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Mixed Reality Training Method: Performance Benefits for Routine Vehicle Maintenance Tasks

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MIXED REALITY TRAINING METHOD: PERFORMANCE BENEFITS FOR ROUTINE VEHICLE MAINTENANCE TASKS

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ABSTRACT

Mixed Reality (MR), as a training medium, has been trialled as method to train New Zealand Army automotive technician apprentices in routine vehicle maintenance tasks. It is important to understand how this might impact the task performance of apprentices. This paper investigates the topic and addresses the research question: How does a MR training method influence productivity and quality of a routine vehicle maintenance task conducted on military vehicles? To address this topic, a pilot study was conducted that compares the performance of eight automotive technician apprentices who were tasked with conducting a routine vehicle maintenance task using the extant or current training method, and MR training method. Apprentices completed pre-training and post-training surveys to provide their perceptions of the experience. The results showed that there is no significant difference between the extant and MR training methods with regards to apprentice's task performance times. However, the MR training method led to fewer errors during the training task. Additionally, participants agreed that MR is easy to use, but would not replace the need to have a qualified instructor on hand. While the small sample size limits the extent to which these finding can be generalised, the contribution of this work is in demonstrating, as a proof of concept, that MR training methods can be a viable option for training routine vehicle maintenance tasks and that it can offer advantages that are not currently observed through the use of the extant training method.

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EXECUTIVE SUMMARY

BACKGROUND

Mixed Reality (MR), as a training medium, has been explored as method to train New Zealand Army automotive technician apprentices in routine vehicle maintenance tasks. The MR training solution was developed as a training tool allowing assessment with the primary aim being enhancement of the training experience. The vehicles were 'augmented' with an interactive virtual environment. The Microsoft HoloLens headset used in this experiment enabled users to interact with computer-generated images, educational video narrations, text and other learning materials 'anchored' to the learning environment (Trade Training School workshop and military vehicles). A pilot study was conducted that compared the performance of eight automotive technician apprentices who were tasked with conducting a vehicle maintenance task using the current or extant training method and MR training method. Additionally, participant's perceptions were elicited with regards to the utility of the MR training method for routine vehicle maintenance tasks in the Trade Training School (TTS) workshop environment.

AIM

The aim of this experiment was to develop an understanding of the performance impacts, and the potential objective and subjective training benefits of using MR for a vehicle maintenance task.

RESULTS AND CONCLUSIONS

This research found that participants (TTS apprentices) produced fewer errors using the MR training method in comparison to the extant training method. A reduction in errors suggests that the MR training method has the potential to reduce re-work, saving valuable resource (time and money). There was no significant difference in task performance (time to complete task) between the extant training method and the MR training method. Participants agreed that the MR training method was easier to use than the extant training method and that the MR training would be beneficial to new apprentices. They strongly agreed that they were more engaged in training tasks when using MR in comparison to using the extant training method. However, they did not agree that MR training would replace the need to have qualified instructors present during the training programme.

SPONSOR

Mr. Hayden Robinson, Experimentation Manager, New Zealand Army.

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1.0 INTRODUCTION

As budgets come under increased scrutiny and the current and future fiscal environment continues to 'compress', it is important that acquisition decisions are based on empirical evidence. Prior to investing resource to provide a MR training medium for automotive technician apprentices, the New Zealand Army wanted to investigate "To what extent can Mixed Reality technology provide enhancement and efficiencies in the delivery of training with Army's Trade Training School?"

The Defence Technology Agency (DTA) was approached by the Experimentation Manager for the New Zealand (NZ) Army to devise an experiment to assess the viability and utility of MR technology as a potential additional training medium for the Army's Trade Training School (TTS). Providing an effective training tool to military apprentices to assist with vehicle maintenance procedures is a relevant educational goal.

The NZ Army has used MR to deliver content to enable automotive technicians to acquire, or increase their previous know-how in a set of procedural vehicle maintenance skills. To achieve this, the training method had to be designed to achieve two main aims:

- The MR training method has to help apprentices to effectively and efficiently perform all the steps to achieve the training goals.
- The MR training method has to engage apprentices in developing core skills for performing the procedures – such as abstract reasoning, visualization and management of complex information.

Automotive technician apprentices learn highly specialised and multi-step tasks. They have to perform these tasks with a series of steps conducted in the correct sequence:

- disassembly of the vehicle and removal of faulty system components
- replacement or repair of these components
- re-assembly of the vehicle part.

The MR training solution was developed by Taqtile as a self-instructional training tool allowing assessment with the primary aim being enhancement of the training experience. The vehicles were 'augmented' with an interactive virtual environment. The Microsoft HoloLens™ headset used in this experiment enabled users to interact with computer-generated images, educational video narrations, text and other learning materials anchored to the learning environment (TTS workshop and vehicles). Participants used natural gestures, body movements to interact with the MR technology and perform their tasks. The HoloLens headset enabled participants to be hands-free and to maintain visual perception of their surroundings.

2.0 BACKGROUND

2.1 What is MR?

According to Milgram and Kishino (1994), mixed reality can be defined by a “reality spectrum” that incorporates both ends of this spectrum, and blurs the boundaries between virtual reality (VR) and augmented reality (AR). MR enables interaction between the real world and virtual world; it brings people, places, and objects from the physical and digital worlds together.

MR is defined by Stone (2018) as a form of simulation that attempts to exploit the existence of real-world objects in order to enhance the believability, and indeed usability, of constituent virtual elements, which are typically projected on (sometimes described as anchored to) those objects.

MR is described by Asgary (2017) as an ‘e-REAL’ experience. An e-REAL experience merges the real and the virtual worlds; an environment where physical and digital objects co-exist and interact in real time which enables a number of activities using gestures and spoken commands. The learner is submerged in an immersive reality that is context related in the form of sophisticated, interactive computer animation in 3D and holographic projections. The information is presented in such a way that it provides systemic understanding and a greater situational awareness through the provision of relevant cognitive aids.

2.2 Literature review: Learning outcomes/benefits of MR as a training tool

According to Cheng (2016), training taught through MR technologies frees up the working memory, which is limited for things that immediately need retrieval. Cowan (2013) defines working memory as “the retention of a small amount of information in a readily accessible form.” Working memory facilitates planning, comprehension, reasoning, and problem-solving. In contrast, the long-term memory holds the vast amount of information saved over one’s life-time. Cheng claims that MR places the training content in the immediate working area and prevents time being wasted retrieving training tools e.g. instruction manuals. MR also uses image recognition to detect and place the training content in contextually-relevant places using simultaneous localisation and mapping (SLAM). SLAM tracks where the trainee is in the real world. The trainee’s working memory is freed up and orientated to work in a sequential and logical way through the steps of the training task.

Fraga and Mallet (2018) report that MR can be used to design and organise the content of the training to best facilitate learning. For example, 3D visualisations for assembly tasks, especially those that require spatial reasoning, frees up the trainees’ capacity to more effectively orientate and conceptualise the application of the training information at hand.

Salvetti et al (2018) explored two self-instruction learning simulation programmes using Microsoft HoloLens technology and found that interactive MR maximised learning results, helping to enhance communication and cognitive flexibility. They found that retention of information improved, and consequently, this reduced the amount of instruction trainees needed. Mateu et al (2014) report that training that utilises MR facilitates the understanding of abstract concepts by performing tasks, which provide immediate feedback allowing for trial-and-error learning.

A meta-analysis conducted by Radu (2014) reports the benefits and efficiencies of using AR/MR in training/education include:

- Training content is represented in innovative ways.
- Training content is presented in multiple forms/representations over space and time.
- The trainee is physically enacting the training content being presented including some of the abstract concepts/tasks.
- The trainee is directed/prompted to relevant content.

Radu points out that when utilising AR/MR technologies for training, educators must take into account that it can be difficult to provide an integrated learning environment. Trainee's attention is honed to attending to the information presented through the headset and not to the wider learning environment they are part of where additional instruction may be given. This point is particularly important to consider in relation to training environments where there are potential hazards that pose a risk to health and safety.

Henderson and Feiner (2011) conducted a pilot experiment with a head-mounted display (HMD) technology to augment 18 tasks carried out by military mechanics. They found that the HMD allowed mechanics to locate tasks more quickly and showed that mechanics found the use of MR intuitive and satisfying for the sequence of mechanical tasks that they performed.

According to Marshall (2007), tangible interfaces delivered through technologies like MR can deliver many benefits to the learning process, such as:

- Accessibility of information for learning (more intuitive and easy to use)
- Providing novelty value (tangible objects may increase reflection).

Mantovani et al (2013) claim that there are three main reasons VR/MR tools are a highly effective medium to train service maintenance operators:

- After the initial investment in VR/MR technology, and the maintenance costs (upgrading software/hardware), VR/MR tools reduce overall training costs.
- Trainees learn while they are actually performing the task and can visualize and interact with simulated objects. The interactive nature of the training improves the operator's acquisition of skills. Furthermore, VR/MR is easily adapted to the trainee's specific learning needs.
- Trainers/instructors can use VR/MR technology to collect an extensive amount of data about the impact of training in terms of learning outcomes.

> They can use this data to adjust the training modules to provide a more tailored and targeted learning outcome. For this reason VR/MR technologies are considered to be powerful and effective means of developing ‘on-point’ training.

Steptoe et al., (2014) and Thorn et al., (2016) describe how MR enables the exploration of digital objects from a first person perspective but also allows the trainee to see the real setup with co-located real objects. They claim that trainees typically perceive the training experience offered by MR technology media as more positive than with traditional training methods (classroom, PowerPoint, workbooks etc.) because VR/MR tools help to improve understanding of tasks and procedures.

Webel et al (2013) studied the effects of training technicians with VR/MR tools who had to assemble an electronic actuator of a motorised modulating valve which took approximately 8-9 minutes to assemble. The results show that the trainees had a significantly lower number of unsolved errors, but that their performance times were not better than those who simply watched an instructional video.

Gurerk et al. (2017) conducted a series of field experiments with apprentices looking at the training benefits of using MR headsets for a real repair task (mending a cracked windscreen). They found that there was no immediate productivity effects when compared to training conducted using traditional methods. They did however find that the use of a MR training method had an immediate and positive effect on work quality. They noted that this positive effect did diminish over time as apprentices gain more experience.

Angelopoulous et al (2018), report that combat lethality depends on a viable and repeatable maintenance process. Specifically, failed maintenance diverts essential resources, increases the risk that mission accomplishment will be unsuccessful, and ultimately could result in diminished combat lethality. They stress the importance of communicating maintenance process information in a manner that reduces the potential for misinterpretation. They conducted a study to examine the effect of mixed reality cued maintenance procedures (using Microsoft HoloLens) on human efficiency and precision. They found that the vehicle maintainers using MR cueing, were more efficient and precise than when maintainers used technical manuals.

According to Williams (2017), many companies around the world are developing MR technology to assist automotive manufacturers to improve efficiency and productivity. BMW has used MR technology to assist with a range of applications including prototype development and inspections.

Doshi (2017) studied the effects of using MR technology in a quality assurance setting at General Motors (GM) Holden plant in Australia. The MR technology was used to highlight spot-weld locations on vehicle panels for welding operators. The aim of the trial was to analyse and validate the precision and accuracy of spot-welds using MR. The visual cues provided by the MR technology enabled operators to spot-weld with a higher degree of precision and accuracy.

The literature outlines a number of benefits of using MR as a media for training. Essentially, the ability to offer multiple ways of presenting training information enables trainers to tailor training solutions that aim to meet training objectives effectively and efficiently.

2.3 Literature review: Evaluating the training outcome

According to Kurilovas (2014), in order to fully evaluate the quality of the learning platform, both expert-centred (so called top-down) and learner-centred (bottom-up) approaches should be applied. The bottom-up approach involves end users commenting on the quality of the learning platform/environment. In line with this approach, this experiment used pre-training and post-training surveys to gauge perceptions regarding the utility and value of using MR technology for training routine vehicle maintenance tasks. In the top-down approach, evaluation is performed by the external investigators using research analysis methods. In both approaches the first step should be to develop a set of quality criteria of the learning platform/environment, against which the evaluation should be performed.

From a technological point of view, Kurilovas (2016) states that it is important to evaluate the quality of the learning and that the learning assessment should consider both internal-quality-criteria and quality-in-use criteria. Internal-quality is a descriptive characteristic that defines the quality of software independently from any particular context of its use (e.g. interoperability, modular authentication, robustness, and stability). Quality-in-use is an evaluative characteristic of software obtained by making a judgement based on the criteria that determine the worthiness of software for particular users.

According to Kurilovas, et al (2014), the learning medium should be personalised. Personalisation refers to developing the learning medium according to the main characteristics/needs of the learner's e.g. prior knowledge, intellectual level, and inductive reasoning ability. Understanding the learning users profile is a critical factor to consider and will ensure that the learning medium achieves the desired learning outcomes.

Stone et al (2017) recommend adopting the human-centred design approach from the outset in the development of any form of technology-based simulation. The principles outlined in the International Standard ISO 9241, Ergonomics of Human-System Interaction (ISO, 2010; specifically, but not exclusively Part 210: *Human-Centred Design for Interactive Systems*). Part 210 stipulates six guiding principles, each of which has relevance to development of training.

They are:

1. That the design is based upon an explicit understanding of training tasks and environments or contexts of use.
2. That end users or 'stakeholders', personnel from the armed services – instructors, plus other subject matter experts (SMEs) – are involved throughout the design and development activities.
3. That the design is driven and refined by user-centred evaluation.
4. That the design process is iterative (e.g. involving regular 'technology refresh' and system development reviews with stakeholders).

5. That the design addresses the entire user experience (takes every opportunity to enhance the user's entire training experience by providing operationally relevant training contexts).
6. That the design team includes multidisciplinary skills and perspectives.

Borsci et al (2015) reviewed a number of studies on the effectiveness of VR and mixed reality tools for training service maintenance operators. Their main findings were:

- MR systems are more useful tools for training assembly and disassembly tasks compared to VR.
- Training on service maintenance with VR/MR tools results in a lower number of errors and less training time compared to traditional training methods.
- Trainees usually perceived the training experience with VR/MR tools as more positive than classic training methods because these tools help them to increase their understanding of tasks and procedures.
- VR/MR tools can be used with different levels of effectiveness on the basis of the operator's experience. For example, an expert operator's training may be accelerated by the computer-generated objects while a novice operator may be overwhelmed and impair their learning experience. This reinforces a well-known principle amongst educators that it is essential to understand the learners' needs when designing training.

The literature clearly outlines the importance of ensuring that VR/MR training is developed with a clear understanding of the training objectives. This will help to ensure the effectiveness of VR/MR training.

3.0 METHODOLOGY

3.1 Participants

Eight automotive technician apprentices from the Trade Training School (TTS), located at the Trentham Military Base, participated in this study. They were six months into their four-year training programme. All participants were male aged between 18-25 years of age. All but one of the apprentices had no experience whatsoever with MR technology. The one participant who had experience had used MR outside of work and only on the one occasion. Because of the proof-of-concept nature of this experiment, a convenience sampling technique was applied.

3.2 Materials

3.2.1 VIDEO RECORDING DEVICES

Participants used either the Microsoft HoloLens™ or the Tobii Pro™ glasses depending on experimental condition. While using the HoloLens, video data was captured using the HoloLens' built-in video capture capability using on-board cameras. This video capture was however restricted to five-minute schedules and therefore required instructor intervention after each five-minute segment to re-enable video capture. For those participants not using the HoloLens, video from the same perspective was captured using the Tobii Pro Glasses.

3.2.2 MR CONTENT

To study the impacts of MR on the training of a vehicle maintenance task, the task, made up of a number of steps, were 'authored' with Manifest software by the TTS instructors.

The Microsoft HoloLens is a head-mounted display with a see-through screen capable of presenting co-located 3D virtual objects within the physical environment and attached to physical surfaces of interest, in this instance, vehicle structures. HoloLens displays virtual objects by relying on infrared scanners to map and understand the area. This enables the stable visualisation of the virtual objects within the physical environment. HoloLens is operated hands-free and is not tethered with a physical connection to a computer when in use. Experiment participants were able to move freely within the workspace.

The content for Manifest (the software used for the MR training method) was developed from vehicle maintenance training manuals and also included annotated photos and videos to prompt participants to perform each step.

3.2.3 VEHICLES

Two New Zealand Army vehicles were used in the conduct of the study, one Light Armoured Vehicle (LAV) and one Medium and Heavy Operational Vehicle (MHOV). These vehicles were located in the Motor Trade Workshop within the TTS. These vehicles were raised on jacks and each had the front wheel on the left and right side removed. Each vehicle was then taped off within each workshop to provide an exclusion zone for safety purposes.

3.2.4 VEHICLE TOOLS

All tools required by participants of the study were provided to them on an adjacent workbench within each vehicle's exclusion zone.

3.3 EXPERIMENTATION DESIGN

Two types of data were collected during the experiment:

- Qualitative (perceptions of participants) data in the form of pre-training and post-training (multi-choice question) surveys, and a workshop where participants provided feedback about their user experience;

- Quantitative data derived from video recordings while participants performed the vehicle maintenance tasks, and error rates were assessed by the instructors.

The researchers aimed to compare the performance of each participant using the extant (paper based maintenance manual) training method with the MR training method to complete training for the vehicle maintenance task. A cross-over experimental design was used to make this comparison. Two similar routine vehicle maintenance tasks (remove and inspect brake drum) were selected, and each was conducted on two different military vehicles, the Light Armoured Vehicle (LAV) and the MAN HX 60 (MHOV) vehicle.

The tasks contained the same number, of steps, in a linear sequence, but as they were performed on different vehicles, the tools and orientation of parts were different. (Figure 1).

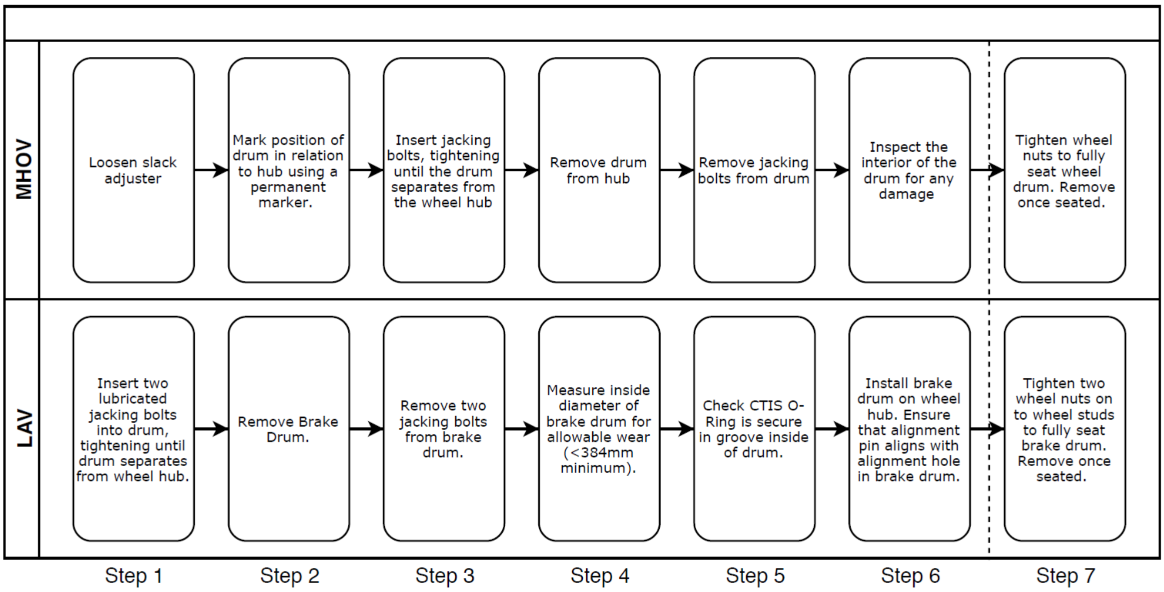

Figure 1. Diagram of vehicle maintenance tasks showing steps.

No participant performed the same vehicle maintenance task using MR or extant training method on the same vehicle. If this approach had not been used a participant might have trained on the same vehicle using the MR and extant training methods and their performance could have been impacted by what they learned during their first training attempt. Moreover, if all participants started with one training method, the result could be subject to an order-induced error. Therefore, the researcher also varied which mode of training was provided to a participant first (half the participants started using MR training and half of the participants started using extant training).

To execute this methodology, the eight participants were divided into four groups of two. Participants in each group would separate, one training on one vehicle using the MR training method and the other training on the second vehicle using the extant training method. They then switched over (vehicles and training method) until they completed training on both vehicles using different training methods for each. Table 1 summarises the division of groups between the vehicles and the training method used. The table which shows that two groups (a total of four participants) completed each vehicle task using each training modality.

Instructors were on hand to manage health and safety and ensure that the vehicle equipment and tools were not damaged during the training tasks.

	Extant (paper-based)		MR	
Group (n=2)	LAV	MHOV	LAV	MHOV
1	1st			2nd
2	2nd			1st
3		1st	2nd	
4		2nd	1st	

Table 1. Order of vehicle task and training modality per participant group

3.3.1 VIDEO FILES/BEHAVIOUR CODING

The video files were interrogated with behaviour coding: participants in the video were identified and different behaviours of interest were assigned different codes. The video was coded whenever a participant completed a subtask or was attending to either the MR or paper-based instructions dependent upon the experimental condition they were assigned. Unfortunately not all video data included the 7th step due to a technical malfunction; therefore these timings were omitted from analysis. Coding began upon the first review of MR or paper-based instructions and ended upon completion of step 6. The duration of time looking at information was defined as the total amount of time participants spent during each of the vehicle maintenance subtasks actively conceptualising what must be done and included inspecting the part of the vehicle they were working on. It also included the direct (physical) actions that led to completion of the vehicle maintenance task.

The coded data was exported into a spreadsheet, recording each step and the time taken for completion by each participant. This enabled the effective transformation of the video file into a series of activities and times associated with each step, i.e. the time each participant need to conduct of the routine vehicle maintenance task using a given the respective training method (extant or MR). The performance and perception data was analysed and is reported in the following section.

The behavioural coding data from the video files were analysed and imported into a statistical software programme in order to conduct a 2x2 repeated measures factorial

ANOVA (MR vs extant training, and MHOV vs LAV). Linear regression was conducted to determine whether error rates (speed vs accuracy) and pre-trial participant questionnaire responses (participants' prior perceptions of MR) predicted task duration. Descriptive statistics were computed for questionnaire data. Finally, the findings were recorded and reported.

3.4 PROCEDURE

3.4.1 Pre-training/familiarisation tasks

All experiment participants were provided with a brief explanation of the purpose of the experiment and the tasks they would be completing. Prior to beginning the experiment, participants were provided with training to use HoloLens. They were shown a MR task that was not related to the routine vehicle maintenance task that they performed in the experiment. This allowed the participants to familiarise themselves with MR interaction (use of gesture-based interaction) without getting extra time to study the vehicle maintenance task. The participants trained with HoloLens until they informed the author, technicians and instructors that they felt comfortable navigating with the MR tools using gestures and voice commands. Finally, a pre-experiment survey was administered to elicit information about the participants' perceptions/expectations around the use of MR for vehicle maintenance tasks.

3.4.2 Conduct vehicle maintenance task

Participants were given unlimited time to complete the task and were able to request information from the available instructor but were encouraged to attempt the subtasks as best as they could with the training information that had been provided.

3.4.3 Post-training tasks

Upon completion of the training tasks, participants were given a post-training survey to capture their perceptions about using MR for vehicle maintenance training. The survey also elicited responses related to perceptions on the viability of onsite use (workshop environment at TTS) of this technology for the purpose of vehicle maintenance training.

Finally, a workshop was conducted where participants were asked about their perception related to their user experience during the training. They were asked to identify strengths/advantages and weaknesses/disadvantages of their training experience while using MR specifically in relation to ease of use.

4.0 RESULTS AND DISCUSSION

4.1 PERFORMANCE

All participants were able to perform the vehicle maintenance task presented using MR or extant training method. To better understand the potential performance differences using MR, the vehicle maintenance subtasks (steps) were divided into behaviours of interest:

a. Interpreting/understanding the information presented, including inspecting and locating the vehicle part to be 'worked on', and accessing any tools that were required to perform the subtask.
b. Execution of the subtask action/s.

These key behaviours were identified to measure the performance of the participants, and enable direct comparison between the two different training methods.

Finally, the average duration to complete the routine vehicle maintenance task was calculated. The duration to complete the vehicle maintenance task was the total time it took participants to complete the task from start to finish. Figure 2 below shows each participant's task total duration, divided into steps.

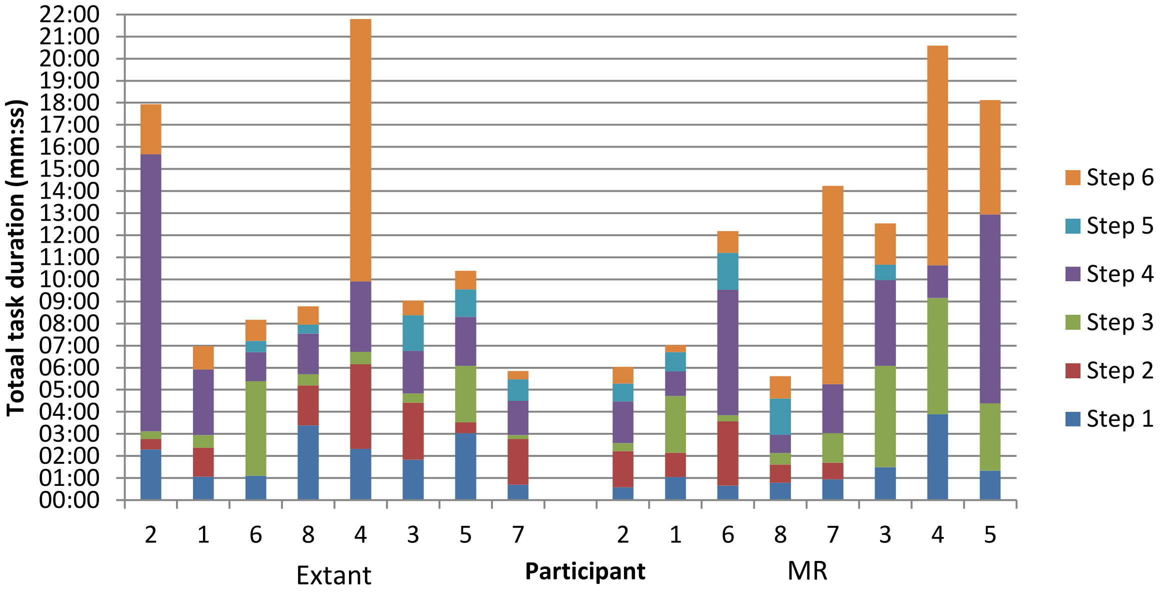

Figure 2. Participant task duration divided into subtasks

4.1.1 BEHAVIOUR DURATIONS FOR DIFFERENT TRAINING METHODS

The time spent interpreting information was defined as the total amount of time participants spent during each of the vehicle maintenance subtasks actively reviewing the information presented (reading, reviewing models, watching videos) in order to understand the vehicle maintenance task.

With the extant training method, it was clear when participants were looking at the training document and when they were conducting the vehicle maintenance task because the two tasks are not performed simultaneously.

With the MR training method, participants saw the information while they were conducting the subtasks. Therefore, the only time that was counted as 'time spent interpreting the information' was the time when participant were viewing the information but not actively (physically), conducting the steps. This enabled a more analogous comparison between time spent looking at information using extant and MR training methods.

The time spent executing the task (physically carrying out the task) was defined as the total amount of time participants spent during the vehicle maintenance task actively or physically executing the task.

The behaviours studied are itemised in Table 2. The average time that each behaviour required, the respective differences in means between using MR and extant training methods, and the p-value of a paired samples *t*-test were used to compare the two means.

Behaviour	**Duration of training (in min:sec).**		**Difference (Extant – MR)**	**P-value N=(8)**
	Extant	**MR**		
Conceptualising information.	2:26	3:41	-1:15	0.149
Execution of subtask.	2:01	2:24	-0:23	0.606

Table 2. Mean behaviour durations

On average a participant spent 3:41 minutes with the MR training method compared to 2:26 minutes conceptualising the extant training information. Although there is a 1 minute 15 second increase in the time for MR over the extant training method, the difference is not statistically significant. This suggests that MR training method does not enable participants to conceptualise how to conduct the vehicle maintenance task in less time than when using the extant training method. This is displayed in Figure 3 below.

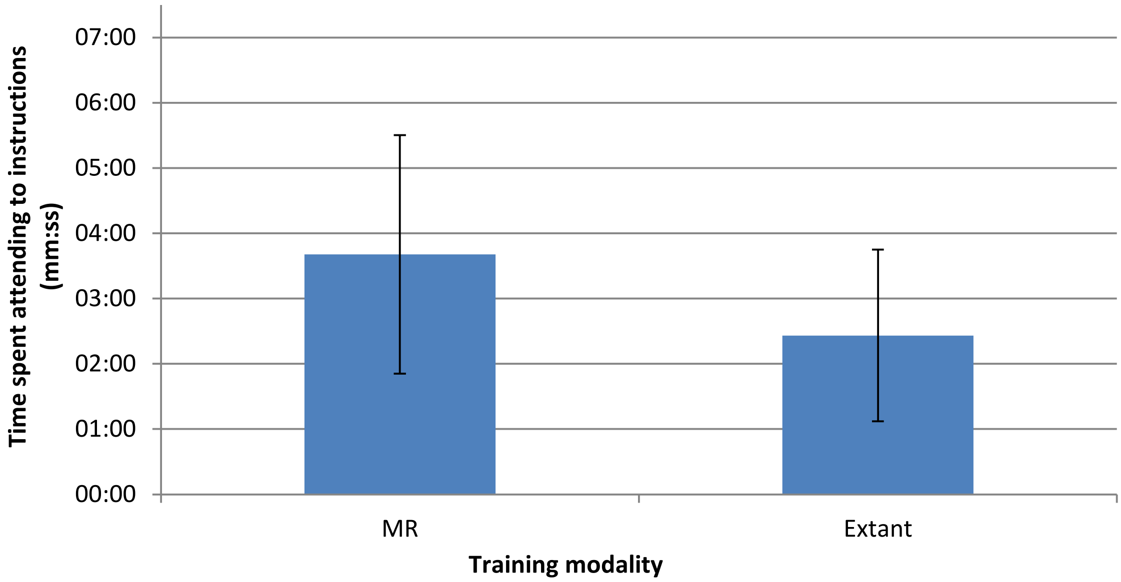

Figure 3. Mean time spent attending to instructions for each training modality
**error bars denote standard deviation*

On average a participant spent 2:24 minutes executing the steps to complete the vehicle maintenance task using MR method compared to 2:01 minutes using the extant training method. This indicates there is not a significant difference in time (p-value = 0.606 n=8). This is displayed in figure 4 below.

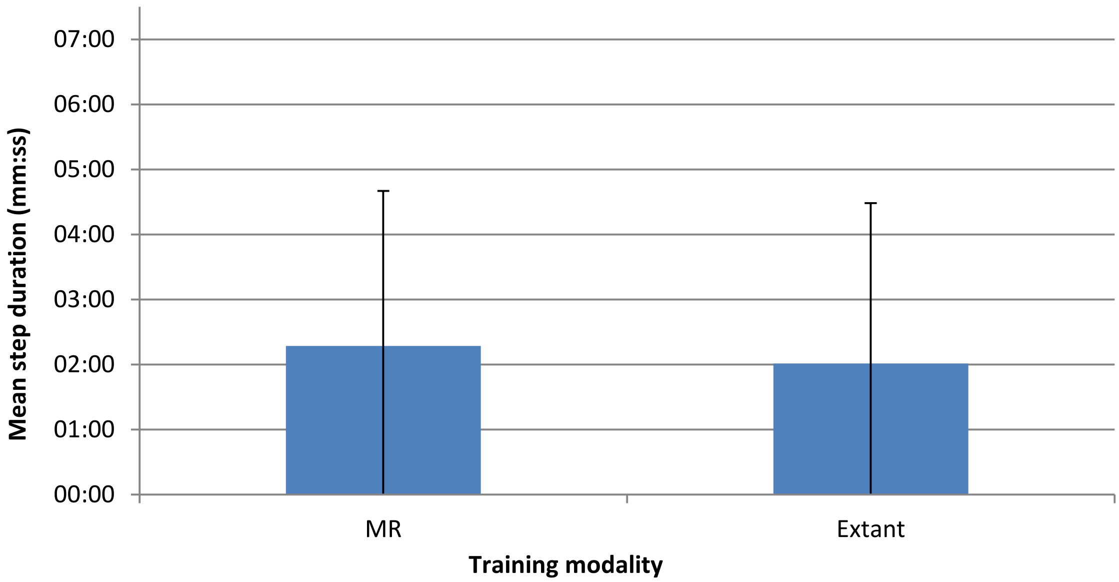

Figure 4. Mean step duration for each modality
**error bars denote standard deviation*

4.1.2 AVERAGE DURATION TO COMPLETE ROUTINE VEHICLE MAINTENANCE TASK.

The time spent to complete the whole routine vehicle maintenance task was the total time it took participants to complete the vehicle maintenance task from start to finish.

Using MR training method, the time started from the moment the task was loaded and accessed on the HoloLens device.

While using the extant method, the time started from the moment a participant received the paper based maintenance document. In both instances, the time ended when a participant declared that he had finished the vehicle maintenance task regardless of whether the finished product was correctly performed or not.

Overall, the average time spent carrying out the vehicle maintenance task from start to completion using MR method was 9.07 minutes compared to 9.29 minutes using the extant training method. Although there is a difference in mean there is considerable variation among participants which means that we cannot confidently conclude that there is any meaningful difference, as is shown in figure 5.

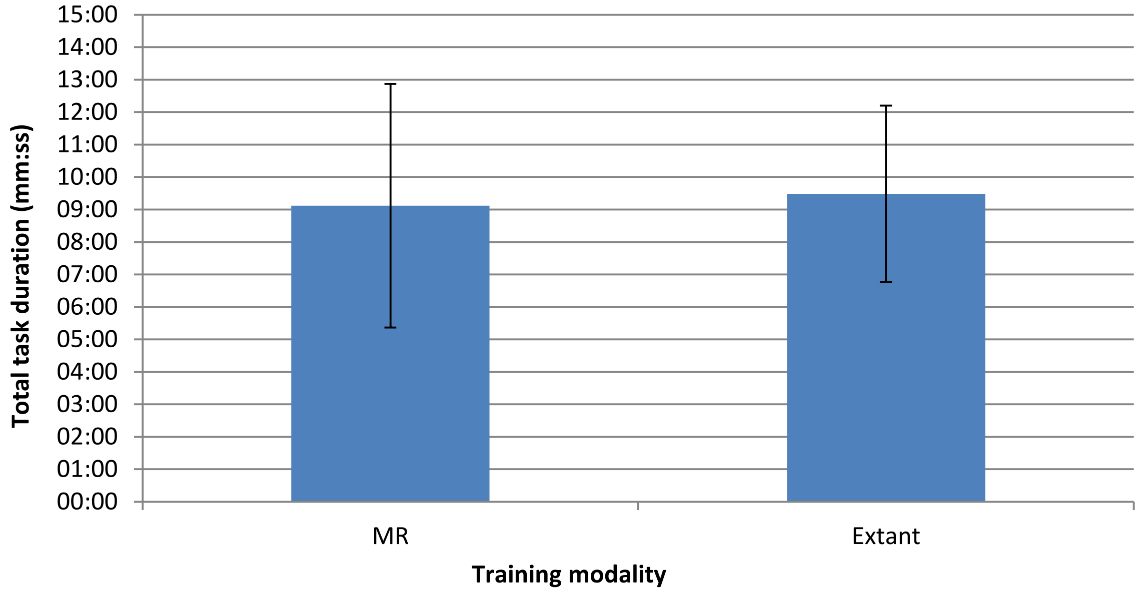

Figure 5. Participant's total duration of training task
error bars denote standard deviation

The authors did expect to find similar or possibly better performance when participants were using the extant training method, given their familiarity with this form (standard maintenance document) of training instruction and participants' relative inexperience using MR technology for training.

4.2 ERROR RATES

Instructors observed all participants (both vehicles, using both training methods) as they performed the vehicle maintenance task. They recorded the number of errors made by the participants during each subtask (step). Each time a participant omitted to perform a subtask or performed the subtask incorrectly, the instructor simply recorded this as an error. The total number of errors for each subtask was tallied. The purpose of recording these errors was to understand how much rework could potentially be required in relation to the training method that was used. Re-work is defined as the act of re-doing, correcting, or rebuilding simply because the maintenance task was not performed correctly the first time. Re-work costs time and money, particularly if vehicle parts are damaged in the process.

The number of errors made per training method is summarised in Figure 6. In total, among all eight participants, they made 14 errors when using extant training method to conduct the vehicle maintenance task, and 9 mistakes using MR training method. Errors made by participants using the MR training method was 39% of the total of all errors. The number of errors made by participants using the extant training method was 61% of the total of all errors. There was a comparative reduction in errors using MR training method by 22%.

Figure 6. Errors per training method

An interesting point to note is that participants had little to no experience using MR technology. Some of the participants needed to be prompted to use the full range of information that was available with MR training method. Nevertheless, they still performed the vehicle maintenance task with fewer errors.

The authors observed that the TTS instructors spend more time actively supervising participants using the extant training method in comparison to the MR training method. This suggests that participants had more difficulty understanding or interpreting the instructions on the paper training document. It is possible that if the participants were not assisted by the instructors, they may have made an even greater number of errors.

4.2.1 ERROR RATES AS A PREDICTOR OF TOTAL TASK DURATION

Hierarchical linear regression was conducted to determine whether participant error rates predicted total task duration. The input for the first model was error rate and the second model was training modality and vehicle type. The error rate was found to significantly predict task duration positively (β = .621, $F(14) = 8.72$, $p < .01$) while the training modality and vehicle type was found not to be significant. A graph demonstrating this positive relationship appears at figure 7 below.

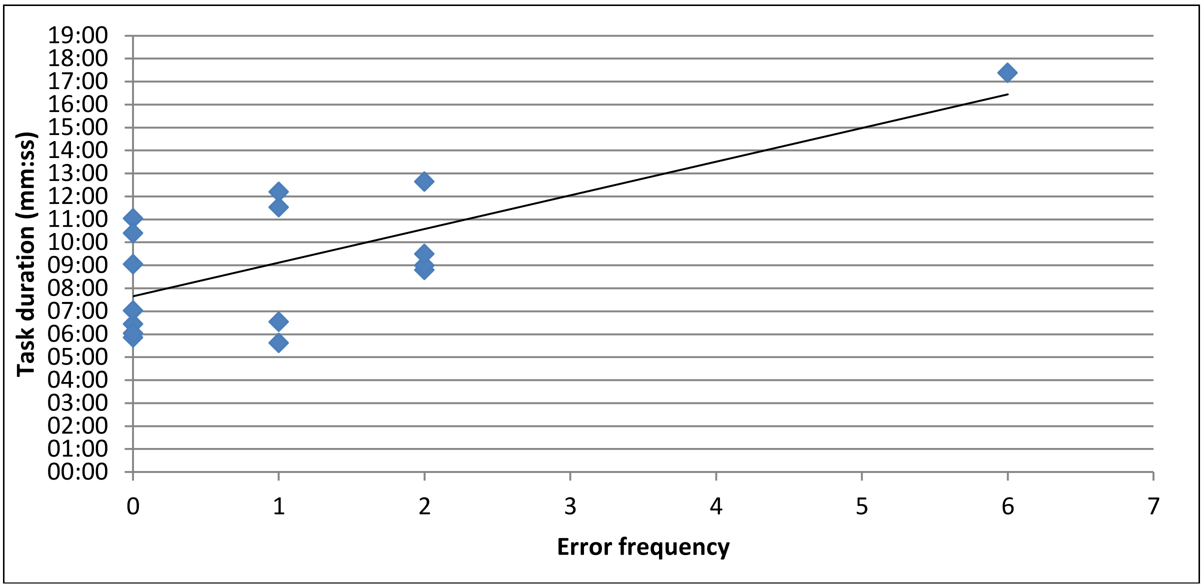

Figure 7. Relationship between error frequency and task duration

4.3 EFFECT OF ORDER

The author also studied the effect of order on the total routine vehicle maintenance times of participants. A repeated measures ANOVA was conducted to determine whether there was a difference between those attempting their first task compared to their second. Those completing their first task took an average of 08:01, whilst those completing their second task took an average of 10:35. There was no significant difference in total task duration between first and second performed tasks, $F(1, 7) = 2.598$, $p = 0.151$. This suggests that the effect of order is minimal and offset by the cross-over design of the experiment, see Figure 8.

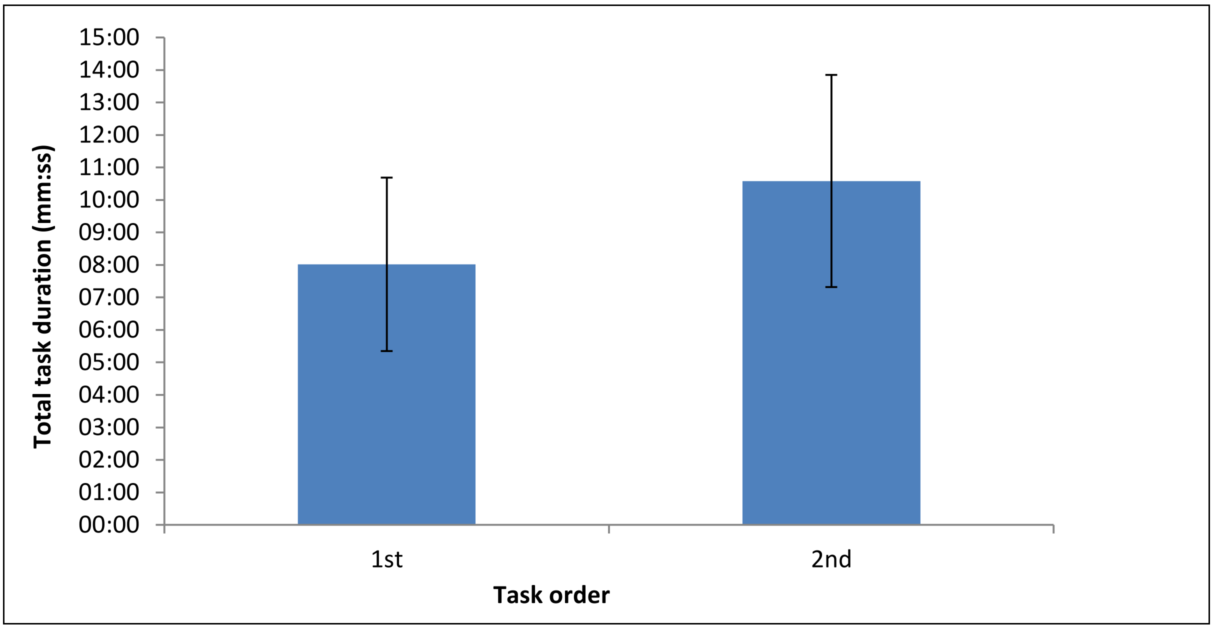

Figure 8. The difference between first and second attempt at routine vehicle maintenance tasks
**error bars denote standard deviation*

4.4 PARTICIPANT'S PERCEPTION OF MR

The NZ Army has introduced MR training for automotive technician apprentices. This represents a major change in how training has been conducted for many years by the TTS. Given the magnitude of change, it is important to explore the participants' perceptions of this method of training. Pre-training and post-training surveys were conducted to elicit participants' perceptions and specifically to identify if there was a change in perception with regards to the utility of MR training method that may have occurred as a result of the training they undertook to participate in this experimental process.

Linear regression was conducted to determine whether participants' pre-trial perceptions of MR significantly affected their subsequent MR performance as measured by task duration. Participant pre-trial responding was not found to significantly predict total task duration.

4.4.1 PRE-TRAINING SURVEY

Directly after completing the introduction training session in how to use HoloLens, participants were asked to complete a pre-training survey with questions that were designed to gauge the participant's anticipation of using MR for training instead of the current extant training method. The survey included questions about whether they believed MR would be a suitable technology for the TTS workshop environment and could potentially replace the extant training method; see Table 3 showing a sample of pre-training survey questions.

Questions:	Strongly disagree	Disagree	Neutral	Agree	Strongly Agree
MR training will be easier in comparison to using paper-based maintenance manual.	0% (n=0)	12% (n=1)	50% (n=4)	37% (n=3)	0% (n= 1)
I believe MR technology will be a suitable to use in the TTS workshop environment.	0% (n=0)	0% (n=0)	25% (n=2)	50% (n=4)	25% (n= 2)
I believe MR will be my preferred method of delivering information for vehicle maintenance training tasks	0% (n=0)	25% (n=2)	62% (n=5)	12% (n=1)	0% (n= 0)

Table 3. Sample of pre-training survey questions.

The results indicated that participants generally felt that MR would be easier to use for training the vehicle maintenance task in comparison to the current extant training method. In addition to this they also reported:

- That they strongly agreed that they would be more engaged in training tasks using MR instead of the current extant training method.
- They agreed that MR training will be capable of fully communicating vehicle maintenance tasks.
- They agreed that using MR training will be suitable for use in the TTS workshop environment.
- They agreed that MR training is likely to make the routine vehicle maintenance task easier to perform in comparison to training using a paper-based maintenance manual.
- However, they did not agree that MR training would replace the need to have qualified instructors' presence with aspects of their training programme.

4.4.2 POST-TRAINING SURVEY

After completing the vehicle maintenance training task using both extant and MR training methods, participants completed a post-training survey about their training experience. The responses from the survey indicated that all participants considered MR to be an effective training method for conducting vehicle maintenance tasks. They also reported:

- MR training was generally easier to use to perform vehicle maintenance training than the current extant training method.
- Participants strongly agreed that that new apprentices would benefit from training, at least in part, using MR.
- Participants strongly agreed that MR simplified vehicle maintenance training.
- However, participants did not agree that MR should be the only information delivery method used in the workshop for training apprentices.

4.4.3 *WORKSHOP FEEDBACK*

On completion of the training, participants were divided into two groups. One group was asked to report the things that they disliked or that they believed were disadvantages in using MR for training; the other group was asked to report the advantages and things they liked about using MR for training in vehicle maintenance tasks. Their comments are summarised in Table 4.

Dislikes/disadvantages	Likes/advantages
• The HoloLens headset was hard to secure to head, while training. We had to readjust so we could see through it. • Due to price of the HoloLens unit, users were concerned about damaging the unit while working under the vehicle or lifting objects. • Sight alignment with the HoloLens was hard to achieve. • Could see that prolonged use would cause eye strain/fatigue. • The headset was just too bulky and heavy and would lead to neck strain. • Potential safety hazards, objects in the peripheral vision, above the line of sight, were occluded by the design of the headset.	• Instructions were simple to follow using MR headset. • Photo/video training aids were really helpful. • Easy to navigate through the training task. • Anyone, at any level, could use this technology. • MR enabled me to keep by eyes on the task and focus closely on the task at hand instead of looking away to read instructions. • It was very engaging to use.

Table 4. Workshop feedback

4.5 LIMITATIONS OF STUDY

This research is presented as a proof of concept with an experimental design that aimed to explore the practicality of using MR technology for training a vehicle maintenance task. The performance of participants using a MR training method was compared to the current, extant training method. The findings of this study do have several limitations related to the artificial nature of this research and implementation methods.

The main limitations of the design this research includes the small number of participants (eight) and the conditions the experiment was conducted in (controlled environment). The sample size was small and results may not be generalisable beyond this particular example within NZDF. The reported benefits do however support claims that MR can enable performance benefits over more traditional training methods. In order to generalise the findings of this study, future research would need to identify statistically representative samples. The research took place in a teaching workshop with an experienced instructor constantly monitoring and supervising participants in relation to ensuring that the health and safety of participants was carefully monitored and managed. Some of the subtasks involved heavy lifting and there was potential for injuries in relation to the activities they conducted. Additionally, the workshop was free of congestion, noise and other activity. This may have affected the training experience and it is possible that these environmental factors could impact the performance benefits observed.

There was no attempt to understand if there was a relationship between training programme aims and the actual training outcomes i.e. without due consideration of the TTS automotive technician training programmes aims and objectives. This research did not investigate the feasibility or the extent to which MR training methods could be adopted for other, or all routine vehicle maintenance tasks at the TTS.

The authors faced some technical difficulties in relation to the HoloLens head mounted device. The video recording capacity (of the training task) was approximately 5 minutes before it automatically paused. Video monitoring data was lost with the first participant as the technician was not aware that this had occurred. This problem was promptly identified and overcome by manually activating the video recording during the training task. It is entirely possible, that the results of one of the participants, who had to repeat the training task using MR technology, may have gained additional training benefits that biased his training performance.

5.0 CONCLUSION

An experiment was conducted to study the potential performance of using MR for training automotive technician apprentices in a routine vehicle maintenance task (remove and refit a brake drum). Additionally, the perception the participants had toward MR training method before and after use was scored.

The MR training method did not significantly alter participant's routine vehicle maintenance task performance (time to complete subtasks and tasks). Participants had had little to no experience in using MR technology for training. Some of the participants needed to be reminded to use the additional information delivery options available with MR technology. If the 'authored' task set-up in Manifest had been more closely scrutinised and refined to ensure that the training media (video, photographs, models, etc.) were best suited to the training objective, there may have been an improvement in task performance.

When using the MR training method, participants performed the vehicle maintenance task with fewer errors. This suggests that the MR training method has the potential to reduce re-work and potentially provides a more complete and comprehensive overview of the training task.

On completion of the routine vehicle maintenance training task, participants agreed that the MR training method was easier to use than the extant training method. Participants agreed that the MR training method would be beneficial for training new apprentices. They strongly agreed that they would be more engaged in training tasks using MR instead of the current extant training method. However, they did not agree that MR training would replace the need to have qualified instructors' presence with aspects of their training programme.

The findings of this study do have several limitations related to the artificial nature of this research and implementation methods. Future research should focus on identifying the attributes of the training task that may maximise the benefits provided by MR to enable instructors to better plan for using MR training methods to ensure that it provides the greatest impact.

6.0 RECOMMENDATIONS

- MR training method was observed within our sample to reduce error rates in routine vehicle maintenance tasks. MR training should be considered as a complementary training tool for training across NZDF. However, the results of this experiment cannot be generalised across all training environments in the NZDF. It is important to seek the right opportunities and to introduce MR training considering the appropriate learning settings/situations. Some consideration should be given to the following points before NZDF invests in MR technology:

  - Select the right opportunities that are likely to show a clear impact and return-on-investment by considering how training with MR method will specifically add to the learner's experience.
  - Take full advantage, and learn how to use the tools available for training offered by the MR training method (video, photographs, 3D models etc.) to fully enhance the learning experience.
  - Design the training carefully for the learner's needs.
  - Consider using MR to enhance training, not to fully replace what is currently on offer.
  - Start small (pilot project) within a particular setting and consider how to scale up to evolve into a training solution that addresses multiple learning requirements.
  - Test and retest training developed using MR for trainees. Obtain user feedback.
  - Consider how to measure the success of implementing MR method of training, both for the training and on the job.

- NZDF should consider adopting the principles outlined in the International Standard ISO 9241, Ergonomics of Human-System Interaction (ISO, 2010; specifically, but not exclusively Part 210: Human-Centred Design for Interactive Systems). Part 210 stipulates six guiding principles, each of which has relevance to development of training (see section 2.3 of this report which outlines the six principles).

- Consideration must be given to the time required to prepare the MR training (authoring of the training task). The instructors responsible for designing and developing the MR training method for this research had experience and expertise not only in understanding the training needs of automotive technician apprentices, but also in using MR technology for training. Instructors reported that it took approximately an hour to 'author' and shape the training task so that it was suitable for training the automotive technician apprentices. It should be noted that additional investment (time/training in using MR technology), over current business as usual, would need to be taken into consideration if this approach to training was to be employed in other areas across NZDF.

- Time and effort needs to be spent focussing on identifying the attributes of the training task selected for MR training method. This will help the instructional designer to select the additional information delivery options that offer the best means to present each attribute, helping to ensure that the MR training method provides the greatest beneficial impact for trainees. Relevant attributes include, for example, training management packages involving significant guiding documentation, remote classrooms/tele-training.

- Appendix A includes comments on a range of technical issues from DTA, about the usability of the software Manifest. This information could be used by the NZ Army to discuss with Taqtile (OEM) the issues that need to be satisfied/rectified in order for the technology solution to be procured for TTS. Microsoft has just released the latest model of HoloLens. This new hardware should be assessed by NZ Army to identify if it rectifies the issues identified with the functionality and usability of the current headset.

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APPENDIX A: SOFTWARE AND HARDWARE ISSUES

Software – MANIFEST

- Gestures
  - Adjust alignment of QR Code with move/rotate buttons is difficult.
  - Voice to “Start Recording” video, but still must click stop manually
  - Voice command to “Take Photo”. There is a slight delay and you don’t know when the photo is actually taken. A camera noise would help
  - When there are errors, no feedback why something went wrong (bad copy to NZMOD production domain).
- Depth of Navigation
  - On admin website (not HoloLens) down arrows are easy to miss ˅ to expand asset attributes.
- Landscape
  - N/A
- Operating System
  - HoloLens specific – OK
  - Website admin should be universal, but MS Edge does not display everything properly.
  - Images uploaded from website admin display wrong in HoloLens
- AutoFill
  - User required to login every time Manifest is started. TYPING ON HoloLens is difficult! There is no ‘remember password’ check box.
  - Voice commands are available – but needs internet.
  - Maybe QR code for login?
  - (If we had proper Microsoft 365 accounts this could be fixed, by automatically using the device login/pw)
- Bad Gestures/ buttons
  - Pin/unpin put windows in strange places – overlapping each other
- Confusing content
  - Notes (images, video, descriptive text) appear way off to the right of the step window. New users often do not see notes window.
  - Notes are in the same 3D plane as the step window. This means that they are always at an oblique angle. The notes window should be bill-boarded to the user.
  - More 3D content (animated arrows etc.) along with the leader lines might make the app more interactive.
  - No indication of job complete – just no more steps.

Hardware – HoloLens

- Gestures
  - People struggle to learn the ”air-tap” gesture
  - Voice commands prefer an American accent
  - TYPING DIFFICULT!
- Spatial tracking

    - Indoor use only, needs to scan walls for tracking.
    - Tracking can drift if user removes HoloLens and puts it down for a few min. Holograms move to different places.
- Visibility
    - Field of view is quite limited ~ 30° x 17°
    - Indoor only – sunlight too bright to see holograms.
- Battery life is OK – couple of hours – enough for most tasks

- Wi-Fi Requirement
    - Very unpractical to use without Wi-Fi.
    - Slow Wi-Fi has a weak or intermittent connection.
- Physical
    - Can be uncomfortable & heavy to wear.
    - Can get eye-strain if not calibrated to user's eye width.

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13. ABSTRACT

Mixed Reality (MR), as a training medium, has been explored as method to train New Zealand Army automotive technician apprentices in routine vehicle maintenance tasks. It is important to understand how this might impact the task performance of apprentices. This paper explores the topic and addresses the research question: How does a MR training method influence productivity and quality of a routine vehicle maintenance task conducted on military vehicles? To address this topic, a pilot study was conducted that compares the performance of eight automotive technician apprentices who were tasked with conducting a routine vehicle maintenance task using the extant or current training method, and MR training method. Apprentices completed pre-training and post-training surveys to provide their perceptions of the experience. The results suggest that there is no significant difference between the extant and MR training methods with regards to apprentice's task performance times. However, the MR training method led to fewer errors during the training task. Additionally, participants agreed that MR is easy to use, but would not replace the need to have a qualified instructor on hand. While the small sample size limits the extent to which these finding can be generalised, the contribution of this work is in demonstrating, as a proof of concept, that MR training methods can be a viable option for training routine vehicle maintenance tasks and that it can offer advantages that are not currently observed through the use of the extant training method.

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