped into three broad categories:

- Research and development;
- Improving readiness for XR training; and
- System specific development activities.

Research and development activities comprised actions that were not specific to the development of an individual training solution, that address shortfalls in knowledge, understanding, and guidance. Completing the research and development activities would provide the foundations on which HF considerations can be addressed in future XR training systems. Specific response actions included capturing lessons learned from initial implementations of XR systems, conducting research into specific topics (such as the duration of XR sessions, the impact of visual conditions on XR use, and using biometric data for training feedback), and developing standards and guidance on topics where existing research could be read across to XR training (e.g. headset weight and balance and instructor interface design).

Activities to **improve readiness for XR training** would better prepare the user population to work effectively with XR training solutions when they are implemented. These activities included education initiatives for the military training community, and increasing exposure of end users to XR systems.

System specific development activities accounted for the majority of response plans. These activities would be taken as part of the acquisition and implementation of a specific training solution. The system specific development activities would be sequenced through the system development cycle and reflect the implementation of a Human Centred Design (HCD) approach. Recommended system specific development activities include:

- Definition of system users, including provision of data to enable appropriate sizing of the headset, and specifying the number of personnel anticipated to work with the system.
- Task analysis of instructor, trainee, and maintainer tasks.
- Setting appropriate user and system requirements to implement known mitigations for HF considerations.
- Conduct of Training Needs Analysis (TNA), integrating an appropriate analysis of training options to allow specification of the required simulation fidelity, presence and immersion; actions to mitigate the risk of negative training; and the selection of appropriate control devices. The TNA should account for the full range of tasks conducted with the XR system including the operation of the XR system itself, instructor activities, and delivery of posttraining feedback.

- Development of design solutions to implement the system requirements and address issues of data privacy, user workload, safety, and the operating environment.
- Undertaking iterative system evaluation, with particular consideration to the impact of using wearables, presentation of key information in the virtual environment, and user workload.

Next steps

To support the implementation of these response plans, the results of the XR training EHFA, including the considerations, their prioritisation and response plans, are to be developed into an HF Advice Tool. The HF Advice Tool will provide UK MOD stakeholders easy access to guidance on the HF considerations when selecting and implementing an XR training solution, with prioritised actions to address those considerations. The next stage of the project is to develop this advice tool.

Conclusions

The increasing maturity of XR hardware has the potential to supplement current training and overcome the challenges associated with existing training methods, reducing costs and personnel risks, and enabling training to take place anywhere at any time. To realise the benefits associated with XR training systems the human-related risks associated with XR training must be controlled. The current study aimed to support this, by identifying the HF considerations associated with using XR for military training, and develop guidance to mitigate any risks that were identified.

Through the application of the EHFA methodology, 55 HF considerations were identified and prioritised by an interdisciplinary team of HF practitioners and XR specialists. This enabled ten high priority considerations – comprising eight risks and two opportunities – to be identified as a particular focus in future system development.

Response plans were established to mitigate the risks and exploit the opportunities identified in the EHFA. Mitigations included undertaking research and development, improving the readiness for XR training, and undertaking system specific development activities. These response plans will be integrated into an HF Advice Tool to provide UK MOD stakeholders with guidance to address HF considerations in their training context.

A key limitation of the work is that XR technologies are changing rapidly and, even during the timeframe of this project, new innovations came to the market that impacted on the HF considerations that were identified. A second limitation of note is that the key consideration of Cybersickness was excluded, as guidance is available separately to address (NATO, 2021). The design of the HF Advice Tool will take these limitations into account and ensure that users are aware of them and can access appropriate guidance when taking action.

Overall, this project has enhanced the understanding of HF considerations associated with using XR in military training. Implementation of the guidance generated by this project will support effective integration of the user in future military XR systems and the ability of XR to address key challenges in military training.

References

Alexander, A. L., Brunyé, T. T., Sidman, J., & Weil, S. A. (2005). From gaming to training: A review of studies on fidelity, immersion, presence, and buy-in and their effects on transfer in PC-based simulations and games. Woburn, MA: DARWARS Training Impact Group.

Balint, B. N., Dudfield, H., & Stevens, B. (2022). Transforming team training: The influence of virtual environment features. Paper presented at the 2022 Interservice/Industry Training, Simulation, and Education Conference.

Bos, J. E., Lawson, B. D., Allsop, J., Rigato, P., & Secci, S., (2021). Introduction. In North Atlantic Treaty Organization (NATO) (2021). Guidelines for mitigating cybersickness in virtual reality systems. TR-HFM-MSG-323.

Knerr, B. W. (2007). Immersive simulation training for the dismounted soldier. United States Army Research Institute for the Behavioral and Social Sciences Study Report 2007-01.

Ministry of Defence (MOD) (2016). Early Human Factors Analysis (EHFA) methodology guide. TG11-1.

North Atlantic Treaty Organization (NATO) (2021). Guidelines for mitigating cybersickness in virtual reality systems. TR-HFM-MSG-323.

Palfrey, N., Taylor, D., & Govan, T. (2021). RAF XR for flying training design considerations report. NSC-820-1147.

Stone, B. (2012). Human factors guidance for designers of interactive 3d and games-based training systems. Human Factors Integration Defence Technology Centre.

Vine, S., Harris, D., Bird, J., Wilson, M., & de Burgh, T. (2021). Guidance for using VR in hard to train tasks literature review. NSC-820-956.