EFFECTS OF DISPLAY POSITION ON GUIDED REPAIR AND MAINTENANCE ASSISTED BY HEAD-MOUNTED DISPLAY (HMD)

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EFFECTS OF DISPLAY POSITION ON GUIDED REPAIR AND MAINTENANCE ASSISTED BY HEAD-MOUNTED DISPLAY (HMD)

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LIST OF SYMBOLS AND ABBREVIATIONS

HMD	Head-mounted Display
CAGR	Compound Annual Growth Rate
AR	Augmented Reality
CRT	Cathode Ray Tube
FoV	Field of View

SUMMARY

Head-Mounted Displays (HMDs) are believed extremely valuable in industrial applications. However, few studies had discussed the impact of different design characteristics of head mounted displays on task performance. This study aimed to find out how different display positions of Head Mounted Displays may affect the performance of workers performing guided repair and maintenance tasks. A set of car maintenance tasks were performed by 20 participants with task guidance presented at four Display Conditions: above-eye HMD, eye-centered HMD, below-eye HMD and the traditional paper manual. Time and errors were measured and discussed, as well as other user experience related measurements.

The result showed that none of the Display Condition conditions had significant main effects on completion time. However, Below-eye HMD outperformed Above-eye HMD in the Action Type that requires certain level of assessment. The result of user experience ratings showed that Eye-central was the most preferred display position among the three HMD conditions.

Human factors implications were also discussed, including the issue of over-reliance and the necessity of designing HMD with adjustable display angle. Designers and engineers may leverage the findings to develop next-generation HMDs that improve the effectiveness, efficiency and satisfaction for workers.

CHAPTER 1

INTRODUCTION

Head Mounted Display (HMD)

Head-mounted Display, by its definition, is a display device, worn on the head or as part of a helmet, that has a small display optic in front of one (monocular HMD) or each eye (binocular HMD) [1]. Today it's usually segmented into two categories: helmet mounted display and wearable glass.

HMD is known for its state-of-the-art display capabilities. In the consumer market, users use HMD to enjoy the high quality image presentation and the immersive experience. On the other hand, HMD also provides additional functions such as Internet access, smart phone access, GPS, navigation, and so on. According to a market research report, the global HMD market is expected to reach up to $12.28 billion by 2020 [2].

In the present study, we only discussed the type of HMDs that are directly attached to the head. HMDs that are worn on or are embedded in a helmet such as the EyeTap welding helmet[3] were not considered.

Attributes of HMD

The various components used in HMDs include: Micro-Display, Camera, Combined Mirror, Control Unit, Helmet, Goggles, Head Tracker, Battery, Accessibility Device, and Controller and Accessories.

There have been dozens of HMD devices with various input methods (voice control, hand-held control panel, touch pad, etc.) and output configurations (opaque vs. see-through, monocular vs. binocular, etc.) but there's lack of evidence showing which

HMD system provide the best results. As more and more companies are starting to realize the potential of HMD in industrial applications, there's a growing demand for empirical study on the attributes of HMD systems.

Display Position

Display position means the position of the display screen in relation to user's eye or eyes. There're three different display positions: Above-Eye, the information is displayed above the user's line-of-sight. Eye-Central, the information is displayed directly in front of the user's line-of-sight. Below-Eye, the information is displayed below the user's line-of-sight.

It's worth mentioning that in Hershberger et al.'s study [4], the position below the line of sight was referred to as a bifocular HMD, while the position above the line of sight was referred to as a bioptic HMD.

Monocular vs. Binocular

A monocular HMD has only one display which would be either in front of the user's left eye or the right eye. A binocular HMD on the contrary has two display screens, one in front of each eye.

Transparent vs. Opaque

Some HMDs use see-through display so that the users can see the real world behind the digital information. Others use opaque screens so the devices actually block users' vision at some extent, some information from the real world might be missing.

Input Method

Input methods may vary from device to device. For example, Epson Moverio allows the user to navigate on the virtual panel using touchpad; Google glass has a touch pad on the frame, it also supports voice command. They both have stand-alone operation systems running on the device, while some other HMDs simply just project images from another device to the near-eye display.

Mounting Method

The two most common mounting methods are the over-the-head system like Golden-i, and the eyeglass solution like Google Glass. Some are relatively unique, for instance, the Vuzix M100 Smart Glasses which can be clipped onto the user's own eyeglasses.

HMD at work

Over the last few years, there have been striking developments in wearable computing. Among all the different forms of wearable devices, Head Mounted Displays (HMDs) are deemed the first seamless solution to enabling workers with real time contextual information and allowing companies to integrate with existing back-end systems. The hands-free feature that comes along with the HMDs is also believed a great advantage over many traditional technologies.

Consulting and research groups believe that smart glasses will have a great impact on heavy industries such as manufacturing, oil and gas where they can enable on-the-job training in how to fix equipment and perform manufacturing tasks hands free [5]. It would also have significant impact on mixed industries such as retail, consumer goods and healthcare, where the benefits may mostly be looking for information via a visual search [6]. Other features such as voice command and video calling also promise easy access to key information and convenient remote collaboration.

Goals of the study

Despite the studies claiming all kinds of benefits that HMD provides. It was unclear whether potential benefits arise out of individual design characteristics of HMDs. Even if an HMD system is shown to be better than current technologies, it is not known if other HMD systems with different design characteristics would also perform similarly. Without the knowledge of how individual design attributes affect task outcomes, designers and developers will not be able to identify the best way to customize an HMD system to best match a specific task scenario.

This study aims to explore some of these variables in a controlled set of guided repair and maintenance tasks. Common car maintenance tasks were used and performed in a realistic environment with procedures and preparations that are low-cost and easy to replicate. The goal is to better understand the implications of the attributes that are essential to Head-Mounted Displays, in particular the position of the display.

CHAPTER 2

BACKGROUND

Procedure Following

The application of HMD covers a wide range of industries, and among all the benefits that HMD is believed to provide, aid in performing procedural task could be one of the most valuable.

Procedure following is commonly used in industries like oil, manufacturing, health care, aviation and retail. It can assist the workers in many types of tasks, including picking, assembly, operation, inspection, and maintenance.

The importance of procedure following is quite obvious [7]. Mainly, it prevents machine components from missing certain inspections, and by presenting a list of easily understood instructions it also guarantees the consistency of the workflow, thus helping workers to work in a more safe, efficient and consistent way. Since the human mind may not be able to remember a large amount of the steps accurately, having a standalone device or system that features procedure following would be a natural solution.

For tasks in which the worker has no previous experience with, procedure following is a good way to equip the worker with adequate knowledge of performing the task, even though he or she may already be capable of doing the job physically. Even when the steps are already well known to the workers, interruptions may occur and in consequence the worker may skip steps or forget where he or she is in the procedure [8].

To summarize, good procedure aid can potentially assist workers in completing their work tasks in a safe and consistent manner. Now the question is, in what media should the procedures be provided?

The traditional way to do this is using a written document. However, there are issues in using a paper document. First of all, the written checklist could be bulky and heavy if the procedure is too long, it would also be very hard to turn the pages. Second, when the information of the procedure is out of date and requires update, it would be troublesome to do it on written documents. Navigation through pages would not be easy when working with a written checklist, especially when the task steps are not sequentially located on the list.

There are studies showing that paper checklists may cause certain types of errors, for example, skipping steps either intentionally or due to interruptions and distractions [9]. There’s also possibility of repeating some steps because the worker forgot what steps he or she had done.

Task Guidance Systems

The term “task guidance systems” was first proposed in Ockerman’s study [8] where it was referred to as the system made up with inexpensive electronics designed to better assist workers to take advantage of the benefits of procedures. In her definition, task guidance systems only provide pre-loaded procedure information about the task (usually the information about the task in general and how to complete it step by step). These task guidance systems however, are not capable of presenting the information that is related to the current state of the environment, the worker, nor the object that is being inspected, maintained or assembled in particular.

In contrast, systems with sophisticated technologies can sense the surrounding environment and contribute to a worker's situation awareness directly. For example, Reif et al. developed an HMD system using Augmented Reality (AR) technology to support the picking system in a real storage environment [10]. These “intelligent” systems can sense environment information, process this information, then display it to the operator. Often, the result instruction is mediated and contains extra real-time information and/or eliminates the part that’s not related to the current task.

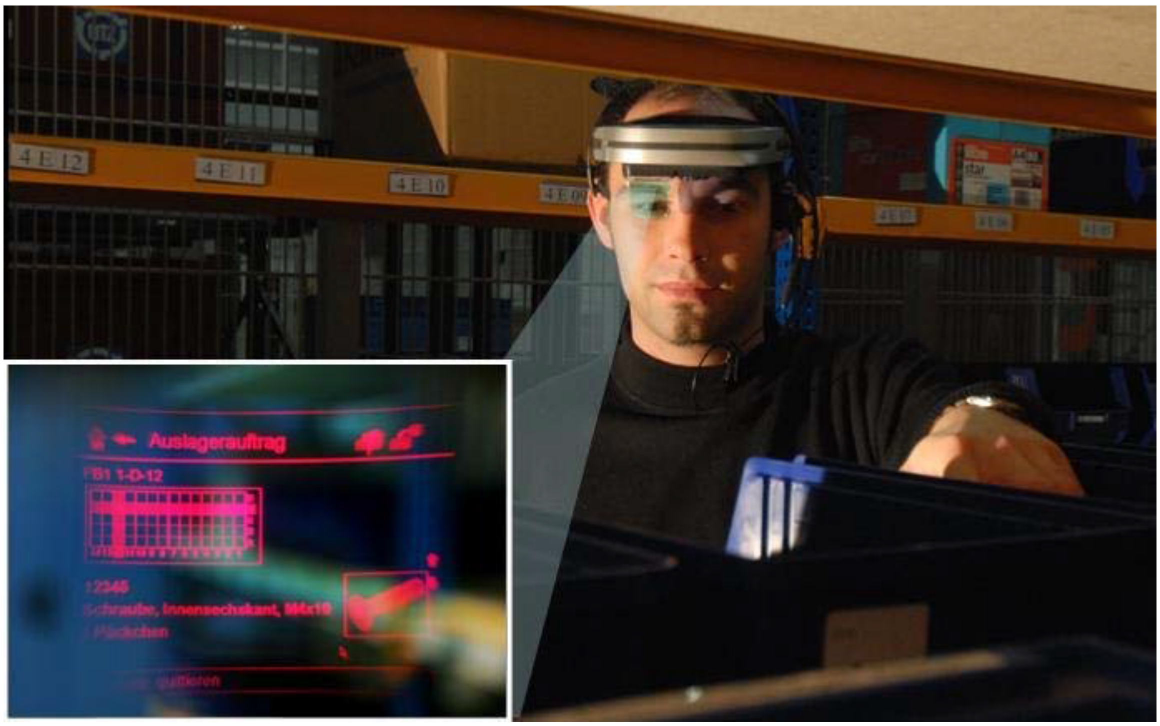


Figure 1. Using AR supported picking system in a real storage environment.

Although these systems appeared more intelligent, they often require special design and configuration for different tasks. In work places where worker’s tasks are fairly easy, task guidance systems would have significant advantages over complex systems due to the minimum implement and reconfiguration requirement.

In the present study, it’s unclear if the additional hardware and set-up time needed for a relatively more intelligent system (augmented reality) would outweigh the benefit over task guidance system. Also, the purpose of this study is to evaluate the effect of display position within the category of HMD, rather than compare it between HMD and other technology. Therefore, task guidance system seems more suitable in this study.

Related Literature

Smailagic & Siewiorek [11] documented the result of engineers of US marines doing a the Limited Technical Inspection (LTI) with VuMan 3, a wearable computer designed at Carnegie Mellon University. They claimed a decrease of up to 40% in inspection time compared to traditional paper handling and a reduction of total inspection/data entry time by up to 70%. However, from the screenshot of the display it could be seen that they just moved the text checklist from paper to the HMD. There was no image of the equipment or visual aid. Therefore, it couldn't prove that the HMD actually helped the engineers in performing and completing the task. In a later work Siegel & Bauer conducted a field study comparing a wearable system with a paper technical orders on two aircraft maintenance tasks. This time the wearable system was able to give task guidance and allowed more manipulation, but the specialists took on average 50% more time to perform the tasks using the wearable system.

In the research by Henderson & Feiner [12], the technology of augmented reality was incorporated into maintenance job aiding (Fig. 2). The raw data of the job aiding information as well as the tracking data received from an inertial-optical tracker was processed by the Valve Source game engine SDK. The stereoscopic content was then rendered onto an InnerOptic Vidsee video see-through HMD. In their example, the user followed the instructions and performed the removal of the Dart 510 oil pressure transducer from the Rolls-Royce Dart 510 prototype component. The highlight of this study is the implementation of AR into a relatively complex task guidance system.

However, there was no statistical result reported by the researchers to prove its advantage over the status quo at that time.

Figure 2. A mechanic wearing a tracked head-worn display performs a maintenance task on a Rolls Royce DART 510 Engine.

Ockerman & Pritchett [13] conducted a study to investigate the capabilities of wearable computers, using a case of procedural task of preflight aircraft inspection. They compared three different methods including a text-based HMD system (Fig.3), a picture-based HMD system and the traditional memory-recall method. The result shows no statistically significant effect on fault detection rate, while the videotape showed that those who used the HMD systems had a higher rate of overlooking the items that were not mentioned on the computer than those who did the same inspection by memory.

Figure 3. Major components of the wearable computer

Weaver et al. [14] in their order pick study however, did find that HMD with task guidance information led to significantly faster completion time and less errors than the audio, text-based and graphical paper methods. A similar work by Guo et al. [15] also stated that HMD was better than LED-indicating system. However, both studies were conducted in a layout optimized for the specific task and because the complexity of this task is relatively low, it was remains unsure if the observed effects could be translated to other task-guidance involved applications.

These aforementioned papers didn't really dig into the discussion of the problems with HMDs. One study from Peli however, focused on the visual issues of a head-mounted monocular display [16]. In this study, a monocular HMD with configurable display location was used to evaluate various visual phenomena (binocular rivalry, image motion, motion sickness, etc.). The results showed that a peripheral display position could effectively reduce binocular rivalry and was preferred by the subjects. Even though, the conclusion was based on the fact that only text was displayed on the HMD. Whether the statement would remain true in an image-based task guidance system was not clear and required further study.

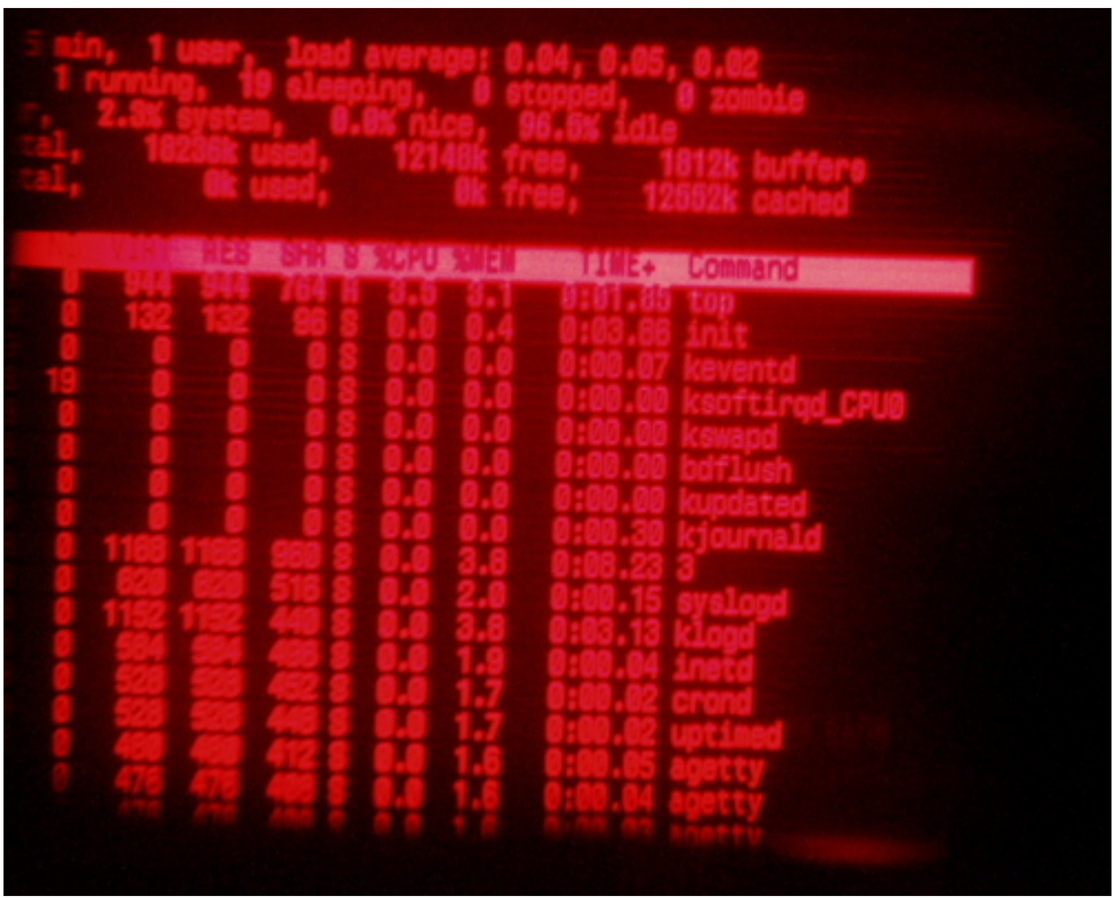


Figure 4. Red LEDs on a black background, resulting in a high-contrast image.

Katsuyama et al. [17] evaluated the effects of various display positions on performance of task and on user's comfort. They designed a study where the subjects had to perform the primary task by focusing on a monitor located 170cm away and meanwhile, a secondary task on a miniature cathode ray tub (CRT) attached to the head through an adjustable chin/head rest. The viewing angle of the secondary CRT relative to the primary monitor was manipulated across 12 treatment conditions (three levels of elevation, +15°, 0°. and - 15°, and four levels of azimuth, 0°, 20°, 35°, 45°). The conclusion of this study was that secondary task displays located 15° below a primary viewing area were better perceived (as a result, better performance and decreased discomfort) in comparison to an identical display located 15° above the primary viewing area. This study was similar to the present one, but in the present study, subjects performed tasks a lot more complex and had to move around instead of sitting in one place.

Hershberger found in his study[4] that resolution, contrast, and luminance of the HMD would influence the level of binocular rivalry in monocular HMDs. However, it was also obtained in the same study that the attenuation of binocular rivalry through manipulation of HMD related parameters had no effect on the performance. The Field of View on the other hand, did have statistically significant performance effect, but further validation showed that this effect was so small that it wasn't deemed important in HMD design with respect to binocular rivalry.

In a previous research, Zheng et al. [18] facilitated an experiment to investigate the effects of multiple eye-wearable technology characteristics on machine maintenance. A series of car maintenance tasks involving Locate, Manipulate, and Compare actions were tested by four different technologies: a peripheral eye-wearable display, a central eye-wearable display, a tablet, and a paper manual. The result showed that the peripheral eye-wearable display yielded longer completion time than the central display. This study was strictly controlled and the methodology was scientific and systematic. However, in the eye-peripheral condition, the wearable device was a monocular HMD, while in the eye-central condition, the device was binocular. It was yet to be proved that the same result would remain true if both conditions were monocular or binocular.

State of Art in HMD

Nowadays many HMD systems have been designed and manufactured in relatively large volumes. These HMD systems are much smaller yet more powerful than the early prototypes which researchers developed for experiment purpose decades ago. With different technical specifications (Table.1), they were designed to meet all kinds of needs.

Table 1. Specs for mainstream HMDs

Factor	Field of view (FoV)	Gestures	Touch pad	Binocular	See through	Stand-alone	Resolutoin
Google glass	12°	✗	✓	✗	✓	✓	640x360
Golden-i	32°	✗	✓	✗	✗	✓	800x600
XOne	/	✗	✗	/	/	✓	/
Vuzix M2000AR	30°	✗	✗	✗	✓	✗	1280x720
Vuzix M100	14°	✗	✓	✗	✗	✗	400x240
Vuzix STAR 1200XLD	35°	✗	✓	✓	✓	✗	852x480
Atheer One	65°	✓	✗	✓	✓	✗	1024x769
Recon Jet	14°	✗	✓	✗	✗	✓	400x240
META Pro	40°	✓	✗	✓	✓	✗	1280x720
Epson Moverio	23°	✗	✓	✓	✓	✓	960x540

Among these HMD systems, some are specifically designed for industrial application such as Golden-I headset (Fig. 5) and Vuzix M2000AR glasses. Others systems are more of a combination of productivity and fashion, such as Google Glass and Recon Jet.

Figure. 5 Golden-I headset

Recent trends showed that even those devices originally targeting consumer markets were being utilized for enterprise in the “service and maintenance” [19]. For example, companies like APX Lab and Thalmic Labs had been working on wearable solutions to help enterprises improve efficiency and reduce cost in heavy and mixed industries using a combination of Google Glass, Epson Moverio Glass and Myo Armband (Fig. 6).

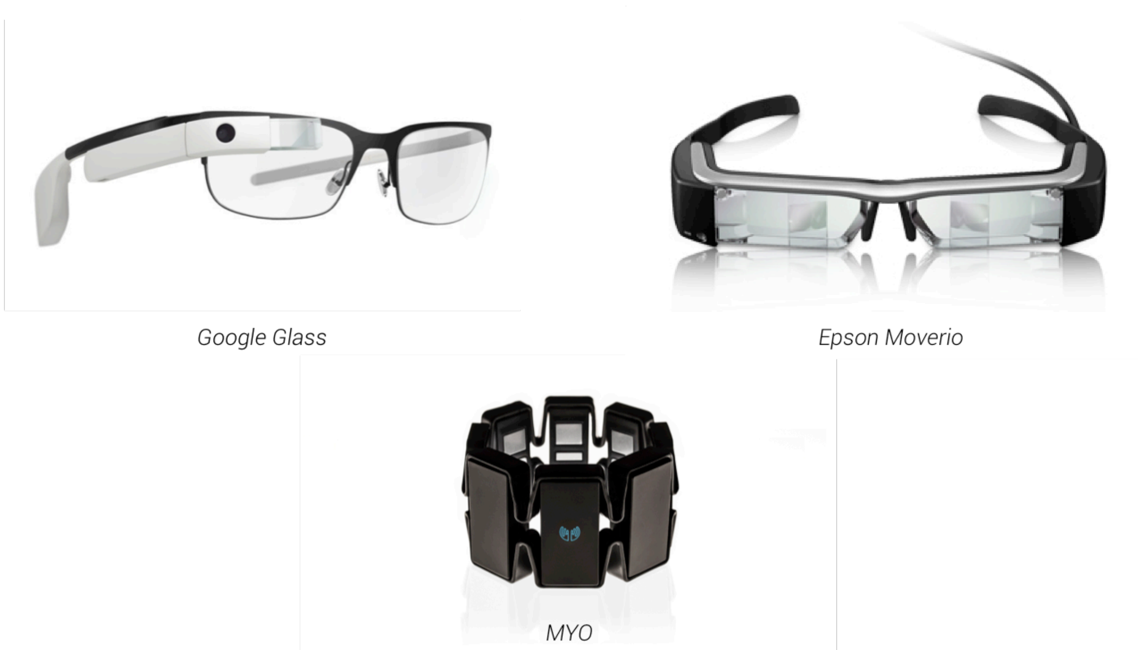


Figure. 6 Wearable solution system with MYO wristband

Significance of the study

Most of the study mentioned in the literature review compared only one HMD technology to the status quo of the domain and the HMD technology in each study were very different from another, it's unclear whether the result would remain the same if all the factors that differentiate different systems were teased out (for example, the size and position of the display was regulated). And it's even harder to tell which attributes of the HMD technology played the most important role in altering the task performance compared to other methods.

This study aimed to investigate the effects of different display positions – a core factor of HMDs – on guided maintenance and repair tasks. Three HMD systems with highly identical design but different display locations were compared.

CHAPTER 3

METHODOLOGY

As of 2010, there were more than 1 Billion cars in operation worldwide [4]. To ensure the condition of car components and safety driving, each car required regular maintenance at several times per year. Cars contain a diverse set of components found in many other machinery equipment.

Car maintenance and repair tasks were used as they were easily accessible to the subjects, similar to many mechanical inspections and frequently performed [20]. Therefore, car repair and maintenance tasks with sufficient complexity were chosen for the present study and it was conducted outdoors in a realistic setting in order to resemble a real life scenario.

Test Device Design

The HMD system was composed of (Fig. 7 & 8) the display of a NTSC/PAL (Television) Video Glass (320x240 pixels), a Raspberry Pi single-board computer, power supplies and 3D printed housings for other parts to reside in. A modem was used to provide internal network connection, pre-loaded instructions were sent from the researcher’s laptop to the near-eye display. During the experiments, participants were asked to carry a waist pack to hold the battery and the Raspberry Pi case.

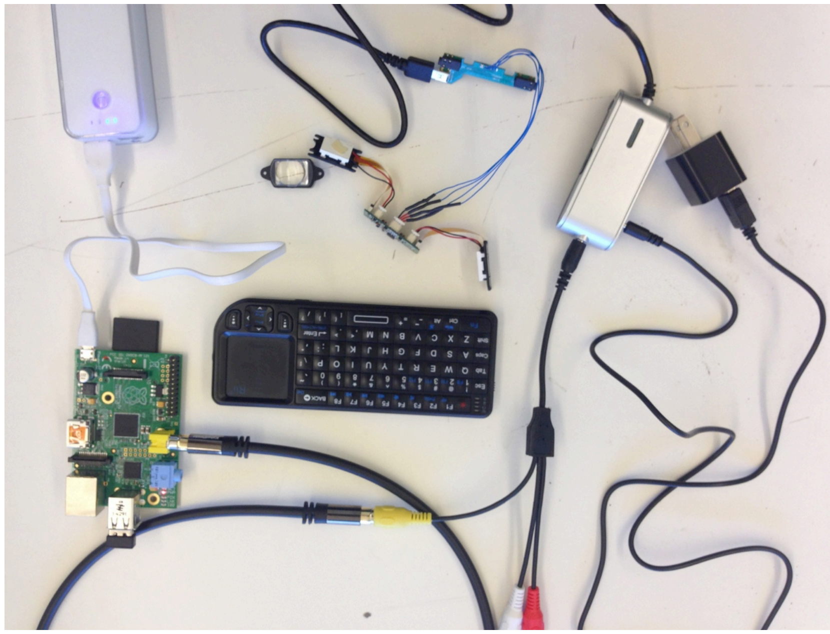


Figure 7. Components for prototyping the test device

Figure 8. Close-up of the display

A mounting system was designed to keep the device on the user's head. It consists of two parts: an adjustable elastic headband and a 3D printed panel on which the display device would be attached. The core display device was mounted onto the headband using

3M fasteners material (2 times stronger than Velcro). This ensures the stability of the connection and the ease of reconfiguration. The headset (headband and the display device) can be adjusted to enable use with user's right eye and can be located above, below, or directly in front of the wearer's line of sight.

Pilot Test

A pilot test was conducted before the formal experiment. Five volunteers tried on the early prototype of the HMD. All three Display Positions were tested (Fig.10 & 11). They were shown the mockup interface of several of the task instructions and feedback was gathered.

Changes were made based on the feedback. Namely, the font size of the text instruction was increased. Some ambiguous photos were either retaken or modified. For Location instructions, four treatment conditions (red outline with yellow fill; red outline with no fill; blue outline with mint fill, blue outline with no fill) were tested to finalize the highlighting method.

Four volunteers out of five mentioned the issue of the headset wobbling when moving the head. As a result, a second prototype was designed. A curved leg was added to the 3D printed panel (Fig. 9 left side). It went behind the user's right ear to prevent the whole device from horizontal movement when the user is moving.

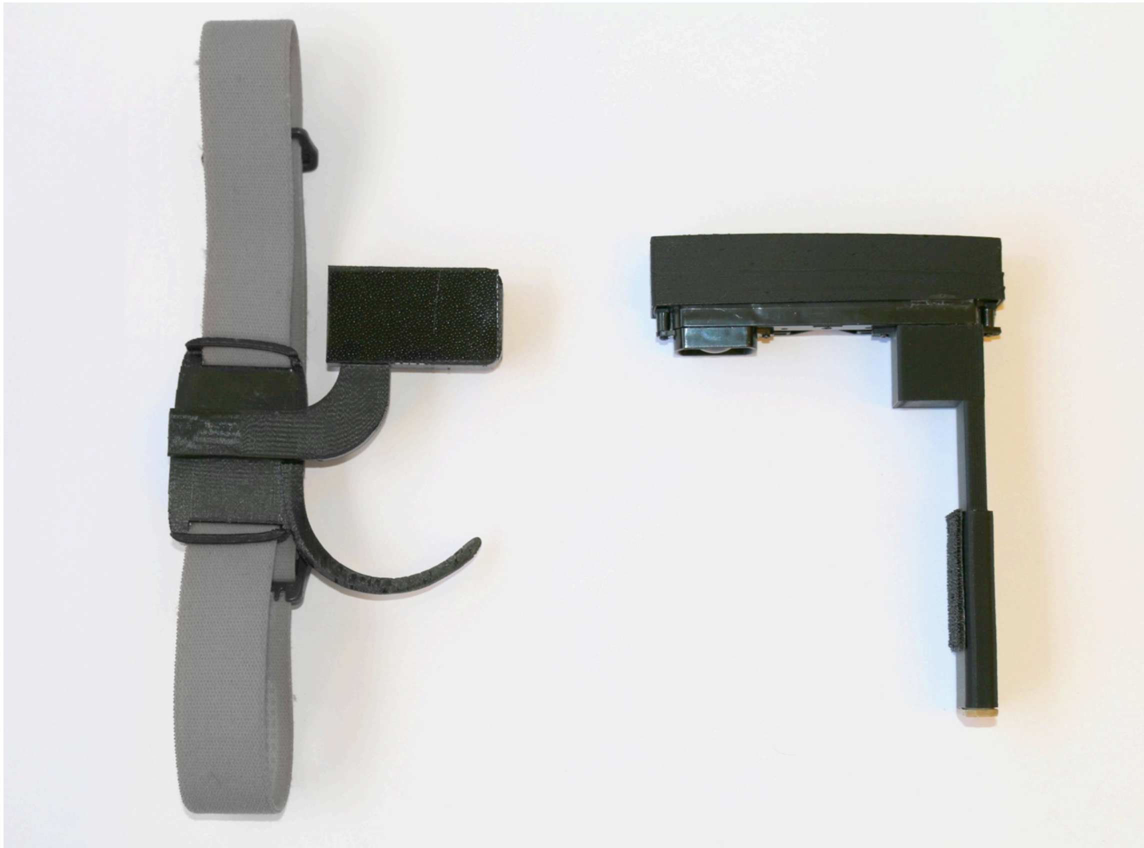


Figure 9. Adjustable headband and the display device

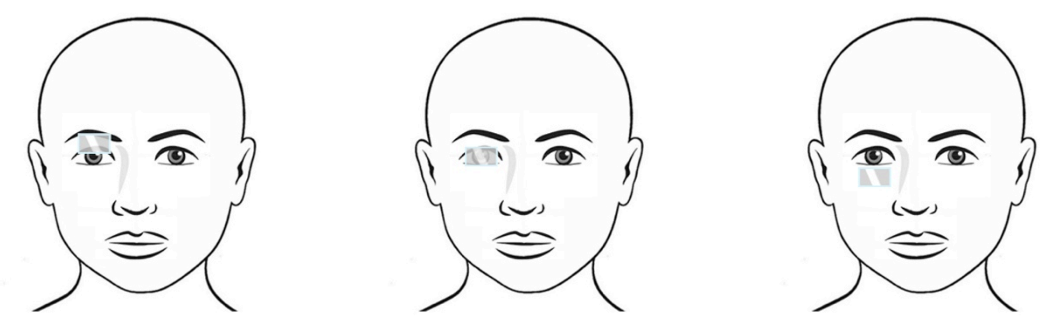


Figure 10. Three different display positions

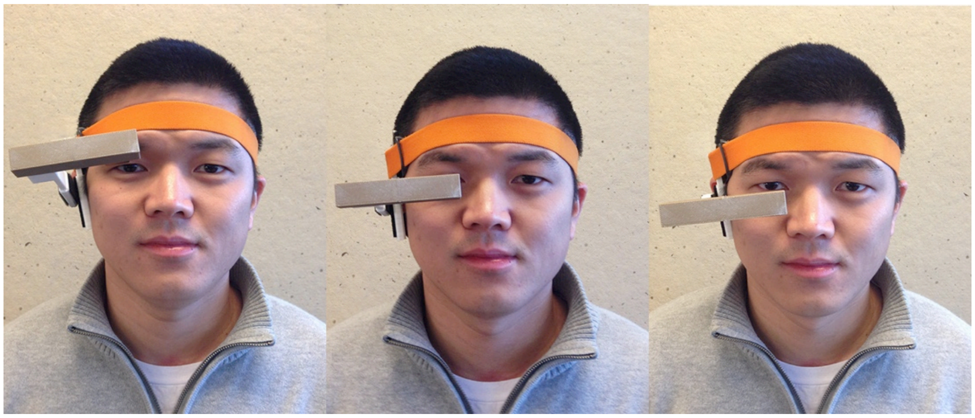


Figure 11. A user wearing the test device in each of the three test configurations during the pilot test

Experimental Conditions

Four different conditions were investigated in this study: three of them used the HMD system and the other used paper manual as a baseline of comparison.

Above-Eye

In this condition, the display is above the participant's line-of-sight. Participants had to move their eyes at a slightly high angle (15° above the line of sight) to read the information (Fig.12).

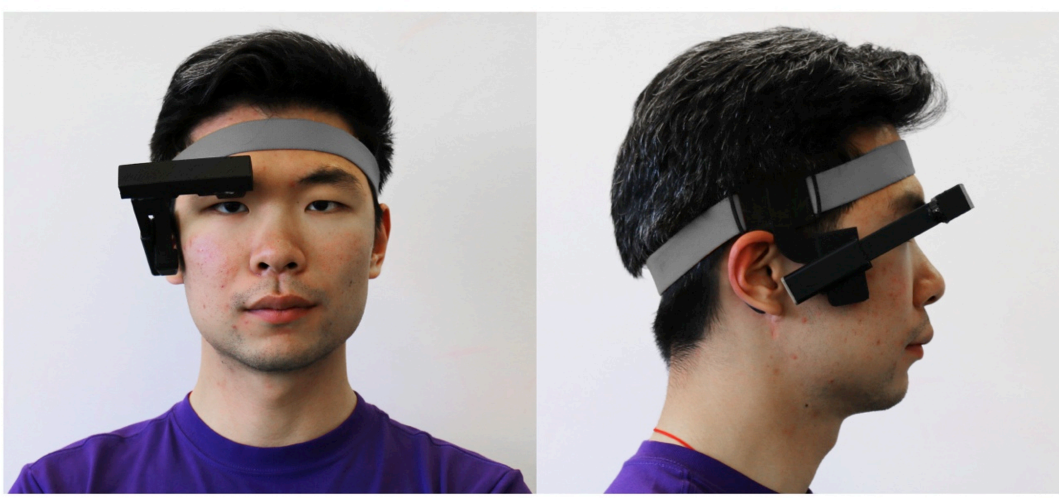


Figure 12. Above-eye condition

Eye-Central

In this condition, the display is centered on the participant's line-of-sight. Participants would look straightforward to read the information (Fig.13).

Figure 13. Eye-central condition

Below-Eye

In this condition, the display is below the participant's line-of-sight. Participants had to move their eyes at a slightly low angle (15° below the line of sight) to read the information (Fig.14).

Figure 14. Below-eye condition

Paper

In this condition, the instructions are printed on a custom-made paper manual, one page per instruction. The size of the image was calculated based on the assumption of an average reading distance of 40 cm [21].

Participants

20 participants (7 female, 13 male) aged 21 to 32 were recruited for the study. All participants had driving experience, 5 years on average. Most participants haven't done any maintenance check themselves in the past 12 months. All participants had normal or corrected-to-normal vision. During the tests, 5 participants were wearing eyeglasses while the rest did not.

Before the task began, participants were told to finish the task as fast and correctly as possible.

At the end of the experiment, each participant received an honorarium of $10.00 in the form of an Amazon Gift Card.

Tasks and Action Types

Each participant performed eight tasks with instructions. These tasks were selected from the official maintenance inspection checklist used at a nationwide auto-care chain company. Decision was made to replace repair tasks with complex maintenance tasks. The reason is listed below:

Repair tasks usually require professional experience and even for a professional mechanic, the execution time (disassembling, operating, assembling, etc.) on one mechanical part may vary greatly from one person to another, leading to significant difference in completion time. This effect is very likely to overpower the effect of the different display conditions and defeat the purpose of the present study.

Task 1: Coolant Level Check

Participant checks the coolant level and adds some coolant liquid.

1. Locate the engine coolant reservoir
2. Locate the max and min markers
3. Clean the dirt on the reservoir to increase visibility
4. Check the coolant level

Task 2: Cabin Air Filter

Participant checks the condition of the cabin air filter.

1. Locate the glove box
2. Open the glove box
3. Loosen the screw on the side
4. Pull off the glove box
5. Remove the cabin air filter cover
6. Take out the air filter
7. Check if air filter is clean
8. Replace the filter and the cover
9. Snap the glove box back to the joints
10. Tighten the screw

Task 3: Engine Oil Level Check

Participant checks if the oil level is sufficient using the engine oil dipstick.

1. Locate the oil dipstick

2. Remove the dipstick
3. Wipe the dipstick with a paper towel
4. Re-insert the dipstick
5. Remove the dipstick again
6. Check the oil level
7. Insert the dipstick back

Task 4: Center Brake Light Check

Participant removes the middle brake light assembly and checks if it is burned out.

1. Locate the trunk release lever
2. Lift the lever to pop the trunk
3. Look under the trunk
4. Locate the bulb assembly
5. Twist counter-clockwise to remove the assembly
6. Check the bulb
7. Put the bulb back
8. Close the trunk

Task 5: Fuse Check (exterior)

Participant pulls out a specific fuse from the exterior fuse box to see if it is blown.

1. Locate the fuse box
2. Press the snap to remove the cover
3. Take out the fuse puller
4. Pull off the #15 fuse on the right

5. Check if the fuse is blown
6. Put the fuse back
7. Close the cover

Task 6: Washer Fluid

Participant checks the washer fluid level and add fluid if necessary.

1. Locate the washer fluid reservoir
2. Open the cap
3. Take out the dipstick
4. Check if the fluid is topped off
5. Top off the reservoir
6. Insert the dipstick and close the cap

Task 7: Air Filter

Participant checks the condition of the air filter contained inside a housing and change it if necessary.

1. Locate the air filter housing
2. Pull the latches on both sides
3. Gently remove the cover
4. Take out the air filter
5. Check if the air filter is clean
6. Put the air filter back
7. Close the housing

Task 8: Headlight

Participant removes the right front light assembly and checks if it is burned out.

1. Look behind the lamp housing
2. Locate the bulb assembly
3. Turn the assembly counter-clockwise to take it out
4. Check the bulb to see if it's blown
5. Put the bulb back

A training task was performed before each the main tasks took place. Participants were asked to open the hood using each test condition. The purpose of the training task was to give the participant the idea of what the instruction interface was like and how to interact with the system.

Each task was decomposed into individual action steps and each step consisted of an actual photo taken on the test car and one simple sentence so that novice users could understand. The instructions were screened and validated with official car manual and online resources [22]. Although some previous works also evaluate the interface design of HMD system [23], it is not the focus of this paper.

Based on the task analysis and literature review on previous research [24, 25], all of the steps were classified into four action types: Read-Locate-Manipulate-Assess. Fig. 15 shows an example of the interface design for the four action types. Locate involves visual search, typically performed to find a specific car component. The part to look for was highlighted by a bright blue outline. Manipulate involves physical manipulation such as unscrewing, lifting and removing, etc. Assess involves visual comparison of what is seen in the real world with what is displayed or described on the screen, such as assessing the condition of a car component, the participants had to speak out the answer regarding the question asked on the Assess instructions.

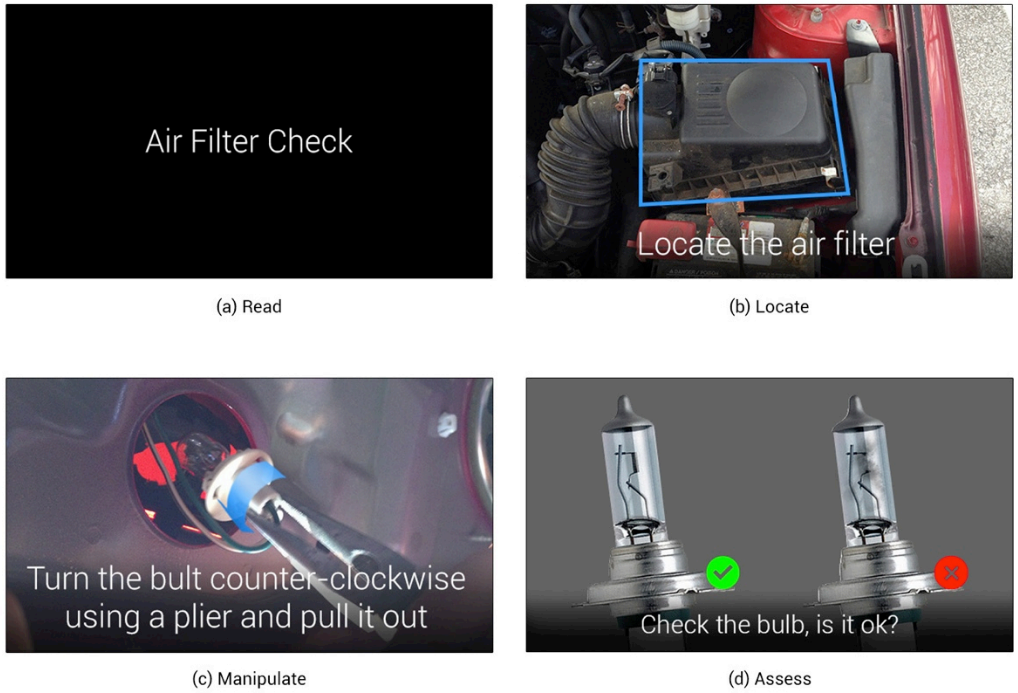


Figure 15. Instruction examples of four action types: Read-Locate-Manipulate-Assess

The eight tasks were then grouped into four trials (Fig. 16) based on the estimate complexity (one relatively easy task paired with one relatively harder task). Tasks with two components sitting next to each other were also intentionally separated into different Trials because otherwise the participant may instantly locate the component for the subsequent task.

By the end of the experiment, each participant performed all the tasks and experienced all the test conditions.

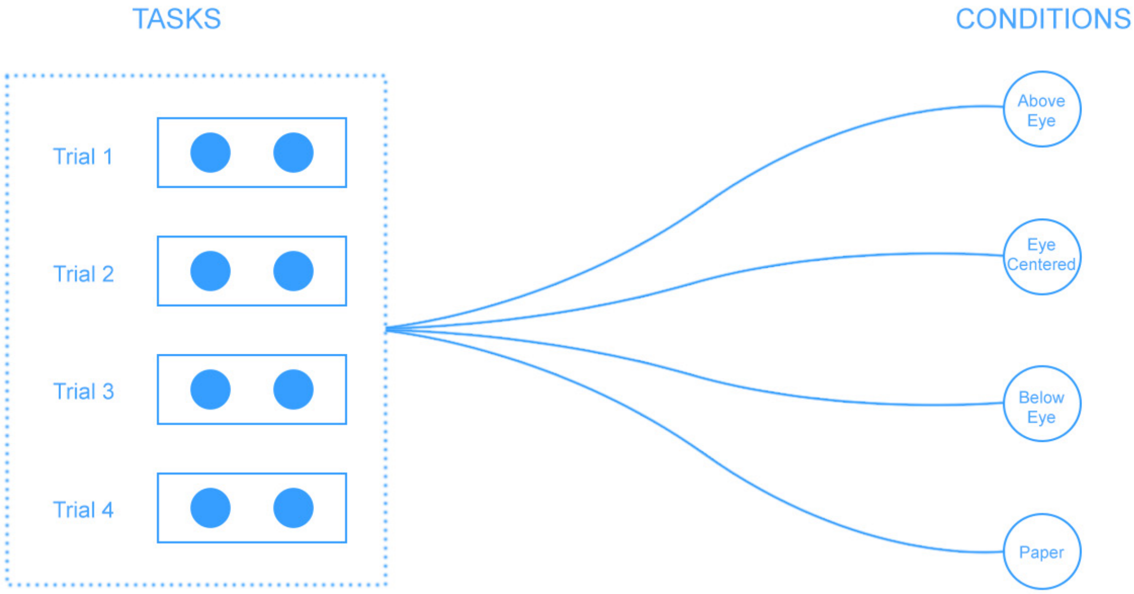


Figure 16. Eight tasks were grouped into four trials, each participant performed one trial using one technology.

Experimental Setup

The study was conducted during the day at an outdoor parking deck. All the tests were conducted either on a cloudy day or in the morning or late afternoon of a sunny day to avoid the influence of bright sunlight. The car used for the experiment was a 2007 Toyota Corolla LE. The tools necessary to complete all the tasks were handed to the participant when needed and consisted of paper towels, a screwdriver, a pair of pliers, and a bottle of washer fluid. Participants were also asked to put on a pair of gloves before performing the tasks.

Two researcher were also involved in the experiment session, as shown on Fig.17. The first person, a facilitator, introduced the procedure to the participant and oversaw the performance of the participant. The facilitator also initiated the computer responses during the tests when participants gave voice commands. The second person, a cameraman, followed the participant and recorded the whole process.

Figure 17. The participant was performing a task while the facilitator oversaw the process and switched screens (photo taken by the cameraman).

Procedures

20 participants were equally distributed amongst four groups at random. Every group performed the same sequence of trials, but received a different sequence of experimental condition (Table. 2). At the end of the experiment, every experimental condition was tested equally often on each task. 20 people ensured 5 people in each sequence of experimental condition, which was sufficient to counter-balance the potential order effects.

Table 2. Test groups and corresponding conditions for different Trials.

	Trial 1	Trial 2	Trial 3	Trial 4
Group 1	Above-eye	Eye-central	Below-eye	Paper
Group 2	Paper	Above-eye	Eye-central	Below-eye
Group 3	Below-eye	Paper	Above-eye	Eye-central
Group 4	Eye-central	Below-eye	Paper	Above-eye

During the experiment, a program coded in Processing was run on a laptop. It served two purposes. One, to allow the researchers remotely control when the participant goes to next/previous step and mirror the image to the HMD. Two, to help the researchers log the exact times of each step in a file, which was later used for data analysis.

To navigate through the instructions, the participants had to speak out voice commands. “Next" to go one step further, and “Previous" to go one step back. Since the image that the user saw was actually mirrored from a monitor next to the car, the researchers were always aware of which step the user was getting guided. When the researcher heard the voice command, he manually switched back and forth the instruction slides. In this way, the experiment could go on smoothly and the user wouldn’t realize any significant pause. As for the paper condition, same instructions were printed out single sided and stapled into a booklet, one step on each page. Participants manually flipped the page to navigate. After he or she finished the current step and before turning the page, the participant must still say “Next” or “Previous”, so that the facilitator could record the time easily by running the same program on the laptop.

An experimental session for each subject lasted 40 to 60 minutes and consisted of three phases. In the first phase, a description of the study was given to the participant. Informed consent was obtained and a demographics questionnaire was then administered, covering some basic information and the experience with the tasks conducted in the experiment. In the second phase, four tests were performed, each one with a different experimental condition. Each test consisted of an introduction to the experimental condition, a practice task, a trial, and a post-trial questionnaire. Subjects could have a short break between each test. In the third phase, the participant was asked to rank the five systems just tested from most favorite to least favorite and was asked to justify the rankings.

Measures

Two kinds of measures were gathered: Objective performance measures and subjective user experience measures. Objective measures included completion time and errors. The completion time is the elapse to complete a step (action). Errors were obtained when participant made a wrong assessment when he or she was performing an Assess action. Subjective user experience measures were gathered through NASA-TLX survey and user experience questionnaire.

Performance measures include completion time and error. The completion time is the time to complete a step and not to complete a whole task. Completion times were obtained by subtracting the instructions arrival time (when a participant arrives on an instruction) to the instructions leave time (when the participant leaves the instruction). Errors were obtained by comparing the participants' answers regarding the condition of the car components with their actual condition.

User experience measures included overall preference ranking, task load, and system usability. Overall preference was obtained by asking the participants to rank the four experimental conditions at the end of the session, from most favorite (1) to least favorite (4). Task load was measured by asking the participants to fill-in the NASA-TLX questionnaire [7, 26](one questionnaire per task, eight total). System usability was measured by asking the participants to answer six questions of the System Usability Scale (SUS) questionnaire[27] that were most relevant (one questionnaire per trial, four total).

Hypothesis

1. At least one of the three HMD conditions would have significant main effects on completion time.
2. Among the four Action Types, Manipulate would yield the longest completion time and Read would yield the shortest.
3. Overall, Paper would yield the shortest completion time among the four Display condition conditions, but the difference won't be significant.
4. One HMD condition may outperform the others for a particular Action Type.
5. Above-eye Condition would most likely be the most preferred position among the three HMD conditions.
6. Over-reliance on the task guidance system might occur, and the effect on HMD conditions would be greater than it on Paper.

CHAPTER 4

DATA ANALYSIS AND RESULTS

Performance

As mentioned in Chapter 3, the performance measures include the completion time and errors. 20 samples were collected and all of them were valid and used in the final analysis.

Errors

Among the 20 participants, only one committed an error in the Oil Level Check Task. The rest finished the tasks with 100% accuracy (0.05 error per person on average). Therefore, the data of error rate is not included and discussed in this study.

Completion Times

A 3-way ANOVA (Display Condition * Task * Action Type) was applied to the Completion time. The result showed that Task ($F = 2.820$, $p = 0.006$, power = 0.922) and Action Type ($F = 86.329$, $p < 0.001$, power = 1.000) had significant effects on the Completion Time. There were also significant two-way interaction effects for every combination of the three independent variables, namely Task * Action Type ($F = 4.608$, $p < 0.001$, power = 1.000), Task * Display condition ($F = 2.078$, $p = 0.003$, power = 0.993) and Action Type * Display condition ($F = 1.893$, $p = 0.049$, power = 0.836). There was no significant three-way interaction effect.

The results are reported in Table 3.

Table 3: 3-way ANOVA (Display Condition*Action Type*Task) on completion time

Tests of Between-Subjects Effects

Dependent Variable: Time

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[b]
Corrected Model	54282.097[a]	127	427.418	4.855	.000	.365	616.618	1.000
Intercept	119565.870	1	119565.870	1358.210	.000	.558	1358.210	1.000
Task	1737.746	7	248.249	2.820	.006	.018	19.740	.922
Action	22799.167	3	7599.722	86.329	.000	.194	258.987	1.000
Position	481.994	3	160.665	1.825	.141	.005	5.475	.476
Task * Action	8518.128	21	405.625	4.608	.000	.083	96.762	1.000
Task * Position	3841.919	21	182.949	2.078	.003	.039	43.642	.993
Action * Position	1499.572	9	166.619	1.893	.049	.016	17.034	.836
Task * Action * Position	4692.258	63	74.480	.846	.798	.047	53.302	.969
Error	94546.323	1074	88.032					
Total	416842.679	1202						
Corrected Total	148828.420	1201						

a. R Squared = .365 (Adjusted R Squared = .290)

b. Computed using alpha =

Post-hoc pair-wise comparisons with Bonferroni corrections on the Task showed that Cabin Air Filter, Fuse Box and Brake Light yielded significantly longer completion time than Coolant, Oil Level and Washer Fluid ($p < 0.030$). No significant difference was found for Air Filter and Headlight, as shown in Fig. 18.

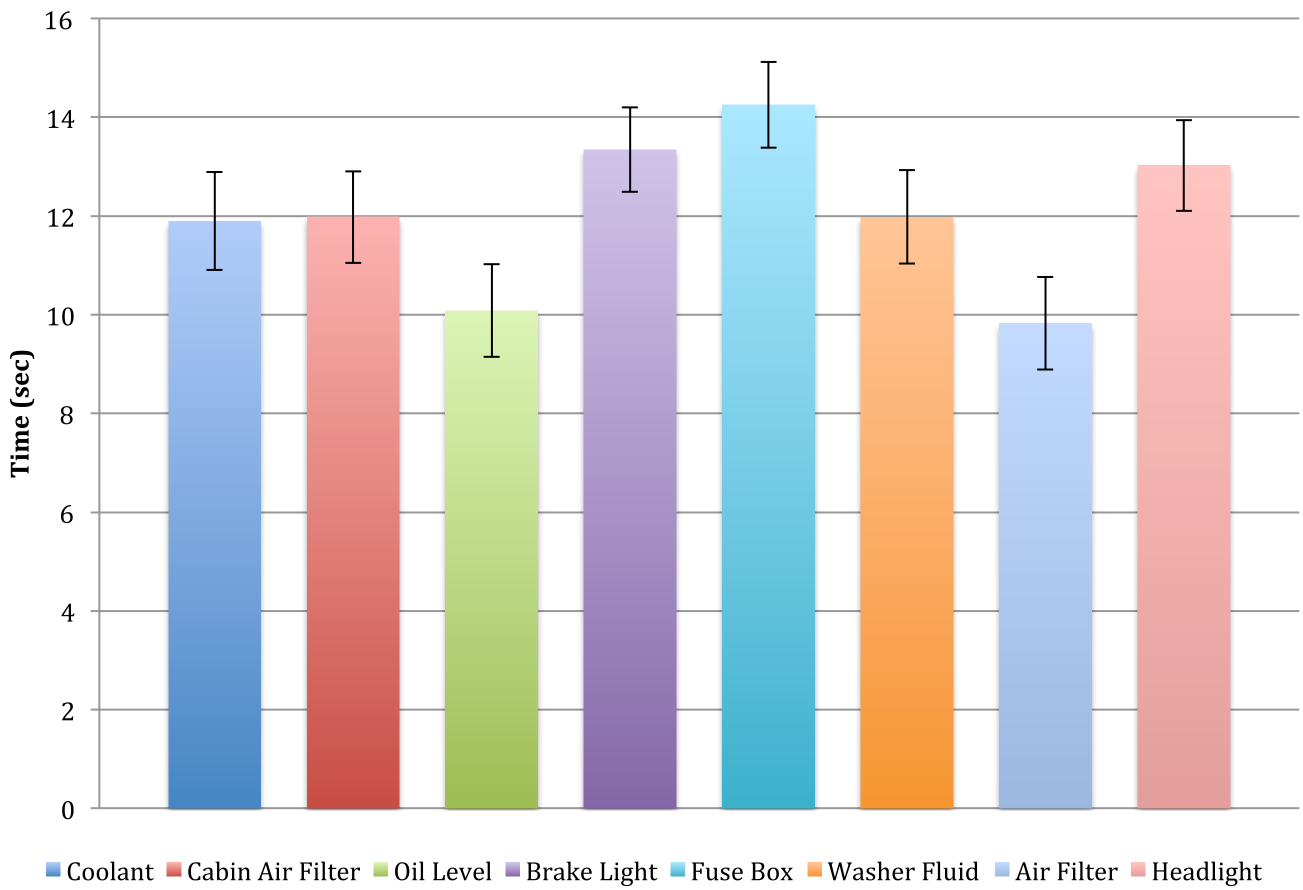


Figure 18. Completion time for different Tasks (with S.E. as the error bar)

The four Action Type conditions yielded different completion times (Fig.19). Post-hoc pair-wise comparisons with Bonferroni adjustments on Action Type showed that Manipulate had longest completion time ($p < 0.001$), and Read had the shortest completion time ($p < 0.\ 001$). There was no significant difference between Locate and Asses ($p = 0.370$).

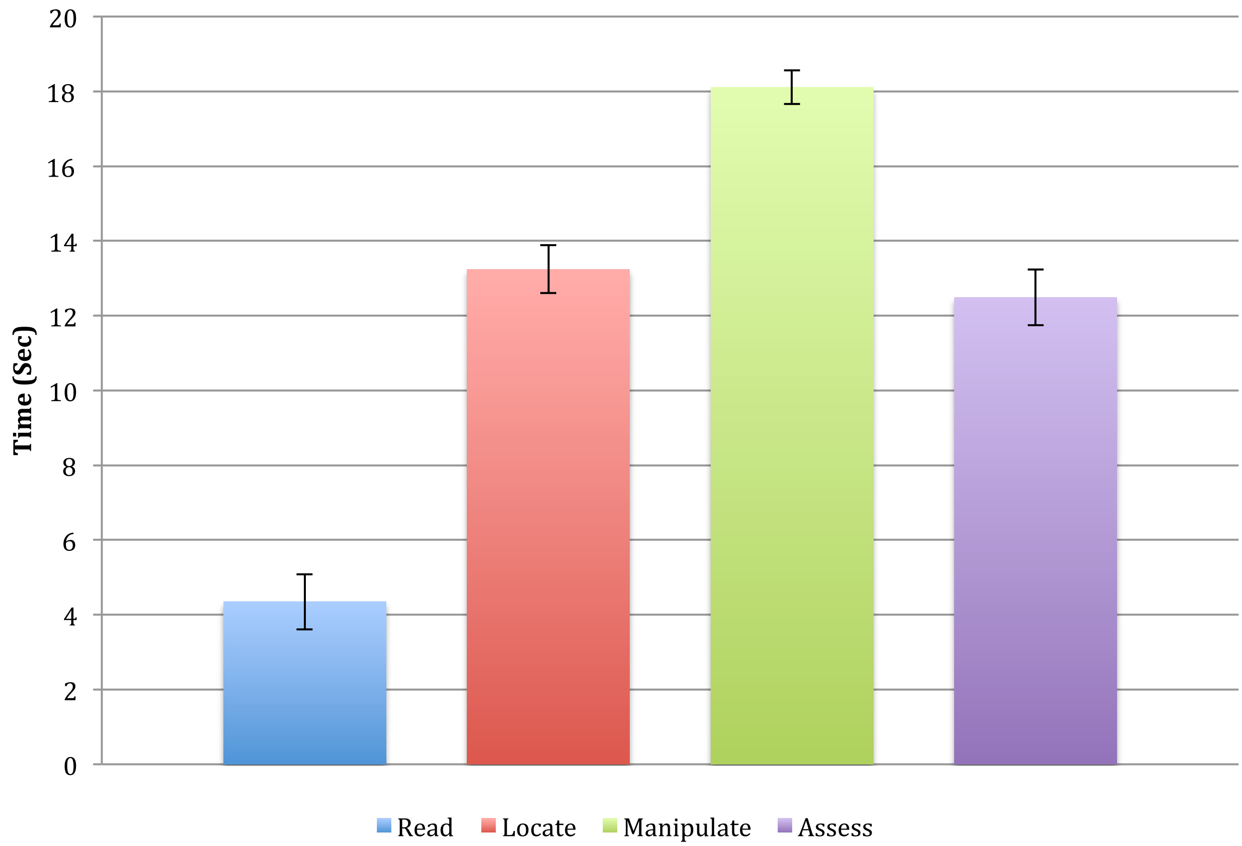


Figure 19. Completion time for different Action Types (with S.E. as the error bar)

There was no significance in the completion time ($p > 0.862$) observed for any of the four Display Condition conditions. A further 3-way ANOVA was performed (without the data of Paper condition) to see if any of the three HMD conditions had significant effects in completion time. Yet the result rejected the assumption again. This result was not anticipated and will be examined in Chapter 5.

The result of the interaction effects between Display Condition and Action Type on completion time revealed an interesting pattern. There's no significant difference among the three HMD Display Condition on completion time for all the four Action Types, as was shown on Fig.20, Paper condition yielded the shortest completion time for

Read, Locate, and Assess actions compared to any HMD condition. However, it also yielded the longest completion time for Manipulate action.

A further examination of Fig.20 also revealed that for Assess action, Below-Eye Position outperformed Above-Eye Position. This finding will also be further discussed in Chapter 5.

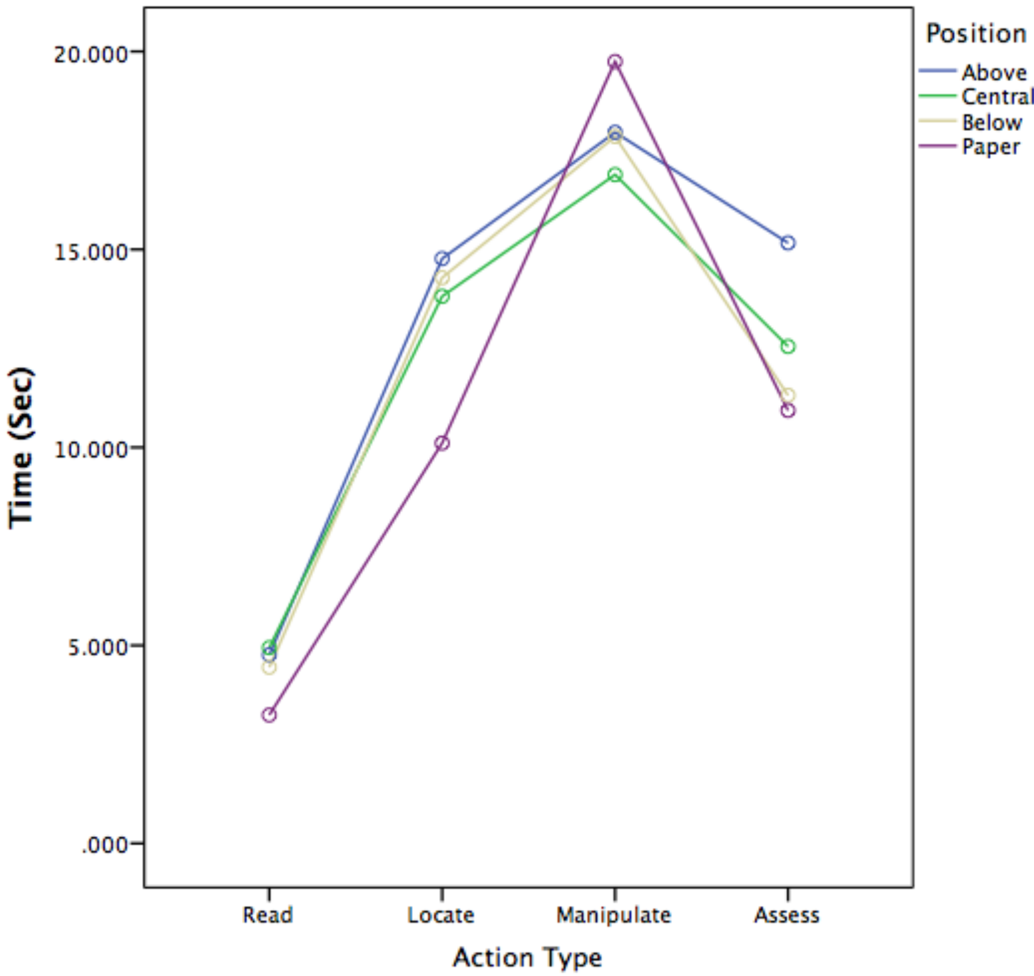


Figure 20. Interaction effects between Display Condition and Action Type on the completion time

The interaction effects between Display Condition and Action Type didn't show any clear pattern. Instead, as shown on Fig.21, it seemed pretty chaotic. To make the plot easier to read, and as the focus of the present study is to evaluate the effects of Display

Conditions among different HMD conditions rather than HMD vs. other technologies, a separate 2-way ANOVA was ran without the data from the paper condition.

The result was showed on Fig. 22, Although each Display Condition appeared to perform better than the other two, the difference was neither significant, nor consistent enough to make any reasonable conjecture.

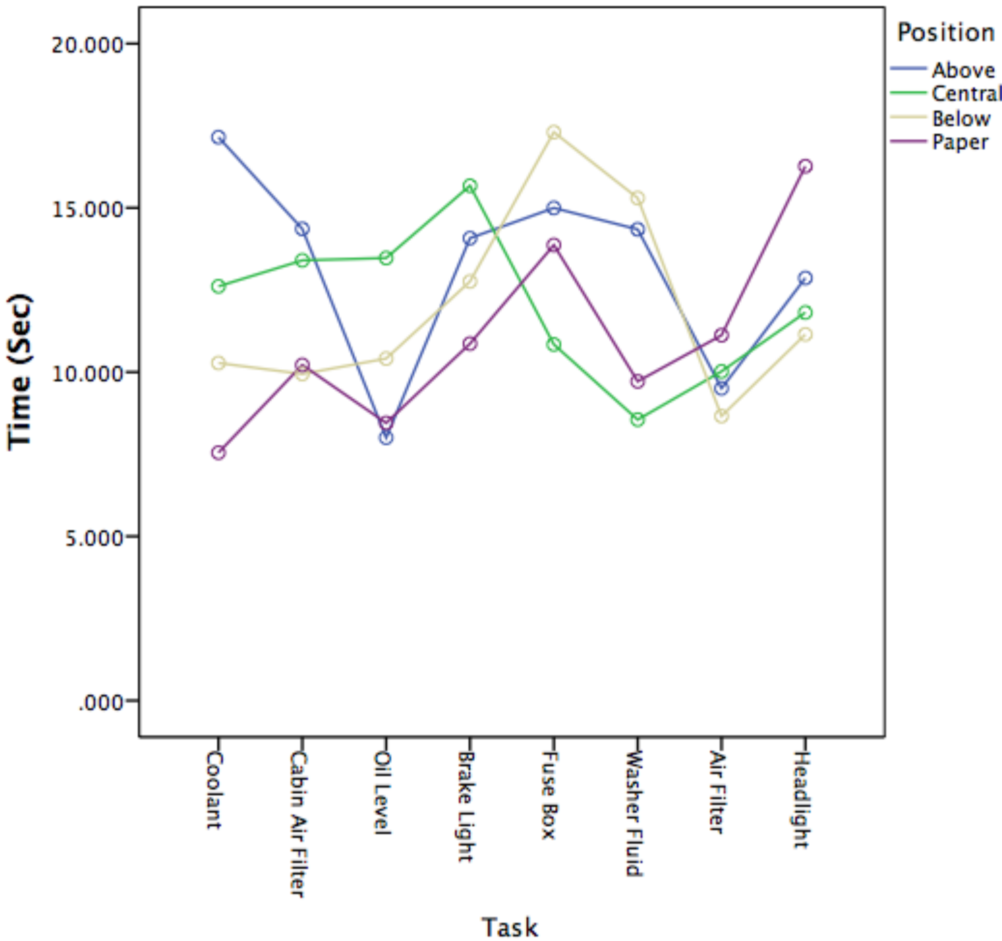


Figure 21. Interaction effects between Display Condition and Task on completion time

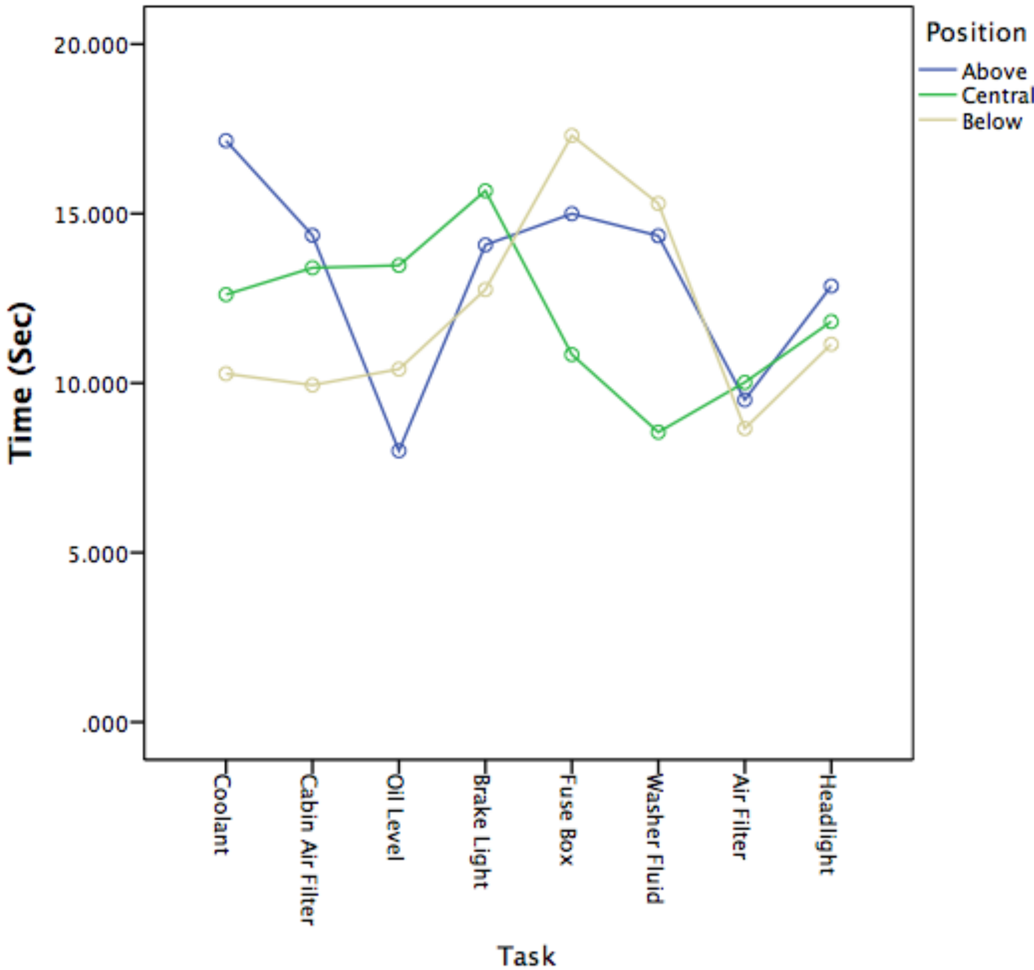


Figure 22. Interaction effects between Display Condition and Task on the completion time (without Paper condition)

Although the interaction effect between Action Type and Task was also reported significant in the ANOVA, there was no pattern observed from the result. As this interaction effect was not the directly related to the objective and hypothesis of the present study, the result of it was not included.

Experience

As mentioned in Chapter 3, experience measures include the NASA-TLX workload ratings, the SUS usability ratings and the overall preference rankings.

NASA-TLX Ratings

A 2-way ANOVA (Display Location * Task) applied to the NASA TLX rating showed no significant main effects, nor interaction effects on overall workload.

SUS Ratings

A 2-way ANOVA (Display Location * Trial) applied to the NASA TLX rating showed that Display Condition had significant main effects on SUS ratings ($F = 3.476$, $p = 0.021$, power = 0.750).

As shown on Fig. 23, Eye-central condition received the highest score among the three HMD conditions.

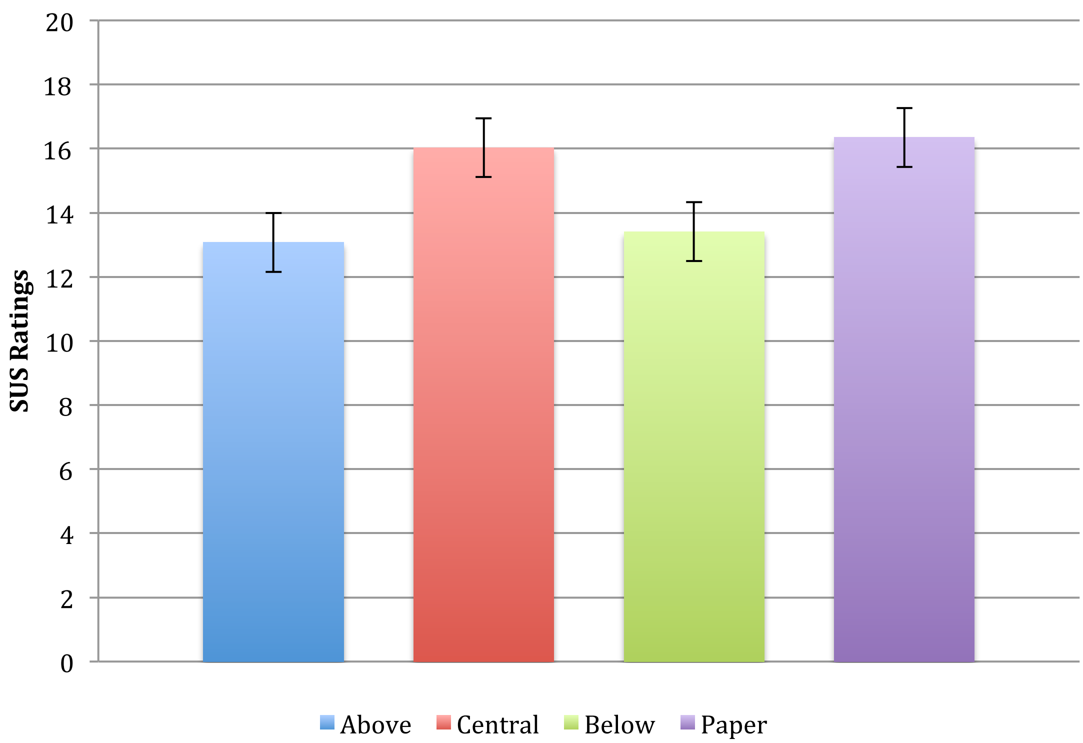


Figure 23. SUS ratings of different Display Conditions

Overall Preference Rankings

One-way ANOVA analysis showed a significant effect on the overall preference rankings for different Display Condition conditions (the lower the score, the higher the rank). Paper was best preferred among the four conditions, followed by Eye-central (Fig.24).

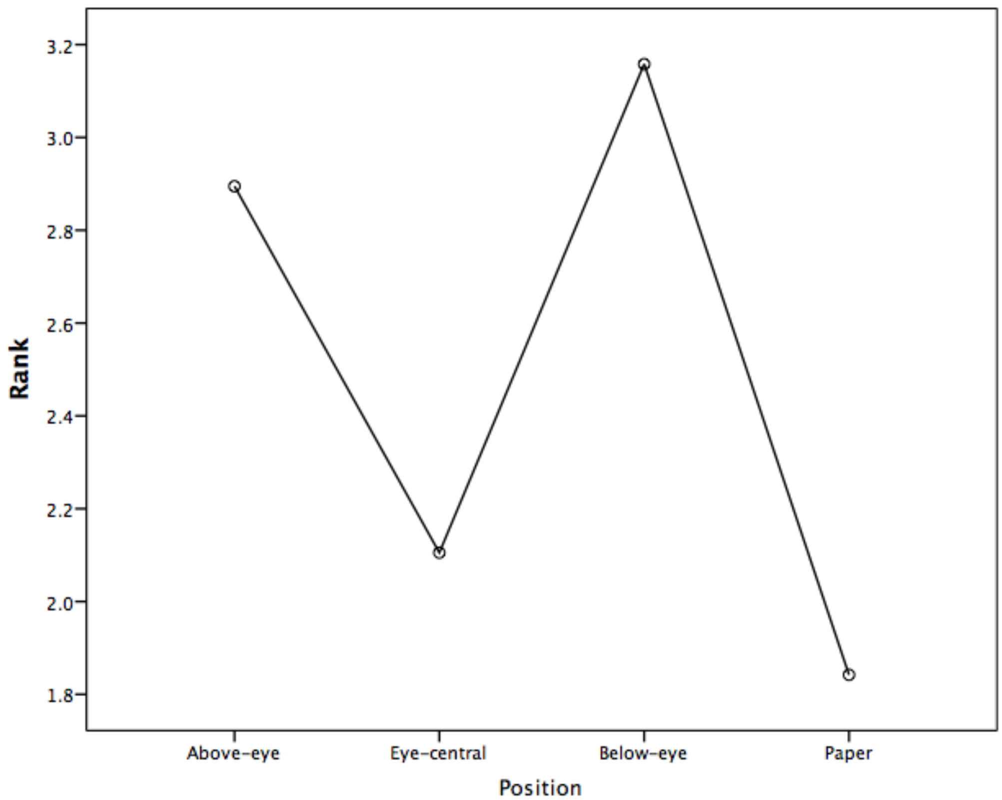


Figure 24. Overall preference rankings (the lower the score, the more preferred) of different Display Conditions

CHAPTER 5

DISCUSSION

Finding 1. There's No Significant Difference In Completion Time Among The Three HMD Display Conditions

As revealed in Chapter 4, there was no significant difference in completion time for the three HMD conditions, namely Above-eye Display, Eye-central Display and Below-eye Display.

The tasks included in this study had some level of complexity, especially that most of the participants (13 out of 20) hadn't done any car repair and maintenance tasks themselves within 12 months before the experiment, the complexity of some tasks were remarkable. For example, for cabin air filter check, participants' completion time varied greatly from 172.72 seconds (total time for the whole task) to 394.24 seconds, both completed with Above-eye Display Condition. After reviewing the time spent for each step, it was found that most of the time difference was caused by Manipulate actions, which could be interpreted as that each user spent significantly different time simply to operate the mechanisms regardless of the Display Condition because the instruction was already processed. As a result, there's no consistent pattern statistically.

As the non-transparent display would block user's field of view, it was expected that Eye-central Display Condition would not perform as well as the other two in particular circumstances. However, the participants adapted to this physical limitation extremely well. On the final open-ended experience survey, only 5 of them complained about the display blocking the FoV, and two out of these five users raised this issue for the Below-eye condition. This interesting finding could also account for why the anticipated difference in Display Conditions didn't happen.

Finding 2. Manipulate had longest completion time and there was no significant difference between Locate and Assess.

This result is likely due to two reasons. First, Manipulate tasks took participants some time to operate the mechanisms and required extra effort than just processing the instruction. Second, reading was a relatively straightforward and easy task, demanding the least amount of information processing.

As for Locate and Assess, the time required mainly depended on how fast the user could process the image information on the instruction screen. As most of the Assessment tasks involved in this study were direct comparisons between real objects and reference images, and most of the parts that needed to be located were exposed and easy to reach, it's fair that they required less completion time than Manipulate.

Finding 3. There's No Overall Difference In Performance Between Paper Condition And HMD Conditions.

The finding can be perceived as the result of several causes.

First, the display used in the present study was monocular and visual information conveyed was less accurate compared to binocular displays. This is due to a phenomenon called binocular rivalry [28]. When two different images are presented to each eye simultaneously, perception alternates between the two images. This interference made it notably harder to focus on the image presented to one eye when the other eye perceives a different image (the ambient scene), as was also discussed by Zheng's et al.[18]. This explains why many participants closed their left eye when reading the instructions, also most participants claimed it was faster to read the instructions from Paper. Second, the experiments were conducted outdoors on March days in Atlanta without shielding the display. Although bright sunny weather was intentionally avoided, the ambient lighting was still brighter than the display, making it difficult to read the low-contrast screen even with the other eye covered [16]. These two facts combined together, might have caused the process time (time to process the instruction) increase in the HMD conditions.

But this difference in process time seemed to be evened out by the fact that participants spent much longer time on Manipulating parts when one of their hands was holding the paper manual. This was not only consistent with the findings shown on the plot (Fig.20), but also supported by the review of the video footages. Almost every participant had trouble switching between turning pages on the manual and attending to the parts on the car. Previous studies showed that users were good at adapting to the context, for example, completing certain step using one hand while usually it requires two. In the present study though, the overall complexity of the tasks were relatively higher than those in the literature, which could lead to a significant difference in operation time (time to manipulate the part).

Finding 4. Below-Eye Position Outperformed Above-Eye Position For Assess Action

Previous empirical study had revealed that “better performance and decreased discomfort in the bifocular position (15° below the line of sight) in comparison to the bioptic position (15° above the line of sight)” [17]. In the present study, the statistic data and the participants’ feedback again supported this conjecture. “It just feels weird to look up”, “It’s harder to get used to the higher angle compared to the lower angle”, as some participants reported. The question is why did this effect only appear during Asses actions? The answer to this might be that Assess required more focus changes between the different images perceived by each eye. Unlike Read and Manipulate where most participants could look at the display once and proceed to operation or to the next action, in Assess participants needed to look back and forth at the screen multiple times to compare the actual part with the reference image. In the observation it was found that participants also checked the display several times when doing some of the Locate Action steps, but there's no notable difference in completion time for this condition. One possible reason was that for Assess, participants needed to perceive the image more accurately compared to Locate instructions. On Locate instructions the components or parts were outlined in high-contrast mint color, and as each component or part was so unique in its form, the participants could usually tell which and where it is even with just a rough glance. Assess on the other hand, required more detailed and thorough look into the images. Therefore, the degraded perception in above-eye display was more notable for Assess action than for Locate action.

Finding 5. Eye-Central Outperformed The Other Two HMD Conditions In Experience And Was The Most Preferred Position for HMD

The result of user experience ratings turned out to be quite surprising. Although Zheng et al.[18] and Peli [16] found in their studies that eye-peripheral position was preferred to eye-central position, the present study showed that eye-central display actually had the highest user experience rating. Here's the interpretation of this opposite finding (as opposed to the literature).

Although the central monocular HMD used in the present study partially blocked the peripheral lateral field, it was not totally occluding. In fact, as described by some participants, he or she could "still see things around pretty well". The literature suggested that such a peripheral field "may be sufficient to maintain binocular fusion and serve alignment of the eyes" [16, 29, 30]. In Zheng et al.'s study, the eye-central HMD was binocular and composed of thick lens frames and wide FoV lenses, participants could only see images through the transparent screen. In other words, they had to filter out the instruction images overlaid on the ambient environment, which caused extra effort and discomfort. Not to mention that the binocular HMD itself reduced the accuracy of depth perception whereas in the present study the peripheral awareness itself was sufficient to judge the spatial relationship between the participants themselves and other objects.

In Peli's study [16], the primary monitor was 170cm away facing the subject, so when the subjects looked at the monitor, they basically looked straightforward. However in the present study, all the car components were located below subjects' head level. When Locate and Assess action were required, subjects tend to turn their eyes downward to look at the components instead of crouching down to align the component with their line of sight and looking straightforward. Therefore, the eye-central display actually wouldn't be in the way, Also when Manipulating the components, the participants didn't feel that the display right in front of the right eye interfered with their performance. As one participant stated, "It felt the same when you are actually working on something" (referring all four conditions).

These unique characteristics of the test device and tasks, along with the widely accepted fact that the human visual acuity is best in the fovea (central pit composed of closely packed cones in the eye), could explain why Eye-central Display Condition performed the best in Experience.

Finding 6. Over-Reliance On The Task Guidance System In Some Tasks

Over-reliance was a concern in most task guidance systems [8], there was also evidence in the present study. It was observed that during the experiments, some participants went to the passenger's side to look for the trunk release. This was surprising because it was assumed that anyone who had at least one year of driving experience should know that the trunk release was usually if not always on the driver's side. One could even argue that people with driving experience would locate the trunk release in any type of car without any visual hint. The task guidance system seemed to actually decrease participants' ability to think by themselves and make decisions based on their previously acquired experience and knowledge.

Same incident of over-reliance was also observed in the Headlight Check task where some participants tried to look for the bulb assembly at the area around the coolant reservoir and the belts (because the instruction image showed the bulb was connected to a wire, and there were many wires in these two areas) instead of the back of the headlight housing.

From the previous study[18], it was learned that ambiguous instructions would significantly increase the completion time compared to more clear and straightforward instructions, especially when using the HMDs. In the present study, all ambiguous instructions were either eliminated or improved in the present experiment. This time the result showed that extra time cost in the aforementioned two Locate steps (headlight and trunk release) was equal between the HMD and the Paper. This finding suggested that the over-reliance on task guidance systems exists even if all the instructions were clear and non-ambiguous, and its impact wasn't necessary stronger in HMD systems.

Limitation

Ideally, in the Above-eye condition, the HMD should be located 15° above the primary viewing area, and 15° below for the Below-eye condition. However, in the real world scenario, it was extremely difficult to keep the angle of the HMD exactly the same among all subjects (by using the photo of the previous user as a reference). This was caused by the individual difference. Different users had variance in the anthropometric measurements such as head circumference, ear-eye distance and ear height. Because the monocular display is relatively small and contains a convex lens with a fixed focal distance, any small individual difference would be amplified, causing the noticeable end effect. This phenomenon was common even in the mainstream HMD products too. The device built for this study was highly adjustable, but slight inconsistency was inevitable and it's arguable that it had affected the final results.

Another limitation was the field of view. Most participants had no problem reading the instructions on the display, but some participants with relatively lower vision complained that the screen size was too small to perceive the information easily. Although in the literature it was proved that FoV had no effect on binocular rivalry, it seemed small FoV would reduce the efficiency in perceiving the procedural instructions.

CHAPTER 6

CONCLUSION

This paper presented a method to evaluate the effect of display positions on user performance and experience of procedure following in guided repair and maintenance. A highly adjustable monocular HMD was designed and built to accommodate three conditions: Above-eye, Eye-central and Below-eye. The display size, interaction modality and instruction design were strictly controlled.

A set of car tasks with adequate difficulty level were performed and the most important findings include:

- No difference was found in completion time among the three HMD Display Conditions.
- Further investigation revealed that each display position had its own pros and cons and should be specified based on the nature of the task.
- Eye-central outperformed the other two HMD conditions in experience due to better perception and peripheral fusion.
- Superior performance associated with below-horizontal eye movements compared with above-horizontal eye movements only occurred during Assess action.

More empirical work is needed in order to fully understand how HMD technology can benefit workers in the industrial settings, and how to maximize these benefits. This study investigated the display location and its impact on guided repair and maintenance. There are other important HMD factors yet to be scientifically studied. Future work can focus on the interaction effect of FoV and display position, or different media of information (still image, GIF and video). Different types of tasks with different complexities in different contexts can also be discussed.

The implication of this study to designers is that different display positions seem to be best suited to different types of action and different tasks. Users also have their own preferences, and sometimes the best display position for one user could turn out to be the worst for another. Therefore, a device with certain levels of freedom that allows users to adjust the viewing angle has great potential. There are problems yet to be solved in terms of how the device should be attached/worn without obstructing user's paracentral and peripheral vision and what mechanism should be used to ensure both flexibility and stability. Leveraging what was learned from the present design, a concept design was proposed. The concept focused on the basic mechanism of the HMD and perhaps could serve as the starting point for further development. As shown on Fig. 25, the display is attached to a ball joint so that the screen angle can be adjusted in the 3D space. The "bridge" of the device can pivot around the point slightly below the user's temple. Ideally this mechanism would provide the level of freedom required for all viewing angles. However, the mounting mechanism is not included in this concept. It could be a rigid frame like Google Glass, or an elastic headband like the one in this study, or perhaps something totally innovative.

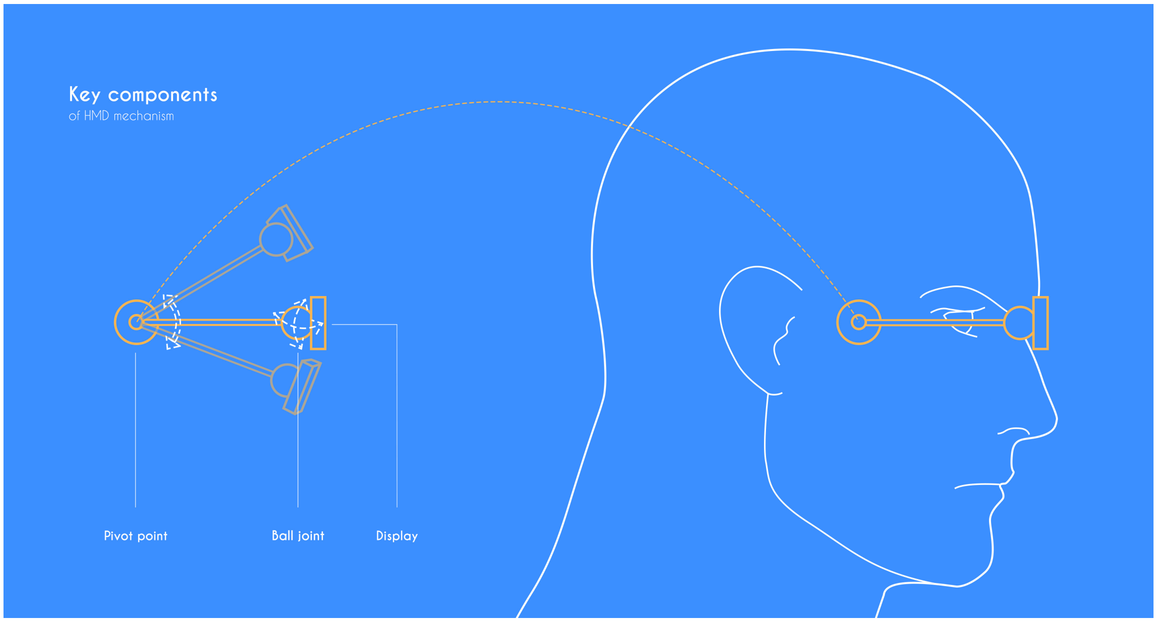


Figure 25. A concept design focusing on the mechanism for future HMD

In addition, it seems that a systematic guideline for procedure following instructions is needed for designers to create different types of task guidance interface that could meet the need of different industrial settings and task requirements. Though not validated in the present study, it was reasonable to expect that the instruction for novice users should be slightly different from that for experienced professionals.

The exploration and method introduced in the present study is still considered as the early stage of the design process. It is the authors' hope that the exploration and findings in the present study could contribute to the future development of a more versatile and successful Head-mounted Display system.

APPENDIX A

TWO-WAY ANOVA (TASK * POSITION) ON WORKLOAD

Tests of Between-Subjects Effects

Dependent Variable: Workload

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[b]
Corrected Model	414.504[a]	31	13.371	.988	.496	.215	30.616	.814
Intercept	5595.442	1	5595.442	413.295	.000	.787	413.295	1.000
Task	179.016	7	25.574	1.889	.078	.106	13.223	.728
Position	12.354	3	4.118	.304	.822	.008	.913	.107
Task * Position	232.629	21	11.078	.818	.693	.133	17.183	.599
Error	1516.325	112	13.539					
Total	7566.250	144						
Corrected Total	1930.829	143						

a. R Squared = .215 (Adjusted R Squared = -.003)

b. Computed using alpha =

APPENDIX B

TWO-WAY ANOVA (TRIAL * POSITION) ON SUS RATINGS

Tests of Between-Subjects Effects

Dependent Variable: Score

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[b]
Corrected Model	482.676[a]	15	32.178	2.024	.028	.336	30.354	.920
Intercept	16311.838	1	16311.838	1025.794	.000	.945	1025.794	1.000
Trial	33.944	3	11.315	.712	.549	.034	2.135	.192
Position	165.803	3	55.268	3.476	.021	.148	10.427	.750
Trial * Position	299.193	9	33.244	2.091	.044	.239	18.815	.823
Error	954.100	60	15.902					
Total	17795.000	76						
Corrected Total	1436.776	75						

a. R Squared = .336 (Adjusted R Squared = .170)

b. Computed using alpha =

APPENDIX C

ONE-WAY ANOVA (DISPLAY CONDITION) ON PREFERENCE RANKING

Ranking

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	22.368	3	7.456	7.391	.000
Within Groups	72.632	72	1.009		
Total	95.000	75			

APPENDIX D

STUDY SCRIPT

THESIS STUDY PROTOCOL

By

Tao Yang
Master of Industrial Design Candidate 2015

In Partial Fulfillment of the
Requirements for the Degree
Master of Industrial Design in the
School of Industrial Design,
College of Architecture

Georgia Institute of Technology
March 2015

Participant No. : ……………………………………..

Date: ……………………………………..

Start Time: ……………………………………..

End Time: ……………………………………..

Group: ……………………………………

Moderator: ……………………………………

Introduction

Thank you for your participation in this study of the wearable technology for machine maintenance. My name is…   and I'll be introducing you to our study today.

[Obtain Consent]

[Obtain Personal Information on Page 3]

Participant Background Information

1. In what year were you born?

2. How old were you when you got your first driver's license?

3. Have you ever done any maintenance for your car or others' car, e.g., changing the air filter, jump start the battery, changing the coolant or wiper fruit, change the engine oil?
   If yes, please write the number of times you've done it in the past 12 months, and what you did.

4. Have you ever used Head-Mounted Display or Smart Glasses before, e.g. Google Glass, Epson Moverio before?

With your permission, I will begin the video recording now.

What we're going to do today is to evaluate how different display positions of Head-Mounted Display (HMD) devices affect the task guidance on car maintenance tasks.

You will be asked to do several car maintenance tasks. We will ask you to complete these tasks using four different experimental conditions:

- Above-eye HMD
- Below-eye HMD
- Eye-centered HMD
- Paper

[Pick up the device]

This device was designed to be worn on the head. It has two parts, the glass *[Point to the glass]* and the head mounting system *[Point to the head band]*. The glass is connected to the a Raspberry Pi micro controller through these cable *[Point to the wires and the Rasp Pi]*. The raspberry Pi will receive the screen information wirelessly from the laptop *[Point to the laptop]* and then send the image to this screen *[Point to the near-eye display]*.

You put on the device like this.

[Demonstrate how to put on the device on self]

Once it's on, I'll adjust the angle of the glass until you can clearly see the image on the screen and let us know. Then I'll fix the position using the fasteners here *[Touch the fastener on the glass and the mounting tab].*

During the study, you'll receive the instructions on the screen, you'll need to finish the tasks step by step. Once you finish the step on the current screen, you can say "next" to move on to the next step. You can also say "previous" to go back if necessary. Remember, you're not allowed to jump to the next screen unless you finish the task on the current one, but you can go back as many steps as you want to check.

There will be four kinds of actions: Read-Locate-Manipulate-Assess. Read instructions are just textual information given so that participants understand what task they are about to start and when they are finished *[show the example of Read instructions]*. Locate involves visual search, typically performed to find a specific car component *[show the example of Locate instructions]*. Manipulate involves physical manipulation such as unscrewing, lifting and removing *[show the example of Manipulate instructions]*. Assess involves visual comparison of what is seen in the real world with what is displayed or described on the screen, such as assessing the condition of a car component *[show the example of Assess instructions]*.

Be aware, in this study, “Replace” means “put (something) back in a previous place or position.“ “Right” and “Left” should be interpreted in the case that you’re standing in front of the hood.

Once you finish all the tasks for condition 1 and the questionnaires and the short break following that, I’ll re-adjust the angle of the glass and continue to condition 2 and so on.

[Demonstrate how to take off the device]

Let’s take a look at the paper manual. *[Pick up the manual].* The rule is similar, there’s one instruction on one page and these pages are all printed one-sided. You should turn the page only when you finish the step on the current page *[Turn the page].*

Ok, let’s get started! Your first condition would be … Before the real tasks, please finish a training task just to get used to the this experimental condition.

[Pass the device/manual to the participant and let the participant perform the training task, guiding where necessary]

[3 minutes of allowing the participant to perform the training task]

Great, you’ve finished the training task. If there’s no doubt on the procedure and the functions, let’s start the real tasks.

[10 minutes of allowing the participant to perform Trial 1]

While this is still really fresh on your mind, would you please take this survey to evaluate the product for me?

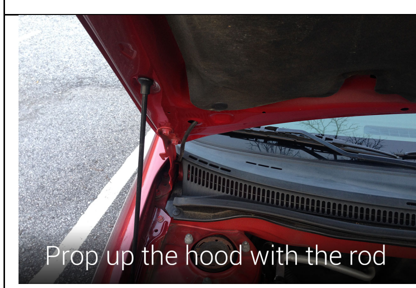
[2 minutes of allowing the participant to finish the survey for Trial 1]

Great. After a short break, let’s move on to the next Trial.

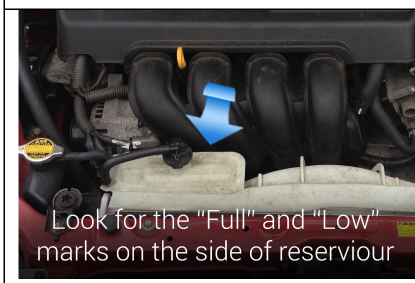
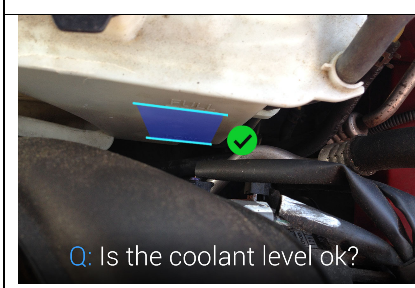
[36 minutes of allowing the participant to perform tasks and finish surveys for Trial 2, 3, 4]

Testing Scenario

Task 0- Open the Hood

Steps	Notes
	
	
	
	

Task 1 – Coolant Check

Steps	Notes
	
	
	
	

Task 2 – Cabin Air Filter

Steps	Notes
 Locate the glove box	
 Open the glove box	
 Undo the screws on the side	
 Pull off the glove box	
 Remove the air filter cover	

N CHINA AIR FLOW ↓ Take out the air filter	
Q: Is the filter clean?	
N CHINA AIR FLOW ↓ Replace the filter and cover	
Snap the glove box back	
Redo the screws on the side	

(NASA TLX) Task 1

<u>Mental Demand</u>: How much mental and perceptual activity was required (e.g., thinking, deciding, calculating, remembering, looking, searching, etc)? Was the mission easy or demanding, simple or complex, exacting or forgiving?

Low High

<u>Physical Demand</u>: How much physical activity was required (e.g., pushing, pulling, turning, controlling, activating, etc.)? Was the mission easy or demanding, slow or brisk, slack or strenuous, restful or laborious?

Low High

<u>Temporal Demand</u>: How much time pressure did you feel due to the rate or pace at which the mission occurred? Was the pace slow and leisurely or rapid and frantic?

Low High

<u>Performance</u>: How successful do you think you were in accomplishing the goals of the mission? How satisfied were you with your performance in accomplishing these goals?

Low High

<u>Effort</u>: How hard did you have to work (mentally and physically) to accomplish your level of performance?

Low High

<u>Frustration</u>: How discouraged, stressed, irritated, and annoyed versus gratified, relaxed, content, and complacent did you feel during your mission?

Low High

(NASA TLX) Task 2

<u>Mental Demand</u>: How much mental and perceptual activity was required (e.g., thinking, deciding, calculating, remembering, looking, searching, etc)? Was the mission easy or demanding, simple or complex, exacting or forgiving?

Low High

<u>Physical Demand</u>: How much physical activity was required (e.g., pushing, pulling, turning, controlling, activating, etc.)? Was the mission easy or demanding, slow or brisk, slack or strenuous, restful or laborious?

Low High

<u>Temporal Demand</u>: How much time pressure did you feel due to the rate or pace at which the mission occurred? Was the pace slow and leisurely or rapid and frantic?

Low High

<u>Performance</u>: How successful do you think you were in accomplishing the goals of the mission? How satisfied were you with your performance in accomplishing these goals?

Low High

<u>Effort</u>: How hard did you have to work (mentally and physically) to accomplish your level of performance?

Low High

<u>Frustration</u>: How discouraged, stressed, irritated, and annoyed versus gratified, relaxed, content, and complacent did you feel during your mission?

Low High

System Usability Scale (Brooke,1986)

In the follow questionnaire we would like you to give a rating of the prototype you just used. You should base your rating on your individual experience using it. The focus is your personal evaluation of the prototype.

Please rate the following statements:

1. I think that I would like to use this system frequently.
   ☐Strongly Disagree
   ☐Somewhat Disagree
   ☐Neither Agree nor Disagree
   ☐Somewhat Agree
   ☐Strongly Agree

2. I think the system was easy to use.
   ☐Strongly Disagree
   ☐Somewhat Disagree
   ☐Neither Agree nor Disagree
   ☐Somewhat Agree
   ☐Strongly Agree

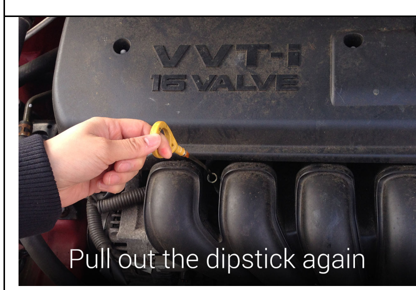
3. I think that I would need the support of a technical person to be able to use this system. ☐Strongly Disagree
   ☐Somewhat Disagree
   ☐Neither Agree nor Disagree
   ☐Somewhat Agree
   ☐Strongly Agree

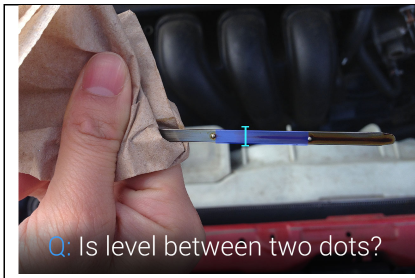
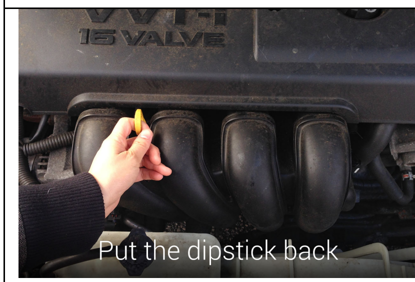
4. I would imagine that most people would learn to use this system very quickly.
   ☐Strongly Disagree
   ☐Somewhat Disagree
   ☐Neither Agree nor Disagree
   ☐Somewhat Agree
   ☐Strongly Agree

5. I found the system very cumbersome to use.
   ☐Strongly Disagree
   ☐Somewhat Disagree
   ☐Neither Agree nor Disagree
   ☐Somewhat Agree
   ☐Strongly Agree

6. I felt very confident using the system.
   ☐Strongly Disagree
   ☐Somewhat Disagree
   ☐Neither Agree nor Disagree
   ☐Somewhat Agree
   ☐Strongly Agree

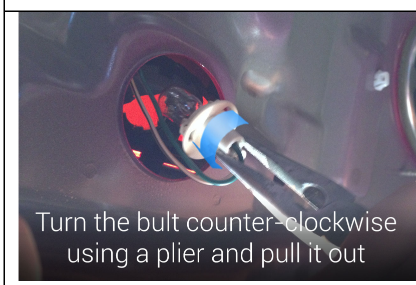
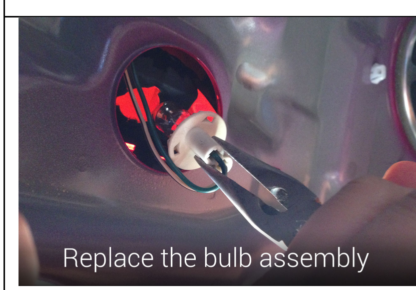
Task 3 – Engine Oil Check

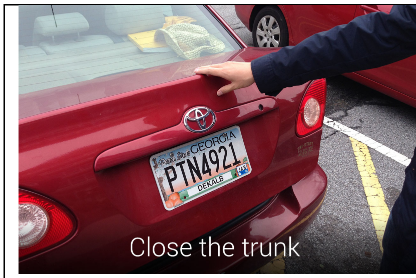
Steps	Notes
	
	
	
	
	

Task 4 – Brake Light Check

Steps	Notes
	
	

 Locate the ceiling of the trunk	
 Locate the bulb on the ceiling	
 Turn the bult counter-clockwise using a plier and pull it out	
 Q: Check the bulb, is it ok?	
 Replace the bulb assembly	

Close the trunk	

(NASA TLX) Task 3

<u>Mental Demand</u>: How much mental and perceptual activity was required (e.g., thinking, deciding, calculating, remembering, looking, searching, etc)? Was the mission easy or demanding, simple or complex, exacting or forgiving?

Low |_|_|_|_|_|_|_|_|_|_|_|_|_|_|_|_|_|_|_|_| High

<u>Physical Demand</u>: How much physical activity was required (e.g., pushing, pulling, turning, controlling, activating, etc.)? Was the mission easy or demanding, slow or brisk, slack or strenuous, restful or laborious?

Low |_|_|_|_|_|_|_|_|_|_|_|_|_|_|_|_|_|_|_|_| High

<u>Temporal Demand</u>: How much time pressure did you feel due to the rate or pace at which the mission occurred? Was the pace slow and leisurely or rapid and frantic?

Low |_|_|_|_|_|_|_|_|_|_|_|_|_|_|_|_|_|_|_|_| High

<u>Performance</u>: How successful do you think you were in accomplishing the goals of the mission? How satisfied were you with your performance in accomplishing these goals?

Low |_|_|_|_|_|_|_|_|_|_|_|_|_|_|_|_|_|_|_|_| High

<u>Effort</u>: How hard did you have to work (mentally and physically) to accomplish your level of performance?

Low |_|_|_|_|_|_|_|_|_|_|_|_|_|_|_|_|_|_|_|_| High

<u>Frustration</u>: How discouraged, stressed, irritated, and annoyed versus gratified, relaxed, content, and complacent did you feel during your mission?

Low |_|_|_|_|_|_|_|_|_|_|_|_|_|_|_|_|_|_|_|_| High

(NASA TLX) Task 4

<u>Mental Demand</u>: How much mental and perceptual activity was required (e.g., thinking, deciding, calculating, remembering, looking, searching, etc)? Was the mission easy or demanding, simple or complex, exacting or forgiving?

Low |_|_|_|_|_|_|_|_|_|_|_|_|_|_|_|_|_|_|_|_| High

<u>Physical Demand</u>: How much physical activity was required (e.g., pushing, pulling, turning, controlling, activating, etc.)? Was the mission easy or demanding, slow or brisk, slack or strenuous, restful or laborious?

Low |_|_|_|_|_|_|_|_|_|_|_|_|_|_|_|_|_|_|_|_| High

<u>Temporal Demand</u>: How much time pressure did you feel due to the rate or pace at which the mission occurred? Was the pace slow and leisurely or rapid and frantic?

Low |_|_|_|_|_|_|_|_|_|_|_|_|_|_|_|_|_|_|_|_| High

<u>Performance</u>: How successful do you think you were in accomplishing the goals of the mission? How satisfied were you with your performance in accomplishing these goals?

Low |_|_|_|_|_|_|_|_|_|_|_|_|_|_|_|_|_|_|_|_| High

<u>Effort</u>: How hard did you have to work (mentally and physically) to accomplish your level of performance?

Low |_|_|_|_|_|_|_|_|_|_|_|_|_|_|_|_|_|_|_|_| High

<u>Frustration</u>: How discouraged, stressed, irritated, and annoyed versus gratified, relaxed, content, and complacent did you feel during your mission?

Low |_|_|_|_|_|_|_|_|_|_|_|_|_|_|_|_|_|_|_|_| High

System Usability Scale (Brooke,1986)

In the follow questionnaire we would like you to give a rating of the prototype you just used. You should base your rating on your individual experience using it. The focus is your personal evaluation of the prototype.

Please rate the following statements:

1. I think that I would like to use this system frequently.
☐Strongly Disagree
☐Somewhat Disagree
☐Neither Agree nor Disagree
☐Somewhat Agree
☐Strongly Agree

2. I think the system was easy to use.
☐Strongly Disagree
☐Somewhat Disagree
☐Neither Agree nor Disagree
☐Somewhat Agree
☐Strongly Agree

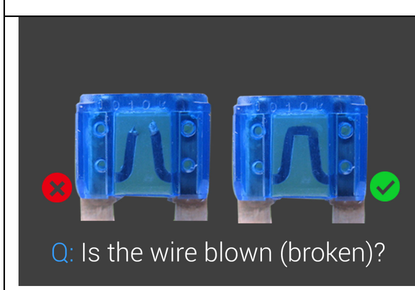
3. I think that I would need the support of a technical person to be able to use this system. ☐Strongly Disagree
☐Somewhat Disagree
☐Neither Agree nor Disagree
☐Somewhat Agree
☐Strongly Agree

4. I would imagine that most people would learn to use this system very quickly.
☐Strongly Disagree
☐Somewhat Disagree
☐Neither Agree nor Disagree
☐Somewhat Agree
☐Strongly Agree

5. I found the system very cumbersome to use.
☐Strongly Disagree
☐Somewhat Disagree
☐Neither Agree nor Disagree
☐Somewhat Agree
☐Strongly Agree

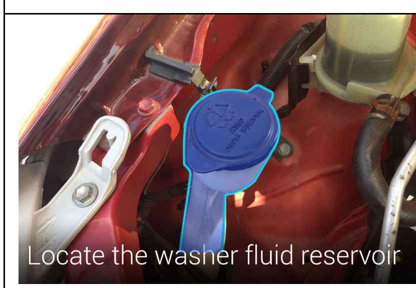
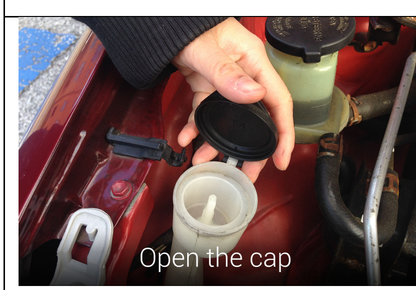
6. I felt very confident using the system.
   ☐Strongly Disagree
   ☐Somewhat Disagree
   ☐Neither Agree nor Disagree
   ☐Somewhat Agree
   ☐Strongly Agree

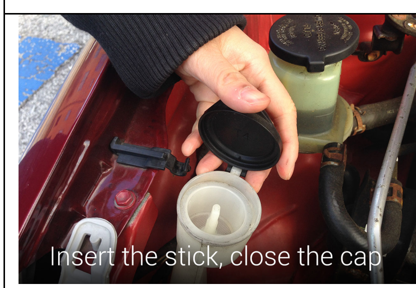
Task 5 – Check Fuse Box

Steps	Notes
	
	
	
	
	

Task 6 – Check Washer Fluid

Steps	Notes
	
	

Take out the filter part	
Q: Is the fluid topped up?	
Top up the reservoir	
Insert the stick, close the cap	

(NASA TLX) Task 5

<u>Mental Demand</u>: How much mental and perceptual activity was required (e.g., thinking, deciding, calculating, remembering, looking, searching, etc)? Was the mission easy or demanding, simple or complex, exacting or forgiving?

Low High

<u>Physical Demand</u>: How much physical activity was required (e.g., pushing, pulling, turning, controlling, activating, etc.)? Was the mission easy or demanding, slow or brisk, slack or strenuous, restful or laborious?

Low High

<u>Temporal Demand</u>: How much time pressure did you feel due to the rate or pace at which the mission occurred? Was the pace slow and leisurely or rapid and frantic?

Low High

<u>Performance</u>: How successful do you think you were in accomplishing the goals of the mission? How satisfied were you with your performance in accomplishing these goals?

Low High

<u>Effort</u>: How hard did you have to work (mentally and physically) to accomplish your level of performance?

Low High

<u>Frustration</u>: How discouraged, stressed, irritated, and annoyed versus gratified, relaxed, content, and complacent did you feel during your mission?

Low High

(NASA TLX) Task 6

Mental Demand: How much mental and perceptual activity was required (e.g., thinking, deciding, calculating, remembering, looking, searching, etc)? Was the mission easy or demanding, simple or complex, exacting or forgiving?

Low High

Physical Demand: How much physical activity was required (e.g., pushing, pulling, turning, controlling, activating, etc.)? Was the mission easy or demanding, slow or brisk, slack or strenuous, restful or laborious?

Low High

Temporal Demand: How much time pressure did you feel due to the rate or pace at which the mission occurred? Was the pace slow and leisurely or rapid and frantic?

Low High

Performance: How successful do you think you were in accomplishing the goals of the mission? How satisfied were you with your performance in accomplishing these goals?

Low High

Effort: How hard did you have to work (mentally and physically) to accomplish your level of performance?

Low High

Frustration: How discouraged, stressed, irritated, and annoyed versus gratified, relaxed, content, and complacent did you feel during your mission?

Low High

System Usability Scale (Brooke,1986)

In the follow questionnaire we would like you to give a rating of the prototype you just used. You should base your rating on your individual experience using it. The focus is your personal evaluation of the prototype.

Please rate the following statements:

1. I think that I would like to use this system frequently.
☐Strongly Disagree
☐Somewhat Disagree
☐Neither Agree nor Disagree
☐Somewhat Agree
☐Strongly Agree

2. I think the system was easy to use.
☐Strongly Disagree
☐Somewhat Disagree
☐Neither Agree nor Disagree
☐Somewhat Agree
☐Strongly Agree

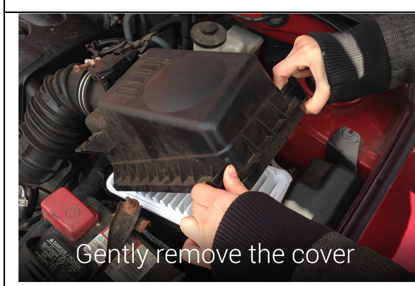
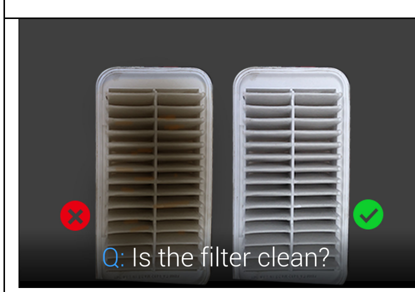
3. I think that I would need the support of a technical person to be able to use this system. ☐Strongly Disagree
☐Somewhat Disagree
☐Neither Agree nor Disagree
☐Somewhat Agree
☐Strongly Agree

4. I would imagine that most people would learn to use this system very quickly.
☐Strongly Disagree
☐Somewhat Disagree
☐Neither Agree nor Disagree
☐Somewhat Agree
☐Strongly Agree

5. I found the system very cumbersome to use.
☐Strongly Disagree
☐Somewhat Disagree
☐Neither Agree nor Disagree
☐Somewhat Agree
☐Strongly Agree

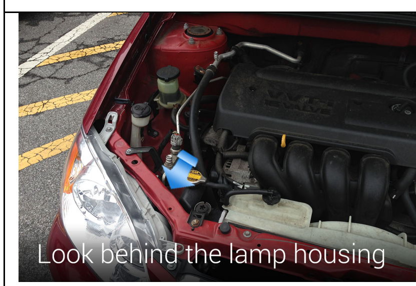
6. I felt very confident using the system.
   ☐Strongly Disagree
   ☐Somewhat Disagree
   ☐Neither Agree nor Disagree
   ☐Somewhat Agree
   ☐Strongly Agree

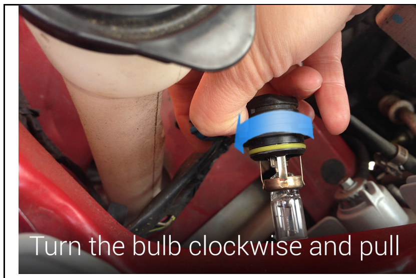
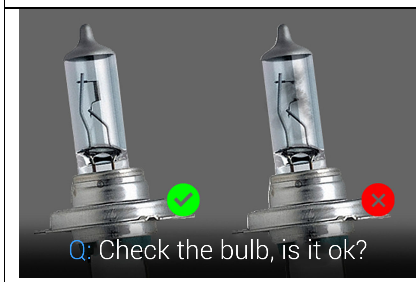
Task 7 – Check Engine Air Filter

Steps	Notes
	
	
	
	
	

Task 8 – Check Headlight Bulb

Steps	Notes
	
	

 Turn the bulb clockwise and pull	
 Q: Check the bulb, is it ok?	
 Put the bulb back	

(NASA TLX) Task 7

<u>Mental Demand</u>: How much mental and perceptual activity was required (e.g., thinking, deciding, calculating, remembering, looking, searching, etc)? Was the mission easy or demanding, simple or complex, exacting or forgiving?

Low High

<u>Physical Demand</u>: How much physical activity was required (e.g., pushing, pulling, turning, controlling, activating, etc.)? Was the mission easy or demanding, slow or brisk, slack or strenuous, restful or laborious?

Low High

<u>Temporal Demand</u>: How much time pressure did you feel due to the rate or pace at which the mission occurred? Was the pace slow and leisurely or rapid and frantic?

Low High

<u>Performance</u>: How successful do you think you were in accomplishing the goals of the mission? How satisfied were you with your performance in accomplishing these goals?

Low High

<u>Effort</u>: How hard did you have to work (mentally and physically) to accomplish your level of performance?

Low High

<u>Frustration</u>: How discouraged, stressed, irritated, and annoyed versus gratified, relaxed, content, and complacent did you feel during your mission?

Low High

(NASA TLX) Task 8

<u>Mental Demand</u>: How much mental and perceptual activity was required (e.g., thinking, deciding, calculating, remembering, looking, searching, etc)? Was the mission easy or demanding, simple or complex, exacting or forgiving?

Low |_|_|_|_|_|_|_|_|_|_|_|_|_|_|_|_|_|_|_|_| High

<u>Physical Demand</u>: How much physical activity was required (e.g., pushing, pulling, turning, controlling, activating, etc.)? Was the mission easy or demanding, slow or brisk, slack or strenuous, restful or laborious?

Low |_|_|_|_|_|_|_|_|_|_|_|_|_|_|_|_|_|_|_|_| High

<u>Temporal Demand</u>: How much time pressure did you feel due to the rate or pace at which the mission occurred? Was the pace slow and leisurely or rapid and frantic?

Low |_|_|_|_|_|_|_|_|_|_|_|_|_|_|_|_|_|_|_|_| High

<u>Performance</u>: How successful do you think you were in accomplishing the goals of the mission? How satisfied were you with your performance in accomplishing these goals?

Low |_|_|_|_|_|_|_|_|_|_|_|_|_|_|_|_|_|_|_|_| High

<u>Effort</u>: How hard did you have to work (mentally and physically) to accomplish your level of performance?

Low |_|_|_|_|_|_|_|_|_|_|_|_|_|_|_|_|_|_|_|_| High

<u>Frustration</u>: How discouraged, stressed, irritated, and annoyed versus gratified, relaxed, content, and complacent did you feel during your mission?

Low |_|_|_|_|_|_|_|_|_|_|_|_|_|_|_|_|_|_|_|_| High

System Usability Scale (Brooke,1986)

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☐Strongly Disagree
☐Somewhat Disagree
☐Neither Agree nor Disagree
☐Somewhat Agree
☐Strongly Agree

2. I think the system was easy to use.
☐Strongly Disagree
☐Somewhat Disagree
☐Neither Agree nor Disagree
☐Somewhat Agree
☐Strongly Agree

3. I think that I would need the support of a technical person to be able to use this system. ☐Strongly Disagree
☐Somewhat Disagree
☐Neither Agree nor Disagree
☐Somewhat Agree
☐Strongly Agree

4. I would imagine that most people would learn to use this system very quickly.
☐Strongly Disagree
☐Somewhat Disagree
☐Neither Agree nor Disagree
☐Somewhat Agree
☐Strongly Agree

5. I found the system very cumbersome to use.
☐Strongly Disagree
☐Somewhat Disagree
☐Neither Agree nor Disagree
☐Somewhat Agree
☐Strongly Agree

6. I felt very confident using the system.
   ☐Strongly Disagree
   ☐Somewhat Disagree
   ☐Neither Agree nor Disagree
   ☐Somewhat Agree
   ☐Strongly Agree

Preference ranking questionnaire

1. Overall, which condition would you prefer to use for doing the car maintenance tasks? Please rank all the four different conditions? And Why?

2. Do you have any suggestions for developing future Head-Mounted Display system?

REFERENCES

1. *Head-mounted display*. Available from: http://en.wikipedia.org/wiki/Head-mounted_display.
2. marketsandmarkets.com, *Head Mounted Display (HMD) Market by Products (Helmet Mounted, Wearable Glass), Components (Micro display, Camera, control unit, Tracker, Accessories), Applications (Defence, industrial, Video Gaming) & Geography - Global Analysis and Forecast to 2020.* 2014.
3. Mann, S., Lo, R., Huang, J., Rampersad, V., Janzen, R., *HDRchitecture: Real-time Stereoscopic HDR Imaging for Extreme Dynamic Range.* 2012.
4. Hershberger, M.L.G., D. F., *Binocular Rivalry in Helmet-Mounted Display Applications.* Aerospace Medical Research Laboratory AMRL-TR-75-48, 1975.
5. Lee, P., Stewart, D., Calugar-Pop, C., *Deloitte Technology, Media & Telecommunications Predictions 2014*. 2014.
6. *Gartner Says Smartglasses Will Bring Innovation to Workplace Efficiency*. Available from: http://www.gartner.com/newsroom/id/2618415.
7. Hart, S.G., *NASA-TASK LOAD INDEX (NASA-TLX); 20 YEARS LATER* Human Factors and Ergonomics Society Annual Meeting Proceedings, 2006(50): p. 904-908.
8. Ockerman, J.J., *Task guidance and procedure context: aiding workers in appropriate procedure following.* 2000.
9. Palmer, E., & Degani, A., *Electronic Checklists: Evaluation Of Two Levels Of Automation.* 1991.
10. Reif, R., Gunthner, A. W., Schwerdtfeger, B., Klinker, G., *Pick-by-Vision comes on age.* AFRIGRAPH: Computer Graphics, Virtual Reality, Visualisation & Interaction in Africa, 2009: p. 23.
11. Smailagic, A., Siewiorek, D., *Application Design for Wearable and Context-Aware Computers.* Pervasive Computing, IEEE, 2002. 1(4): p. 20 - 29.
12. Henderson, S.J., Feiner, Steven K., *Augmented Reality for Maintenance and Repair (ARMAR)*. 2007
13. Ockerman, J.J., Pritchett, A. R., *Preliminary investigation of wearable computers for task guidance in aircraft inspection.* Proc. 2nd International Symposium on Wearable Computers, 1998: p. 33 - 40.
14. Weaver, K.A., Baumann, H., Starner, T., Iben, H., Lawo, M. , *An Empirical Task Analysis of Warehouse Order Picking Using Head-Mounted Displays.* 2010.
15. Guo, A., Raghu, S. R., Xie, X., Ismail, S., Luo, X., Simoneau, J., Gilliland, S., Baumann, H., Southern, C., Starner, T., *A Comparison of Order Picking Assisted by Head-Up Display (HUD), Cart-Mounted Display (CMD), Light, and Paper Pick List.* 2014.
16. Peli, E., *Visual issues in the use of a head-mounted monocular display.* Optical Engineering, 1990. 29(8): p. 883-892.
17. Katsuyama, R.M.D.U., OH, USA ; Monk, D.L. ; Rolek, E.P., *Effects of visual display separation upon primary and secondary task performances.* Proceedings of the IEEE 1989. 2: p. 758 - 764.

18. Xianjun Sam Zheng, C.F., Patrik Matos da Silva, Siddharth Dasari, Tao Yang, Stuart Goose, *Eye-Wearable Technology for Machine Maintenance: Effects of Display Position and Hands-free Operation.* 2014.
19. *The State of Smart Glasses in the Enterpris*. Available from: http://www.apx-labs.com/2014/08/07/the-state-of-smart-glasses-in-the-enterprise/.
20. *World Vehicle Population Tops 1 Billion Units*. Available from: http://bit.ly/1jugNFm.
21. Bababekova, Y., et al., *Font Size and Viewing Distance of Handheld Smart Phones.* Optometry and Vision Science, 2011. 88(7): p. 795-797.
22. *carcarekiosk.com*. Available from: http://www.carcarekiosk.com/.
23. Nicolai, T., Sindt, T., Witt, H., Reimerdes, J., Kenn, H., *Wearable Computing for Aircraft Maintenance: Simplifying the User Interface.* International Forum on Applied Wearable Computing (IFAWC), 2006: p. 1 - 12.
24. Neumann, U., Majoros, A., *Cognitive, Performance, and Systems Issues for Augmented Reality Applications in Manufacturing and Maintenance.* Proc. of Virtual Reality Annual International Symposium, IEEE 1998.
25. Arthur, K.W., *Effects of Field of View on Performance with Head-Mounted Displays.* 2000.
26. Hart, S.G.S., Lowell E., *Development of NASA-TLX (Task Load Index): Results of Empirical and Theoretical Research.* Advances in Psychology, 1988. 52: p. 139-183.
27. Brooke, J., *SUS-a quick and dirty usability scale.* Usability evaluation in industry, 1996. 189.
28. *Binocular rivalry*. Available from: http://en.wikipedia.org/wiki/Binocular_rivalry.
29. Burian, H.M., *Fusional movements. Role of peripheral retinal stimuli.* Archives of Ophthalmology, 1939. 21: p. 486-491.
30. J. E. Winkelman, M.D., *Peripheral fusion.* Arch. Ophthalmol, 1951. 45: p. 425—430.