Measuring differences in eye glance behaviour for heavy equipment operators while driving in naturalistic worksite environments

by

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Abstract

Struck-by accidents continue to be a predominant issue with catastrophic consequences in both construction and mining industries. These incidents are found to be largely caused by blind spots due to the equipment or environment, along with human error. Blind spots are considered to be non-visible areas where operator line-of-sight is impeded by parts of the heavy equipment, buildings or other objects in their environment. Eye-tracking (ET) research has mostly focused on the eye behaviour while operating passenger vehicles. This research includes, but is not limited to, eye scanning patterns of drivers, development and implementation vehicle interaction devices for safe use and enhanced education through training programs. Visual scanning patterns of heavy equipment operators cannot be lumped into that of those driving passenger vehicles as the design of various machinery is vastly different in addition to differences of driving on a public road compared to a worksite environment. The intention of this research was to initiate research specifically for ET data while operating various types of heavy equipment. The purpose of this research was to quantify typical heavy equipment operator eye gaze behaviour in natural worksite settings in both construction and mining industries. First, the objective was to determine the similarities on where operators naturally look while driving in a field setting. Key areas of interest (AOI) operators looked were identified during forward and rearward movements. The most noticeable difference was that the front view ahead was fixated the most while driving forwards, whereas the mirrors were tended to the majority of rearward movements basically never looking within the front views.

As some heavy equipment, such as a load-haul-dump (LHD) have very unique characteristics including operator seated position within the machine, it was important to measure their visual scanning pattern while driving, especially in an underground mine. Therefore, the second objective was to obtain data to quantify typical LHD operator eye gaze behaviour in addition to determining differences between novice and expert operators. This was accomplished by comparing novice operator completing a four-day training program on an LHD simulator to a similar trial completed by the expert operator. Results demonstrated that visual scanning patterns of the novice operator was considerably more dispersed than that of the expert which was much more focal. However, it should be noted that the scanning pattern of novice operators did become more focal and less dispersed at the end of training, starting to resemble that of the expert. Other main findings revealed that regardless of direction travelled, operators spend the majority of time fixating within the central view ahead. Findings suggest that novice operators experienced an overall decrease in cognitive workload and relied less on using the edge of machine and wall as sightlines to monitor LHD speed and position within the mine as experience increased. Interestingly enough it appears that the expert operator utilized the right wall as a sightline while driving forwards, differing from novice operators.

Determining the gaze behaviour of heavy equipment operators on various machines is important to have a baseline typical eye gaze behaviour to be able to detect deviations that can provide a measure of how technologies, policies or training programs affect gaze behaviour. Eye gaze behaviour needs to be incorporated in the design of future technologies (ex. proximity detection and awareness technology) to provide modifications to reduce cognitive workload and distraction that can occur when implementing devices. Findings of this research could also aid to enhance current training programs and advise the development of new training programs or policies to minimize human-equipment interactions.

Keywords: Eye-Tracking; Occupational Health and Safety; Heavy Equipment; Construction; Mining; Accident Prevention

Co-Authorship Statement

The following dissertation was conceptualized in a manuscript-based format to disseminate the research as one cohesive work. A summary of the nature and scope of work of the individual co-authors for each manuscript is outlined in the associated tables.

Chapter 3

Author Contribution	A. Brunton	B. Vance	K. Goggins	P. Scherzinger	T. Eger	A. Godwin
Study Design	√			√	√	√
Data Acquired/collected	√	√				
Supervision						√
Advice		√	√	√	√	√
Organized study	√					√
Provided equipment					√	√
Data analysis	√		√			
Manuscript Preparation	√					
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Technical assistance		√	√			
Financial support					√	√
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Chapter 4

Author Contribution	A. Brunton	B. Vance	K. Goggins	P. Scherzinger	T. Eger	A. Godwin
Study Design	√			√	√	√
Data Acquired/collected	√	√				
Supervision						√
Advice		√	√	√	√	√
Organized study	√					√
Provided equipment					√	√
Data analysis	√		√			
Manuscript Preparation	√					
Manuscript revision	√		√	√	√	√
Technical assistance		√	√			
Financial support					√	√
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Glossary of Abbreviations and Terminology

Abbreviation	Long Form
AOI	Area of Interest
CMS	Camera Monitoring System
ET	Eye-Tracking
FCV	Front Central View
FLM	Front Left Mirror
FLV	Front Left View
FRM	Front Right Mirror/
FRV	Front Right View
IR	Infrared
I-VT	Velocity-Threshold Identification
LHD	Load-Haul-Dump
LLM	Left Lower Mirror
LOS	Line-Of-Sight
LTI	Long Term Injury
LUM	Left Upper Mirror
LW	Left Window
M	Machine
PAT	Proximity Awareness Technology
PD	Pupil Diameter
PPE	Personal Protective Equipment
PV	Peak Velocity
RGM	Right Ground Mirror
RLM	Right Lower Mirror
RUM	Right Upper Mirror
RW	Right Window
SA	Situation Awareness
TOI	Time of Interest

Terminology and Definitions

Area of Interest: Defined areas over certain parts of a display or visual interface under evaluation that are of interest to researchers. Analysis method utilized in eye-tracking research to be able to analyze only eye movements that fall within these areas (Poole & Ball, 2006).

Automaticity: Good performance with a very low level of attention required of the operator that may develop with more experience (Endsley, 2000).

Blind Spot: A non-visible area where an operator's line-of-sight is impeded by parts of the heavy equipment or obstructions or other objects in their environment (Golovina, Teizer, & Pradhananga, 2016).

Eye-Tracker: Tool used to determine point-of-regard and measure eye movements (ex. fixations, saccades) by tracking the position of corneal reflection created by infrared (Poole & Ball, 2006).

Eye-Tracking: A technique used to measure an individual's eye movements to determine where a person is looking within their environment or on a system interface at any given time, and the movement behaviour of their eyes when moving to different locations (Poole & Ball, 2006).

Fixation: Instant where an individual's eyes are relatively stationary, subsequently gathering visual information. Fixations are typically 66 to 416 ms in duration (Carpenter, 1977; Holmqvist et al., 2011; Poole & Ball, 2006).

Gaze (Also referred to as dwell, fixation cluster and fixation cycle): Sum of all the fixations durations within a specified area. (Hauland, 2003; Mello-Thoms, Nodine, & Kundel, 2002).

Line-of-Sight: Line-of-sight is an operator's unobstructed visibility from their position to their intended view of the environment, objects or personnel around the machine. Consequently, poor line-of-sight refers to the inability of an operator to see particular areas around the machine due to the machine itself or other obstructions in the environment (T. R. Eger et al., 2010; A. A. Godwin, Eger, Salmoni, & Dunn, 2008; J. W. Hinze & J. Teizer, 2011).

Point-of-Regard: Point in space where an individual is looking at any given time, used to disclose where an individual is directing their visual attention (Poole & Ball, 2006).

Proximity: Nearness in space, time or relationship. Proximity is an indicator of potential collision events (Golovina et al., 2016).

Saccade: Rapid eye movement that repositions the fovea to new locations within the visual environment. Typically range from 20-35 ms but can be as long as 100 ms in duration (Carpenter, 1977; Poole & Ball, 2006; Shebilske & Fisher, 1983).

Situation Awareness: An individual's perception of the elements in their environment within a specific location and instant in time, an understanding of their meaning and ability to project their status in the near future (Endsley, 1987, 1988).

Smooth Pursuits: When eyes visually track a moving target (Duchowski, 2007; Megaw & Richardson, 1979).

CHAPTER 1: INTRODUCTION

In Canada there were 890 long term injury (LTI) claims and 28 fatalities in 2018 caused from a pedestrian or worker-on-foot being struck by a vehicle or mobile equipment, an increase from 2016 (Association of Workers' Compensation Boards of Canada, 2018). Struck-by accidents continue to have the second highest LTI rate for priority hazards, just below musculoskeletal disorders in Ontario over the past 4 years (Infrastructure Health and Safety Association, 2018). The Workplace Safety and Insurance Board (WSIB) of Ontario reported 195 and 8 LTI claims in 2017 that resulted from contact with machinery within the construction and mining industries, respectively (Workplace Safety and Insurance Board, 2018). Struck-by accidents were the reported cause of 3 traumatic fatalities within construction and 2 within the mining industry (Workplace Safety and Insurance Board, 2018). Within Ontario's entire industrial sector, there were 295 struck-by injuries in 2018 resulting from contact with machinery or other moving equipment (Infrastructure Health and Safety Association, 2018). It is important that efforts are made to reduce the number of fatalities occurring from being struck by heavy equipment in the workplace to produce greater results than just slight decreases in numbers. Similarly, in the United States struck-by accidents are problematic within the construction industry where they consist of 22% of fatalities that occur on worksites (Hinze, Huang, & Terry, 2005). Accidents and fatalities related to reversing machinery continue to be a large issue and are very costly to the industrial sector regardless of current efforts to minimize occurrence (Koppenborg, Huelke, Nickel, Lungfiel, & Naber, 2016). It is pertinent that there is an increased focus on developing and researching more effective ways to prevent and hopefully eradicate the occurrence of struck-by accidents with heavy equipment. Therefore, the main focus of efforts is to work towards having zero fatalities involving the operation of heavy equipment in addition to reducing the overall number and severity of non-fatal injuries.

Due to the ongoing issue of struck-by accidents among heavy equipment, there is a dire need to evaluate existing technology and develop appropriate policies for use in heavy industry. As workers and equipment are frequently required to operate within close proximity to one another, this increases the chance of struck-by accidents happening (Marks & Teizer, 2012). Golovina et al. defined proximity as “nearness in space, time or relationship and an indicator of potential collision events” (2016). Workers are legislated to use passive safety devices on worksites, which includes hard hats, high visibility apparel and other PPE, however, these are not able to warn the workers or operators of a potential collision (Marks & Teizer, 2012).

The first line of alert while using many heavy machines is an auditory back-up alarm. In Ontario, it is mandated that a dump truck must have an automatic audible alarm that alerts individuals when the truck is reversing (s.105) (OHSA, 2020). With numerous machines operating in close proximity combined with the hearing protection requirements of the workplace, workers become complacent to the repetitive beeping of back-up alarms in their vicinity (Hinze & Teizer, 2011). Anecdotally, the constant beeping is considered a nuisance noise; and operators reportedly disable these alarms. In fact, in 56 out of 69 fatalities using heavy machinery reviewed by Hinze and Teizer, the back-up alarms were disabled or non-functional (2011). The main purpose of the back-up alarm is to alert nearby pedestrians and workers-on-foot that the heavy machinery is reversing. It is also required in Ontario to have a signaler with appropriate personal protective equipment (PPE) and training assist the heavy equipment operator if their intended path is obstructed or when a person might be injured by the vehicle, equipment or by its load (s. 104(3)and s.106) (OHSA, 2020). It was found in one study that unqualified individuals often attempted to work as a signaller to accelerate worksite operations (Sertyesilisik, Tunstall, & McLouglin, 2010). Where qualified signallers were found to require a higher level of training, which included a longer training course, if followed that there were safer practices within the worksite (Sertyesilisik et al., 2010). Current mining regulations states employers at a mine must develop and maintain a written traffic management program that includes measures and procedures to prevent collisions by addressing hazards relating to impeded visibility of operators as well as protect the health and safety of workers and pedestrians (s. 105.1) (OHSA, 2019).

Even with the policies and legislation efforts established on worksites that aim to reduce the number of equipment-human interactions, these accidents and fatalities continue to occur. This can be attributed to the dynamic environment of worksites and the somewhat common requirement for workers-on-foot to perform tasks within these spaces (Hinze & Teizer, 2011). A major component that contributes to the hazardous nature of both construction and mining industries is the aspects within their worksite environment are constantly changing. This may include but is not limited to the number, location and proximity of the workers-on-foot as well as other mobile equipment and infrastructure and objects that differ between sites. Unique to the underground mining environment, there is a lack of natural light resulting in poorly lit areas throughout the mine. Thereby, the operators may have reduced or no visibility due to the underground low lighting levels (Tammy Eger, Salmoni, & Whissell, 2004). In most cases, the dark background of the mine helps operators to see lights and reflective striping. However, too much lighting or glare from overhead lights can wash out the reflection of a vehicle strobe off of the roof of the mine passage which can contribute to fatal collisions (Tammy Eger et al., 2004). Other work environment factors that operators believe contribute to reduced visibility include:

dust, fog, steep hills, distracting noises and vibration (Tammy Eger et al., 2004). The most common contributing causes to struck-by accidents have been found to be human factors involving misjudgment of a hazardous situation, as well as large blind spots (Hinze et al., 2005). In turn, this creates an even more hazardous workplace when new hazards are continuously arising while working in close proximity to other machinery, workers-on-foot and pedestrians. Therefore, there is a need to develop effective ways to enhance awareness in an effort to reduce struck-by accidents.

Eye-tracking (ET) allows measurements such as fixations, saccades and pupil diameter to be collected, which are then used as a correlate for situation awareness (SA) or other measures of attention and cognitive load (Beatty & Wagoner, 1978; Just & Carpenter, 1993; Sodhi, Reimer, & Llamazares, 2002). This allows researchers to investigate driver behaviour and any changes that arise due to different environments, in-vehicle devices or other factors that may alter their driving behaviour. The area of ET research is relatively new; especially field studies using an eye-tracker while a participant drives a vehicle or operates machinery rather than a controlled simulator situation. In the past few years, researchers have started to apply ET to heavy equipment operators in the field to gain valuable information on the operators and their work. Haggstrom et al. (2015) examined the eye gaze behaviours of forest harvesting machine operators in a natural setting, determining where the harvester operators were looking during specific work tasks. Another study investigated how excavator operators utilized their mirrors and camera monitoring system as viewing aids while reversing in a naturalistic environment (Koppenborg et al., 2016). An eye-tracker can be a useful tool to gain more knowledge of realistic operator eye behavior, how they are acquiring visual information during work tasks in an effort to determine more effective ways to prevent struck-by accidents.

1.1 STRUCTURE OF DOCUMENT

The overall purpose of this thesis is to gain a better understanding of heavy equipment operators' gaze patterns to help improve safety measures on worksites and prevent struck-by accidents from occurring. This thesis is comprised of an introduction, two papers and a final overall discussion. First, this work will capture and summarize typical eye glance behaviours used by heavy equipment operators while performing a variety of work tasks in a natural work setting. Secondly, the eye-tracker will be used to quantify the evolution of gaze patterns for novice load-haul-dump (LHD) operators involved in an LHD simulator training program, and compare those to an expert's gaze pattern. This chapter will provide an introduction to the industrial sector, common occupational hazards within the industrial sector, an overview of accident statistics, and will conclude by outlining the overall objectives of the thesis in the following section. An overview of the document layout and research objectives corresponding to each chapter is outlined in Figure 1.1. The second chapter consists of a literature review providing a summary of literature pertaining to evidence of injury from struck-by accidents, eye-tracking and previously reported driver gaze behaviors along with various factors related to the unique construction and mining worksite environments. Chapters three to four include two research paper manuscripts that form the original contributions of this thesis as outlined by the co-authorship statements. The fifth and final chapter provides a general discussion, summary of the conclusion and implications of the research and outlines directions for future research related to eye-tracking research involving heavy equipment operator populations.

1.2 RESEARCH OBJECTIVES

The objectives of this research in order to complete the Masters of Human Kinetics (MHK) include the following:

1. To quantify typical operator eye behavior from a heavy equipment operator in a field setting. Determine similarities on where operators naturally look while driving in varied work scenarios (closed worksites, urban sites, with and without pedestrians or other machinery). Thereby providing baseline data on heavy equipment eye glance behaviour.
2. Quantify novice and expert LHD operator eye glance behaviour within a simulated mining environment. Compare how a novice LHD operator gaze pattern changes over a four-day LHD simulator training against an expert LHD operator.

Chapter 1: Introduction

An overview of the industrial sector, hazards associated with industrial occupations and thesis outline.

Chapter 2: Literature Review

A review of literature and background of knowledge on relevant concepts and terms relating to operating heavy equipment, proximity detection devices and eye-tracking to provide justification for current research project.

Chapter 3: Paper 1

Field Study: Natural Eye Glance Behaviours of Heavy Equipment Operators when driving in a Naturalistic Worksite Environment

Objectives:

1. Quantify typical heavy equipment operator eye glance behaviour in a field setting.
2. Determine whether there are similarities on where operators naturally look while driving.

Chapter 4: Paper 2

Simulator Study: Comparisons between the differences in scanning patterns between novice and experienced load-haul-dump operators pre- and post- mining equipment simulator training

Objectives:

1. Quantify novice and expert LHD operater eye glance behaviour within a simulated mining environment.
2. Measure how a novice LHD operator gaze pattern changes over a four-day LHD simulator training.
3. Compare an expert LHD operator's natural gaze patterns to novice LHD operators on day one and four of training.

Chapter 5: Discussion

Findings from both studies are reviewed as well as implications, applicability to workplaces, future research directions, and final conclusions.

Figure 1.1: Overview of lines of investigation included in paper to accomplish objectives of study.

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CHAPTER 2: LITERATURE REVIEW

This chapter will provide a summary of literature pertaining to heavy equipment operators and the risk for struck-by accidents, the potential use and implications of vehicle interaction technologies and the utility of ET. The first part of the chapter will provide background on line-of-sight when operating heavy equipment, and how this can be a major causative factor in struck-by accidents. In addition, it will highlight the importance of situation awareness for heavy equipment operators, especially in a worksite environment and the ramifications that can occur if an individual's situation awareness is compromised. Further, a discussion on typical driving behavior in passenger vehicles will be reviewed, and how this may differ from that of an individual driving heavy equipment. The second part will introduce the potential need for vehicle interaction technology in a worksite environment and how it may affect an operator's situation awareness or other implications that may arise. The third part of the chapter introduces ET, providing background information on how this tool can be used to measure the utility of vehicle interaction technologies and how their implementation may be detrimental to the operator's performance or safety. The chapter will conclude with summaries and critiques of previous research that has been conducted within the various fields outlined in order to provide justification for the current research.

2.1 LINE OF SIGHT WHEN OPERATING HEAVY EQUIPMENT

In over 70% of visibility related construction site accidents, the heavy machinery was travelling in reverse when they occurred (Hinze & Teizer, 2011). Blind spots appear to be the primary visibility impairment that results in accidents within the industrial sector due to lack of operator sightlines from the cabin to their surrounding environment, including pedestrians, hazards and obstacles (Hinze & Teizer, 2011; Koppenborg, Huelke, Nickel, Lungfiel, & Naber, 2016). Golovina, Teizer & Pradhananga (2016) describe blind spots as a non-visible area where an operator's line-of-sight (LOS) is impeded by parts of the heavy equipment or other objects in their environment. A heavy equipment operator's LOS has been found to be severely restricted at many points around the machinery (Godwin & Eger, 2009). Blind spots where line-of-sight is impeded by the machine itself, when stationary both dump trucks and load-haul-dumps have large blind spots around the machine. Eger et al. (2010) found that irrespective of whether the machinery was travelling backwards or forwards, the operator glances were concentrated on a few moderately unobstructed regions around the machine, neglecting other important areas.

In addition to the machine itself, obstructions are another variable that creates a blind spot when also impede an operator's LOS when driving heavy equipment. Obstructions are referred to a visual impediment such as a mound of dirt or fill material that blocks the operator's LOS by hiding the worker or hazard (Hinze & Teizer, 2011). Even with current precautions such as spotters, back up alarms, personal protective equipment (PPE) in place these incidences still manage to occur. Therefore, efforts have been made to improve access to information about the environment, and to help improve an operator line of sight. This has led to the creation of devices designed to increase the situational awareness of the operator. The most basic of vehicle interaction technologies includes solutions that fall into a category called proximity awareness technology (PAT). The focus of this work includes camera systems that provide additional views around the machine sometimes combined with additional, basic information about the environment.

2.2 SITUATION AWARENESS OF VEHICLE OPERATORS

A large proportion of accidents on the road are found to be a result of visual attention deficiencies (Chapman & Underwood, 1998). Situation awareness is an important aspect of operating any vehicle effectively and safely. SA is referred to as an individual's perception of the elements in one's environment within a capacity of time and space (Endsley, 1987, 1988). There are three levels of SA which include; Level 1 - Perception of data, Level 2- Comprehension of meaning and Level 3- Projection of near future events and dynamics in the near future (Endsley, 1987, 1988, 2000). To achieve SA, an individual must first observe the relevant elements in the surrounding environment along with their status, characteristics and dynamics such as knowing where other equipment and objects are, as well as pertinent information about their own machine (Endsley, 1995). For an operator to achieve the Level 2 SA it goes further than just noticing elements in the environment, it requires the operator to understand the significance of the various elements thereby creating a holistic picture of their surroundings (Endsley, 1995). The highest level of SA requires an individual to be able to project future actions of the these elements, at least in the very near future which is achieved from the information gathered from both Level 1 and Level 2 SA (Endsley, 1995). Level 3 SA provides an operator with the ability to detect potential future collisions in order to act effectively and choose the best course of action for a favourable outcome (Endsley, 1995). Due to the vital role of SA in dynamic decision making it is imperative that we understand the process and the factors that influence it as shown in Figure 2.1.

An individual operator's SA is important, considering team SA is also essential due to the several operators and workers-on-foot working together on dynamic worksites. Team SA can be obtained from each team members individual SA, the quality of team members' SA of particular elements they all share can be an indicator of team coordination (Endsley, 1995).

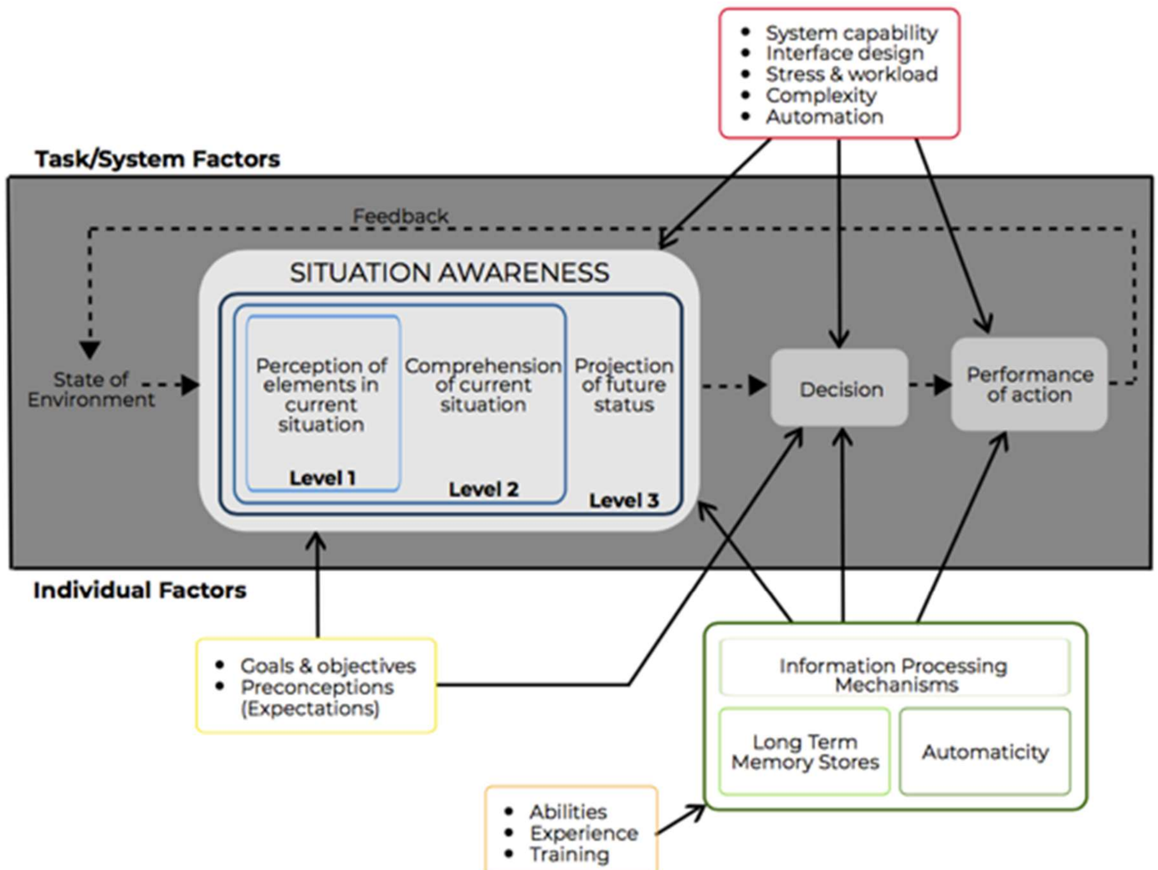


Figure 2.1: Endsley's (1995) Model of situation awareness in dynamic decision making adapted by Brunton (2020).

Figure 2.2 depicts the SA of a team, outlining how an individual team member has their own SA requirements, specific to their responsibilities within the team, as well as how some overlap of SA requirements between each team member (Endsley, 1995). This overlap of SA requirements provides information that establishes most of a team's coordination (Endsley, 1995). Each team member must obtain SA for all of their own requirements in addition to the overlapping SA requirements, if one team member lacks SA for all their requirements then the SA of the entire team is affected (Endsley, 1995). In turn the SA and performance of the team will suffer as well unless any discrepancies are corrected (Endsley, 1995). Establishing team SA can be done through different modes depending on the task, individual factors, and the environment. Endsley (1995) discussed that this could include communicating information to one another verbally or through viewing separate displays while each individual is also acquiring information on their own. However, a team can attain a higher-level of SA without increased verbal communication, as it has been found that teams that performed well communicated less than the teams who had poor performance (Mosier & Chidester, 1991). This is attributed to the level of accurate SA each team member possesses on the teams shared perceived SA elements, facilitating improved and more efficient communication (Endsley, 1995).

Working in the industrial sector with heavy equipment in a dynamic environment, an operator's SA becomes extremely important to ensure the safety of not only the operator but also those in the surrounding environment. There are many factors that determine how individuals direct their attention when acquiring information, which includes but is not limited to scanning patterns, goals and expectations (Endsley, 2000). Construction workers perform repetitive tasks within the worksite, leading to decreased awareness and loss in focus (Pratt, Fosbroke, & Marsh, 2001). The repetitive nature of the work tasks in the industrial sector is one of many factors that can contribute to a decrease in an operator's SA. Automaticity may develop as one becomes more experienced, resulting in good performance with a very low level of attention required of the operator (Endsley, 2000). Automaticity can be beneficial as it allows the operator to reduce demands on limited attention resources, however it can also lead to critical information outside of their routine being missed (Endsley, 2000). Proximity hazards are also known to contribute to a lack of SA within a worksite (Golovina et al., 2016; Teizer & Cheng, 2015). Factors that can create proximity issues on worksites include: level of consciousness and awareness of both operators and workers-on-foot, education and training of all individuals onsite, personal protective equipment or proximity detection devices that alert operator in real-time (Golovina et al., 2016). The main proximity hazard consists of workers being within close proximity to static or dynamic equipment but can also include monitoring the use of signs, sidewalks and pedestrian crosswalks (Teizer & Cheng, 2015). To prevent proximity hazards from occurring within the worksite it is imperative to eliminate or put in place preventative measures to decrease the chance of accidents while also maintaining, and not degrading, an operators' SA.

Figure 2.2: Endsley's (1995) model of team situation awareness adapted by Brunton (2020).

2.3 TYPICAL DRIVING BEHAVIOUR

Understanding the visual search strategies of drivers is important as it provides important techniques for understanding the nature of specific driving tasks as well as developing improved driver training strategies and accident countermeasures (Chapman & Underwood, 1998). Typical driving behaviour of individuals when backing up in passenger vehicles consists of the driver looking over their right shoulder for an average of 50% of one's glances while backing, while approximately 8%, 4.5% and 9% of the glances during backing tasks are fixated on the driver's mirror, rear mirror and right mirror, respectively (Harpster, Huey, & Lerner, 1996). Heavy equipment operators are unable to look over their right shoulder due an absence of a rear window or fully obstructed view by part of the equipment. If an operator's behaviour resembles that of the average driver, then they will be forced to use the mirrors more to look for the signaller as they have a large blind spot behind them. Another concern may be if the driver is looking in the mirrors while backing, the signaller may be located within a blind spot outside of the view provided by the mirrors. This could potentially result in a struck by accident, therefore the need to increase an operator's LOS with other resources such as vehicle interaction technologies.

Mental tasks performed while driving have been found to change practical driving behaviours, this includes inspection of mirrors and speedometers (Nunes & Recarte, 2002; Recarte & Nunes, 2002; Recarte & Nunes, 2003). Recarte & Nunes also noted that mental-spatial imagery tasks produced more noticeable effects in driving behaviour than verbal tasks (2003). When mental workload increased, it was found that drivers increased their speed independently of speedometer availability (Recarte & Nunes, 2002). Understanding that mental tasks effect driving behaviour can help with future policies and designs of vehicles and in-vehicle devices. When driving, individuals reduce their visual inspection window when they narrow their attentional focus size resulting in decreased glance frequency at one's mirrors and speedometer (Recarte & Nunes, 2002; Recarte & Nunes, 2003). Spatial reduction of a driver is a predictor of decreased probability of detecting traffic thereby increasing the chance of a potential collision or struck-by accident (Recarte & Nunes, 2003). Minimizing mental tasks performed while driving and ensuring adequate visual inspection is essential to operate a vehicle safely.

2.3.1 Effect of Age and Experience on Driver Behaviour

Studies have found that driver behaviour differs by an individual's age and experience. Ho, Scialfa, Caird and Graw found that older adults are less accurate than younger adults in addition to younger adult's faster reaction time made them able to respond more quickly than the older adults (2001). It was noted that errors were more common in high clutter areas compared to low clutter areas, reaction time also decreased in high clutter areas (Ho et al., 2001). In general, younger adults have shorter fixation durations than older adults, however fixation durations and number of fixations increased for both younger and older adults from low clutter to high clutter scenes (Ho et al., 2001).

Evidence shows that fixation and attentional patterns in drivers are learned (Hayhoe et al., 2002). Drivers must initiate active search in order to visualize stimuli in their surroundings, conditional on the driver's internally generated schedule which depends on observer goals and learned probabilities and regularities in the environment (Hayhoe et al., 2002). Increased training and experience are expected to improve visual search strategies resulting in a decrease in number of fixations (Gramopadhye, Drury, & Sharit, 1997; Liu, 1998; Megaw & Richardson, 1979). The implication of a reduction in number of fixations without an increase in mean fixation time is that individuals may inspect the environment more quickly, perhaps due to familiarity gained through training, reducing the time required to visually rest on particular stimuli in the environment (Duchowski, 2007). Although this may appear as an improved visual search strategy as they can do it in a timely manner, one must ensure that they are not performing their visual search so rapidly that they are missing important stimuli and jeopardizing safety. Häggström et al. (2015) found that a group of experienced tree harvester operators had similar gaze patterns that varied depending on what task or work element they were doing. Therefore, different tasks may require the operator to pay more attention to different areas within their work environment. Studies have found that fixation duration may be influenced by feed forward training, where an individual is instructed on where they should be looking (Sadasivan, Greenstein, Gramopadhye, & Duchowski, 2005). Those who reaped the benefits from training had significantly increased fixation durations than those who did not benefit from training (Sadasivan et al., 2005). Studies have found that novice operators generally have longer fixations whereas experienced operators spend less time fixating while completing tasks (Chapman & Underwood, 1998; Ottati, Hickox, & Richter, 1999). Studies argue that this reflects additional time required by novice operators to process information in the environment and extract useful data (Chapman & Underwood, 1998; Ottati et al., 1999). Overall, training is extremely important to an individual's visual search strategy and it is crucial that training programs for anyone operating a vehicle are of benefit to the operators, and not hindering their visual search and driving behaviour.

2.4 EYE MOVEMENTS

The movement of the human eyeball depends on six muscles that include; the medial and lateral recti (sideways movements), superior and inferior recti (up and down movements) and superior and inferior obliques (twist) (Davson, 1980). Eye movements are never perfectly still due to motion-sensitive cells, these constant tiny movements are referred to as microsaccades (Hubel, 1988). The three main eye movements are classified as fixations, saccades and smooth pursuits. These movements are the main metrics used within ET research to gain information on individual attention-allocation patterns, experience and underlying cognitive workload or strategies. The most widely used and reported eye movement are fixations, occurring when the retina is stabilized over stationary object of interests, the eyes remain relatively stationary for 66-416 ms in duration (Carpenter, 1977; Holmqvist et al., 2011; Poole & Ball, 2006). Rapid eye movements used to reposition the fovea to a new location in the visual environment is referred to as a saccade, this movement is both voluntary and reflexive (Carpenter, 1977). Saccades typically range from 20-35 ms in duration but can be up to 100 ms, individuals are practically blind during this movement as the image is very blurred (Megaw & Richardson, 1979; Poole & Ball, 2006; Shebilske & Fisher, 1983). Saccade destinations are pre-programmed, saccades cannot be altered once next desired fixation location has been chosen as there is insufficient time for visual feedback (Duchowski, 2007). This is thought to be due to an insufficient amount of time for visual feedback to guide the eyes during a saccade (Carpenter, 1977). Smooth pursuits are involved when visually tracking a moving target, the eyes are capable of matching the velocity of the moving target (Duchowski, 2007; Megaw & Richardson, 1979). Obtaining measures of both fixation and saccade movements are important for deducing what information reaches the fovea, as visual information is only gathered during fixations and one is literally blind during saccades (Häggström et al., 2015). Due to the hazardous nature of mining and construction occupations, it is valuable to gain insight into the differences in eye fixations and saccades of heavy equipment operators, when driving and using PATs.

2.5 EYE-TRACKING

The development of non-intrusive, head-mounted eye-trackers has made it possible to conduct research on driver eye behaviour in the field in areas such as driving, overland navigation and flight control. This has allowed researchers to monitor the level of a driver's distraction while driving and in turn, adjust feedback provided to the driver (Donmez, Boyle, & Lee, 2007). To develop safe, efficient machines and procedures in the workplace it is important to understand workers' visual behaviour (Häggström et al., 2015). Eye saccade and fixation movements can be used to interpret an individual's expertise and confidence level (Crundall, Chapman, Phelps, & Underwood, 2003; Jacob, Karn, Radach, & Deubel, 2003). It has also been found to be an indicator of cognitive workload (Di Stasi, Catena, Cañas, Macknik, & Martinez-Conde, 2013) or arousal (Di Stasi, Antolí, & Cañas, 2011). An eye-tracker enables researchers to obtain data on where, when and for how long an individual is looking at certain areas or objects in their surrounding environment during the trial.

Eye-trackers work by looking at the relationship between the pupil and corneal reflection changes during eye movements and can be used to calculate where an individual is looking at any point in a recording session (Poole & Ball, 2006). The Tobii Pro Glasses 2 used to collect data for this study uses the dark pupil method to measure the point-of-regard, the point in space where an individual is looking at a specific instant in time (Poole & Ball, 2006; Tobii Pro, 2017a). The dark pupil method is achieved by placing the illuminator away from the optical axis, this causes the pupil to appear darker than the iris (Tobii Pro, 2017a). To calculate the point-of-regard through the dark pupil method, infrared (IR) light is directed into each eye which creates strong reflections, as the IR light enters the retinas and is reflected back this makes the pupil a dark and defined disc (Poole & Ball, 2006; Tobii Pro, 2017a). In addition to making the pupil appear darker, the IR light simultaneously creates a corneal reflection that appears as a small sharp glint (Poole & Ball, 2006; Tobii Pro, 2017a). The eye-tracker's image processing software determines the center of the pupil and location of the corneal reflection, the vector between them is measured followed by trigonometric calculation to determine the individual's point-of regard (Poole & Ball, 2006; Tobii Pro, 2017a).

2.5.1 Distraction While Driving

Variables that have been used to identify an operator's cognitive workload include; heart rate variability, eye movements, quantitative electroencephalography, levels of SA and driving performance metrics (Donmez et al., 2007). Eye-tracker data can be used to determine an operator's level of distraction via fixation location and duration. In passenger vehicle driving, off-road glances are a good indicator of visual distractions, but not for auditory or cognitive distractions (Donmez et al., 2007). Drivers, who voluntarily divert their attention towards competing activities such as changing the radio station, adjust their driving behaviour to compensate for any anticipated deviation in their driving performance, which allows them to maintain SA (Regan, Hallett, & Gordon, 2011). However, when secondary tasks compete for visual resources such as fixations it results in a decrease in visual resources (fixation durations) allocated to the driving task (Sodhi et al., 2002). With the complexity of driving conditions, such as those found on a construction site, there is an increased need for frequent scanning, and secondary tasks such as in-vehicle devices may require one's attention to be directed away from the road for longer durations; together these can create a hazardous situation (Sodhi et al., 2002). Weirwille (1993) noted that there is a threshold of 1.6 seconds where a driver's attention can be directed away from the road to attend to an in-vehicle device: beyond this threshold there is an increased risk of potential adverse events to occur.

2.5.2 Measuring Cognitive Workload

Through ET we can also determine whether the operator is experiencing an increased cognitive workload resulting from changes implemented in the workplace. Di Stasi et al. (2013) found that the peak velocity (PV) of eye saccades was a good indicator of mental workload, mental fatigue and arousal. A reduction in PV indicates higher workload conditions, as well as mental fatigue (Di Stasi et al., 2011). Contrary, increased arousal results in higher PV and decreased arousal levels result in a reduced PV (Di Stasi et al., 2013). Another indicator of mental workload level is pupil diameter (PD), higher workloads increase PD while low workloads have smaller PDs (Beatty & Wagoner, 1978; Just & Carpenter, 1993). Beatty (1982) found that as the task became more difficult, it produced larger pupil dilations. PD is sensitive to cognitive workload and may include tasks that require a different composition of processing resources (Beatty, 1982; Recarte & Nunes, 2002). The eye-tracker will give insight into whether a proximity detection device that has been implemented is distracting to an operator or increases their cognitive workload in a worksite environment.

2.5.3 Vehicle Interaction Technologies and Driver Eye Behaviour

Previous studies have found that navigational displays may cause driver distraction, thereby degrading the driver's performance and compromising their safety, even on straight roads (Donmez et al., 2007). The drivers' general scanning patterns can be disrupted by some in-vehicle systems, resulting in the driver being less likely to scan their mirror or to the sides

(Taylor et al., 2013). This could be problematic, since although they have improved LOS with a rear-view camera, they are potentially ignoring hazards that are outside of this view. Requiring the operator to pay attention to another screen or input, reading text or dealing with extra information may result in more distraction of the driver as it pulls their eyes off the road (Hoffman, Lee, McGehee, Macias, & Gellatly, 2005). To combat proximity issues, the development of PATs to increase available LOS, and by extension improve SA, has been researched but not pertaining to the relevance for heavy equipment purposes (MOL, 2015). For this reason, it is important to ensure that the PATs being implemented are increasing the operators LOS as well as SA, and not distracting them causing increased risk of an accident. Consequently, it is imperative to know how different PATs change scanning patterns, and how they are currently being used in industrial sectors. The literature in this sector is generally lacking.

2.6 CONCLUSIONS

The findings from this research could guide the design of vehicle interaction technologies for use in heavy equipment, training programs and policies to improve worker safety and reduce equipment-worker interactions. There is a gap in literature pertaining to heavy equipment operators and their typical eye gaze behaviour during typical worksite tasks, especially with mining machinery. This information is needed to be able to have a baseline of eye scanning behaviour of heavy equipment operators, therefore important changes can be detected when implementing new strategies to help improve safety. With more commercially available safety technologies on the market, there is a desire for industry to implement them on various machines to improve equipment-worker safety on worksites (Marks & Teizer, 2012; Marks & Teizer, 2013). Presently, there has been no comprehensive study to determine how heavy equipment operators have utilized visual aid technology while performing construction tasks. There has also been no research that quantifies how heavy equipment operators' change their work patterns to utilize the implemented visibility enhancements. Minimal information and data are available to evaluate how existing construction safety technologies can be implemented to help warn the workers of the presence of hazardous proximity situations in their surroundings (Marks & Teizer, 2013). A large body of literature exists to guide the design and implementation of similar devices into passenger vehicles; however, the same principles that work in automobiles cannot be brought over to heavy equipment industry without more thorough research that simulates the specific worksite environment.

There is a lack of evidence for how novice and experienced users perform on objective measures of workload including; response or reaction times, and eye movements (Tichon and Burgess-Limerick 2011). Previous literature specific to simulator training in the mining industry has mostly been conducted by mining or simulator companies themselves, focusing solely on improvements to efficiency or procedures (ie. performance score).. The subsequent two chapters attempt to contribute literature to help address each of these gaps.

CHAPTER 3:
Field Study: Natural Eye Gaze Behaviours of Dump Truck Operators when driving in a Naturalistic Worksite Environment

ABSTRACT

In construction, heavy equipment operators work within dynamic environments, and at times confined areas, where they must continuously monitor their surroundings for hazards while completing various worksite tasks. Injuries and fatalities resulting from accidents involving an individual being struck by machinery in the construction industry continue to dominate the statistics, therefore it is essential to understand the natural gaze behaviour of heavy equipment operators. A study was conducted in a naturalistic environment, where eye movement behaviour data was collected through an eye-tracker donned by heavy equipment operators. Data analysis was completed through Tobii Pro Lab. Findings show that while driving forward, all operators spend the majority of time fixating within the front central view. In contrast, while reversing, none of the operators looked within any of the front views, and the majority of fixations and time is spent glancing at the mirrors. Longer fixation durations occurred within the right mirrors for both forward and reversing tasks potentially suggesting the increased importance of that location. It may also point to the increased cognitive workload experienced by operators trying to extract necessary information from a small viewing area on the opposite side of their truck. The eye behaviour while driving heavy equipment compared to passenger vehicles differed greatly. The findings from this study will develop and assist future studies to further the understanding of heavy equipment operator glance behaviours and may allow for improved safety practices in the workplace.

KEYWORDS: Eye-Tracking, Eye Behaviour, Dump Truck, Construction

3.1 INTRODUCTION

Among various pieces of equipment, dump trucks have the highest incidences of visibility-related accidents resulting in fatalities (Hinze & Teizer, 2011). In 31% of all the visibility-related fatalities examined in the United States, struck-by accidents were the source of injury (Hinze & Teizer, 2011). Further, it was found that out of 173 fatal accidents attributed to visibility and/or awareness issues that involved dump trucks, 91.1% of the accidents occurred when the dump trucks were travelling in reverse, and in 12.1% of the cases examined, the back-up alarm was not functioning (Hinze & Teizer, 2011). In Ontario, struck-by accidents remain the second highest type of incident to occur resulting in workplace injuries within industrial sector over the past four years (Infrastructure Health and Safety Association, 2018). Results from the construction industry alone in that province counted 195 struck-by injuries and 3 traumatic fatalities in 2018 resulting from contact with a vehicle or mobile equipment (Workplace Safety and Insurance Board, 2018). Struck-by accidents involving machinery consist of 8.8% long-term injury claims in Canada and 22% of fatalities in the United States that occur on construction worksites (Association of Workers' Compensation Boards of Canada, 2018; Hinze, Huang, & Terry, 2005). Even with current policies and legislation efforts that focus on reducing the number of equipment-human interactions occurring on worksites, struck-by accidents and fatalities continue to occur. In addition to the devastation from lives lost and critical injuries incurred on the worksite, these accidents can also be very costly to the construction industry. There is an obvious need to focus efforts on researching and evolving more effective preventative measures to reduce the number of struck-by accidents occurring with heavy equipment.

The ongoing struggle to reduce struck-by accidents can be attributed to the dynamic environment of construction worksites, in addition to confined spaces in which workers are required to navigate this large machinery (Hinze & Teizer, 2011). Construction worksites are especially dynamic due to workers-on-foot, their location and knowledge of the worksite, proximity of mobile equipment to pedestrians and other mobile equipment, mobile objects and infrastructure present within the worksite. Causal factors of struck-by accidents have been found to be due to human factors such as misjudging hazardous situations and large blind spots (Hinze et al., 2005). Together, these factors create a hazardous workplace, especially when the surrounding environment along with new hazards are continuously arising.

A heavy equipment operator's line-of-sight (LOS) is very limited, and as a result, this increases the risk of potential struck-by accidents transpiring (Godwin & Eger, 2009). The most common visibility impairment resulting in accidents within the industrial sector are blind spots, due to the deficient operator sightlines from the machine cabin to the environment, workers-on-foot/pedestrians and other obstacles (Hinze & Teizer, 2011; Koppenborg et al., 2016). Blind spots are non-visible areas where an operator's LOS is obstructed by parts of the heavy equipment as well as various objects or infrastructure in the environment (Golovina et al., 2016). An operator's LOS in heavy equipment is severely limited in many regions around a stationary machine, where blind spots contribute to 56% of visibility-related fatalities involving dump trucks (Godwin & Eger, 2009). Furthermore, obstructions within the environment are another variable that creates a blind spot that also impedes operator LOS. Obstructions can include mounds of dirt or fill material, buildings or other equipment within the worksite that conceals the worker or hazard from operator visibility and these were found to contribute to 23% of visibility-related fatalities by dump trucks (Hinze & Teizer, 2011).

Previous research on large machinery in underground mining has also determined that, regardless of which direction the heavy equipment was travelling, an operator's glances were focused on a few unobstructed areas, disregarding other potentially important areas (Eger et al., 2010). This reveals that in addition to blind spots created from the machine that already impede operator LOS, their LOS is further restricted by not utilizing all of the unobstructed visibility around the machine.

Eye-tracking (ET) has been valuable in human behaviour research, and the advancement of eye-trackers has greatly impacted the scope and utility of ET. Progress has allowed for the development of head-mounted eye-trackers that are non-intrusive and portable, permitting field studies researching driver eye behaviour. By gaining a greater understanding of operator visual behavior, researchers can assist in the development of safe and efficient machinery, as well as improve procedures within the workplace (Häggström et al., 2015). Studies have revealed that tree harvester operators and excavator operators have similar gaze patterns noting that their gaze patterns varied depending on each task performed and the tasks demands (Häggström et al., 2015). This indicates that where operators direct their attention is dependent on the task being performed as certain tasks may require an operator to fixate on different regions within the cab or environment. One study studied eye movements of excavator operators with access to a viewing aid, data was collected from 9 different sites that differed in regard to their surrounding conditions, number of co-workers, machines, obstacles as well as the lay person on or around the worksite (Koppenborg et al., 2016). All excavators were equipped with a camera monitor system (CMS) that provided a view of the area directly behind the machine where direct sight is obstructed (Koppenborg et al., 2016a). Koppenborg et al., determined the importance of the mirrors for excavator operators, especially the left mirror in addition to turning their head for a direct view and utilization of a CMS to gain an understanding of rear areas while reversing (2016). Operators were found to look more at the left mirror and CMS during the task (64.1 %

and 56.9%, respectively) along with glancing over their shoulder (19.3%), while only looking at the right mirrors occasionally (Koppenborg et al., 2016). These studies are valuable in helping evolve accident prevention research by further developing methods aimed at preventing struck-by accidents when operating heavy equipment thereby improving worker safety within various worksites.

Typical driving behaviour of individuals in passenger vehicles has been studied along with deviations from typical driving behaviour that arise when proximity awareness technology (PAT) is implemented. It is difficult to apply that same information directly to heavy equipment use due to the vast differences including large blind spots, size of vehicle and absence of rear window. These differences may significantly change the typical driving behaviour of heavy operators when compared to individuals driving passenger vehicles. With respect to reversing in a passenger car, nearly 50% of one's glances happen to be over their shoulder (Huey, Harpster, & Lemer, 1997). However, dump trucks typically lack a rear window thereby eliminating the option to look over their right shoulder when reversing. Consequently, it is logical to assume that the dump truck operator would utilize their side view mirrors more to compensate for the lack of a rear window however, no research could be found to document this practice. The potential implications of changing eye behaviours arise when considering what happens when an operator's focus is primarily on one area viewed only through a mirror. This may mean less time spent scanning around the machine, leading to difficulty in adapting to the dynamic environment. Obtaining data on typical eye behaviour would allow for increased understanding of operating heavy equipment, and may lead to the development of more effective PAT.

In order to design and implement an effective PAT to assist heavy equipment operators in a worksite environment, it is important to understand the behavior of operators, especially while reversing. By obtaining information about typical operators' glance patterns, it can help inform decisions about implementing PAT into heavy equipment. Given the paucity of ET data from industrial workers, this research sought to quantify typical scanning behavior of dump truck operators while driving forwards and reversing. The main objective will be to compare gaze time and fixation length in areas of interest for forward and reverse travel for operators of dump trucks and compare those to known data from passenger vehicle research.

3.2 METHODS

3.2.1 Participants

The procedures followed in this study were approved by the Laurentian University Research Ethics Board (Appendix A). Eye movements during typical work tasks were tracked from three dump truck operators within the construction sector. The operators that participated in the study were recruited from partner companies, each operator was informed of the research objectives and participated voluntarily (Table 3.1). The study was conducted in a naturalistic setting on three construction worksites in Ontario. The heavy operators were all males, 22-63 years of age and their years of driving heavy equipment experience ranged from 0-38 years. Two of the operators had sight impairments that needed to be corrected for this study. A participant package (Appendix B) was provided for participants to complete, this included a consent form and questionnaire to collect basic demographics, and to gain knowledge on their heavy equipment experience. Due to insufficient ET data collected during the trial, P8 and P9 had to be excluded from the study and only the forward trial was analyzed for P3 and P7.

Table 3.1: Heavy equipment characteristics and operator demographics.

Parameter (unit)	Operators								
	P1	P2	P3	P4	P5	P6	P7	P8	P9
Operators									
Age (yrs)	63	22	33	32	24	24	23	62	61
Construction Experience (yrs)	28	5	15	0	6	0	6	5	38
Experience driving heavy equipment (yrs)	28	5	15	16	3	8	6	42	38
Sight Impairment	N	N	N	N	N	N	Y	Y	N
Sight Correction	N	N	N	N	N	N	Y	Y	N
Most common equipment driven	**Dump Truck**, Transport, Loader, Backhoe	**Dump Truck**	**Excavator**, Dump Truck, Skid Steer	**Personal vehicle**, 40 ft truck, boat	**Personal vehicle**, Fire truck (engine)	**Personal vehicle**	**Dump Truck**, Excavator, Backhoe	**Delivery Truck**	**Loader**, Trucks, Other heavy equipment
Heavy Equipment									
Machine Brand	Mack	Mack	Mack	Freightliner	Freightliner	Freightliner	Freightliner	Freightliner	Freightliner
Towing Trailer		Y	Y						
Data Recordings									
Analyzed time (min:s)									
Driving Forward	05:07	05:47	07:28	05:03	05:47	05:43	06:10	-	-
Reversing	00:28	00:25	-	00:20	00:31	00:22	-	-	-

Note:
Bold indicated most common piece of equipment operator interacts with.
- missing data

3.2.2 Eye-Tracker Set-Up

Eye movement data was recorded with Tobii Pro glasses 2 eye-tracker with a sample rate of 50 Hz, which utilizes the corneal reflection and dark pupil technique to record saccades, fixations and pupil diameter as well as a simultaneous scene video (Tobii Pro, 2017a). This lightweight head-mounted eye-tracker does not impede the operator's 'normal' movement while operating equipment (Häggström et al., 2015; Tobii Pro, 2017a),therefore, it was not expected to alter the operator's visibility or driving behaviours. The eye-tracker system consists of the head unit, recording unit, and a Windows tablet. The headset consists of a high-definition scene camera, microphone, ET sensors, illuminators and a micro HDMI connector (Figure 3.1).

The high-definition scene camera captures a video of what the participant is seeing in front of them, and the point of regard, representing focus location is later superimposed onto the video using Tobii software (Tobii Pro, 2017a). The headset also has a microphone that picks up sounds from the participant as well as the surrounding environment (Tobii Pro, 2017a). For the purpose of this study, the participants were informed of the microphone and that the audio was being recorded during the trials but was not going to be used as a data source for this study. The ET sensors are located slightly inferior to both eyes, recording the eye orientation (direction of eye gaze) of the participant while the IR illuminators support the sensors by illuminating the eyes and are located around both eyes (Tobii Pro, 2017a). Together these determine where the participant's eye gaze is directed at any moment in time. The headset is controlled by the recording unit and stores all ET data on an SD memory card (Tobii Pro, 2017a).

Figure 3.1: Tobii Pro Glasses 2 system (Tobii Pro, 2017a).

The eye-tracker was calibrated once the participant donned the device, and before data collection started. To calibrate the eye-tracker, the calibration card was held up against a neutral, non-busy background about 2.5 to 4.1 feet away from the participant (Tobii Pro, 2018). The participant was then instructed to focus directly at the center of the calibration target, the calibrate icon on the tablet was then pressed to initiate the calibration process (Tobii Pro, 2018). Once calibration was successful, verification of quality was done by checking the calibration results box as well as instructing the participant to look at a few objects (Tobii Pro, 2018). If adequate calibration was achieved, recording was started to commence data collection. If the calibration process was unsuccessful or inaccurate, the calibration process was restarted to ensure acceptable ET accuracy was obtained.

3.2.3 Eye Movement Measurement

This study was conducted in an outside environment, meaning that direct sunlight was a significant factor to consider. Calibration and ET usually will not work in strong direct sunlight, due to interference with the IR light, resulting in missing data in the recording (Tobii Pro, 2017a). To evade issues related to direct sunlight, calibration was conducted inside the cab of the heavy equipment, away from direct sunlight and within the environment data collection was taking place. The cab structure of the heavy equipment appeared to provide shielding from the direct sunlight and allowed for adequate ET samples to be processed in most cases.

Following successful calibration, ET data from each operator was collected over driving trials lasting approximately 20-30 minutes in duration in which they completed typical work tasks in a variety of settings (gravel pit, worksite, and urban settings). The heavy equipment involved in this study were not equipped with any vehicle interaction technologies, just a standard back-up alarm as required by legislation. During the trial run P1, P2 and P3 maneuvered around the worksite driving forward and reversing while driving to their intended destinations and completing required work tasks. There was no ET data obtained while reversing for the duration of P3 trials due to technical difficulties. Data from the other participants (P4, P5, P6 and P7) was done in an urban setting and they all completed the exact same route. Only reversing segments where the operator was going straight backwards were chosen, any turn portions that occurred prior were removed. Data collection was preceded by a 5-10 minute familiarization period (Koppenborg et al., 2016), to ensure that any initial change in the operator's driving behaviour by wearing the eye-tracker did not significantly or adversely alter the data.

3.2.4 Data Analysis

The data obtained from the Tobii Pro 2 glasses was analyzed using Tobii Pro Lab analysis software, quantifying eye fixations and saccades into defined areas of interests (Tobii Pro, 2017b). This allowed the data to be analyzed frame by frame; there was occasional loss of tracking during the trial, resulting in some of the video frames not having ET samples (Häggström et al., 2015; Tobii Pro, 2017b). Due to poor ET-samples for P8 and P9 likely due to the reflection of sunlight off the snow, there was significant loss of tracking throughout the video, which prohibited accurate data analysis. For this study, gaze sample percentages above 60% were deemed acceptable. Gaze sample percentages for P8 and P9 were 50% and 41%, respectively, as a result, the ET-data collected these participants were not included in the data analysis. For the remaining participant trials included in the study, an average of 87% gaze samples was achieved. The reversing maneuver for both P3 and P7 were both excluded from this study as well due to poor ET samples which could be due to excessive sunlight during the maneuver. For the forward driving task, eight sections (lasting an average of 35s in duration) were mapped manually for each participant, and one section (ranging from 23 – 35s in duration) for the reversing task. The metrics that were extracted from all 8 segments were the total fixation duration (s), mean fixation duration (s) and total fixation count, all 8 segments for each participant were then averaged for each area of interest (AOI). The main AOIs chosen for the snapshots are described in Table 3.2 and actual position illustrated in Figure 3.2. Two of the dump trucks were equipped with front mirrors located on the hood of the dump trucks, which were made into AOIs and labeled as the front left mirror (FLM) and front right mirror (FRM) whereby left refers to the driver-side and right refers to the passenger-side of the machine. This allowed for exportation of eye movement metrics (number, duration, and order of fixations) for each AOI for easy comparison between forward and reversing.

For this study, the Tobii-I-VT fixation filter was applied to the raw data to reduce noise and classify data points into fixations and saccades with the settings found in Appendix C. Reduction of noise was accomplished by using the moving median to reduce noise within the raw data without shifting data to extreme coordinates, and this method also preserves the beginning and ends of saccades (Tobii Pro, 2017b). A Velocity-threshold identification (I-VT) classifier applied an angular velocity to each data point: an angular velocity threshold of 30°/s was used to classify data points above the threshold value as saccades, and data points below being part of a fixation (Salvucci & Goldberg, 2000). This value was chosen to ensure that data was not skewed too high, which would cause saccades to be missed. On the contrary, a threshold set too low will produce longer saccades, and have shorter or completely missed fixations (Tobii Pro, 2017b). To accommodate for any fixations that were incorrectly classified as multiple short fixations instead of a longer fixation by the I-VT classifier, adjacent fixations were merged as per Tobii protocols (Tobii Pro, 2017b). Therefore, adjacent fixations were aggregated if located within a maximum visual angle of 0.5° of each other and a maximum time of 75 ms between separate fixations that should be merged. This allowed for microsaccades and blinks to be filtered out as they have amplitudes less than 0.5° and maximum blink durations have been found to range from 75-425 ms (Evinger, Manning, & Sibony, 1991). In addition, fixations that were incorrectly classified due to the duration being too short to qualify as a true fixation were discarded (ie. fixations less than 60 ms).

Gaze plots were utilized to show the position of fixations on the snapshot images to accompany quantitative data to assist with communicating data by providing a visualization of each participants viewing behaviour (Tobii Pro, 2017b). Each dot shows the sequence and location of where each fixation was made by the operators during times of interest, the size of the dots indicates the duration of each fixation (Tobii Pro, 2017b). Longer fixations are represented by a larger dot while shorter fixations by a smaller dot (Tobii Pro, 2017b).

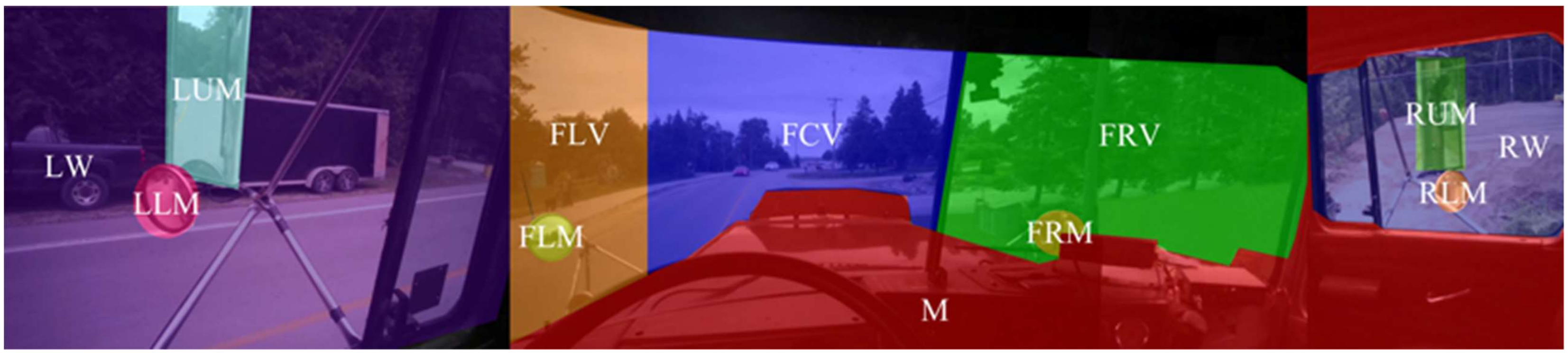
Table 3.2: Description of AOIs used in eye-tracking analysis of the current dataset

AOI	Description
Front central view (FCV)	Looking within the central portion of the windshield, consisting of views of the majority of their own lane and shoulder of road, as well as a portion of the closest left lane.
Front left view (FLV)	Looking within the left portion of the windshield, consists of views of mainly the left lane and shoulder of road.
Front right view (FRV)	Looking within the right portion of the windshield. Views consisting of objects, infrastructure and environment to the right of the road.
Front left mirror (FLM)	Circular mirror located on top of the dump truck's hood on the left side, providing an additional view of the left side of the dump truck.
Front right mirror (FRM)	Circular mirror located on top of the dump truck's hood on the right side, providing an additional view of the right side of the dump truck.
Left window (LW)	Left window
Left upper mirror (LUM)	Rectangular mirror located within the left window, providing views of some of the rear areas on the left side of the dump truck.
Left lower mirror (LLM)	Square or circular mirror located directly below the LUM, provides views of some of the rear areas closer to the ground on the left side of the heavy equipment.
Right window (RW)	Right window
Right upper mirror (RUM)	Rectangular mirror located within the right window, providing views of some of the rear areas on the right side of the dump truck.
Right lower mirror (RLM)	Square or circular mirror located directly below the RUM, provides views of some of the rear areas closer to the ground on the right side of the heavy equipment.
Right ground mirror (RGM)	Small rectangular mirror located within the RW, above and to the right of the RUM and RLM. This mirror provides a view of the area right below the passenger side door.
Machine (M)	The area inside of the heavy equipment, including but not limited to the speedometer, gauges, and airbrakes.

a)


LUM
LW
LLM
FLV
FCV
FRV
M
RUM
RW
RLM

b)


LUM
LW
LLM
FLV
FLM
FCV
FRV
FRM
M
RUM
RW
RLM

c)
d)

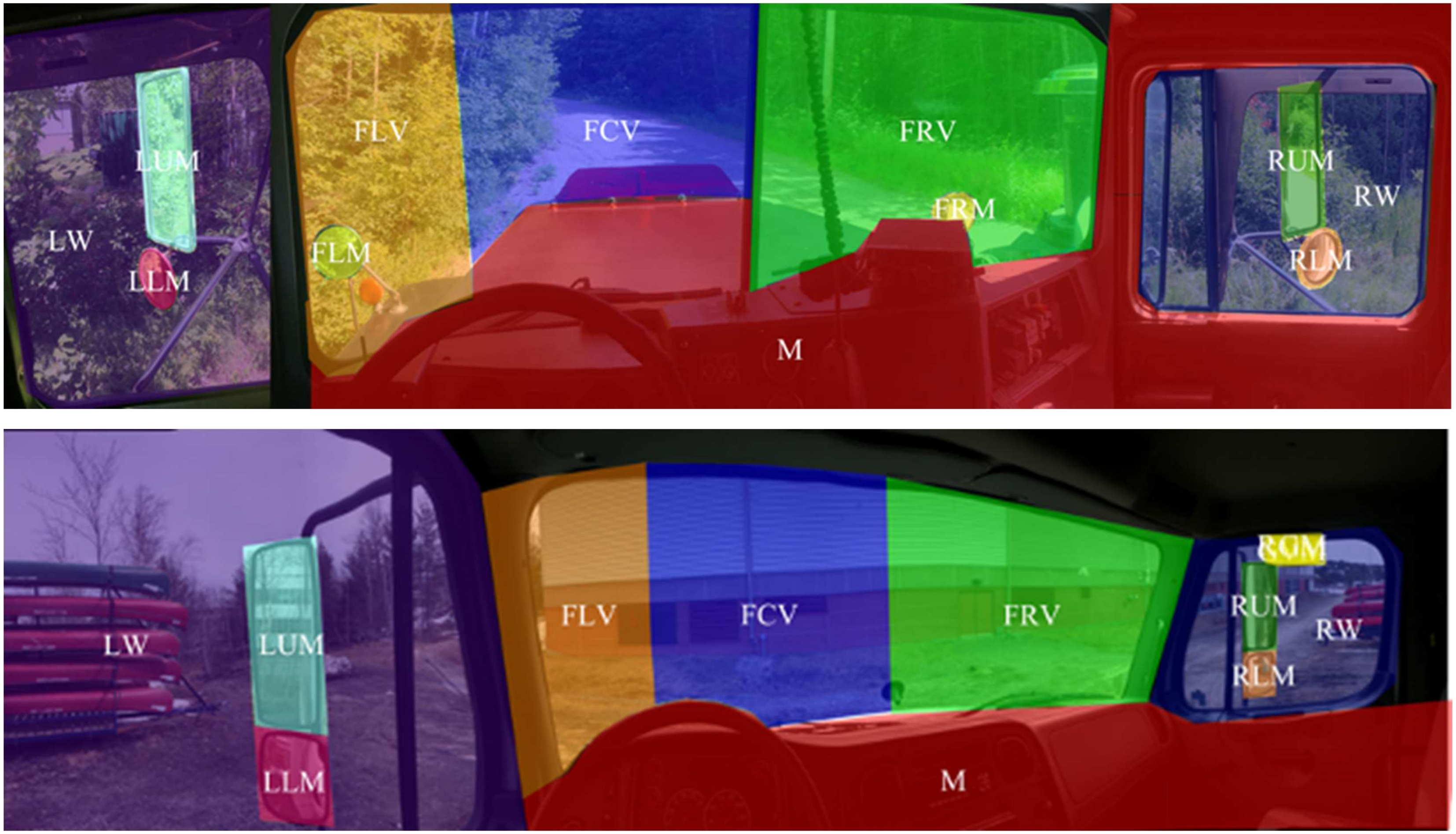


Figure 3.2: Location of AOIs on snapshot of P1s dump truck without front mirrors (a) and dump trucks equipped with front mirrors operated by P2 (b), P3 (c) and P4-P6 (d) with a ground view mirror.

3.3 RESULTS

The majority of each operator's fixations were clustered within the FCV while driving forwards as depicted in Figure 3.3, which is supported by the metric values. As observed, their visual scanning patterns within the front view varies slightly between each operator. For instance, P1 and P4 concentrated mainly within the FCV with a slight shift to the right side of the AOI, occasionally looking to the FLV or FRV. The other operators also fixate for similar amounts within the FCV however a shift to the left side of AOI is noted. Although, P2 appears to have more of a horizonal scanning strategy than the other operators, with more fixations within the FRV than all other operators. This differs from the other operators' scanning patterns where it can be seen that the operators appear to favour the left side of the FCV and FLV. Most scanning patterns appear to be relatively focal to certain areas, however P5's scanning pattern is much more dispersed. The LUM was tended to more by all operators than the LLM, with the exception of P5 and P6 that looked at the LLM more. The opposite is observed with the right mirrors as almost all operators except P3 preferred the RLM compared with the RUM. Longer fixations were made within the right mirrors compared to the left mirrors by all operators. The use of the mirrors varied greatly between operators as some operators did not use certain mirrors while others may have used all mirrors. The LW was looked at more often than the RW by all operators. The machine was fixated mainly to look at the speedometer as observed, although P1, P2 and P3 also looked at their other switches/ buttons including the air brakes while P4 mainly looked within the cab of the truck with P5, P6, P7 sometimes looking within the cab.

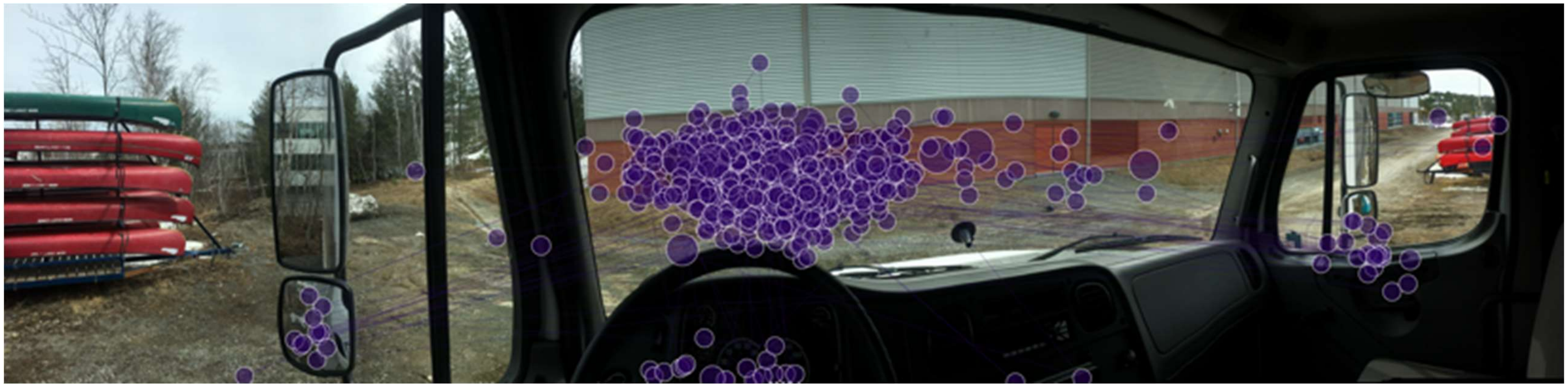
While reversing operators basically never fixated within any of the front views, fixating solely on the left and right mirrors with a few glances within the left and right windows as illustrated in Figure 3.4. It is also observed that the fixations within the RUM and RLM appear to be longer in duration compared to the LUM and LLM having much shorter fixations as depicted by the size of the circles. Although mirror use while reversing is quite different between operators, more operators appear to use the upper mirrors compared to the lower mirrors. Only one operator (P4) did not use any mirrors, only looking out the windows while reversing. In terms of preference, each operator differs in whether they prefer to use the upper or lower mirrors more often along with using the left or right mirrors more. The RW was fixated more frequently than the LW by almost all operators with the exception of P2. Only P4 fixated within the machine on the speedometer during the reversing task.

a)
b)
c)

d)

e)

f)



g)

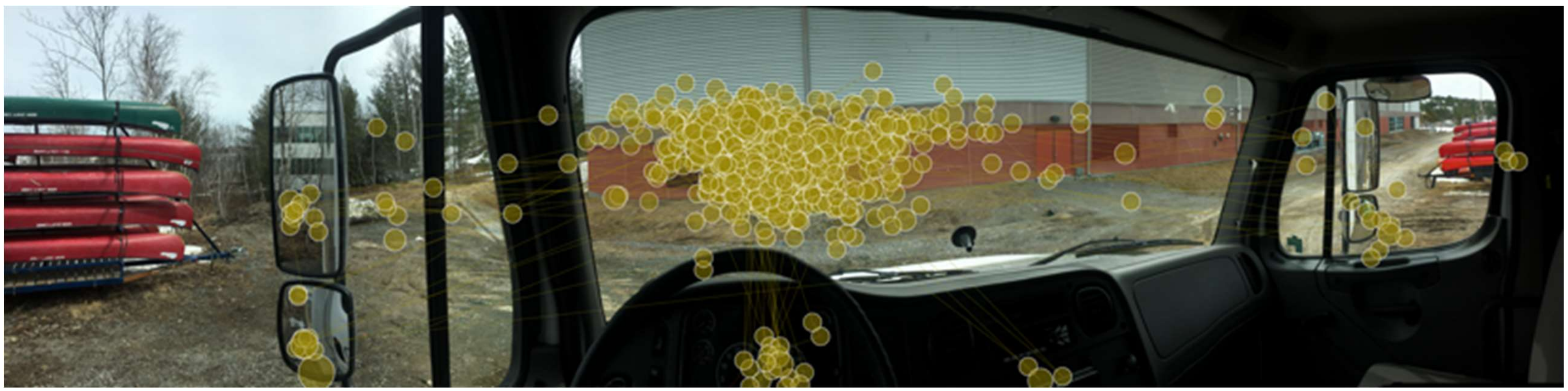


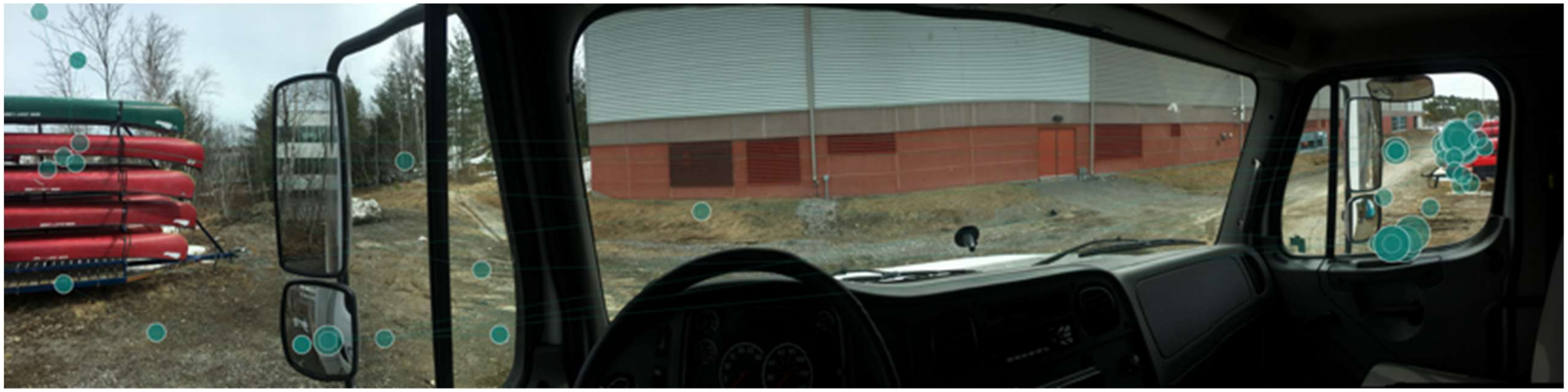
Figure 3.3: Gaze plots of gaze behaviour of each operator while driving forwards (P1- a, P2 – b, P3 – c, P4 – d, P5 – e, P6 – d, P7 – e), illustrating the physical fixation location within the field of view and duration indicated by size of the circle.

a)

b)

c)

d)



e)

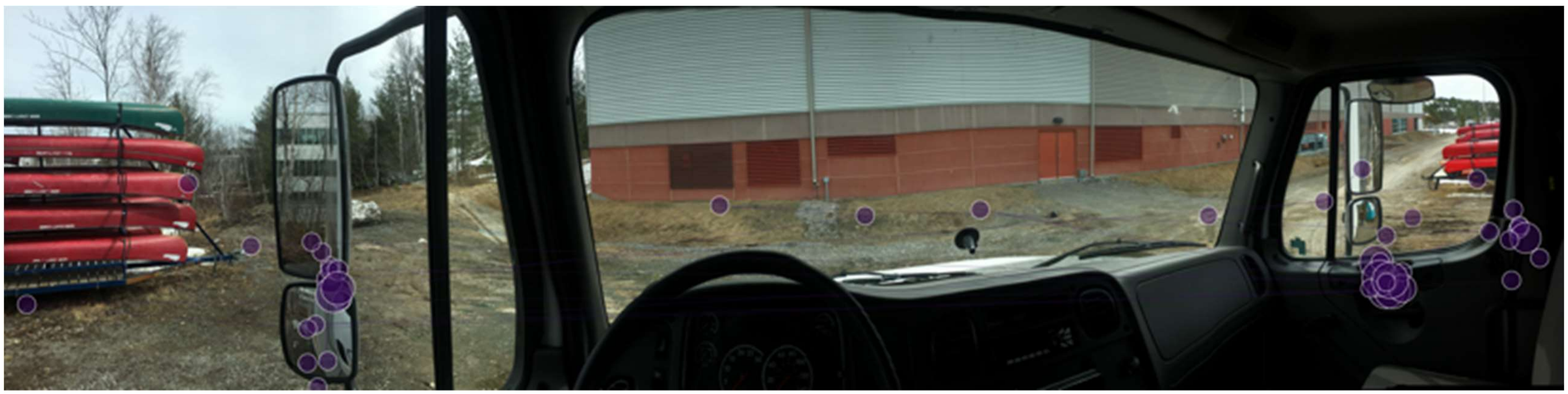


Figure 3.4: Gaze plots of gaze behaviour of P1 a), P2 b), P4 c), P5 d) and P6 e) for the reversing maneuver, illustrating fixation location and duration by size.

3.3.1 **Heavy Equipment Operator Eye Gaze Behaviour While Driving Forwards**

Table 3.3: Heavy equipment operator eye-tracking measurements while driving forwards.

Area of Interest	Eye-tracking metrics		
	Mean total fixation duration (%)	Mean fixation duration (s)	Median total fixations (#)
Front central view	79.0	0.205	644
Front left view	8.1	0.184	60
Front right view	4.6	0.162	27
Front left mirror	0.1*	0.270*	0*
Front right mirror	0.1*	0.135*	0*
Left window	2.3	0.140	21
Left upper mirror	1.1	0.122	8
Left lower mirror	0.6	0.157	5
Right window	1.2	0.136	11
Right upper mirror	0.2	0.187	1
Right lower mirror	0.5	0.140	3
Right ground mirror	0*	*	0*
Machine	2.3	0.139	24

*Value consists of only one participant as other dump trucks were not equipped with the front left and right mirrors and right ground mirror.

Total Fixation Duration

While driving the dump truck straight forward on a 2-lane road and within a gravel pit the three dump truck operators spent the majority of the time with their gaze focused in the front view, specifically the front central view (FCV) as illustrated in Figure 3.5. The operators fixated within the FCV for a mean duration of 79.0% (Table 3.3) throughout the forward time trial. The next two most consistently looked at AOIs were the front left view (FLV) and the front right view (FRV). The FLV and FRV were glanced at 8.1% and 4.6% of the trial by the operators while driving forwards, respectively. Each operator fixated within the FCV, FLV and FRV for very similar proportions with a few exceptions (ie. FCV was only fixated for 58.0% of the time by P4 while observing FLV for 18.6% of the time). Individual ET measurements are displayed in Appendix D and Appendix E, where other exceptions can be found to be more apparent between operators. During the forward task the machine (M), which constitutes any part of the machine body in front of the operator, was tended to for 2.3% of the trial. Similar to the machine, the LW was fixated 2.3% of the entire forward task. The remaining AOIs were basically rarely, or never glanced at while the operators were completing forward driving tasks.

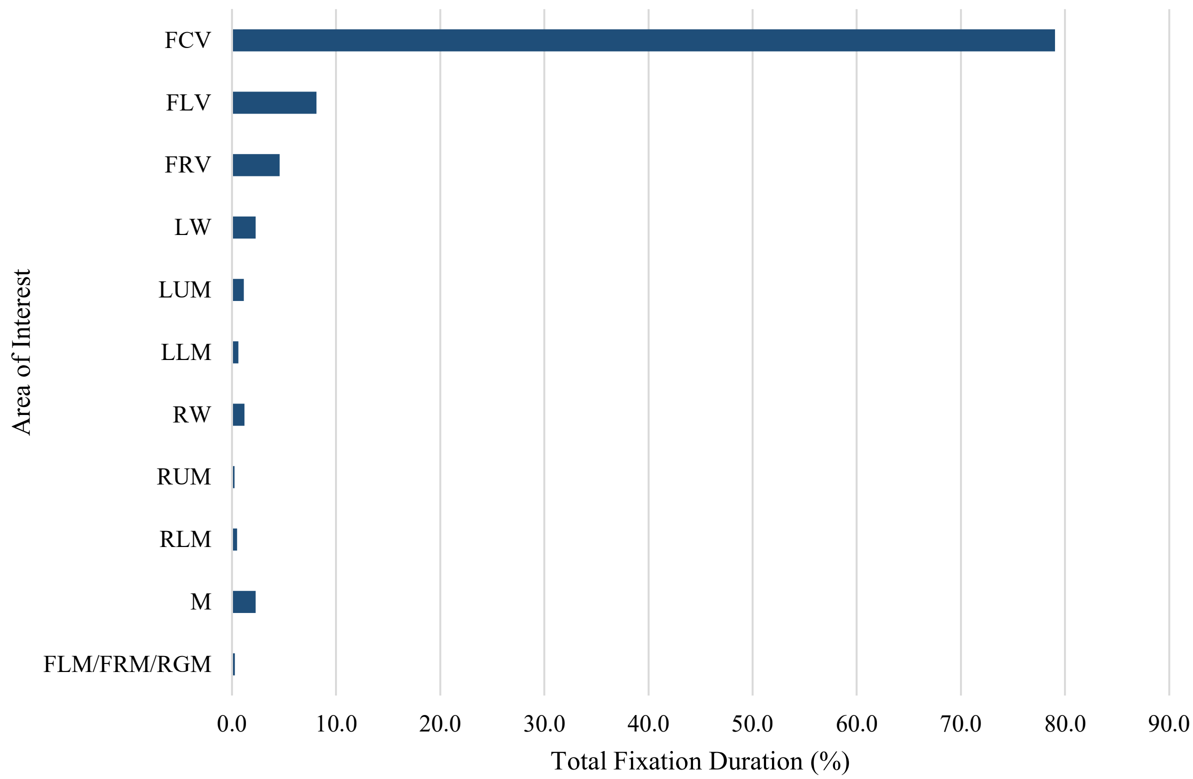


Figure 3.5: Percentage of time heavy equipment operators spent fixating each AOI during forwards movement.

Mean Fixation Duration

While driving straight forwards, all dump truck operators fixated slightly longer and a lot more frequently within the FCV for all of the segments analyzed as illustrated in Figure 3.6. Operators fixated within the FCV for a mean duration of 0.205 seconds (s) and median count of 644 fixations while driving forwards (Table 3.4). All operators mean fixation durations were quite similar, although there were some individual variations (0.154 s -0.264 s). Although fixated less than the FCV, the FLV and FRV were the next most fixated AOIs and were fixated within for slightly shorter durations. The FLV was fixated for a median count of 60 times and 27 fixations within the FRV, both AOIs had similar mean fixation durations of 0.184 s (FLV) and 0.164 s (FRV). Both the LW and M were fixated for very similar counts and durations with 21 and 24 fixations made within the AOIs and fixations with mean durations of 0.140 s and 0.139 s, respectively.

The AOIs with the highest mean fixation duration included the FLM and FCV with fixations 0.270 s and 0.205 s in length, respectively. Although, it should be noted that the FLM was only fixated a total of 2 times by only one participant with a dump trucked equipped with the FLM and FRM. The RUM and FLV had similar mean fixation durations of 0.187 s and 0.184 s, along with the FRV (0.162 s) and LLM (0.157 s), which are slightly longer than the main cluster of AOIs. The main cluster of AOIs consist of the FRM, LW, RW, RLM and M, and had mean fixations ranging from 0.135 s – 0.140 s in length. The shortest fixation duration occurred within the LUM with a mean duration of 0.122 s.

The mirror use between all operators is inconsistent as not all the operators looked at each individual mirror, in addition there were no overt trends observed between the mean fixation duration of individual operators. Overall, the main observation between most operators that did fixate, is that they fixated more on the left mirrors (LUM, LLM) than the right mirrors (RUM, RLM).

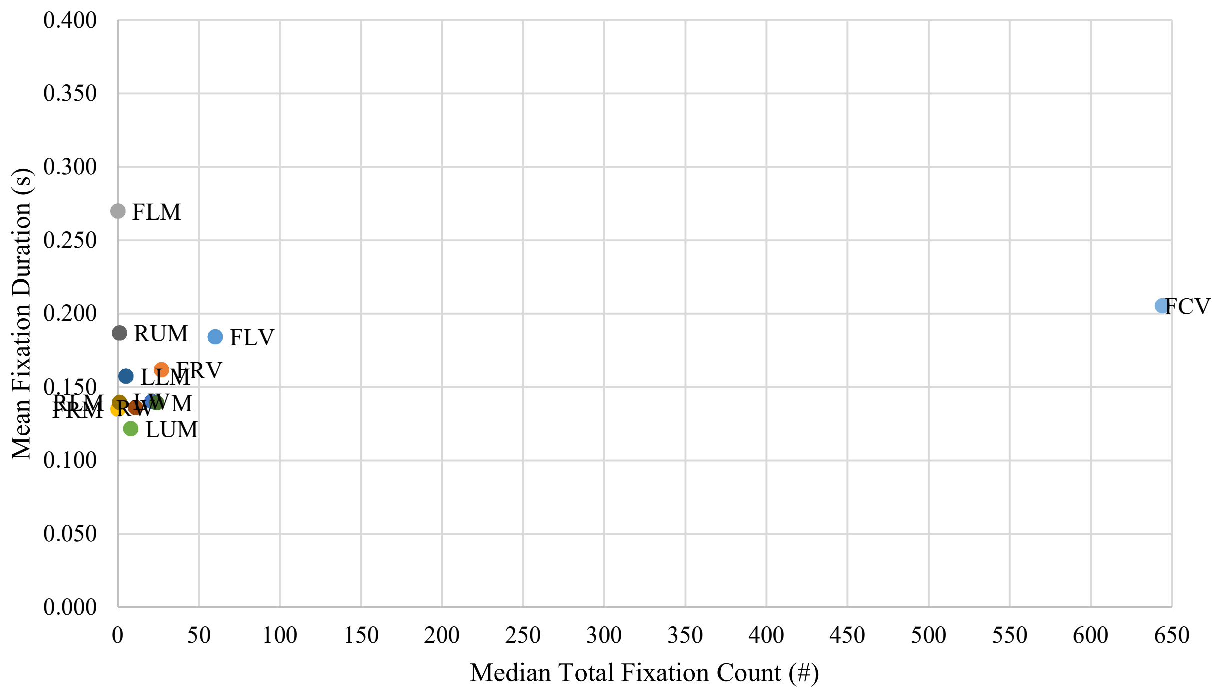


Figure 3.6: The mean duration and total fixation count heavy equipment operators made within AOIs while driving forwards.

3.3.2 Heavy Equipment Operator Eye Gaze Behaviour While Driving in Reverse

Table 3.4: Heavy equipment operator eye-tracking measurements during rearward movement.

Area of Interest	Eye-tracking metrics: Mean total fixation duration (%)	Mean fixation duration (s)	Median total fixations (#)
Front central view	0.9	0.140	0
Front left view	0.1	0.080	0
Front right view	0.5	0.100	0
Front left mirror	0.0*	*	0*
Front right mirror	0.0*	*	0*
Left window	4.8	0.127	3
Left upper mirror	11.7	0.154	6
Left lower mirror	6.5	0.169	5
Right window	29.9	0.201	8
Right upper mirror	13.7	0.248	1
Right lower mirror	20.4	0.381	6
Right ground mirror	0.0*	*	0*
Machine	11.4	0.276	1

*Value consists of only one participant as other dump trucks were not equipped with the front left and right mirrors and right ground mirror.

Total Fixation Duration

During the reversing task where operators performed a right turn in reverse, the operators spent most of the time fixating within the right-side window and mirrors. The most fixated AOI was the RW where operators spent 29.9% fixating within the AOI (Table 3.4). Operators utilized the view from the RUM and RLM compared to the LUM and LLM as observed in Figure 3.7. Between the right mirrors, operators spent more time looking within the RLM than the RUM, spending 20.4% and 13.7% fixating within each AOI respectively. The left mirrors were consulted for approximately half the time the right mirrors were with operators fixating for 11.7% (LUM) and 6.5% (LLM) of the task. The percentage of time spent looking at the M (11.7%) is comparable to the time operators spent looking within the LUM and RUM. The LW was fixated for considerably less (4.8%) of task duration compared to the RW. The remaining AOIs within the dump truck were basically never fixated within during the reversing movement ie FCV, FLV, FRV, FLM, FRM, RGM, and altogether operators who used those AOIs spent less than 3.0% of the total time fixating within the front view.

Overall, operators fixated on the collective mirrors for the majority of time during the reversing maneuver except P5 who spent the majority of time fixating within the RW (82.2%). Although preference on mirror use differed between operators, most operators favoured the right mirrors more than the left mirrors except for P5 and P6 who did not fixate at all or rarely fixated within the right mirrors. Similarly, the RW was looked at for a greater portion of time by operators compared to the LW during the reversing task. The M was only consulted by a few operators and those operators demonstrated a large range of time spent fixating in that AOI, from 1.2% to 38.4%.

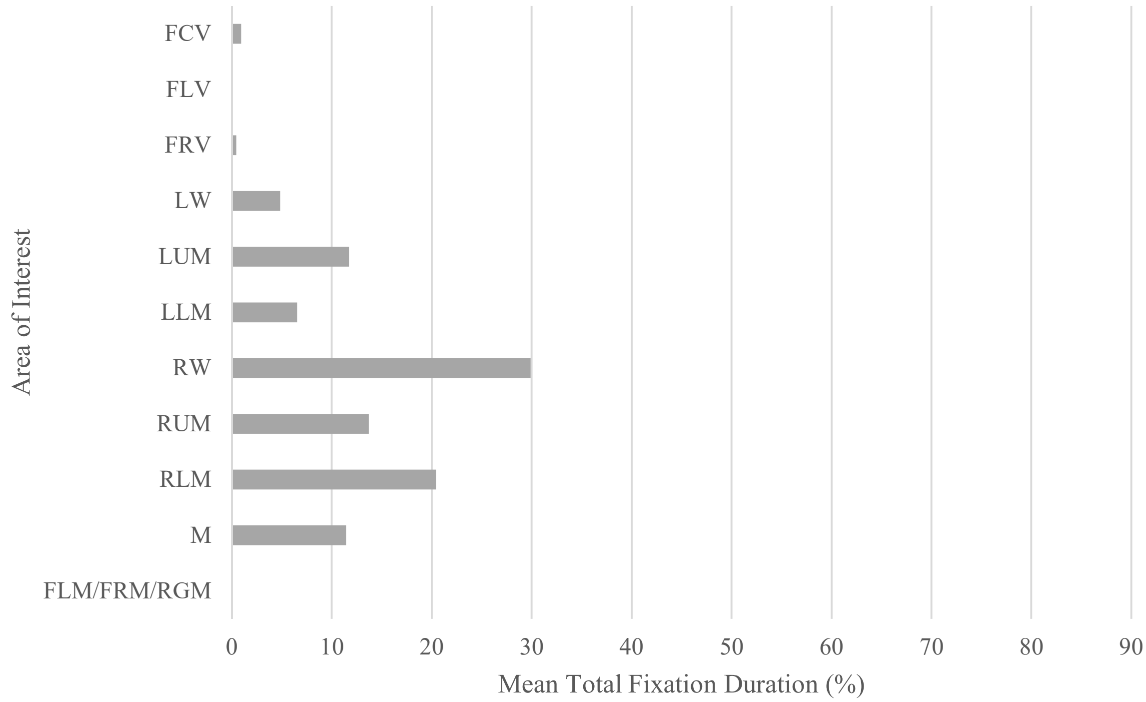


Figure 3.7: Total percentage of time heavy equipment operators spent looking within each AOI while driving in reverse.

Mean Fixation Duration

While performing the reversing maneuver, operator fixations within the right mirrors (RUM and RLM) and machine were much longer in duration compared to the mean fixation duration made within the remaining AOIs. The longest fixation durations were made within the RLM having a mean duration of 0.381 s, followed by 0.276 s (M) and 0.248 s (RUM) as illustrated in Figure 3.8. The RW was fixated the most with a median of 8 times, while the mean fixation duration was shorter than the right mirrors with a value of 0.201 s. The LUM and LLM had a similar fixation duration to the RW with fixations 0.154 s and 0.169 s in length, respectively. Operators looked within the LW 5 times throughout the tasks for a mean duration of 0.127 s. The residual AOIs consisting of all three front views were basically never looked at, while only making very quick fixations within these AOIs ranging from 0.080-0.140 s in length.

Amongst all operators, their mirror and window use differ drastically in terms of how much they look at each mirror and for how long their fixations are. Although most operators did look within each mirror during the reversing maneuver, fixation durations within these AOIs were quite different between operators (0.080 s - 0.480 s) as with the both windows (0.100 s – 0.213 s). Other notable differences include the duration operators fixated within the M (0.079 s – 0.182 s) The front views were only consulted once or twice by one or two operators, the operators only fixated within these views for 0.080 s – 0.100 s with the exception of P1 that fixated within the FCV for 0.200 s.

All operators differ slightly on how often they looked at the mirror AOIs, as almost all operators had more fixations looking at the mirrors in relation to the windows. With the exception of P5 that utilized the right and left windows rather than using the mirrors with majority of fixations occurring within these AOIs and never consulting the mirrors aside from the LLM 6 times. Differences between the number of fixations made within the LUM, RW and M observed between operators show that one operator made more fixations than the rest of the operators that looked each AOI which could have skewed the overall mean fixation count. The M was looked at 1-10, the LUM fixated 3-30 times and the RW was fixated 1-45 times by operators during the reversing task.

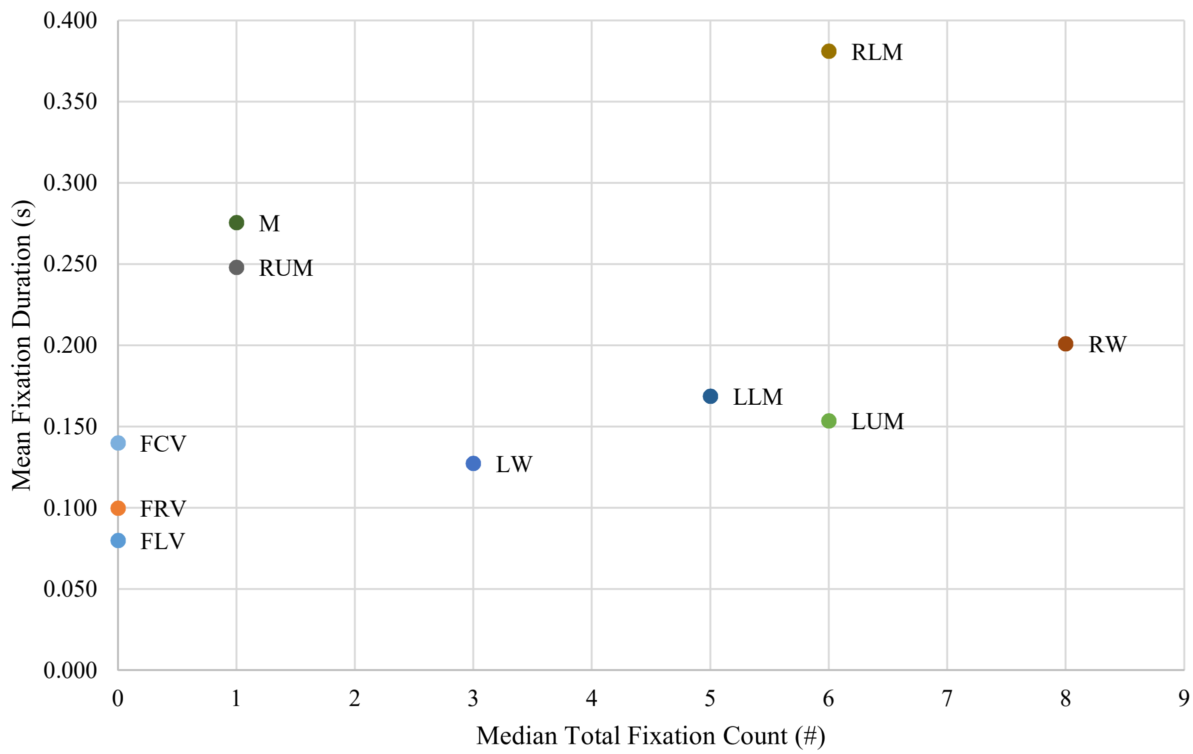


Figure 3.8: The mean duration and total fixation count heavy equipment operators made within the AOIs while performing a reversing task.

3.4 DISCUSSION

All operators in this study were found to look straight forward in the FCV for the majority of the time while driving a dump truck straight forwards on a 2-lane road and within a gravel pit. This is consistent with other studies on passenger vehicles and 12-meter trailer trucks that found that drivers also look straight ahead within the front central view while driving straight for the majority of the time (Harbluk, Noy, & Eizenman, 2002; Häggström et al., 2015; Kito, Haraguchi, Funatsu, Sato, & Kondo, 1989; Olson, Battle, & Aoki, 1989). Fixations within the FCV were made more often compared to other AOIs as observed in the results. Studies have found that a predominant eye behavior used on straight sections involved a straight ahead close-far variation or 'sawtooth' pattern where the driver makes a series of fixations where each consecutive one is a bit further down the road then fixates closer to the vehicle again, repeating the sequence (Bengler, Bernasch, & Lowenau, 1996; Zwahlen, 1993). This could support the findings of the operators spending the majority of time (79.0 %) fixating within the FCV but also why they had considerably more fixations (644) within this AOI. In addition, the fixation pattern for most operators within the FCV appeared to have more of a vertical scanning strategy compared to other AOIs with a more horizontal scanning strategy. Each operator fixated slightly longer (0.205s) within this AOI compared to the other AOIs. However, there was slightly larger differences in the mean fixation duration of P2 and P5 was much higher than other operators. The observed variability between operators could be due to each one's level of experience as both operators had less than 5 years of experience driving heavy equipment compared to other operators that had more than 6 years (Duchowski, 2007; Sodhi et al., 2002). Differences in traffic and pedestrians that may have been within the operator's environment as well as numerous other factors may have also played a role in differences observed (Duchowski, 2007; Sodhi et al., 2002).

The FLV and FRV were the next most frequently looked at AOIs by all operators. The fixations within the FLV and FRV were slightly shorter with a mean duration of 0.184 s and 0.162 s respectively. The operators fixated within the FLV 60 times and FRV 27 times which is considerably less than the FCV and had more variation between participants in regard to the number of fixations made on these AOIs. These areas are largely monitored by the far peripheral vision, which is responsible for movement detection that diverts eye focus away from the FCV towards peripheral objects upon recognition of events and hazards (Mourant & Rockwell, 1972; Recarte & Nunes, 2003; Victor, Harbluk, & Engström, 2005). These areas may have only been tended to in certain environments when the operator was required to monitor pedestrians, workers-on-foot, objects or other vehicle within their proximity, not requiring great mental effort thereby a quicker glance was sufficient (Duchowski, 2007; Land, 1998; Sodhi et al., 2002).

All mirrors were rarely looked at while the operators drove forwards, the left mirrors were looked at slightly more compared to the right mirrors with the LUM being looked at the most. The frequency operators looked at each mirror differed between mirrors as well as between each operator, with the results being more variable on the left. Although it was rare when operators fixated on the RUM, the length of fixation was much longer with a mean duration of 0.187 s than in the LUM with fixations 0.122 s long. The use of the LUM appeared to be primarily for slightly more frequent, shorter length fixations. The observed increase in fixation duration to the RUM may be due to that mirror containing more complex or important information that was associated with increased cognitive workload compared to the information intake from the left mirrors (Dehais, Causse, & Pastor, 2008; Häggström et al., 2015). This could also be a result of the RUM being farther away from the operator (physically), resulting in the image in the mirror being much smaller and therefore, requiring a longer fixation. However, it should be noted that opposite trends were observed for the lower side mirrors. The lower mirrors were tended to only occasionally, and when used, only five operators fixated within the LLM, while six operators used the RLM.

The variation in mirror use between the operators may be a result of different operator goals and/or their learned fixation and attentional behaviours (Hayhoe et al., 2002; Häggström et al., 2015). For instance, the two dump trucks that were towing a trailer (P1 and P3) may have changed the operator eye behavior enough to glance more frequently at certain mirrors than they typically would or compared to the other operators without a trailer. There is no existing work to support this finding on eye behaviour when pulling trailers. It is also reasonable to propose that environmental factors may have changed scanning behaviours, as it was observed that the left and right mirrors were mainly fixated by operators when driving within the gravel pit or high traffic areas where there were more workers-on-foot/pedestrians, machinery or vehicles and obstructions due to fill material. The change in scanning patterns suggests that the operators are reacting to environmental changes with methods to enhance their situational awareness at the appropriate times.

Dump truck operators with access to a FLM and FRM basically never used these mirrors. In contrast to the RUM and LUM, when the operators did look at the FLM AOI, it was for a much longer fixation duration than the FRM fixations, that were moderate in length compared to the other AOIs. Few conclusions can be drawn in this case since there were only a few glances to the FLM and FRM to analyze, and due to their small area, the operators may have been fixating just above these mirrors in the overlapping area between AOIs. Overall, more studies should be conducted with a greater population to determine if the front mirrors supply relevant and useful information to operators or if they are even used at all by most operators.

While driving forwards, the frequency with which the operators fixated within the machine differed between operators, as some did not fixate within the machine at all while others only fixated a few times, or a lot more. Operators did have similar overall number of fixations to the machine, but the duration of each fixation varied greatly between operators. The reason for this variation could be due to experience and an improved visual search strategy or familiarity with the dump truck as it does appear that operators with less experience (P2, P5 and P7) had longer fixation durations than more experienced operators (P1, P3, P4 and P6) that had shorter fixation durations within the machine (Duchowski, 2007).The most frequent parts of the machine that operators looked at while driving on a straight section were the speedometer and other switches/ buttons including the air brakes, when permitted. Although rarely viewed, the LW was observed more frequently than the RW with operators fixating for similar durations of 0.140 s and 0.136 s, respectively. This is similar to the other mirror trends with the left mirrors being fixated more often than the right mirrors.

There are some substantial differences between the scanning behaviour of an individual driving a dump truck compared to driving a passenger vehicle. Throughout a reversing task the dump operators in this study never looked within the front view that consisted of the FCV, FLV, FRV, which is very different than what studies have found in the eye behaviors of those who are reversing in passenger vehicles. In a passenger vehicle, the front view is glanced at for 10.6% of the backing task (Huey et al., 1997). A potential reason that the heavy equipment operators in this study did not fixate anywhere within the front view could be a result of a smooth pursuit or peripheral vision, as they do not require the operator to actually fixate on stimuli to observe. Only P4, P5 and P6 fixated within the front view once or twice in these AOIs, which could have been a result of an object or individual within that view that required further attention. It has been found that rapid movements of an object (ex. worker-on-foot, pedestrian) can be noticed without visual supervision, although when fine tuning of movement or action is required to reach an individual's goal, the operator will need to fixate on the object (Ballard et al., 1992; Recarte & Nunes, 2003; Victor et al., 2005). Studies have also noted that during certain tasks operators make look-ahead fixations where they are able to plan and look ahead to the goal location or maintain gaze in a location where an object previously existed while simultaneously steering the machinery away from the object (Häggström et al., 2015). Therefore, it could be likely that most of the heavy equipment operators were in smooth pursuit or made look-ahead fixations when transferring their gaze from the left and right mirrors and did not require to fixate within the front view for more careful movements. Reversing maneuvers, occurred in a controlled zone, where operators knew there was no risk of pedestrians or other machinery only workers-on-foot that operators were familiar with. Therefore, due to familiarization operators may not have felt the need to check these areas as they were comfortable and confident that their crew members were out of their way. This becomes problematic when a crew member may stray from the 'usual' routine, or if there was one or more crew members not familiar with how the operators maneuver. In these cases,the risk for a struck-by accident increases greatly. Other reasons that heavy equipment operators use the front view differently may be due to the dynamic environment and confined spaces on the worksite, being unfamiliar with other workers or an increased workload from handling a larger machinery (Dehais et al., 2008; Häggström et al., 2015).

The mirrors were tended to most frequently by the operators while backing the dump truck. The dump truck operators demonstrated different eye behaviours than a previous study on reversing passenger vehicles. In that study, the right mirror and left mirror were glanced at 9.2% and 8.2% of the time in addition to 4.5% on the rear mirror in a passenger vehicle (Huey et al., 1997). Passenger vehicle operators also have the ability to look over their right shoulder, which they did for roughly 50.9% of the time while backing (Huey et al., 1997). The heavy equipment operators in this study were observed using their left and right-side mirrors for a larger portion of the reversing maneuver which they used for a combined 52.35 % of the reversing task. This is likely due to the absence of a rear-view mirror, typically present in passenger vehicles, and the inability to turn around for a better view. Essentially, heavy equipment operators have replaced their time spent looking over their shoulder with mirror time. This could cause implications as the human eye has a wider range of vision than the mirrors can provide including peripheral vision. Both the dump truck and passenger vehicle operators looked at the right mirror for more time than the left mirror throughout the entire reversing task. The RUM and RLM also had longer fixations of 0.248 s and 0.381 s in duration along with consistently more fixations for both types of operators than the LUM (0.154 s) and LLM (0.169 s), which had shorter durations and for the most part, fewer fixations. Overall, the LUM did have slightly more fixations than the other mirrors including the LLM, RUM and RLM. Using the mirrors more often emphasizes their importance for the operators in gaining an understanding of the areas behind them and in turn, their important role in the prevention of accidents when reversing heavy equipment (Häggström et al., 2015; Koppenborg et al., 2016). Increased fixation duration and number of fixations to a specific region have been found to indicate an increased cognitive workload, importance or measure of search efficiency. (Dehais et al., 2008; Duchowski, 2007; Poole & Ball, 2006; Scialfa, Thomas, & Joffe, 1994). The trend towards spending more time focused on the right mirror would support the concept that there is more important or critical information to be sought out of the right mirror, or that its location on the far side of the cab, thus providing a smaller target area, required an increase in cognitive workload. The findings of operators fixating within the right mirrors for longer gaze periods suggests that the operators have a greater mental workload to decipher information from the right mirrors. The angle of view from flat (LUM) and convex (RLM) mirrors could account for the differences observed between the durations of fixations made within these mirrors. As operators had longer fixations within the RLM which is convex and shorter fixations in the flat LUM, this could indicate that the convex shape is more difficult to extract information from than when looking within a flat mirror. Therefore, the shape of the mirror may also have an impact on one's cognitive workload. This is supported by studies that show that dwell times have been positively correlated with informativeness, difficulty extracting information, increased interest but can also be correlated with lack of SA and uncertainties (Dehais et al., 2008; Duchowski, 2007; Holmqvist et al., 2011). Another reason operators may have an increased use of the right windows and mirrors could be due to the automaticity of looking to the right when reversing a passenger vehicle which is duplicated when operating heavy equipment (Huey et al., 1997). It may have also been context dependent as P1 and P2 were both making a right turn when reversing into a driveway for this study, where P4, P5 and P6 where backing into a private single lane roadway. It should also be noted that attentional switching is demonstrated by the operators as their eyes are continuously shifting back and forth between the left and right mirrors as viewed in the recording (Duchowski, 2007; Victor et al., 2005). Since this was observed in the recording, it can be assumed that there was something about the task requiring a higher cognitive load. The variation between upper and lower mirror use could be due to operator goals, and learned fixation and attentional patterns, as it has been found that the diversity noted between the operators eye behaviour can be due to personal preferences of task type (Hayhoe et al., 2002; Häggström et al., 2015).

The LW was looked at for a short period of time during the reversing task, which differs drastically from the RW where operators spent 29.9% of time looking within this AOI. The machine was also fixated for a larger portion of time compared to the LW, although only by a few operators for long durations and only a couple times. Generally, operators looked out of the RW more often than the LW although it should be noted that the actual percentage of time fixated may be considerably skewed due to P5 spending a much greater percentage of time (82.2%) looking within the RW for the majority of the reversing task. This may have resulted from pedestrians moving within close proximity on the right side while performing the reversing task, and the need to monitor their position while P5 was reversing. Other reasons may include an event or hazard detected in that area for P5 while the other operators may have been utilizing their peripheral view to monitor the window views while looking at the mirrors with no recognition of peripheral events (Mourant & Rockwell, 1972; Recarte & Nunes, 2003; Victor et al., 2005).

Experience could also play a large factor as P5 had only a few hours of experience driving heavy equipment prior to data collection, also consistently making higher fixation durations to almost all other AOIs compared to other operators. This could be the result of inefficient gaze patterns as the operator has not learned the best areas at which to look while reversing, in addition to an increased mental workload resulting in a narrowed visual search pattern from being overwhelmed. Operator interviews after data collection such as retrospective think-aloud (RTA) interviews where operators review ET-video of where they were looking could help narrow down certain observed behaviours (Häggström et al., 2015). This method may be able to shed light on why operators choose to drive certain ways. This could potentially be the reason for the windows not being tended to as often or never, as the operators are using their peripheral view and nothing requires additional attention where they need to actually fixate (Mourant & Rockwell, 1972; Recarte & Nunes, 2003; Victor et al., 2005). Overall, each operator had shorter fixation durations within the windows and only a few fixations within these AOIs. This could be due to the operators just quickly checking their position while making a reversing right turn into the driveway or checking on individuals in the vicinity that did not require excessive visual demand, or they were quickly trying to prioritize visual resources from the mirrors that were more important (Dehais et al., 2008; Victor et al., 2005).

The inside of the machine was also glanced at by the dump truck operators for 11.4 % of the time while reversing, this differs from findings with passenger vehicles where only 1.0% of the time was spent looking at the machine (Huey et al., 1997). Some operators glanced into the machine as many as 1-10 times, which is different from passenger vehicle research. This could be due to the additional gauges and processes that need to be monitored on the truck as well as inexperience with location or use. The reason some operators did not or rarely looked within the machine compared to others could be due to experience and familiarity with the heavy equipment such as, where the air brake location is, therefore this task is more automated.

3.5 LIMITATIONS AND FUTURE RESEARCH

There were a few limitations to this study which included the type of study and measurement tools used. The limitations that were associated with conducting a field study involved low participant numbers, variation in heavy equipment used and lack of control of route and external factors. As recruitment was done from small companies, there were limited employees that drove heavy equipment available and willing to participate in the study. Therefore, due to very small participant number, statistical analysis was not able to be performed or generalized to a greater population. Using multiple small companies also resulted in different heavy equipment being used, and although they were similar, there were slight differences in appearance of heavy equipment that could have affected results. Another potential limitation is the inability to control the route driven and other environmental factors such as amount of traffic or pedestrians and types of roads used. Two of the participants had quite similar routes, however the traffic and pedestrians changed slightly within the routes. The other participants were also driving on 2-lane roads within a more rural area however, in addition to traffic and pedestrians, some areas had more trees and rocks surrounding the roadways compared to the more open roads of the other participants.

Another limitation of the study was the use of the eye-tracker itself to measure eye metrics. As this study was conducted in an outside environment, direct sunlight was a major factor that resulted in some difficulties calibrating as well as loss of ET data in the recording. This is a result of the direct sunlight interfering with the IR light inhibiting successful calibration and/or eye-tracking (Tobii Pro, 2017a). Calibration was occasionally time-consuming due to issues with sunlight, although to help avoid these issues, calibration was conducted inside the cab sheltered from direct sunlight. For the most part, sufficient percentages of samples obtained from each recording with only two participants having insufficient data, however throughout each participant trial there was some missing data due to the sunlight. Video containing missing data was unable to be analyzed, which would have included more reversing tasks for each participant on the route.

For future studies, a greater population size would be needed to to gain a greater understanding of heavy equipment operators gaze behaviour, determining significant similarities and differences between operators, their experience and task being performed. By having a larger population size, it would also allow for generalizations to be made within this population and one could look at differences between experienced and novice operators, which could provide valuable information for training or implementing new policies and procedures. It would also be beneficial to look at a greater variation of worksite tasks to further our understanding of operator eye scanning patterns, and to distinguish differences between the various task conditions and movements. In addition to looking at more tasks, it would also be of value to look at different worksites and companies. This would hopefully determine if these have an effect on operator scanning patterns in relation to how they are trained at certain companies and other worksite factors such as the environment and crews that have worked together for a long time compared to a relatively new crew. When developing future studies, it may be of interest to look to see if there are similarities or differences in operator eye behaviour between small and large construction companies. Lastly, further studies need to explore how operator eye gaze behaviour and mirror use changes when back-up cameras or other technologies are implemented into heavy equipment.

3.6 CONCLUSIONS

The major findings of this study were the significant difference in operator eye behaviour when driving forwards compared to reversing a dump truck. All operators spent the majority of time fixating within the FCV when driving forward compared to reversing where they basically never glanced within any of the front view the entire time. During the reversing task, all operators spent the majority of the time glancing within the mirrors. Due to the dependence on the mirrors this highlights the importance of training of both operators and workers-on-foot, making appropriate adjustments where needed to accommodate where operators are looking thereby improving overall safety. In addition, the findings also emphasize the importance of ensuring regular maintenance with respect to mirrors is completed to ensure these views are not compromised.

Although similar to findings from other studies, there were some major differences between the visual behaviour in operating heavy equipment and passenger vehicles, requiring further investigations. This further confirms the need to conduct more in-depth studies within this area of heavy equipment and dynamic environments, which will allow for improved policies, training and technologies to be developed and implemented to promote a safer workplace. Especially with the recent shift towards using vehicle interaction technologies to increase line-of-sight and operator situational awareness, it is imperative that further understanding of eye gaze patterns during specific worksite tasks is obtained to prevent any distraction or increased cognitive workload that may compromise safety. As found in this study, all operators fixated within the mirrors for the majority of the reversing task and basically never tended to the front view. Even though there were only a few participants that performed this task, if these findings did reflect the natural reversing eye behaviour of all heavy equipment operators, it provides baseline data for comparison against an intervention such as proximity awareness technology. Depending on where the proximity awareness technology, specifically a backup camera view, is displayed, it could negatively disrupt the operator's gaze pattern and use of peripheral and smooth-pursuit movements during the task.

CHAPTER 4:
Case Study: Comparisons between the differences in scanning patterns between novice and experienced load-haul-dump operators pre- and post- mining equipment simulator training

ABSTRACT

Previous literature specific to simulator training in the mining industry has mostly been conducted by mining or simulator companies, focusing on improvements to efficiency or procedures. There is a lack of evidence for how novice and experienced users perform on objective measures of workload including response times or eye movements. Eye fixations are found to be a useful measure of expertise and confidence as well as an indicator of arousal or mental workload. The objective of this study is to determine differences in fixations between novice and expert load-haul-dump (LHD) operators, when completing training in a simulator. Novice operators completed a four-day training program on an LHD simulator and were assessed on a similar trial as the experienced operator. Tobii Pro Glasses 2 were used to collect eye movement data during first and last training runs. Particular emphasis was placed on maneuvering and tramming, two work activities linked to fatal interactions with pedestrians. Scanning patterns of novice operators were compared to expert using Tobii Pro Lab software. Results demonstrated that the scanning patterns of the novice were more diverse and less focal than the expert, and that a noticeable change in novice operators scanning pattern between their first and last training run was evident. Operating heavy machinery within dynamic environments of mines can be quite hazardous due to limited line of sight and confined spaces. Simulator training can minimize risk to operators and equipment, by allowing operators to gain skills in a controlled environment. These results will allow training facilities to recognize expert eye movement patterns and provide cues to novice users that will rapidly improve their learning and ultimately lead to the prevention of accidents.

KEYWORDS Eye Tracking, Eye Behaviour, Mining, Mine Training, Load-Haul-Dump, Occupational Health and Safety

4.1 INTRODUCTION

In Ontario, Canada alone, there were 8 reported long-term injury (LTI) claims and 2 traumatic fatalities that occurred within the mining industry in 2017 as a result of struck-by accidents (Workplace Safety and Insurance Board, 2018). In 2018, there were 890 long term injury (LTI) claims and 28 fatalities reported due to pedestrians or workers-on-foot being struck by vehicles or mobile equipment in Canada (Association of Workers' Compensation Boards of Canada, 2018). This was an increase from 2017 where the reported numbers were 844 and 26 , respectively (Association of Workers' Compensation Boards of Canada, 2018). Struck-by accidents have severe consequences due to the large size of heavy equipment along with factors such as speed, worksite layout, noise, etc. Unfortunately, accidents and fatalities that are related to reversing machinery remain a significant issue within the industrial sector (Koppenborg et al., 2016). Although there are policies and legislations that work to mitigate the occurrence of equipment-human interactions and subsequent injuries, struck-by accidents continue to occur. This is due to the dynamic environment of worksites, along with the confined spaces workers are often required to perform tasks within (Hinze & Teizer, 2011). In addition, worksite environments are constantly changing, which contributes to the hazardous nature of the workplace. On a construction site, these factors might include workers-on-foot, mobile equipment, objects and infrastructure in terms of the number, location and/or proximity on the same site and between worksites. In mining, the underground environment has a lack of natural light resulting in poorly lit areas with reduced or no visibility. Equipment design and large blind spots are frequently cited as factors that lead to struck-by accidents (Hinze et al., 2005). There is a need within the industry to develop effective ways to reduce struck-by accidents that considers the unique worksite characteristics in which heavy equipment operators operate.

In over 70% of visibility related construction site accidents, the heavy machinery was travelling in reverse at the time of the incident (Hinze & Teizer, 2011). Blind spots appear to be the primary visibility impairment that result in accidents within the industrial sector due to lack of operator sightlines from the cabin to their surrounding environment, including pedestrians, hazards and obstacles (Hinze & Teizer, 2011; Koppenborg et al., 2016). Golovina, Teizer & Pradhananga (2016) describe blind spots as a non-visible area where an operator's line-of-sight (LOS) is impeded by parts of the heavy equipment or other objects in their environment. A heavy equipment operator's LOS has been found to be severely restricted at many points around the machinery (Godwin et al., 2008). Underground mining machines referred to as a load-haul-dump (LHD) have severe LOS restrictions which has been found to be a primary causative factor in 50% of accidents involving an LHD (Tyson, 1997). In addition to poor visibility, the LHD operator must simultaneously operate hand and foot controls, monitor the environment and detect hazards in a confined space with poor lighting (Tyson, 1997, Marx, 1987).

In Ontario (Canada), many mines only have the minimal required height clearance between the machine and the walls of the tunnel, this leaves very little side and overhead clearance and in turn little room for error when obstacles are not detected by LHD operators (Godwin, 2009). Eger et al. (2010) found that irrespective of whether the machinery was travelling backwards or forwards, the operator glances were concentrated on a few moderately unobstructed regions around the machine, neglecting other important areas. In addition to the machine itself, obstructions are another variable that creates a blind spot that might impede an operator's LOS when driving heavy equipment. Obstructions are referred to a visual impediment such as a mound of dirt or fill material that blocks the operator's LOS by hiding a hazard (Hinze & Teizer, 2011). Even with current precautions such as spotters, back up alarms, and personal protective equipment in place these incidences still manage to occur. Therefore, efforts have been made to improve access to information about the environment and improve operator LOS and situation awareness (SA) through improved policies, training or machine technologies.

To some extent, safety training and education are measures that have been found to help increase the awareness of close proximity problems for workers and operators (Marks & Teizer, 2012). Operators adjust where their attention is directed when gathering information from various elements and their machine according to their scanning patterns, goals and expectations (Endsley, 2000). Therefore, scanning patterns can give us insight into the level of an individual's SA and areas that may be neglected, allowing the potential to guide operators to develop more effective scanning patterns and increase their SA (Chapman & Underwood, 1998; Endsley, 1995; Pratt et al., 2001). Operating heavy machinery within the dynamic environment of mines can be quite hazardous due to limited LOS and confined working spaces. Due to the many hazards within the mining environment, training becomes a critical piece for safe equipment operation.

Simulator training can minimize risk to operators and equipment, by allowing operators to gain skills in a controlled, essentially risk-free underground mine environment (Tichon & Burgess-Limerick, 2011). Combining eye-tracking (ET) within the simulator environment provides a further mechanism to understand visual behaviours that are important for safe and efficient use of machinery (Chapman & Underwood, 1998; Häggström et al., 2015). Many studies have been conducted on eye behaviour while driving passenger vehicles, and how the implementation of proximity awareness technology affects driving behaviour. However, due to the substantial differences, such as large blind spits, vehicle size and absence of rear window, between driving a passenger vehicle and heavy equipment, it is difficult to apply these findings directly to heavy equipment use. In passenger vehicles, drivers utilize mirrors and look over their shoulder for a significant amount of time while reversing (Huey et al., 1997). An LHD is not equipped with any mirrors, and the operator relies on small areas of available LOS from the windows; specifically when driving forwards, the operator has to look to the left through the front window and while reversing they look to their right out the back window (Eger, Stevenson, Callaghan, Grenier, & VibRg, 2008).

Due to the hazardous nature of mining and the operation of an LHD, it is vital that operators do not endure any additional or unnecessary increases in cognitive workload while maneuvering the LHD within the mine. An increased cognitive workload results in operators narrowing their attentional focus size (decreased fixations), which can lead to missing critical information, increasing the chance of collisions and struck-by accidents (Recarte & Nunes, 2002; Recarte & Nunes, 2003).

Pupil diameter (PD) is a measure that has been shown to be sensitive to changes in cognitive workload that may occur from changes to the environment, task or displays that require processing resources (Beatty, 1982). Increases in cognitive workload result in an increased PD or dilation of the pupil, in contrast to situations requiring low cognitive workload (Beatty & Wagoner, 1978; Just & Carpenter, 1993). The magnitude of change in PD size is dependent on the level of cognitive workload required for a given task. Measurements of PD can provide insight into an operator's cognitive workload during certain tasks and may isolate certain tasks that require a greater cognitive workload.

Studies have explored how experience affects a driver's eye behaviour while driving. As driver training and experience increased, their visual search strategy improved resulting in a decreased number of fixations (Gramopadhye et al., 1997; Liu, 1998; Megaw & Richardson, 1979). The implication of a reduction in number of fixations without an increase in mean fixation time is that individuals may inspect the environment more quickly, reducing the time required to visually rest on particular stimuli in the environment (Duchowski, 2007). This may occur naturally as a function of training. An increase in fixation duration and the number of fixations was observed when driving in high clutter areas compared to low clutter areas (Ho et al., 2001). High clutter areas were also associated with more errors and decreased reaction times (Ho et al. 2001). Evidence shows that fixation and attentional patterns in drivers are learned and can be influenced by feed forward training (Hayhoe et al., 2002; Sadasivan et al., 2005). Increased training and experience are expected to improve visual search strategies resulting in a decrease in number of fixations (Gramopadhye et al., 1997; Liu, 1998; Megaw & Richardson, 1979). The consequence of a reduced fixation count without a concomitant increase in fixation durations is that the environment is inspected more quickly by individuals as a result of familiarity gained through training and experience, requiring less time to fixate stimuli (Duchowski, 2007). This may appear that an operator has improved their visual search strategy as they can scan the environment quickly, although we need to ensure the visual search is not too rapid resulting in important missed stimuli that could jeopardize worker safety. Novice operators generally have longer fixations whereas experienced operators spend less time fixating while completing tasks (Chapman & Underwood, 1998; Ottati et al., 1999). This is attributed to the additional time required by novice operators to process information in the environment and extract useful data while operating a vehicle (Chapman & Underwood, 1998; Ottati et al., 1999). Overall, training is extremely important to an individual's visual search strategy and it is crucial that training programs for operators are benefiting and not hindering visual search strategies and driving behaviour.

Previous literature specific to simulator training in the mining industry has mostly been conducted by mining or simulator companies themselves, focusing mainly on improvements to efficiency or procedures (ie. performance score). There is a lack of evidence for how novice and experienced users perform on objective measures of workload including; response or reaction times, and eye movements (Tichon and Burgess-Limerick 2011). Eye fixations are found to be a useful measure of expertise and confidence (Jacob and Karn, 2005; Crundall et al. 2003) along with an indicator of arousal (DiStasi et al. 2011) or mental workload (DiStasi et al. 2013). An increased understanding of heavy equipment operator eye behaviour, specifically when operating the LHD due to its uniqueness, is essential to help improve future training, safety measures and development of technologies such as PAT within the mining industry. This work will establish the area of interests at which operators are frequently glancing during an LHD training simulation, and it will quantify the time spent within those areas using mean number and duration of fixations. The evolution of fixation behavior will be quantified by comparing data collected for novice operators on day one and day four of LHD simulator training and will further compare their data to an expert operator.

4.2 METHODS

This study was performed in accordance with the ethical guidelines of Laurentian University (Appendix A). After obtaining participant informed consent a questionnaire to collect basic demographics and heavy equipment experience was completed by each participant (Appendix F).

4.2.1 Participants

Eye movement data was collected from eight novice LHD operators completing a four-day training program along with one expert LHD operator (Table 4.1). The LHD operators were recruited from a local company that provides LHD simulation training to individuals. Each participant was informed of the research objectives and participated voluntarily. Eight male novice LHD operators with an average (± standard deviation) age of 23 (± 1.1) years with 0.25 (± 0.5) years of experience driving heavy equipment. Of the novice operators, six had less than a few, partial days of experience operating an LHD underground, and two had at one year of experience. The expert LHD operator was 69 years of age with 51 years of experience driving heavy equipment and eight years of experience operating an LHD underground.

4.2.2 Load-Haul-Dump Mining Simulator

The simulated mining environment replicating local (Ontario) underground mines was supplied by a Cybermine Thoroughtec LHD simulator (Sandvik Toro 007) as pictured in Figure 4.1. The LHD simulator is utilized to provide training, re-training and evaluations in a safe and controlled environment that simulates the dynamic and unique environment of mines (Thoroughtec Simulation, 2017). Within the simulator, the underground mine environment is projected on three widescreen displays surrounding the LHD, while the physical LHD cab is replicated to provide the operator with the exact controls and instruments they would encounter in real life (Thoroughtec Simulation, 2017). The screen and the LHD cab interact together to mimic the actual movement, sounds, and environmental characteristics present within an actual mine site. These immersive aspects of the LHD simulator delivers a highly realistic LHD operation in a mining environment. The LHD simulator requires the operator to use correct techniques and adjust for a variety of conditions including terrain type and slope to efficiently complete tasks (Thoroughtec Simulation, 2017). The simulator also creates an output that details operator performance on three aspects of operation (performance, health and safety and machine use) and some of the errors will be used as a comparison metric in this study.

Figure 4.1: Cybermine Thoroughtec LHD simulator (Thoroughtec Simulation, 2017).

Table 4.1: Heavy equipment characteristics and operator demographics.

Parameter (unit)	Operators								
	P1	P2	P3	P4	P5	P6	P7	P8	P9
Operators									
Age (yrs)	22	23	22	24	24	25	24	23	69
Experience driving heavy equipment (yrs)	0	1	0	0	0	1	0	0	51
Experience operating LHD underground	20 min	1yr	0	0	0	20 min	4 days	1 day	8yrs
Past video game experience	N	Y	Y	Y	Y	Y	Y	Y	N
Age started playing video games	-	4-5	7	5	10	2	14-15	5	0
Experience with simulator training	N	N	N	N	N	N	N	Y	Y
Sight Impairment	N	N	N	N	N	N	N	N	N
Sight Correction	N	N	N	N	N	N	N	N	N
Heavy Equipment									
Machine Brand	Sandvik	Sandvik	Sandvik	Sandvik	Sandvik	Sandvik	Sandvik	Sandvik	Sandvik
Model Type	Toro 007	Toro 007	Toro 007	Toro 007	Toro 007	Toro 007	Toro 007	Toro 007	Toro 007

4.2.3 Eye-Tracker Set-Up

Eye movement data was collected using Tobii Pro glasses 2 eye-tracker. The corneal reflection and dark pupil technique is used to collect eye movement measurements including saccades, fixations and pupil diameter (Tobii Pro, 2017a). Typical operator head movements were not impeded while wearing the eye-tracker, and therefore did not affect visibility or the ability to use the simulator (Häggström et al., 2015; Tobii Pro, 2017a). Eye-tracking data was collected on day one and day four of LHD simulator training for each novice participant. One trial was collected from the expert operator, which used the same route that novice operators performed on day four of training, including normal mine traffic. Calibrating the eye-tracker for each participant was achieved by holding the calibration card 2.5 to 4.1 feet in front of the participant against a neutral wall and instructing the individual to focus directly at the center dot on the card (Tobii Pro, 2017a). Once calibration was successful, novice participants were set up in simulator and instructed on how to operate the LHD simulator by the instructor.

4.2.4 Eye Movement Data

Participants completed two trials that were 30-60 minutes in duration: one trial was completed on day one and the second trial on day four of training. The participants were required to complete tasks of driving the LHD forward, reversing, dumping, filling the bucket and turning within the mine. Participants operated the LHD on the same route for both trials on day one and day four with one exception to the consistency: on day four, the simulated environment also contained workers-on-foot and other heavy equipment operating along the route whereas these were missing on day one. The four-day training program consisted of each novice operator completing two sessions practicing on the LHD simulator each day, allowing approximately 225 to 300 hours of practice between the two trials that were tested as previously specified above. Other workers and mine traffic were only added on day four of training.

4.2.5 Data Analysis

The Tobii velocity-threshold identification (I-VT) fixation filter was used to filter the raw data collected; the parameters are outlined in Appendix C. This filter allows for a reduction of noise by moving the median without shifting data to extreme coordinates while also preserving the beginning and ends of saccades (Tobii Pro, 2017b). Using a I-VT classifier of 30°/s to classify data points into saccades (above threshold) and fixations (below threshold) to ensure data was not skewed too high or too low causing saccades and fixations to be missed (Salvucci & Goldberg, 2000; Tobii Pro, 2017b). Accommodations were made for fixations that were incorrectly classified as multiple short fixations by merging adjacent fixations if located within a maximum visual angle of 0.5° or a maximum time of 75ms between separate fixations (Tobii Pro, 2017b). These parameters allow for microsaccades and blinks to be filtered out as they typically have amplitudes less than 0.5° and maximum blink durations range from 75-425ms (Evinger et al., 1991). Fixations less than 60ms that were incorrectly classified were discarded as they were not long enough to qualify as a true fixation. Analysis allowed the percentage and duration of fixations for each AOI to be determined for comparison between novice and expert. Additionally, visualizations of the mapped eye movements were made into heat maps to allow visual comparison of novice and expert operator gaze patterns while driving forward and reversing.

All eye measurement data was processed using Tobii Pro Lab analysis software, allowing eye fixations and saccades to be quantified into defined areas of interest (Tobii Pro, 2017b). Data was analyzed frame by frame, however occasional loss of ET occurred during the trial resulting in some frames lacking ET samples (Häggström et al., 2015; Tobii Pro, 2017b). The average gaze sample percentage for all trials was 82.5% with the trial with the lowest gaze sample of 62%. The combination of eye shape and dim lighting in the test environment caused significant loss of tracking and poor ET-samples during the trials for some participants, which made accurate data analysis difficult. As a result, the ET-data collected was not matched exactly for time and area within the route for each participant. For both the forward and reversing driving task, four time of interests (TOI) were mapped manually for each participant, each approximately 35s in duration. Results were averaged together for these TOIs, thus providing a general analysis of driving forward (or backward) within any part of the simulated mine.

Table 4.2: Description of AOIs used in eye-tracking analysis of data.

AOI	Description
Front central view (FCV)	View directly ahead of LHD, consists of central portion of the mine tunnel directly in front of the LHD bucket.
Front left view (FLV)	Looking within the left portion of the mine tunnel, consists of views of mainly the left side of tunnel and edge of LHD bucket.
Front right view (FRV)	Looking within the right portion of the mine tunnel, consists of views of mainly the right wall of the mine and edge of machine.
Light bracket (LB)	Area includes the light bracket and the area between that provides view of part of the right side of tunnel.
Rear central view (RCV)	View directly behind the LHD, consists of central portion of the mine tunnel directly in behind LHD bucket and large part of the left mine wall, and small portion of right mine wall.
Rear left view (RLV)	View to left of LHD, consists of views of left side of tunnel closest to LHD.
Rear right view (RRV)	View to right of LHD, consists of views of right side of tunnel closest to LHD.
Side Window (SW)	Provides view of small area of left side of mine tunnel directly to the left of LHD.
Console (C)	Consists of all controls as well as speedometer.
Guagues (G)	The three gauges located within the left view of the side window.
Machine (M)	Consists of the entire exterior parts of the LHD.

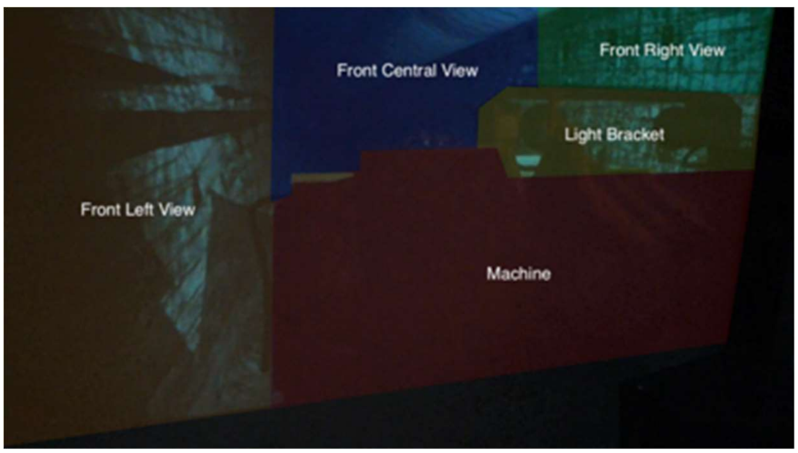
The metrics extracted from each TOI included; total fixation duration (s), mean fixation duration (s) and total fixation count. The total fixation duration was then calculated into percentage of time spent fixating within each area of interest (AOI). The mean fixation duration and total fixation count were averaged for each AOI. Snapshots of the LHD operators front, side and rear views were broken into defined AOIs as listed in Table 4.2 and illustrated in Figure 4.2.

Visualizations in the form of heat maps were utilized to accompany quantitative data to help communicate data and provide illustrations of participants viewing behaviour and distribution of attention on each snapshot. To eliminate bias from unequal exposure times the gaze duration data was normalized by using the relative duration to create the heat maps. This shows the accumulated time each participant spends fixating various areas that is relative to the total time the participant spent looking at the area during the TOI (Tobii Pro, 2017b). The colour scale is defined as the colour red representing more time (seconds) spent fixating each point while green is where participants spent less time fixating (Tobii Pro, 2017b). To produce a more 'smooth' heatmap image of colour distribution results, the width of colour mapping around a single fixation referred to as kernel size is set to 50 pixels (Tobii Pro, 2017b). This kernel size reflects the human visual field as within the eye the fovea has the highest visual acuity while acuity decreases as you get further away from the fovea (Tobii Pro, 2017b). These values represent the yellow and orange colours viewed in the heatmaps.

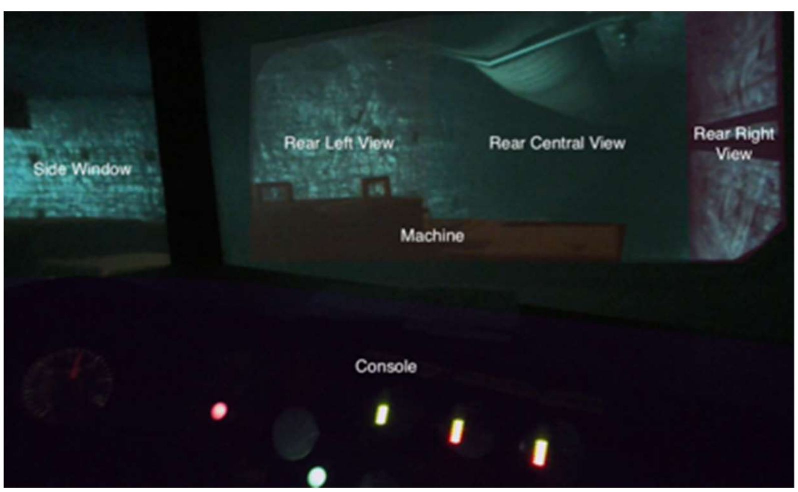
The raw pupil diameter data was pre-processed with Tobii Pro software using the entire trial for each participant from day one and day four. Pre-processing by the software included linear interpolation when missing a value for one eye by using the value from the other eye as there is a high correlation (>0.9) for pupil diameter size between left and right eyes (Geangu, Hauf, Bhardwaj, & Bentz, 2011; Klingner, Kumar, & Hanrahan, 2008). Blinks with values of zero were handled as missing data and were removed (Ekman, Poikola, Mäkäräinen, Takala, & Hämäläinen, 2008; Marshall, 2000). Once raw data was pre-processed, the pupil diameter values for left and right were averaged and then a mean pupil diameter (mm) was produced for each participant (Jainta & Baccino, 2010; Kuchinke, Schneider, Kotz, & Jacobs, 2011).

The simulator log output of operator performance from the Cybermine Thoroughtec LHD simulator was obtained after each trial. The error counts for each driving procedure measured were averaged across all eight novice operators for the entire trial recorded on day one and day four of training.

a)



b)



c)

Figure 4.2: Snapshots of LHD simulator views and location of areas of interests.

4.3 RESULTS

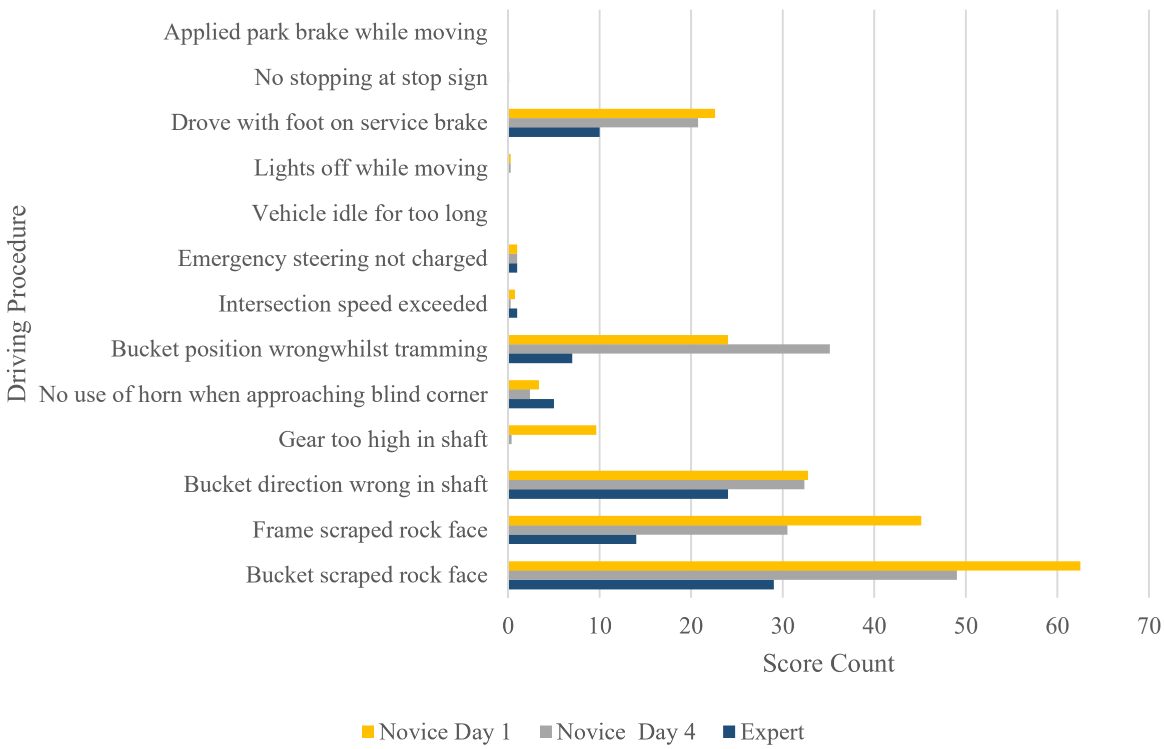


Figure 4.3: LHD operator scoring counts for load-haul-dump driving procedures during simulator trial.

During the entire trial, the novice operators had a higher count than the expert operator for all items on both days except; no use of horn when approaching blind corner (5) and intersection speed exceeded (1) as illustrated in Figure 4.3. Driving procedure error counts for all operators can be found in Appendix G. The expert operator's highest counts were for bucket scraping rock face (29), bucket direction wrong in shaft (24) and frame scraping rock face (14). Novice operators also had higher counts for these tests, however they were much higher than the expert on both day one (62.5, 32.8, 45.1) and day four (49, 32.4, 30.5) of training. Having the bucket position wrong whilst tramming occurred 24.0 times on day one and 35.1 times on day four for novice operators, while only occurring 7 times for the expert. Operators drove with foot on service break a mean total of 22.6 (day one), 20.8 (day four) and 10 (expert) times during the trial. On day one, novice operators had the gear too high in shaft 9.6 times while on day four this almost never occurred (0.4).

4.3.1 LHD Operator Eye Gaze Behaviour While Driving Forwards

Table 4.3: LHD Operator eye-tracking measurements while driving forwards.

Area of Interest	Eye-tracking metrics								
	Mean total fixation duration (%)			Mean fixation duration (s)			Median total fixations (#)		
	Day 1	Day 4	Expert	Day 1	Day 4	Expert	Day 1	Day 4	Expert
Front central view	40.5	69.1	55.0	0.277	0.271	0.140	194	278	122
Front left view	31.0	17.0	0.3	0.250	0.219	0.100	190	73	1
Front right view	0.2	0.8	17.5	0.130	0.170	0.140	1	4	39
Light Bracket	5.5	5.8	20.2	0.190	0.221	0.136	26	24	46
Console	1.1	1.9	0.0	0.149	0.315		10	11	0
Guages	0.2	0.2	0.0	0.148	0.149		2	1	0
Side window	0.2	0.4	0.0	0.101	0.146		2	3	0
Rear central view	0.2	0.7	0.0	0.131	0.152		1	5	0
Rear left view	0.1	0.0	0.0	0.260	0.080		0	0	0
Rear right view	0.0	0.1	0.0	0.190	0.084		0	0	0
Machine	21.1	4.1	7.0	0.247	0.194	0.162	100	22	14

Mean Total Fixation Duration

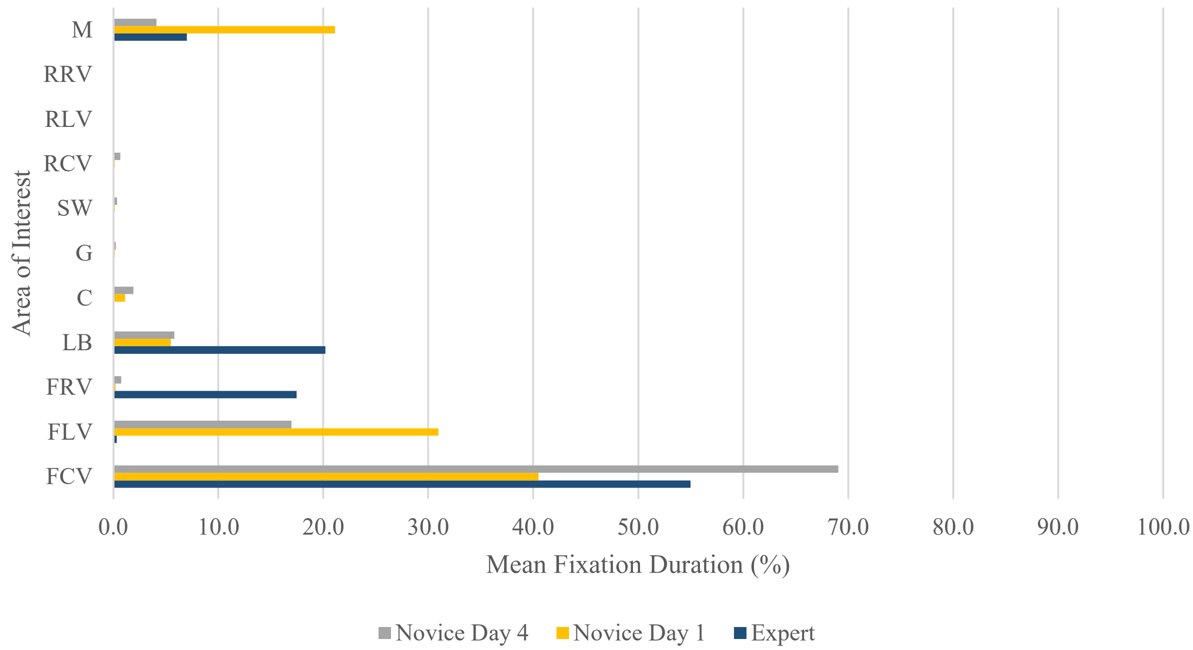


Figure 4.4: Percentage of time LHD operators spent fixating AOIs while driving forwards.

While driving forwards, the FCV was fixated the most (Figure 4.4), the expert fixated within the FCV for 55.0 % of the time while novice operators fixated there for 40.5 % on day one and 69.1% by day four of the training program (Table 4.3). Individual ET metric values can be located in Appendix H and Appendix I, subsequent graphical representation is displayed in Appendix J. The other most fixated AOIs by the expert operator were within the LB (20.2 %) and FRV (17.47 %). These AOIs were fixated less by novice operators on both day one (5.5 %, 0.2%) and day four (5.8 %, 0.8 %) of training. The FLV was the second most viewed AOI by the novice operators on both day one (30.96 %) and day four (16.98 %) of training, whereas the expert operator (0.3 %) rarely looked within this AOI. While maneuvering forwards throughout the mine, the machine (M) was tended to a total duration of 7.0 % by the expert operator, where novice operators fixated for 21.1 % of the time on day one compared to only 4.1 % on day four of training. The outstanding AOIs were never glanced at by the expert while the novice used them rarely or never during forward driving segments.

Mean Fixation Duration and Fixation Count

The mean duration and total fixation count of both expert and novice operators while driving forwards is depicted in Figure 4.5. All operators fixated the FCV the most times driving forwards including the expert, novice day one and novice day four operators (122, 194, 278). Operators fixated within the FCV for a mean duration of 0.140 s, 0.277 s and 0.271 s while driving forwards, respectively. The novice operators appeared to look within the FLV more often and for longer durations on both day one (190, 0.250 s) and four (73, 0.219 s) than the expert operator (1, 0.100 s). Compared to novice operators on day one (0.130 s) and day four (0.170 s) rarely fixated within the FRV but had similar fixation durations as the expert (0.140 s). The LB was fixated noticeably more than operators on both days although each fixation was shorter in duration (0.136 s). Although, the mean fixation duration for novice operators on day on increased from 0.190 s to 0.221 s on day four. The machine was fixated 14 times with a mean duration of 0.162 s by the expert operator. The novice operators had much higher values on day one (100, 0.247 s), however by day four (22, 0.194 s) these had decreased. On day one and four of training, a decrease in fixation duration made by novice operators was observed within the console (C) from 0.315 s to 0.149 s while driving forwards, compared to the expert who did not fixate within the console at all.

Figure 4.5: Fixation durations and counts made within AOIs by expert operator (a) and novice operators on day one (b) and day four (c) of training when driving forwards.

4.3.2 LHD Operator Eye Gaze Behaviour While Driving Rearward

Table 4.4: LHD operator eye-tracking measurements during rearward movement.

Area of Interest	Mean total fixation duration (%)			Mean fixation duration (s)			Median total fixations (#)		
	Day 1	Day 4	Expert	Day 1	Day 4	Expert	Day 1	Day 4	Expert
Front central view	0.1	0.9	0.0	0.163	0.193		0	5	0
Front left view	0.5	0.6	0.0	0.162	0.140		1	1	0
Front right view	0.0	0.0	0.0	0.140	0.120		0	0	0
Light Bracket	0.2	0.1	0.0	0.192	0.143		0	1	0
Console	2.3	3.5	0.2	0.217	0.172	0.223	22	27	5
Guages	0.3	0.1	0.0	0.174	0.225		1	1	0
Side window	1.0	0.4	0.0	0.136	0.115		10	4	0
Rear central view	59.9	73.3	99.4	0.258	0.270	0.571	344	413	729
Rear left view	4.3	2.9	0.1	0.222	0.210	0.300	28	19	1
Rear right view	16.9	10.6	0.2	0.244	0.220	0.260	103	67	3
Machine	14.4	7.5	0.1	0.305	0.228	0.180	67	42	3

Total Fixation Duration

The total percentage of time spent viewing each AOI while reversing is displayed in Figure 4.6. When driving the LHD in reverse, the expert spent the majority of time (99.4 %) fixating within the RCV, rarely spending any time looking within any other AOI (Table 4.4). Novice operators also spent the most time looking within the RCV on day one (59.9 %) and day four (73.3 %) however they also spent time used the RRV and M far more often than the expert. In the RLV, RRV and M rarely used by the expert, the novice participants showed decreasing reliance from day one to day four for those areas (showing a mean decrease of 4.9%). In turn, an increase in usage for the RCV of 13.3% moves towards the 99.4% used by the expert operator.

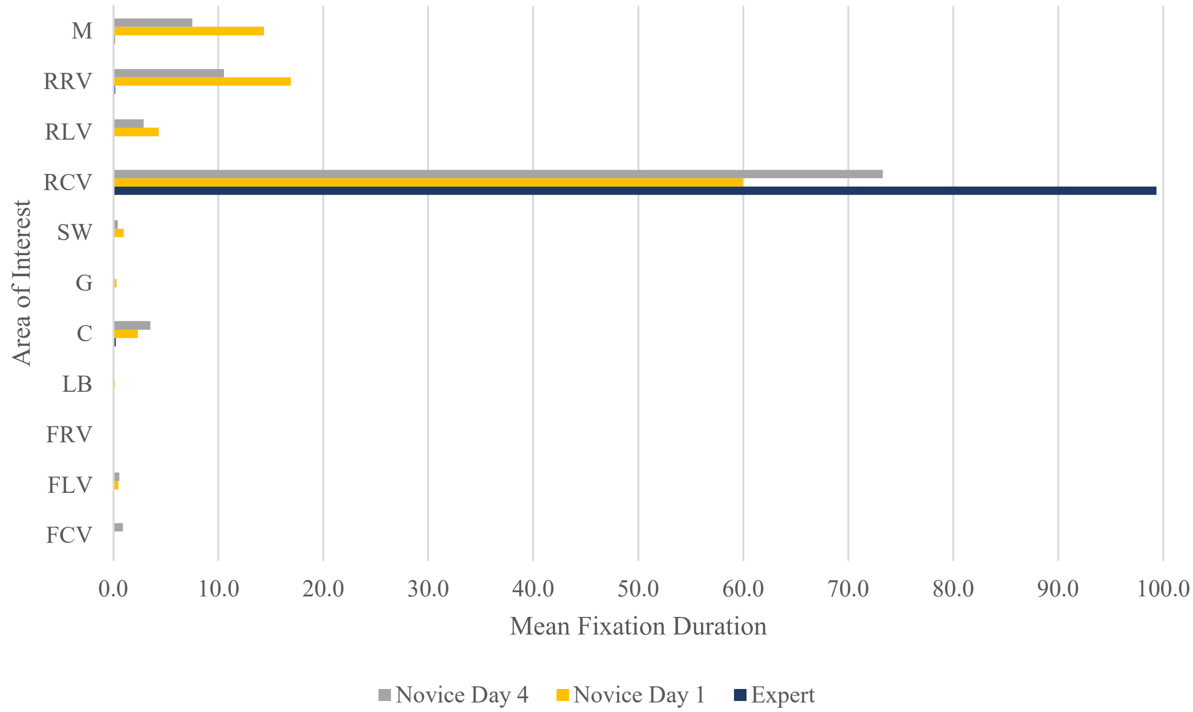


Figure 4.6: Percentage of time LHD operators spent fixating AOIs during rearward movement.

Mean Fixation Duration and Fixation Count

While reversing through the mine, the expert LHD operator fixated within the RCV a mean of 729 times, while the RLV (1), RRV (3), C (5) and M (3) were rarely consulted as depicted in Figure 4.7. Mean fixation duration times for the expert operator in decreasing order were 0.571 s, 0.300 s, 0.260 s, 0.223 s and 0.180 s, respectively. Novice operators on day one and four of training also made the most fixations (344, 413) within the CRV with similar mean fixation durations (0.258 s, 0.270 s) on both days. The RRV was fixated 103 times on day one and 67 times on day four, with mean fixation durations of 0.244 s and 0.220 s. The machine AOI was fixated 67 times with a mean fixation duration of 0.305 s on day one, compared to 42 times and 0.228 s, on day four. The RLV had slightly more fixations on day one (28) than on day four (19), with similar mean fixation durations (0.222 s, 0.210 s). Whereas, the console had a similar fixation count between day one (22) and four (27) with a decrease in fixation duration between days (0.217 s, 0.172 s).

a)

b)

c)

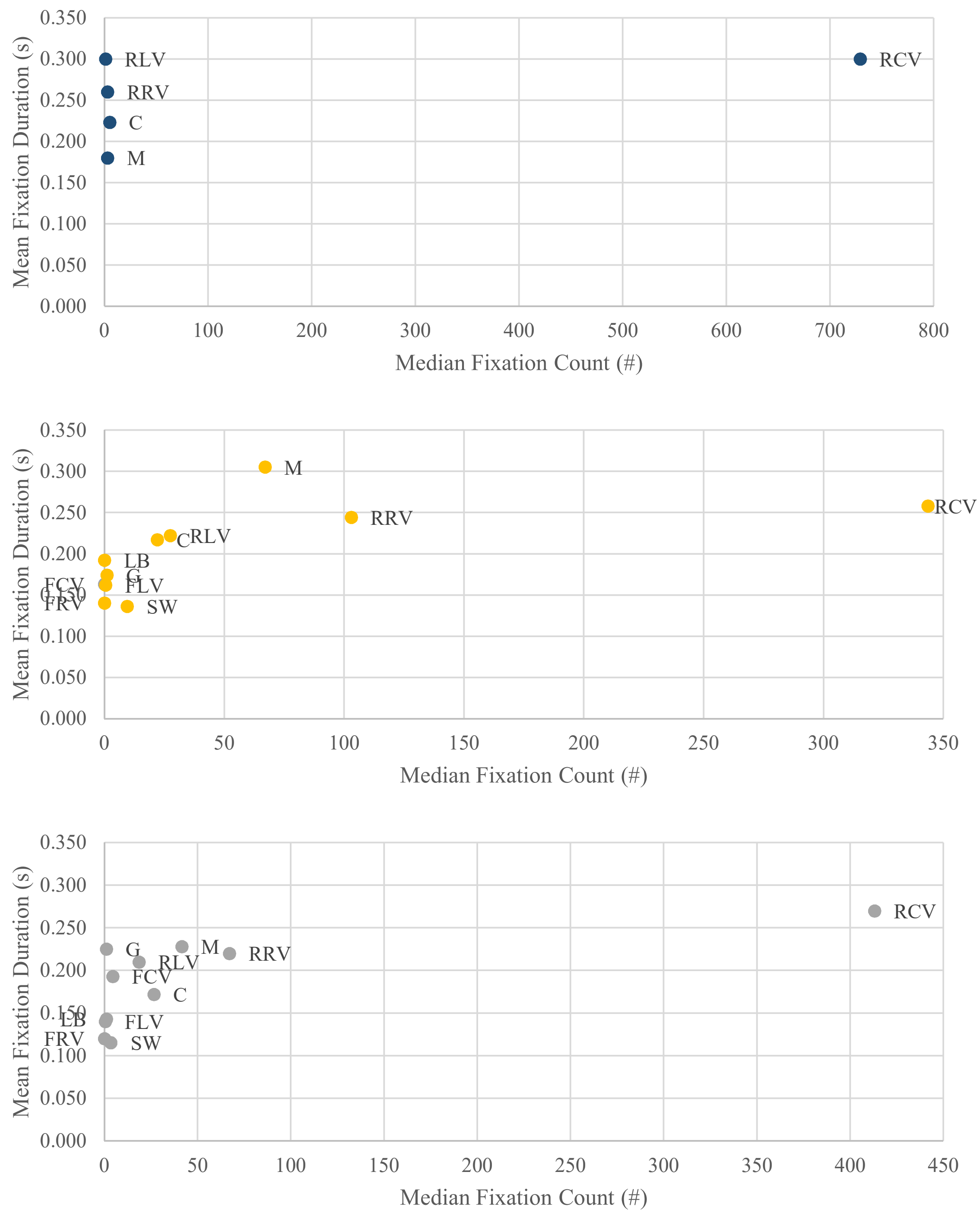


Figure 4.7: Fixation durations and counts made within AOIs by expert operator (a) and novice operators on day 1 (b) and day 4 (c) of training while reversing.

4.4.3 Visual Scanning Behaviour

While driving forwards within the mine, the expert operator solely fixates within the front view as illustrated in Figure 4.8, with majority of focus on FCV and occasionally glancing at the right wall (FRV), LB and machine. Novice operators on day one of training utilized all three views from the LHD. Within the front view the FCV had more fixations, however the density of fixations was slightly shifted to the left compared to the expert operator. In addition, the visual attention of novice operators had more focus on the left wall (FLV) and right corner of the machine. The right wall (SW) and gauges were fixated on through the side view from the LHD and mostly the speedometer area in the rear view, occasionally fixating within the RCV. On the last day of training (day four) novice operators fixated more in the middle of the FCV rather than slightly lower and to the left as observed on day one of training. Similarly, to day one, novice operators still glanced at the right wall (SW) and gauges through the side view, however in the rearview the speedometer was mainly fixated with rare glances within the RCV. Individual visualizations of eye scanning behaviour while operating the LHD are found in Appendix K and Appendix L.

The expert operator's visual attention while reversing the LHD throughout the mine was exclusively focused within the RCV looking directly down the mine tunnel, the side and front views were not consulted (Figure 4.9). Novice operators scan pattern utilized all three views from the LHD. On day one of training, the majority of fixations were made at the corner of the LHD and just above, and slightly to the right within the RCV. The right wall (RRV) was also fixated more often. Novice operators focused their visual attention to the left and right walls (FLV and FRV) and machine when occasionally consulting the front view. No real pattern was observed when novice operators looked through the side window, various locations on the right wall (SW) and gauges were fixated. On day four of training, novice operators fixated higher up and to the right within the RCV as well as the RRV, only occasionally fixating the corner of the LHD. When using the front view, the FCV was fixated more than on day one, still looking at the left and right walls (FLV and FRV). The machine was hardly fixated in the front view on day four compared to being fixated a lot more on day one. Novice operators were less sporadic in where they looked within the side view, the gauges were consulted more often and a few areas on the right wall (SW).

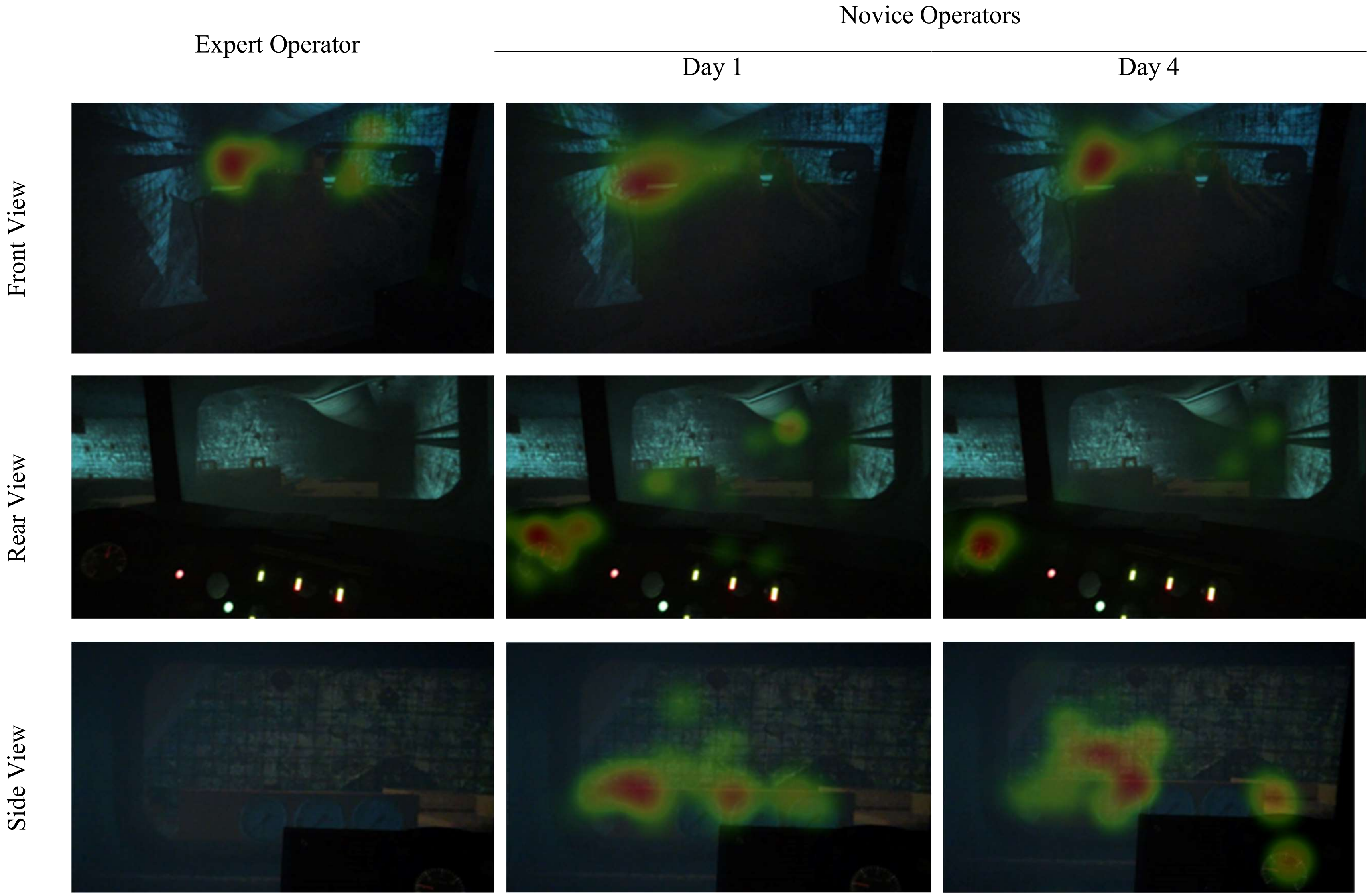


Figure 4.8: Heat maps of expert and novice operators gaze behaviour on day one and day four of training while driving LHD forwards.

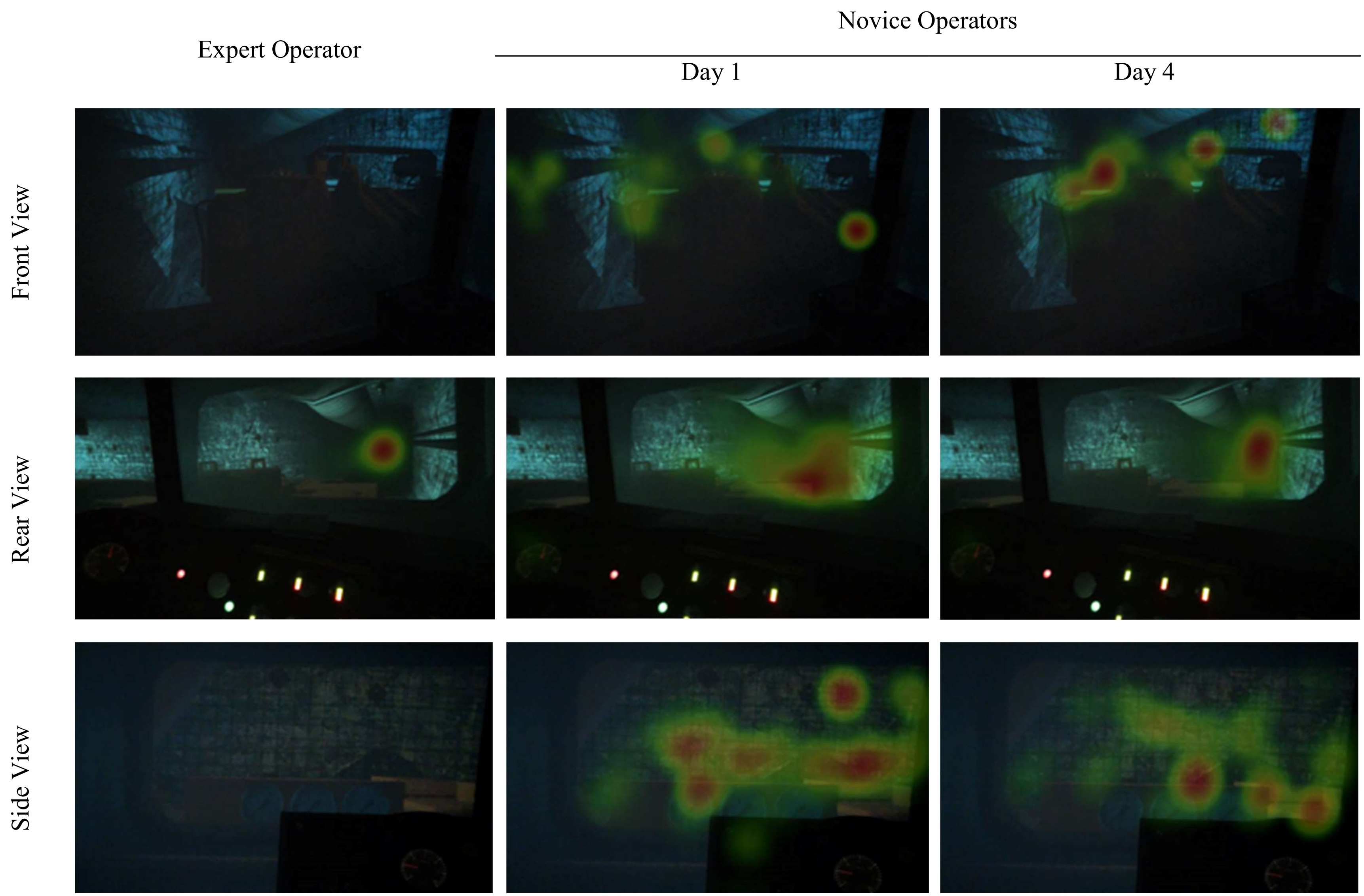


Figure 4.9: Heat maps of expert and novice operators gaze behaviour on day one and day four of training while reversing the LHD.

4.4.4 Pupil Diameter

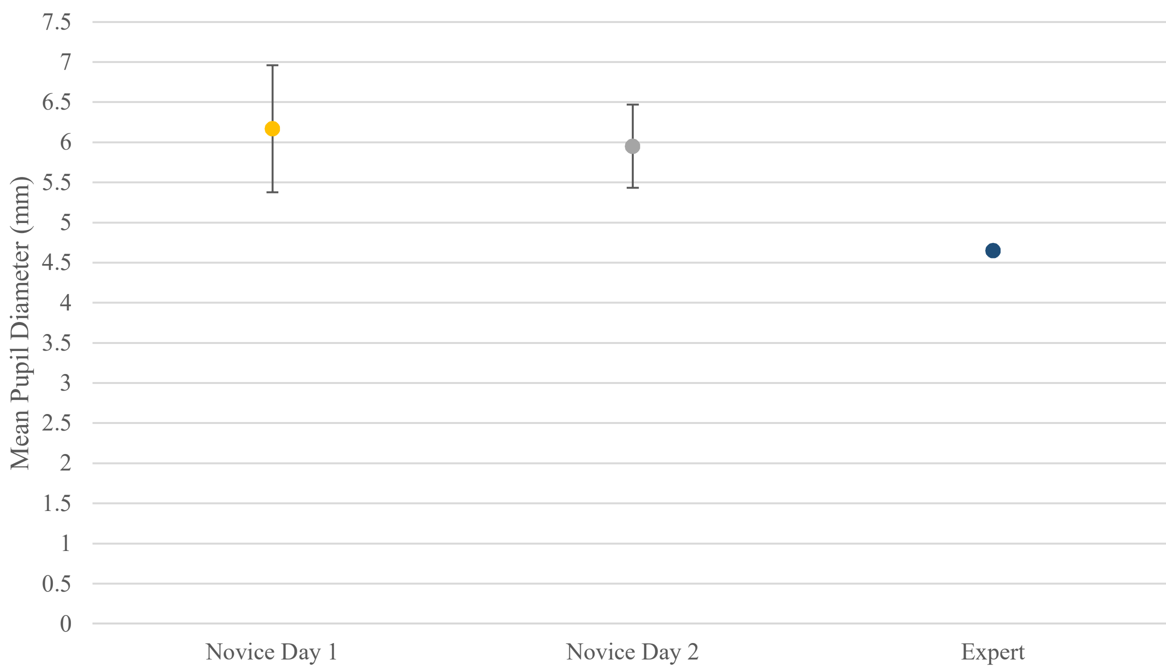


Figure 4.10: Mean pupil diameter of LHD operators.

The mean pupil diameter for each operator was calculated from the entire trial, where they maneuvered throughout the mine (Figure 4.10). The mean pupil diameter for novice operators decreased from 6.17 mm on day one of training to 5.95 mm on day four. This is compared to a pupil diameter of 4.65mm for the expert operator.

4.4 DISCUSSION

Overall there were large observable differences between the exert operator's gaze behaviour compared to the novice operators, and over the four-day training program the novice operator's gaze behaviour started to resemble that of the expert's in quantifiable ways. Throughout the duration of both trials, novice operators had higher error counts than the expert operator for all items except; no use of horn when approaching blind corner and intersection speed exceeded. This could be a result of the expert becoming lax in these procedures due to their familiarity of driving an LHD in the simulator. As expected, on items requiring skill and knowledge, novice operators had higher counts for bucket scraping rock face, bucket direction wrong in shaft and frame scraping rock face, bucket position wrong whilst tramming, driving with foot on service break and having the gear too high in shaft. Most items demonstrated a decreasing frequency for novice operators going from day one to day four, likely a function of novice operators becoming more aware of LHD size and position within the mine, and how fast they were traveling.

The expert LHD operator's eye gaze behaviour while driving forwards through the mine consists of exclusively fixating within the front view of the LHD whereas novice operators spread their focus across all three views (FCV, FLV, FRV). All operators in this study were found to focus the majority of their time within FCV while driving forwards, looking ahead into the mine tunnel. This finding is consistent with concurrent studies using passenger vehicles and large trucks, observing drivers tend to look straight ahead within the front central view while driving straight forwards (Harbluk et al., 2002; Häggström et al., 2015; Kito et al., 1989; Olson et al., 1989). Many fixations were made within the FCV as a result of this being the AOI where operators spent most of their time. The predominant eye behaviour that drivers use on straight sections of road has been one in which they use a series of fixations at increasing locations further down the road and then fixate close to the vehicle repeating the pattern again (Bengler et al., 1996; Zwahlen, 1993). This supports the finding of having a high fixation count within the FCV for all operators, also emphasizing the relevance of information within this AOI for operators (Koppenborg et al., 2016). The expert operator had a mean fixation duration of 0.140s within this AOI compared to novice operators had much longer fixations on both day one and day four (0.277 s, 0.271 s). The observed difference between expert and novice operators is most likely due to each one's level of experience, as it has been found that more experience results in shorter fixation durations (Duchowski, 2007; Sodhi et al., 2002). The lack of difference observed between day one and day four for novice operators could result from differences in traffic and pedestrians that were present within the operators environment on day four but not day one (Duchowski, 2007; Sodhi et al., 2002) . Therefore, even though the novice operators had gained experience, no decrease in fixation duration was observed as they were now introduced to driving with pedestrians and other traffic instead of an empty tunnel while operating within the mine, suggesting cognitive effort remained relatively unchanged (Dehais et al., 2008; Duchowski, 2007; Poole & Ball, 2006; Scialfa et al., 1994). It may also be a function of requiring more than a four-day training program in a simulator to elicit the scanning behavior of an expert performer.

A large difference was observed between the expert and novice operators, as the expert fixates the FRV and LB much more and rarely consults the FLV whereas the novice operators on both days fixate more within the FLV and rarely the FRV and LB. This diversity could be explained by personal difference such as novice operators referencing how close they are to the mine wall by looking at the space between the machine and left wall, where the expert uses the right wall to reference closeness (Ballard et al., 1992). Novices use the more available left side of the tunnel, but the expert operator may be able to judge machine position quite well by looking across the machine through the LB to the right wall, therefore making it the preferred sightline. One consideration is that novice operator scanning behaviours may change once underground in a live, working environment. Novice operators had longer fixations within the FLV on both day one and day four (0.250 s, 0.219 s) compared to the FRV (0.130 s, 0.170 s). In comparison, the expert fixates more quickly than the novice in both the front right view and front left view. Therefore, in the simulator there may be more value in referencing the front right view, across the hood of the machine to extract important information instead of the front left view as the expert relies on the former. In addition, the novice operators mimic this pattern such that on day four they are using the front left view much less often and the front right view was moving towards a more frequent and slightly longer gaze strategy. These findings differ slightly from previous research that found that visibility was better on the left side of the LHD while driving forwards compared to the front right corner where visibility was rated very poor to poor (Eger et al., 2004). Light brackets were also found to obstruct operator vision, however visibility of the right corner and light brackets were found to only be a problem for certain LHD models (Eger et al., 2004). The LHD model used in the simulator may have had somewhat better visibility in these areas, therefore the expert was able to visualize these sightlines. Additional investigations with more expert operators and more LHD models would be required to make solid conclusions about why this area is fixated more often, and it would be necessary to observe the same visual behaviours in real-life machine operation. All operators, regardless of experience, had shorter fixation durations within both the FLV and FRV compared to the FCV. This may be the result of using peripheral vision for movement detection, which results in diverting ocular focus briefly away from the FCV towards a peripheral object in one of the two other areas but dwell times remain low since it did not require great mental effort (Mourant & Rockwell, 1972; Recarte & Nunes, 2003; Victor et al., 2005).

The machine was fixated considerably more on day one with a total of 113 fixations compared to only 25 times on day four of training for the novice participants. The expert only had 14 fixations on the machine. Again, this disparity was likely due to the novices' minimal experience resulting in lack of situation awareness, and difficulty extracting information when glancing quickly to this area (Chapman & Underwood, 1998; Dehais et al., 2008; Duchowski, 2007; Holmqvist et al., 2011; Häggström et al., 2015; Ottati et al., 1999). As a result, it may have led novice operators to reference the left wall (FLV) and edge of machine more often and for longer to check their space and position within the mine. This leaves less time for scanning other areas in the environment quickly to locate important stimuli, and as a result having poor SA overall. With the experience gained over the four days, novice operators do move towards the expert's low number of fixations to the left wall and edge of machine, which suggests that they do not have to continually monitor the LHDs position using these sightlines. Consequently, this provides the operators with more time to rapidly scan other areas in the environment for potential stimuli and hazards, in turn improving their SA.

The console was used by novice operators mainly to check the speedometer; however, the expert never consulted the console or speedometer throughout the trial. This may indicate that the expert was less reliant on the speedometer to judge speed of LHD within the mine, using peripheral vision continuously to assess position and speed of machine (Horiguchi et al., 2015; Häggström et al., 2015; Mourant & Rockwell, 1972; Traschütz, Zinke, & Wegener, 2012). As operators were instructed to stay within a certain speed range and reminded to be cautious of speed, this would account for why the novice operators frequently looked to that location. The expert may have not looked at the speedometer/console due to familiarity with the simulator environment, which may also suggest reduced situation awareness or visual narrowing and could be supported by the fact that the expert was found to exceed intersection speed more often than novice operators on both days (Dehais et al., 2008; Duchowski, 2007; Holmqvist et al., 2011;

Recarte & Nunes, 2003). That being said, it is difficult to say if this is truly a result of visual narrowing or if the expert is able to use his peripheral vision to continuously assess position and speed of the LHD while driving (Mourant & Rockwell, 1972; Traschütz et al., 2012). It is more likely that the expert has developed automaticity from experience combined with his extreme comfort with the virtual layout of the mine, meant that he required a very low level of a attention but was able to maintain good performance (Endsley, 2000).

The scanning behaviours recorded during LHD operation differed substantially compared to existing research available on driving a passenger vehicle. While reversing in a passenger vehicle and some heavy equipment, individuals rely heavily on the view obtained from the mirrors and/or from looking over the shoulder through a back window when available, and occasionally fixating within the front, left and right views provided (Huey et al., 1997). However, while driving an LHD, the operator is seated perpendicular to the line of travel and in order to view the rear of the LHD (engine side), the operator must turn their head to the right and maintain this head position whilst driving through the tunnel. Further, they typically have no mirrors to help with forward or backward navigation.

The expert operator's visual attention was solely focused within the RCV (99.4%) while reversing throughout the mine tunnel. Novice operators also mostly fixated the RCV while reversing, but also used the side and front views for obtaining information, which the expert operator never fixated. These findings are consistent with other studies that found that while driving, the operator's gaze was directed towards the forest or road for the majority of the time (Harbluk et al., 2002; Häggström et al., 2015; Kito et al., 1989; Olson et al., 1989). The expert could simply be very comfortable with rearward travel and this view allowed him to see workers-on-foot and other machinery moving into his path prior to approaching adjoining tunnels while using peripheral vision that did not require a dynamic eye movement to monitor additional areas. This would explain why the expert operator solely looked within the RCV while reversing. The expert was found to have longer fixations to the RCV than novice during this rearward travel movement and this may be linked to age: younger adults have been found to have shorter fixation durations compared to older adults, and when combined with the dim lighting in the simulator, could have required the expert to focus longer to visualize the surroundings and extract information (Ho et al., 2001; Ottati et al., 1999).

When using the heatmap plots to understand the evolution of the novice operator's scanning behavior, several trends were observed. On day one of training, the majority of fixations for the novice participants during forward driving segments were made at the right corner of the machine and just above, slightly to the right within the RCV with mean fixation duration of 0.258 s. The gaze behaviour on day four changed, as the density of fixations made occurred higher up and to the right within the RCV as well as within the RRV, looking less at the corner of the machine. This is consistent with findings that suggested expert operators looked at areas further away from the machine while novice operators looked at areas closer to the machine (Forsman, Sjörs-Dahlman, Dahlman, Falkmer, & Lee, 2012). Therefore, novice operators start to adopt a scanning behavior that better matches the experts visual scanning behaviour by moving their gaze away from the machine (day one) to looking further away from the machine on day four.

Furthermore, during rearward driving, the RCV was consulted more, and fixations were 0.270s in duration, slightly longer than on day one whereas the machine AOI was fixated less and had shorter fixations. As stated previously, it appears as though the novice operators required a different reference point from the experts in order to gauge where the LHD was within the mine. While reversing they relied heavily on the RCV and corner of the machine but as they gained more experience, they appeared to use these areas less for reference. Both the RRV and RLV were fixated more frequently on day one by novice operators, and the fixation durations were also longer than on day four. This may be explained by an improved visual search strategy and decreased cognitive workload by day four, suggesting that simulation-based training is useful for training gaze behaviours that will be used in real-world driving. Since the expert operator never moved their gaze into those RRV and RLV regions, one might assume that by day four, novice participants were beginning to use their periphery to monitor some of those sections rather than moving their entire gaze into that AOI while performing the main task of reversing (Ballard et al., 1992; Drury, Gramopadhye, & Sharit, 1997; Liu, 1998; Recarte & Nunes, 2003; Victor et al., 2005). Novice operators did fixate both the front and side views around the LHD, while the expert never looked to the side or to the front of the LHD. Novice operators fixated within the tunnel and right wall (FCV) as well as the left wall (FLV) on both days, in addition to a few areas on the right wall (SW) and gauges. The focal areas for these areas intensified from day one to day four suggesting that the novice operators had less sporadic fixations by the end of the training period. The pattern of more focal, and less dispersed, fixations by novice operators on day four may suggest they have moved to an improved visual search strategy, and the ability to prioritize visual resources for the driving demands placed on them (Dehais et al., 2008; Hayhoe et al., 2002; Häggström et al., 2015; Victor et al., 2005). The sporadic fixations observed on day one may be made due to low situation awareness as well of uncertainties or difficulties the operator may be experiencing while driving; both of these lessen as the operator gains experience and confidence in the driving environment (Dehais et al., 2008; Duchowski, 2007; Holmqvist et al., 2011).

Over the four-day LHD simulator training program, the mean pupil diameter of novice operators decreased. This decrease in pupil diameter could be a direct result of gaining expertise and confidence, which made the task less difficult than novice operators perceived on day one, thereby reducing their cognitive workload by day four (Beatty, 1982; Recarte & Nunes, 2002). Studies have found that even small changes in pupil diameter, within tenths of a millimeter can correlate with changes in an individual's cognitive workload while completing tasks (Beatty, 1982; Szulewski, Roth, & Howes, 2015). Amplitudes of the pupil dilation response have been found to range from 0.10 mm for easy discrimations to0.20 mm for more difficult discriminations, and even small changes in pupilary dilations of 0.015 mm have produced highly significant differences depending on conditions (Beatty, 1982). This further supports the decrease in pupil diamter by 0.22 mm from day one to day four of training suggesting these operators may have experienced a reduction in cognitive workload. However due to the time of trial completed on day four, the cognitive workload may have slightly increased for novice operators on their final test trial due to the addition of normal mine traffic and workers-on-foot. This may have resulted in a smaller change in pupil diamter between days, whereas a larger change may have been observed if both trials were identical. It should also be noted that fatigue and luminance were not controlled in this study therefore potential effects from these factors on the operators size of pupil diameter during the trials cannot be ruled out (Beatty, 1982; Szulewski, Roth, & Howes, 2015). The expert operator appeared to experience a lower cognitive workload than novice operators on both days while operating the LHD, as evidenced by a much smaller pupil diameter which is consistent with the literature (Beatty & Wagoner, 1978; Just & Carpenter, 1993; Szulewski, Roth, & Howes, 2015).

4.5 RESEACRH LIMITATIONS

Limitations associated with this study included participant size, type of study and measurement tools utilized. Due to participants being recruited from a small company that held a four-day LHD simulator training program for local mining companies there were limited learners (novice operators) taking the program and only one expert operator willing to participate in the study. Due to low participant numbers, statistical analysis could not be performed, nor could we generalize results to another population. The expert had ample real-world experience with operating heavy equipment (51 years) and an LHD underground (8 years), he also had lots of experience with the LHD simulator itself. Since the expert operator's current job involves him using the simulator more than operating underground, this could have skewed the data away from typical expert operator eye behaviour when operating underground due to his familiarity with the simulator and virtual mining environment. Another potential limitation was that some aspects of the route differed between the trial on day one and on day four of training with respect to the addition of typical mine traffic, including other heavy equipment and workers-on-foot.

Using an eye-tracker as a measurement tool is a limitation itself, although this study was conducted within a controlled (simulated) environment, and sufficient gaze sample percentages above 60% were achieved for all trials. However, ET quality was poor at various points throughout each trial resulting in a loss of data at certain times. Video containing missing data was unable to be analyzed, therefore the exact same forward and reversing segments were not used across all participants. In addition, using the simulator to simulate both operating an LHD and a mining environment is also a limitation as it cannot fully replicate all aspects of actual experience of operating an LHD within a mine. Participants using the simulator may have slightly different gaze behaviour or laxity in following procedures due to there being no severe consequences if a collision occurs within the simulator therefore not exhibiting as much cognitive workload they would have in real life.

4.6 CONCLUSIONS

Overall, the gaze pattern for the expert operator appears more focal and has less dispersion when compared to novice operators while driving the LHD both forwards and reversing. Following a four-day period of training a novice LHD operator's eye behaviour began to resemble that of an expert operator, becoming more focal and less dispersed. However, there still appears to be some dispersion of isolated fixations on day four of training in defined areas while driving forwards and reversing. This suggests that novice operators rely less on peripheral vision and must make a full fixation to the areas that contain that critical information. Generally, the expert operator made shorter fixations than novice operators while driving forwards, differing from rearward travel where expert operators fixated for longer than the novices. This could be attributed to a combination of factors including the older age of the expert operator with the decreased luminance of the mine, or a general ease with simulator operation. Regardless of direction, the expert operator made less fixations on most areas than novice operators with the odd exception of key areas the expert appeared to find important.

A major finding of this study was that whether driving forwards or reversing, all operators spent the majority of time fixating down the tunnel and straight ahead within the central view. Novice operators appeared to use the tunnel wall (left wall) and edge of bucket to navigate in tight tunnels driving forwards. During rearward travel, the right wall and corner of machine was referenced to monitor position of the LHD within the mine to avoid hitting the rockface. These sightline points were fixated considerably less and had shorter fixations on day four of training, indicating increased training and experience has developed an improved situation awareness and ability to monitor LHD position and speed with peripheral vision rather than fixating. In contrast, the expert seemed to prefer to look across the machine at the right tunnel wall while forward driving as more fixations were made to these sightlines, an area previously thought to have substantially reduced visibility below 2m (A. Godwin & Eger, 2009). A major limitation to these findings is that the simulator is projected onto a flat screen rather than real-world 3-dimenstional space. This may impact the preferred areas for machine navigation compared to an actual underground trial. The mean pupil diameter of novice operators was larger than the expert on both days, and the novice operators showed a decrease in pupil diameter over the training period. This could indicate that novice operators experienced an increased cognitive workload compared to expert operators that decreased somewhat with training and experience. The current work represents a useful initial baseline model for gaze behaviour of both novice and expert LHD operators. It also provides some evidence that mining simulator training programs can objectively move a user's gaze patterns towards the features found in the expert's scanning behaviours. With this type of information, future studies could use the expert operator's heat maps in an intervention style study to see if providing that information can further accelerate the novice user's acquisition of desirable gaze patterns. Furthermore, the results from this study could aid in determining potential locations of proximity awareness technologies to be in line with operator typical gaze behaviour. Further investigation of potential locations can determine which of the locations is best to minimize distraction or increased cognitive workload which can in turn comprise worker safety.

CHAPTER 5: SUMMARY & CONCLUSIONS

This final chapter looks to summarize the material presented in the two manuscript chapters included in this dissertation. The main findings along with implications for construction and mining industry stakeholders are discussed. Finally, recommendations for future research is explored.

5.1 RESEARCH FINDINGS SUMMARY

The main research objective of this work had an overall purpose to enhance understanding of heavy equipment operator gaze behavior in naturalistic worksites. Specific research objectives and key findings from each chapter are summarized in Table 5.1.

Table 5.1: Overview of objectives and key findings from each chapter.

Chapter	Objectives	Key Findings
THREE	• Quantify typical heavy equipment operator eye glance behaviour in a field setting. • Compare natural gaze patterns between forward and rearward travel for operators.	• All operators fixated within the FCV for the majority of time driving forwards, compared to reversing where operators basically never fixated within any part of the front view. • Mirrors were fixated occasionally while driving forwards, left mirrors slightly more than right mirrors. • Operators made longer fixations within the FLM and RUM, which may be attributed to importance/complexity of information provided by these views. • While reversing, operators spent 52.4% of the time fixating within the mirrors, diverting gaze away from the general surroundings. • Operators looked within right mirrors more often than left mirrors. Longer fixation durations were made within the right mirrors compared to the left mirrors. • The views provided by the left and right windows were fixated considerably more while reversing than driving forwards. Specifically, the right window was a frequent gaze point while reversing. • Operators looked inside the machine for a larger portion of time while reversing than while driving forwards.

FOUR	• Quantify novice and expert LHD operator eye glance behaviour within a simulated mining environment. • Depict how a novice LHD operator gaze pattern changes over a four-day LHD simulator training. • Compare an expert LHD operator’s natural gaze patterns to novice LHD operators on day one and four of training.	• Fixations for the expert LHD operator appear more focal and have less dispersion when compared to the novice operators while driving forward and reversing. • Following a period of training, novice operator's eye behaviour began to better resemble that of the expert operator. However, there still appears to be some dispersion of isolated fixations on day four of training in defined areas during each movement. • It was found that novice operators spent a greater percentage of time fixating both the FLV and part of the machine on day one. These AOIs were fixated considerably less on day four. Expert operator was found to fixate FRV much more than novice operators, only occasionally looking within the FLV. • All operators looked within the RRV more than RLV while reversing. • While reversing, novice operators made shorter fixations, or the length of fixation remained unchanged, as training increased. • Expert operator made longer fixations to all areas while reversing than driving forwards. • A decrease in time spent fixating on the machine was observed from day one to day four of training, regardless of direction travelled. • The expert operator made shorter fixations on the machine than novice operators when driving both forwards and reverse. Novice operator fixations were much shorter in duration on day four than on day one. • The average pupil diameter of the novice operators decreased slightly from 6.17 mm on day one of training to 5.95 mm on day four. This is compared to the expert’s average pupil diameter of 4.65mm, suggesting that the novice operators experience an increased cognitive workload compared to expert operators.

5.2 RESEARCH IMPLICATIONS

5.2.1 Workplace Health and Safety

Struck-by accidents continue to be a large issue within the construction and mining industries and are largely a result of misjudging hazardous situations and large blind spots (AWCBC, 2017; Hinze et al., 2005; WSIB, 2017a, 2017b). The findings of this research reported large differences between heavy equipment operators and LHD operators compared to the eye behaviour of individuals passenger vehicles in other studies. Essentially, heavy equipment operators have replaced the time spent looking over their shoulder with mirror time. When driving a mining LHD that is not equipped with mirrors, operators look within the areas that provide direct views. The human eye, even in the over-the-shoulder position has a larger range of vision, including peripheral vision, than what is provided by the machine mirrors. Although, periphery is likely capturing some movements that may be occuring forward and to the side of the operator, it may not be sufficient to pick up hazards or important movement cues. This is a learning opportunity for pedestrians working around this equipment, since if the machine is moving backwards, it is highly likely that the operator is looking in one of the mirrors. Therefore, pedestrians should know that if they are not visible in a mirror, they are more likely to be missed by the operator. Since operators have a clear preference for either the right or left side mirror (chapter 3) dependent on direction of travel, pedestrians should be informed that when they are located to the right side of the machine while it is driving forwards, and the left side while it is reversing, they are less likely to be seen and more likely to be missed (chapter 3).

Heavy equipment operators did not utilize the front view while reversing the machinery. This could be due to experience, and the ability to make smooth pursuits or look-ahead fixations when looking from the left and right mirrors, while simultaneously not detecting any stimuli within the front view that required a fixation (Dehais et al., 2008; Häggström et al., 2015). However, this could also be due to attentional tunneling as a result to backing up in a controlled zone and a very familiar simulator environment. Operators backing up within a controlled zone with the knowledge that there is no risk of interaction with pedestrians or other machinery may be comfortable to omit this view from their scanning behaviour. The simluator environment likely added to this effect. However, demonstration of this complacency in real-life could result in a fatal error if an on-foot-worker accidently walked into this unmonitored view. This information could be implemented into the training of workers-on-foot and signallers or operatering smaller vehicles in the vicinity of heavy equipment especially when reversing. Providing further understanding of blind spots surrounding heavy equipment and where individuals should position themselves to ensure they are within the view of the heavy equipment operator at all times.

Overall, it was found that in both chapter 3 and chapter 4, operators glanced into the machine more often, which differs from passenger vehicle research. This could be due to the additional guages, proccesses and other information that required monitioring on the machinery. This takes away from 'outside' monitoring time in some way that is different from backing up passenger vehicles. As we already know, for large trucks users spent more time looking in the mirrors in addition to spending more time looking 'down' into the machine. This changes the amount of available attention and peripheral tracking that could be detecting stimuli in key locations outside the machine, compromising the safety of workers in the environment.

With these implications in mind, policies and training programs could use operator eye behaviour to inform workers-on-foot about what to expect and where to position themselves within a dynamic work environment.

5.2.2 Design Engineers

To protect workers from hazards that can potentially lead to occupational injuries and illnesses the hierarchy of controls has been established (NIOSH, 2015). There has been increased focus on engineering to isolate workers from the hazard, with elimination and substitution being most effective (NIOSH, 2015). The findings related to operator gaze behaviours from this research (chapter 3 and 4) can be utilized by design engineers to develop vehicle interaction technologies designed to prevent struck-by accidents. The industry must consider that there is the potential for vehicle interaction technologies to negatively disrupt an operator's gaze pattern, peripheral and smooth-pursuit movements in addition to increase distraction and cognitive workload that may compromise safety. This research provides some initial understanding of how operators use the space around them and their mirrors while driving forwards and backwards in the workspace. This information should be considered when designing and implementing vehicle interaction technologies such as proximity awareness technologies (PAT). Further, the change in observed behaviours should be compared after introduction of these technologies in the workplace. As it was shown that heavy equipment operator and LHD operator gaze behaviours differ from passenger vehicles, PATs for these industries should be designed to accommodate differences in gaze pattern.

Further down the hierarchy, we can focus on the role of the administration/education component to improve safety and reduce machine-pedestrian interactions. With a clearer understanding of where operators fixate during forward and reversing maneuvers, safety training and education can be adjusted to include information about where operators are typically looking and provide an emphasis on avoiding blind spots. In addition, the information can be used to train future operators to utilize more cautious and safe gaze strategies.

5.3 RECCOMENDATIONS FOR FUTURE RESEARCH

This research has provided a start for understanding heavy equipment operator eye gaze behaviour. The data collected in chapter 3 and 4 has characterized the eye gaze behaviour of both heavy equipment within a naturalistic environment and LHD operators within a simulator environment. However, there are numerous factors that can affect operator gaze behaviour that still need to be studied. As detection of stimuli is found to divert operator gaze, future research should examine the rationale behind why operators gaze patterns moved in specific ways where they did. This could be achieved by going over eye-tracking recording with each participant and using a verbal account to determine why they fixated in a certain location at a certain time. This can also be achieved by utilizing audio recording during real-time performance of tasks.

In future, a larger population size (chapter 3 and 4) of both novice and expert heavy equipment operators and LHD operators is necessary to reduce variability and discover significant similarities and differences among gaze patterns. This would also allow for generalizations to be made across a larger operator population, and further investigate differences between experienced and novice operators to establish significance of results. The information resulting from a more robust dataset could provide valuable information to improve training programs and institute policies to mitigate the occurrence of workplace accidents, more specifically struck-by accidents.

There are many factors that might affect observed differences in eye gaze behaviour between individuals. In future studies, it would be worthwhile to better control and define driving or equipment experience with similar hours, days or years. Participants in both studies had a broad range of experience. Specifically, in chapter 4, the novice operators had less than one-hour underground LHD operation whereas other novice operators had upwards of a few days to a year of experience. By defining novice operators further into experience by hours, days and years, a better understanding of gaze pattern could be obtained.

It would also be beneficial to look at a greater variation of worksite tasks outside of just driving forwards and reversing to further our understanding of operator eye scanning patterns, and to distinguish differences between the various task conditions and movements. In addition to looking at more tasks, it would also be of value to look at different worksites and companies. This would hopefully determine if these have an effect on operator scanning patterns in relation to how they are trained at certain companies, or whether other worksite factors such as the environment and crews that have worked together for a long time compared to a relatively new crew also have an effect. Lastly, when developing future studies, it may be of interest to look to see if there are similarities or differences in operator eye behaviour between small and large construction companies. Difference could occur as a result of operator training, compliance to safety policies, different equipment and technology on site among other factors.

Due to the shift towards using vehicle interaction technologies to improve line-of-sight and operator situation awareness, it is crucial that a further understanding of both heavy equipment and LHD operator eye gaze patterns are obtained. The findings of this research could provide baseline data for comparison against implementation of vehicle interaction technologies such as PAT. Future research can investigate optimal position in cab, display information and luminance for both heavy equipment and LHDs. Thoroughly exploring optimal position and display features for PAT is crucial to ensure that operator line-of site is improved while minimizing operator distraction, cognitive workload and disruptions to operator gaze pattern and use of peripheral and smooth-pursuit movements that can occur with PATs. This is especially important due to the unique aspects of construction and mining worksites and respective machinery used that are vastly different from driving passenger vehicles. Having this understanding will aid in the development and implementation of technologies and procedures that do not create an increased cognitive workload or distractions to an already difficult and hazardous task.

Previous literature specific to simulator training in the mining industry has mostly been conducted by mining or simulator companies themselves, focusing on improvements to efficiency or procedures such as performance scores. There is a lack of evidence for how novice and experienced users perform on objective measures of workload including; response or reaction times, and eye movements (Tichon & Burgess-Limerick, 2011). Simulator training can minimize risk to operators and equipment, by allowing operators to gain skills in a controlled environment. This research is just the beginning to help enhance the training value of LHD simulator operation by teaching optimal attention allocation techniques to novice operators by knowing when and where to look. Future research should further investigate how applicable LHD simulator training is to real life operation of an LHD underground. By improving training programs, novice operators can increase their learning more rapidly and accurately, with the end of goal of better occupational safety and prevention of accidents.

5.4 OVERALL CONCLUSIONS

The main purpose of this research study was to investigate the typical gaze behaviour of heavy equipment and LHD operators when operating within a naturalistic worksite environment. The measurement of time spent fixating, fixation duration and number of fixations were identified and found to vary with changes in movement direction (forwards and reverse) along with operator experience (chapter 4). These findings are important as they establish a baseline for heavy equipment and LHD operator eye gaze behaviour for continued development and understanding. Expansions of the baseline eye gaze behaviour to test for additional components and other conditions is crucial for appropriate implementation of technologies, training and policies to prevent future struck-by accidents.

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APPENDICES

Appendix A: Laurentian University Research Ethics Certificate

APPROVAL FOR CONDUCTING RESEARCH INVOLVING HUMAN SUBJECTS
Research Ethics Board – Laurentian University

This letter confirms that the research project identified below has successfully passed the ethics review by the Laurentian University Research Ethics Board (REB). Your ethics approval date, other milestone dates, and any special conditions for your project are indicated below.

TYPE OF APPROVAL / New X / Modifications to project / Time extension	
Name of Principal Investigator and school/department	Alison Godwin, Human Kinetics, Tammy Eger, co-PI, Alyssa Brunton, Brandon Vance, student investigators
Title of Project	The use of eye tracking to understand operator behaviour and use of visual aids in the construction industry.
REB file number	6009793
Date of original approval of project	May 15, 2017
Date of approval of project modifications or extension *(if applicable)*	
Final/Interim report due on: *(You may request an extension)*	May 15, 2018
Conditions placed on project	

During the course of your research, no deviations from, or changes to, the protocol, recruitment or consent forms may be initiated without prior written approval from the REB. If you wish to modify your research project, please refer to the Research Ethics website to complete the appropriate REB form.

All projects must submit a report to REB at least once per year. If involvement with human participants continues for longer than one year (e.g. you have not completed the objectives of the study and have not yet terminated contact with the participants, except for feedback of final results to participants), you must request an extension using the appropriate LU REB form. In all cases, please ensure that your research complies with Tri-Council Policy Statement (TCPS). Also please quote your REB file number on all future correspondence with the REB office.

Congratulations and best wishes in conducting your research.

Rosanna Langer

Rosanna Langer, PHD, Chair, *Laurentian University Research Ethics Board*

Appendix B: Participant Package for Heavy Equipment Operators.

LaurentianUniversity
Université**Laurentienne**

The use of eye tracking to understand operator behaviour and use of visual aids in the construction industry

I, ________________________, am interested in participating in the study by Alison Godwin from Laurentian University. The purpose of the study is to investigate how driver behavior and workload changes when using proximity detection systems (ie. Video cameras, rear-view cameras, back-up cameras, displays etc). In the long term, this research will provide ideas for designing these systems and the machines that use them.

If I agree to participate I will be asked to complete to wear a special set of glasses that have cameras to look at my eye movements. The glasses can be fitted to my prescription if I have mild vision problems. The device will record my eye movements and save it as a video. I can ask the researchers to mute the audio portion of the recording. If necessary in my workplace, the researchers can put clip-on side shields to the special glasses. I will also complete a short survey about age, height and driving experience. I will complete my regular job requirements for a period of 20 minutes and then return to the researchers. If I have access to a back-up camera (or other driving aid), I will do another round of working for 20 minutes using that unit.

I have been informed that only members of the research team will have access to the questionnaire and recorded eye moment data. My participation will have no influence on my job security, or my future with this company. My supervisor, and the company is in support of my participation, and will not use the collected data in any way against my performance with the company. My personal information will be removed from any presentations. The researchers will not identify me by company, or machine driven. **My participation is strictly voluntary** and I am free to withdraw from completing the study at any moment. I can request that my data be removed from the dataset. I am aware that I will continue to complete the NORCAT training as scheduled. I have received assurance from the researcher that all individual data collected will remain strictly confidential using a unique coded identifier. All collected data will be coded with a subject number and stored in a locked filing cabinet (in Professor Godwin's office) or a password secured laptop (only members of the research team will have access to the data). After a period of 5 years, all electronic and paper documents will be shredded.

I understand that I will receive no immediate benefit from my participation.

There are two copies of this consent form; one which the researcher keeps and one that I keep.

If I have any questions or concerns about the study or about being a participant, I may contact the lead researcher, Professor Alison Godwin via email agodwin@laurentian.ca and by phone at 705 675 1151 ext 1079 If I have any questions or concerns surrounding the ethical conduct of the study, I may contact the Laurentian University Research Office (ethics@laurentian.ca) or telephone # 705-675-1151 ext 3681 (toll free 1 800 461 4030. If I would like to receive a copy of the study results I can contact Professor Alison Godwin anytime after Sept. 1, 2018 using the contact information on this form.

I agree to participate in this study.

Participant's Signature: ________________________ Date: ________________________

Researcher Signature: ________________________ Date: ____________________________

Basic Information

Part 1: Personal Information

Age (years): __________ Height (cm): ___________ Sex: _______________

Number of years in construction industry: ____________________

Number of years driving heavy equipment: ___________________________________

Part 2: Equipment Experience

1. Name the most common piece of equipment that you operate

   I. Equipment **MOST** interacted with: _______________________________

   II. Equipment **2nd MOST** interacted with:

   ____

   III. Equipment **3rd MOST** interacted with:

   ____

Part 3: Visibility Technology

1. Rate this technology using the scales below for use with heavy equipment:

Technology	**Describe Your Use** 1 = Never use 2 = Sometimes use 3 = Always use if available 4 = Not available	**Perceived Effectiveness** 1 = Not effective 2 = Somewhat effective 3 = Very effective 4 = Not applicable
Mirrors		
Sensor system		
Camera systems (video displays)		
RFID systems (information display)		
Signaller/ Flag person		
Audio (radio, walkie-talkie, phone)		

2. Roughly, how many months/years have you used proximity awareness technology (ie. Back-up camera) in a personal vehicle:

____

3. How many approximate months/years have you used proximity awareness technology (ie. Back-up camera) in heavy equipment:

____

Part 3: Previous Driving Record

1. Have you ever hit another vehicle or object while driving a personal vehicle?:

   YES/NO (please circle)

   I. If yes, how many approximate times has your vehicle come in contact with an object or another vehicle?: ________________________

   II. What driving tasks were you performing? (ie. Driving forward, reversing, turning etc.) ________________________

2. Have you ever hit another vehicle or object while driving heavy equipment?:

   YES/NO (please circle)

   I. If yes, how many approximate times has the machine come in contact with an object or another vehicle?: ________________________

   II. What driving tasks were you performing? (ie. Driving forward, reversing, turning etc.) ________________________

   III. What environment did it occur in? (ie. Gravel pit, roadside worksite etc.):

Appendix C: Tobii I-VT Fixation Filter parameters adapted from Tobii Pro Lab software (Tobii Pro, 2017b).

Gaze filter	Tobii I-VT (Fixation)
Gap fill-in (interpolation)	Off
Noise reduction	Moving median
Window size (samples)	3
Velocity calculator – Window Length (ms)	20
I-VT classifier – Threshold (°/s)	30
Merge adjacent fixations	On
Maximum time between fixations (ms)	75
Maximum angle between fixations (°)	0.5
Discard short fixations	On
Minimum fixation duration (ms)	60

Appendix D: Heavy Equipment Operator individual eye-tracking measurements.

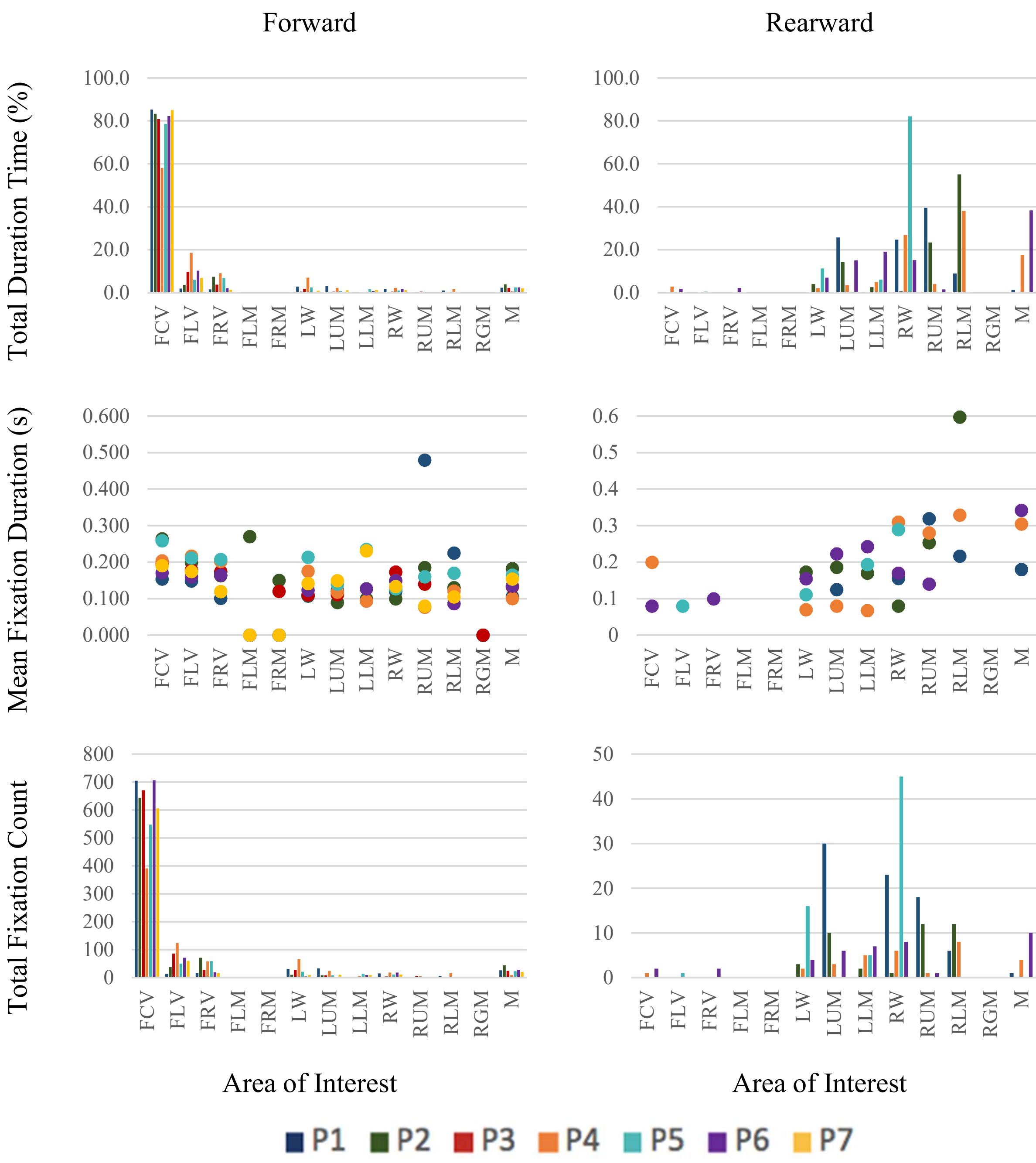
FORWARD

		Area of Interest												
		FCV	FLV	FRV	FLM	FRM	LW	LUM	LLM	RW	RUM	RLM	RGM	M
Total Fixation Duration (%)	P1	85.29	1.89	1.59	*	*	2.84	3.10	0.00	1.69	0.37	0.98	*	2.26
	P2	83.26	3.59	7.32	0.26	0.14	0.54	0.35	0.09	0.15	0.32	0.12	*	3.85
	P3	80.88	9.61	3.77	0.00	0.15	1.83	0.54	0.00	0.54	0.51	0.00	*	2.17
	P4	58.04	18.62	9.01	*	*	7.03	2.15	0.37	2.15	0.29	1.66	0	0.66
	P5	78.58	5.96	6.89	*	*	2.41	0.69	1.72	1.01	0.09	0.19	0	2.47
	P6	82.27	10.24	2.06	*	*	0.38	0.00	0.74	1.73	0.00	0.18	0	2.40
	P7	84.94	6.82	1.34	*	*	0.89	1.14	1.32	1.21	0.06	0.24	0	2.05
Mean Fixation Duration (s)	P1	0.154	0.148	0.101	*	*	0.107	0.122		0.120	0.480	0.225	*	0.079
	P2	0.264	0.199	0.163	0.270	0.50	0.109	0.089	0.100	0.100	0.185	0.130	*	0.182
	P3	0.195	0.179	0.174		0.120	0.111	0.111		0.173	0.140		*	0.133
	P4	0.204	0.217	0.202	*	*	0.175	0.118	0.093	0.149	0.077	0.121		0.101
	P5	0.259	0.212	0.208	*	*	0.213	0.140	0.235	0.127	0.160	0.170		0.164
	P6	0.171	0.160	0.165	*	*	0.123		0.127	0.149		0.087		0.135
	P7	0.191	0.175	0.120	*	*	0.142	0.149	0.232	0.133	0.080	0.105		0.154
Total Fixations (#)	P1	705	14	16	*	*	31	33	0	15	1	6	*	26
	P2	644	38	71	2	2	10	8	2	3	3	2	*	44
	P3	671	86	27	0	2	27	8	0	4	6	0	*	24
	P4	391	124	58	*	*	66	24	5	18	5	16	0	9
	P5	548	50	59	*	*	21	8	14	11	1	2	0	23
	P6	707	71	19	*	*	4	0	9	18	0	3	0	28
	P7	606	60	16	*	*	9	10	9	11	1	3	0	20

REARWARD

		Area of Interest												
		FCV	FLV	FRV	FLM	FRM	LW	LUM	LLM	RW	RUM	RLM	RGM	M
Total Fixation Duration (%)	P1	0.00	0.00	0.00	*	*	0.00	25.78	0.00	24.61	39.46	8.94	*	1.24
	P2	0.00	0.00	0.00	0.00	0.00	4.00	14.30	2.61	0.61	23.37	55.12	*	0.00
	P4	2.89	0.00	0.00	*	*	2.03	3.47	4.92	26.92	4.05	38.07	0.00	17.66
	P5	0.00	0.50	0.00	*	*	11.22	0.00	6.11	82.17	0.00	0.00	0.00	0.00
	P6	1.79	0.00	2.24	*	*	6.94	15.00	19.03	15.22	1.57	0.00	0.00	38.28
Mean Fixation Duration(s)	P1				*	*		0.125		0.156	0.319	0.217	*	0.180
	P2						0.173	0.186	0.170	0.080	0.253	0.598	*	
	P4	0.200			*	*	0.070	0.080	0.068	0.310	0.280	0.329		0.305
	P5		0.080		*	*	0.111		0.194	0.290				
	P6	0.080		0.100	*	*	0.155	0.223	0.243	0.170	0.140			0.342
Mean Total Fixations (#)	P1	0	0	0	*	*	0	30	0	23	18	6	*	1
	P2	0	0	0	0	0	3	10	2	1	12	12	*	0
	P4	1	0	0	*	*	2	3	5	6	1	8	0	4
	P5	0	1	0	*	*	16	0	5	45	0	0	0	0
	P6	2	0	2	*	*	4	6	7	8	1	0	0	10

Appendix E: Individual glance response during forward and rearward travel while operating heavy equipment.



Appendix F: Participant Package for LHD Operators.

Evaluating the impact of simulator training for improving mining health and safety outcomes

I, ________________________, am interested in participating in the study by Alison Godwin from Laurentian University. The purpose of the study is to investigate how worker characteristics impact the efficacy of simulator training. This will be done by measuring things like learning style and work experience using questionnaires while monitoring your heart rate variability and your eye movements. In the long term, this research will help to individualize simulator training programs.

If I agree to participate I will be asked to complete two questionnaires during my time at the NORCAT training centre. Each questionnaire will take about 10 minutes. If I agree to participate I will also be asked to wear a special set of glasses to monitor my eye movement. The researcher will instruct me on how to attach the harness, which is worn under my clothing and they will confirm that the glasses allow me to see the necessary screens adequately. I understand that the results of my training runs in the simulator will be printed and stored by the research team and that my name will be immediately blacked out on that document and replaced with a unique code. Electronic data from the eyetracker will be stored as a file with a coded identifier on the password-protected computer, and later encrypted and saved to a USB drive. Individual results from the questionnaires, heart rate monitoring and eyetracking will not be reported in publications nor given to my employer. Results from this study will only be reported as averages. In the event that researchers notice something potentially abnormal in your heart rate data, they will ask you in a private session to consider speaking with your family doctor, or a local health care clinic about having a full evaluation by a qualified professional.

I have been informed that only members of the research team will have access to the questionnaire and heart rate data collected. NORCAT will keep records of the simulator data. **My participation is strictly voluntary** and I am free to withdraw from completing the study details at any moment. I am aware that I will continue to complete the NORCAT training as scheduled. I have received assurance from the researcher that all individual data collected will remain strictly confidential using a unique coded identifier. All collected data will be coded with a subject number and stored in a locked filing cabinet (in Professor Godwin's office) or a password secured laptop (only members of the research team will have access to the data). After a period of 5 years, all electronic and paper documents will be shredded.

I understand that I will receive no immediate benefit from my participation.

There are two copies of this consent form; one which the researcher keeps and one that I keep.

If I have any questions or concerns about the study or about being a participant, I may contact the lead researcher, Professor Alison Godwin via email agodwin@laurentian.ca and by phone at 705 675 1151 ext 1079 If I have any questions or concerns surrounding the ethical conduct of the study, I may contact the Laurentian University Research Office (ethics@laurentian.ca) or telephone # 705-675-1151 ext 3213 (toll free 1 800 461 4030. If I would like to receive a copy of the study results I can contact Professor Alison Godwin anytime after Sept. 1, 2014 using the contact information on this form.

I agree to participate in this study.

Participant's Signature: ________________________ Date: ________________________

Researcher Signature: ________________________ Date: ____________________________

How I am in general

Here are a number of characteristics that may or may not apply to you. For example, do you agree that you are someone who *likes to spend time with others*? Please write a number next to each statement to indicate the extent to which **<u>you agree or disagree with that statement.</u>**

1 Disagree Strongly	**2** Disagree a little	**3** Neither agree nor disagree	**4** Agree a little	**5** Agree strongly

I am someone who…

1. _____ Is talkative
2. _____ Tends to find fault with others
3. _____ Does a thorough job
4. _____ Is depressed, blue
5. _____ Is original, comes up with new ideas
6. _____ Is reserved
7. _____ Is helpful and unselfish with others
8. _____ Can be somewhat careless
9. _____ Is relaxed, handles stress well.
10. _____ Is curious about many different things
11. _____ Is full of energy
12. _____ Starts quarrels with others
13. _____ Is a reliable worker
14. _____ Can be tense
15. _____ Is ingenious, a deep thinker
16. _____ Generates a lot of enthusiasm
17. _____ Has a forgiving nature
18. _____ Tends to be disorganized
19. _____ Worries a lot
20. _____ Has an active imagination
21. _____ Tends to be quiet
22. _____ Is generally trusting
23. _____ Tends to be lazy
24. _____ Is emotionally stable, not easily upset
25. _____ Is inventive
26. _____ Has an assertive personality
27. _____ Can be cold and aloof
28. _____ Perseveres until the task is finished
29. _____ Can be moody
30. _____ Values artistic, aesthetic experiences
31. _____ Is sometimes shy, inhibited
32. _____ Is considerate and kind to almost everyone
33. _____ Does things efficiently
34. _____ Remains calm in tense situations
35. _____ Prefers work that is routine
36. _____ Is outgoing, sociable
37. _____ Is sometimes rude to others
38. _____ Makes plans and follows through with them
39. _____ Gets nervous easily
40. _____ Likes to reflect, play with ideas
41. _____ Has few artistic interests
42. _____ Likes to cooperate with others
43. _____ Is easily distracted
44. _____ Is sophisticated in art, music, or literatur

Experience Questionnaire

Please take the time to fill out this short questionnaire which aims to provide a summary of your experience in mining specific machine use, mining related activities and underground experience.

All of the information in this questionnaire will be kept confidential.

Date of birth (YY/MM/DD): ____

Sex: **M** or **F**

Please answer the following questions as accurately as possible.

1. How many total years of experience do you have in operating heavy equipment of any kind:

   ____

2. Do you have any past experience with simulator training: **Yes** or **No**

   If yes, what specific type of equipment were you trained on: ________________________

   ____

   If yes, how many days of training did you receive: ________________________________

3. Do you have any past experience of video gaming: **Yes** or **No**

   If yes, at what age did you begin playing video games: ______________________________

   If yes, what specific type of gaming system(s) did/do you use:

   ____

   ____

   ____

   If yes, what kinds of controller did/do you use:

   ____

   ____

4. What piece of mining machinery are you currently being trained on in the Cybermine Simulator at NORCAT: ____

5. Are you currently completing a 4-day session or 2-day session of simulator training?

   4-day ________ 2-day _______

6. Approximately how much time have you spent on this piece of machinery in an underground environment?

   _________ years or _________ months or __________ days

7. What type of training (if any) have you had on this specific piece of machinery?

   ____

   ____

Appendix G: Operator error count for load-haul-dump driving procedures.

Day One											
	Operators										
Parameter (unit)	P1	P2	P3	P4	P5	P6	P7	P8	P9	Mean	Expert
Bucket scraped rock face	85	21	112	38	53	23	12	156	29	62.5	29
Frame scraped rock face	47	16	79	21	35	59	5	99	14	45.1	14
Bucket direction wrong in shaft	23	31	28	36	27	31	37	49	24	32.8	24
Gear too high in shaft	22	0	11	44	0	0	0	0	0	9.6	0
No use of horn when approaching blind corner	3	5	5	5	5	1	0	3	5	3.4	5
Bucket position wrong whilst tramming	2	7	2	4	3	104	47	23	7	24.0	7
Intersection speed exceeded	2	0	2	2	0	0	0	0	1	0.8	1
Emergency steering not charged	1	1	1	1	1	1	1	1	1	1	1
Vehicle idle for too long	0	0	0	0	0	0	0	0	0	0	0
Lights off while moving	0	0	0	0	0	0	2	0	0	0.3	0
Drove with foot on service brake	0	25	32	32	8	3	73	8	10	22.6	10
No stopping at stop sign	0	0	0	0	0	0	0	0	0	0	0
Applied park brake while moving	0	0	0	0	0	0	0	0	0	0	0

Day Four										
	Operators									
Parameter (unit)	P1	P2	P3	P4	P5	P6	P7	P8	Mean	Expert
Bucket scraped rock face	24	45	31	31	16	33	70	142	49	-
Frame scraped rock face	20	11	13	20	15	10	22	133	30.5	-
Bucket direction wrong in shaft	34	31	34	28	23	21	44	44	32.4	-
Gear too high in shaft	1	1	1	0	0	0	0	0	0.4	-
No use of horn when approaching blind corner	5	2	3	3	5	0	0	1	2.4	-
Bucket position wrong whilst tramming	22	27	16	54	4	43	35	80	35.1	-
Intersection speed exceeded	2	0	0	0	0	0	0	0	0.3	-
Emergency steering not charged	1	1	1	1	1	1	1	1	1	-
Vehicle idle for too long	0	0	0	0	0	0	0	0	0	-
Lights off while moving	1	0	0	1	0	0	0	0	0.3	-
Drove with foot on service brake	5	52	2	1	3	23	24	56	20.8	-
No stopping at stop sign	0	0	0	0	0	0	0	1	0.1	-
Applied park brake while moving	0	0	0	0	0	0	0	0	0	-

Appendix H: Individual mean eye metric measurements while driving LHD forwards and rearwards on day one of training.

FORWARD

		Area of Interest										
		FCV	FLV	FRV	LB	C	G	SW	RCV	RLV	RRV	M
Total Fixation Duration (%)	P1	55.46	11.73	0.86	14.95	0.00	0.14	0.00	0.00	0.00	0.00	16.87
	P2	61.71	27.05	0.40	4.00	3.23	0.04	0.08	0.41	0.00	0.00	3.08
	P3	21.20	45.32	0.00	4.59	1.07	0.23	0.43	0.00	0.00	0.00	27.14
	P4	30.55	23.10	0.00	3.44	0.00	0.32	0.15	0.07	0.00	0.00	42.36
	P5	50.62	39.84	0.03	0.35	0.56	0.12	0.00	0.00	0.00	0.00	8.47
	P6	31.52	42.11	0.08	0.12	1.10	0.00	0.12	0.18	0.00	0.00	24.77
	P7	30.79	45.86	0.34	6.25	1.24	0.27	0.36	0.08	0.44	0.32	14.04
	P8	42.21	12.69	0.00	10.22	1.73	0.14	0.11	0.56	0.00	0.00	32.35
Mean Fixation Duration (s)	P1	0.127	0.110	0.090	137		0.100					0.142
	P2	0.401	0.416	0.320	0.247	0.246	0.060	0.060	0.165			0.306
	P3	0.350	0.362		0.212	0.106	0.400	0.142				0.276
	P4	0.275	0.197		0.218		0.147	0.125	0.120			0.315
	P5	0.295	0.205	0.040	0.153	0.104	0.080					0.210
	P6	0.223	0.202	0.100	0.140	0.140		0.070	0.110			0.230
	P7	0.289	0.295	0.100	0.196	0.148	0.160	0.140	0.100	0.260	0.190	0.263
	P8	0.258	0.211		0.219	0.149	0.090	0.070	0.158			0.235
Total Fixations (#)	P1	315	77	7	74	0	1	0	0	0	0	86
	P2	252	105	2	27	17	1	2	4	0	0	13
	P3	97	217	0	38	14	1	5	0	0	0	174
	P4	172	186	0	23	1	4	2	0	0	0	197
	P5	227	233	1	3	7	2	0	0	0	0	52
	P6	162	263	1	1	9	0	2	2	0	0	103
	P7	130	194	4	25	10	2	3	1	2	2	97
	P8	215	79	0	62	14	2	2	5	0	0	183

REARWARD

		Area of Interest										
		FCV	FLV	FRV	LB	C	G	SW	RCV	RLV	RRV	M
Total Fixation Duration (%)	P1	0.00	0.00	0.00	0.00	0.00	0.20	0.14	65.37	2.68	26.67	4.95
	P2	1.31	0.75	0.00	0.05	6.23	0.00	1.08	53.23	5.38	29.98	1.97
	P3	0.00	0.00	0.00	0.00	0.82	0.04	0.81	60.98	5.85	23.88	7.62
	P4	0.00	0.00	0.00	0.00	1.11	0.16	2.25	53.20	0.37	5.28	37.63
	P5	0.00	2.73	0.00	0.00	0.41	0.00	0.38	66.16	15.50	14.83	
	P6	0.00	0.00	0.00	0.00	2.46	0.00	0.23	56.13	1.05	21.94	18.20
	P7	0.34	0.11	0.00	0.13	4.71	1.80	2.14	58.46	3.32	11.21	17.78
	P8	0.74	1.15	0.08	1.12	9.21	0.05	2.02	53.89	3.20	4.76	23.78
Mean Fixation Duration (s)	P1						0.180	0.060	0.187	0.105	0.155	0.172
	P2	0.158	0.189		0.100	0.244		0.123	0.376	0.338	0.352	0.453
	P3					0.283	0.060	0.155	0.366	0.250	0.368	0.205
	P4					0.106	0.340	0.188	0.286	0.390	0.192	0.510
	P5		0.154			0.300		0140.	0.136	0.132	0.209	
	P6					0.140		0.085	0.235	0.194	0.193	0.350
	P7	0.193	0.160		0.200	0.260	0.210	0.132	0.235	0.165	0.179	0.230
	P8	0.139	0.144	0.140	0.274	0.189	0.080	0.203	0.244	0.200	0.300	0.216
Total Fixations (#)	P1	0	0	0	0	0	1	2	327	24	145	26
	P2	16	8	0	1	51	0	12	275	30	164	9
	P3	0	0	0	0	6	1	7	283	39	110	57
	P4	0	0	0	0	19	1	23	382	2	58	150
	P5	0	13	0	0	1	0	2	333	90	57	0
	P6	0	0	0	0	25	0	4	354	10	164	77
	P7	4	1	0	1	37	11	18	383	27	96	121
	P8	9	13	1	7	81	1	17	372	28	25	159

Appendix I: Individual mean eye metric measurements while driving LHD forwards and rearwards on day four of training.

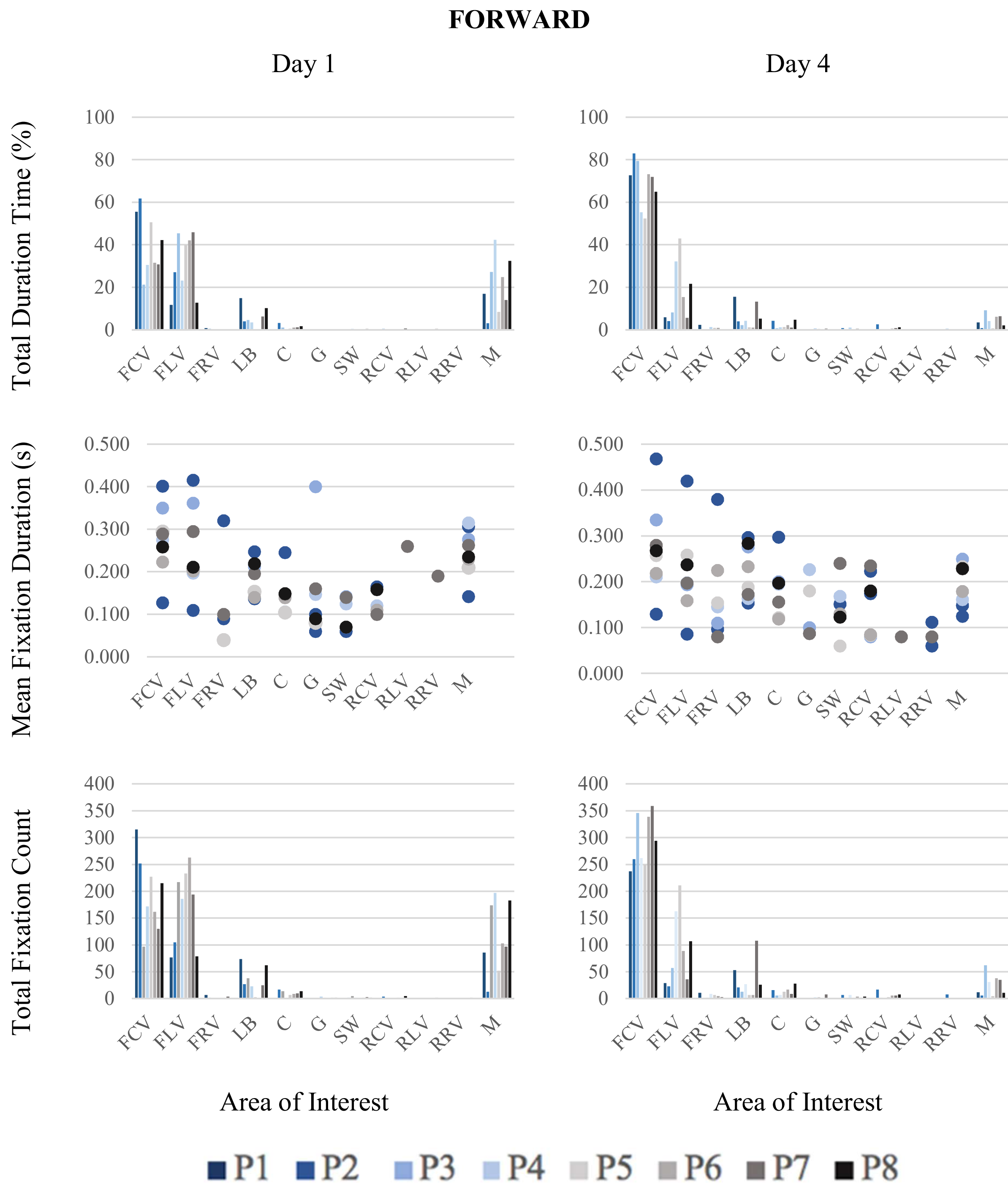
FORWARD

		Area of Interest										
		FCV	FLV	FRV	LB	C	G	SW	RCV	RLV	RRV	M
Total Fixation Duration (%)	P1	72.7	5.9	2.4	15.5	0	0	0	0	0	0	3.5
	P2	82.9	4.1	0.3	3.9	4.3	0	0.8	2.5	0	0.4	0.8
	P3	79.4	8.1	0.2	2.2	0.7	0.1	0	0.1	0	0	9.2
	P4	55.3	32.1	1.3	4.2	1.2	0.7	1.1	0	0	0	4.2
	P5	52.3	43.0	0.9	1.1	1.3	0.4	0	0.2	0	0	0.7
	P6	73.2	15.4	0.9	1.1	2.2	0	0.5	0.5	0	0	6.2
	P7	71.9	5.6	0.2	13.2	1.0	0.6	0.3	0.8	0.1	0	6.3
	P8	64.9	21.6	0	5.3	4.7	0.1	0.2	1.2	0	0	2.0
Mean Fixation Duration (s)	P1	0.130	0.086	0.097	0.154	0.297			0.223		0.060	0.148
	P2	0.468	0.420	0.380	0.297	1.324		0.151	0.174		0.112	0.125
	P3	0.335	0.194	0.110	0.276	0.200	0.100		0.080			0.249
	P4	0.211	0.198	0.146	0.163	0.195	0.227	0.168				0.161
	P5	0.257	0.259	0.154	0.188	0.122	0.180	0.060	0.083			0.233
	P6	0.219	0.159	0.225	0.233	0.119		0.130	0.085			0.179
	P7	0.280	0.197	0.080	0.173	0.156	0.087	0.240	0.235	0.080	0.080	0.229
	P8	0.268	0.238		0.284	0.198		0.123	0.180			0.229
Total Fixations (#)	P1	237	29	11	53	0	0	0	0	0	0	12
	P2	260	23	1	21	16	0	7	17	0	8	6
	P3	346	57	2	13	6	1	0	2	0	0	62
	P4	262	163	9	27	7	3	7	0	0	0	31
	P5	250	211	7	7	13	3	1	3	0	0	5
	P6	339	89	5	7	17	0	4	6	0	0	38
	P7	359	36	3	108	9	8	2	6	1	0	35
	P8	294	107	0	26	28	0	4	8	0	0	11

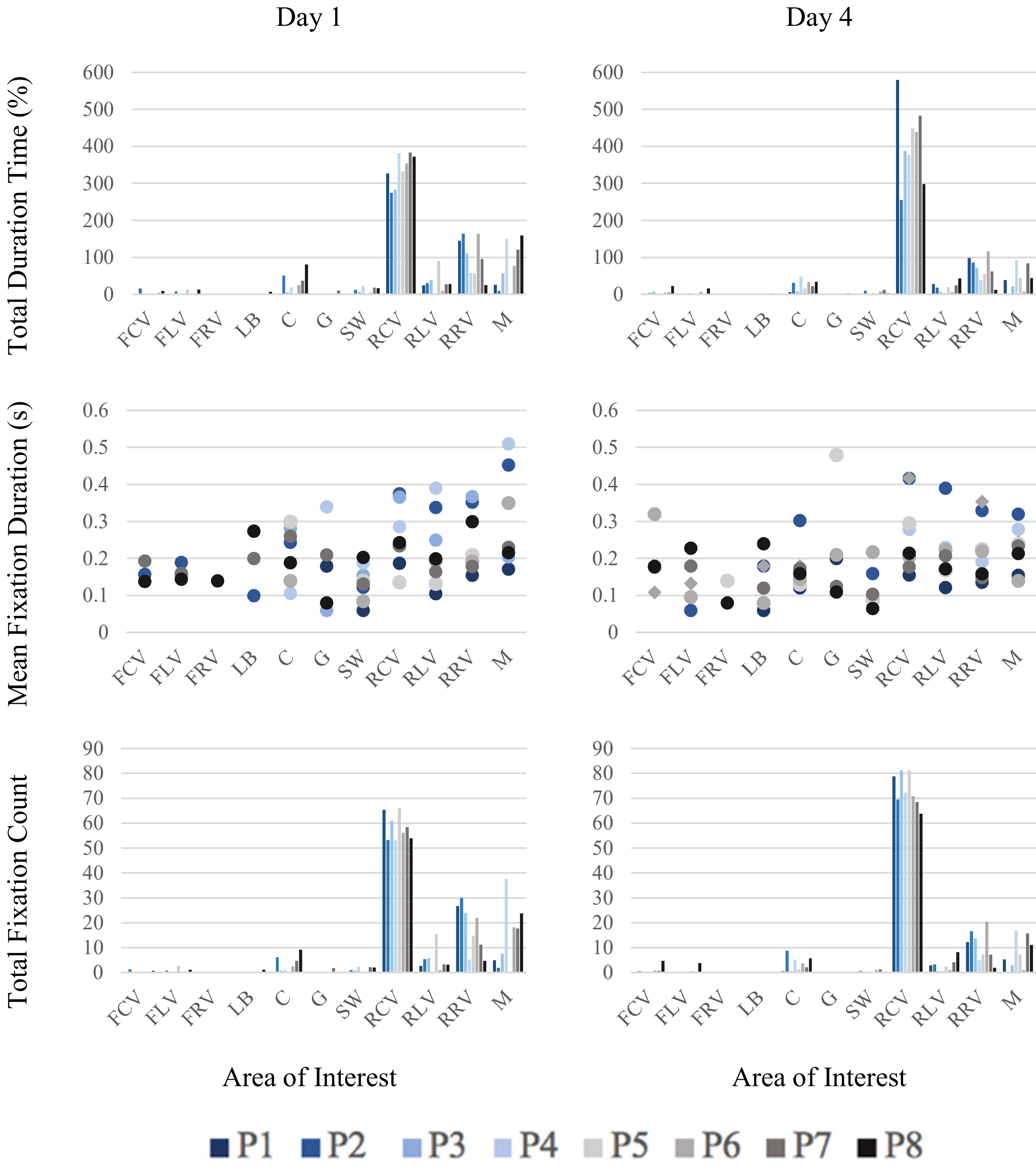
REARWARD

		Area of Interest										
		FCV	FLV	FRV	LB	C	G	SW	RCV	RLV	RRV	M
Total Fixation Duration (%)	P1	0.0	0.0	0.0	0.1	0.6	0.0	0.0	78.9	3.0	12.2	5.2
	P2	0.5	0.0	0.1	0.3	8.8	0.0	0.6	69.5	3.3	16.6	0.2
	P3	0.5	0.2	0.0	0.1	0.6	0.0	0.0	81.3	0.6	13.7	2.9
	P4	0.0	0.0	0.0	0.0	5.2	0.0	0.3	72.3	0.6	4.9	16.7
	P5	0.0	0.0	0.1	0.0	1.4	0.3	0.1	81.2	2.4	7.3	7.3
	P6	0.9	0.5	0.0	0.2	3.8	0.1	1.0	70.9	1.0	20.5	1.0
	P7	0.7	0.0	0.0	0.1	2.2	0.4	1.2	68.5	4.1	7.2	15.7
	P8	4.7	3.9	0.1	0.2	5.7	0.2	0.1	63.8	8.2	1.9	11.2
Mean Fixation Duration (s)	P1				0.060	0.121	0.200		0.156	0.121	0.136	0.155
	P2	0.177	0.060	0.140	0.180	0.302		0.159	0.417	0.390	0.330	0.320
	P3	0.109	0.133		0.180	0.180		0.080	0.417	0.167	0.354	0.245
	P4					0.165		0.087	0.278	0.230	0.191	0.279
	P5			0.140		0.130	0.480	0.090	0.296	0.169	0.225	0.239
	P6	0.320	0.096		0.080	0.145	0.210	0.218	0.205	0.223	0.220	0.140
	P7	0.180	0.180		0.120	0.173	0.125	0.104	0.177	0.208	0.149	0.234
	P8	0.178	0.228	0.080	0.240	0.159	0.110	0.065	0.214	0.172	0.158	0.214
Total Fixations (#)	P1	0	0	0	1	6	1	0	579	28	98	39
	P2	4	1	1	2	31	0	10	255	18	86	2
	P3	8	3	0	1	8	0	1	388	7	72	22
	P4	0	0	0	0	48	0	4	377	4	39	92
	P5	0	0	1	0	16	1	2	449	19	55	45
	P6	5	7	0	3	34	2	8	438	6	116	8
	P7	5	0	0	1	22	3	12	483	24	62	84
	P8	23	16	1	1	34	2	3	298	43	12	44

Appendix J: Individual eye metrics response during forward and rearward travel while operating LHD.



REARWARD



Day 1
Day 4
Total Duration Time (%)
Mean Fixation Duration (s)
Total Fixation Count
FCV FLV FRV LB C G SW RCV RLV RRV M
Area of Interest
Area of Interest
P1 P2 P3 P4 P5 P6 P7 P8

Appendix K: Gaze maps of novice operator’s gaze behaviour while driving LHD forwards and rearwards on day one of training.

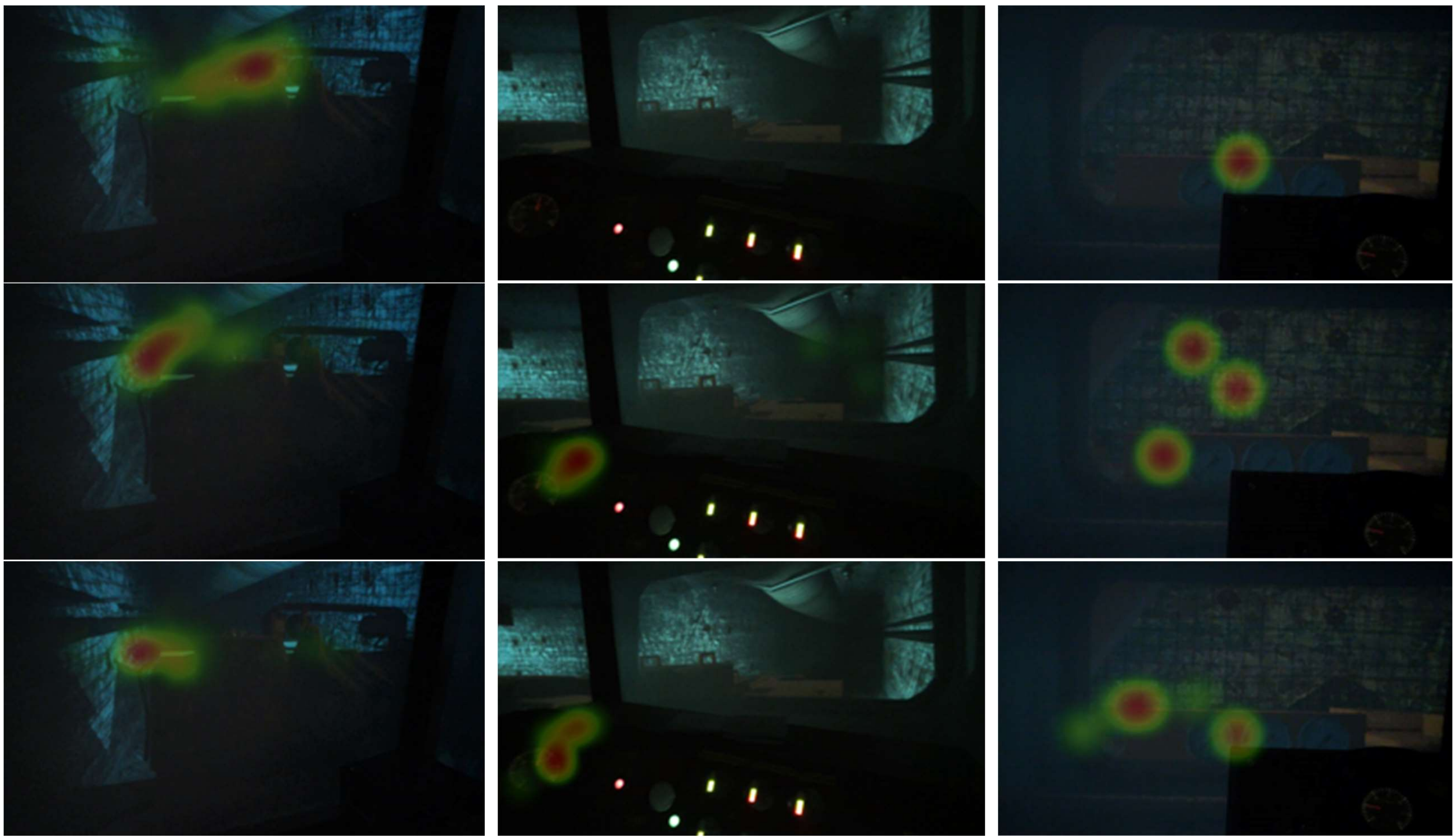
FORWARD

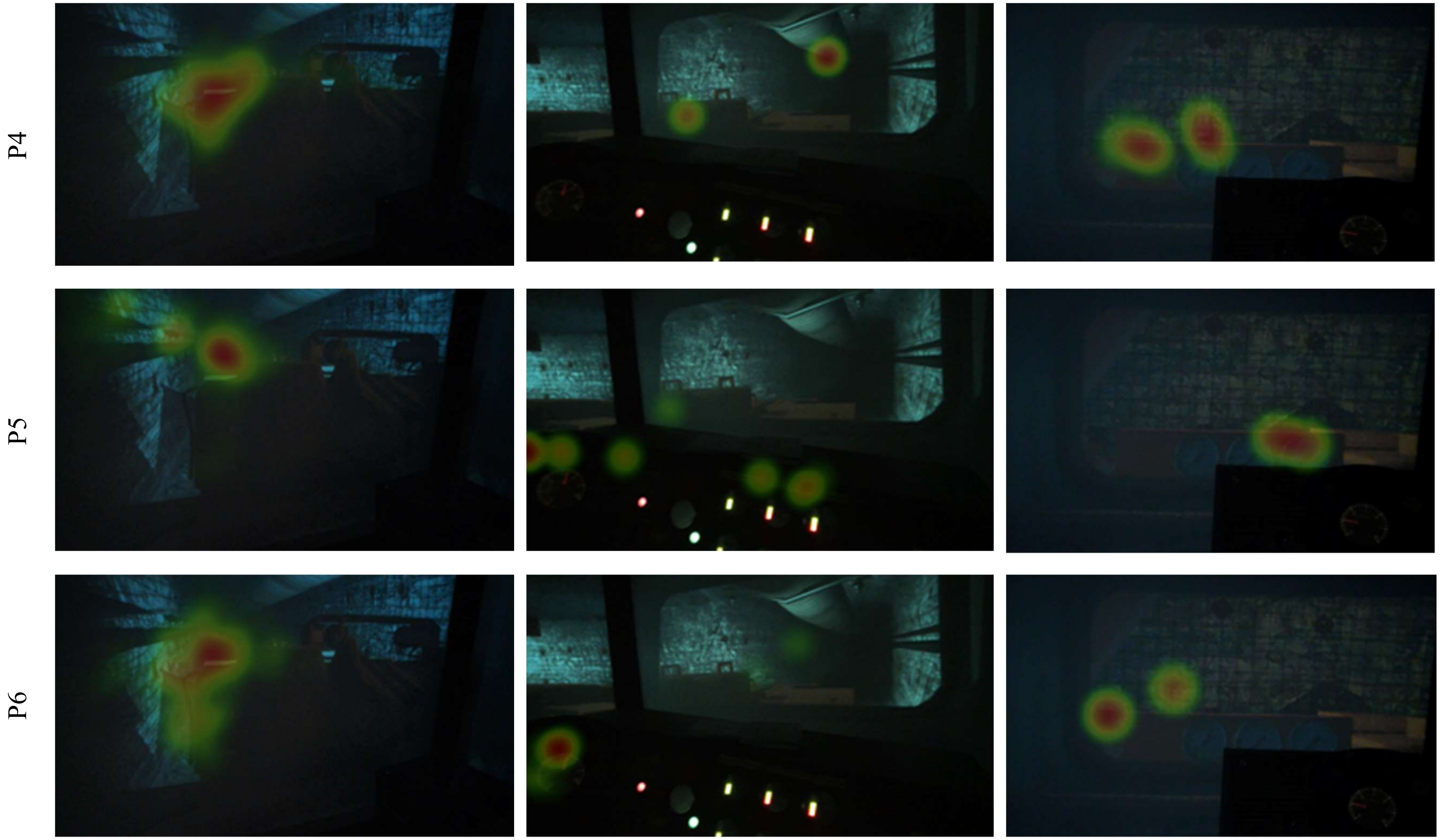
Front View | Rear View | Side View

P1

P2

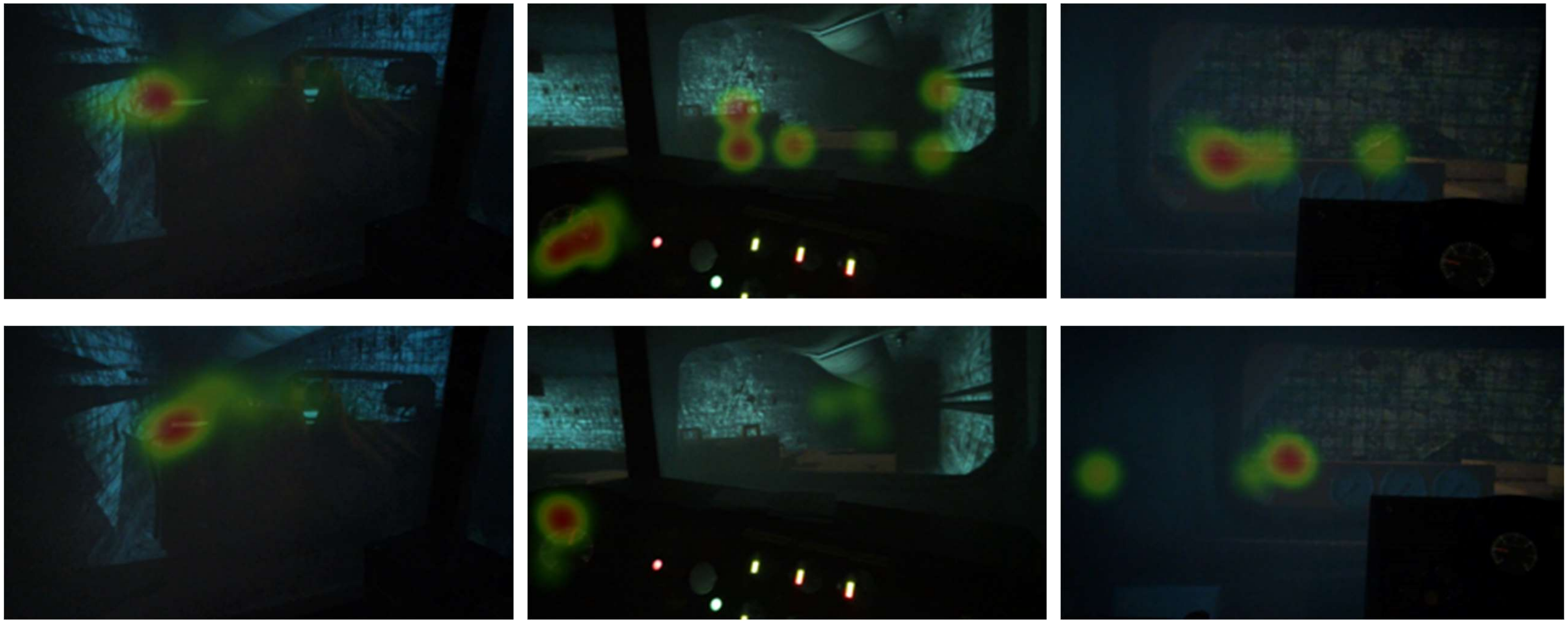
P3



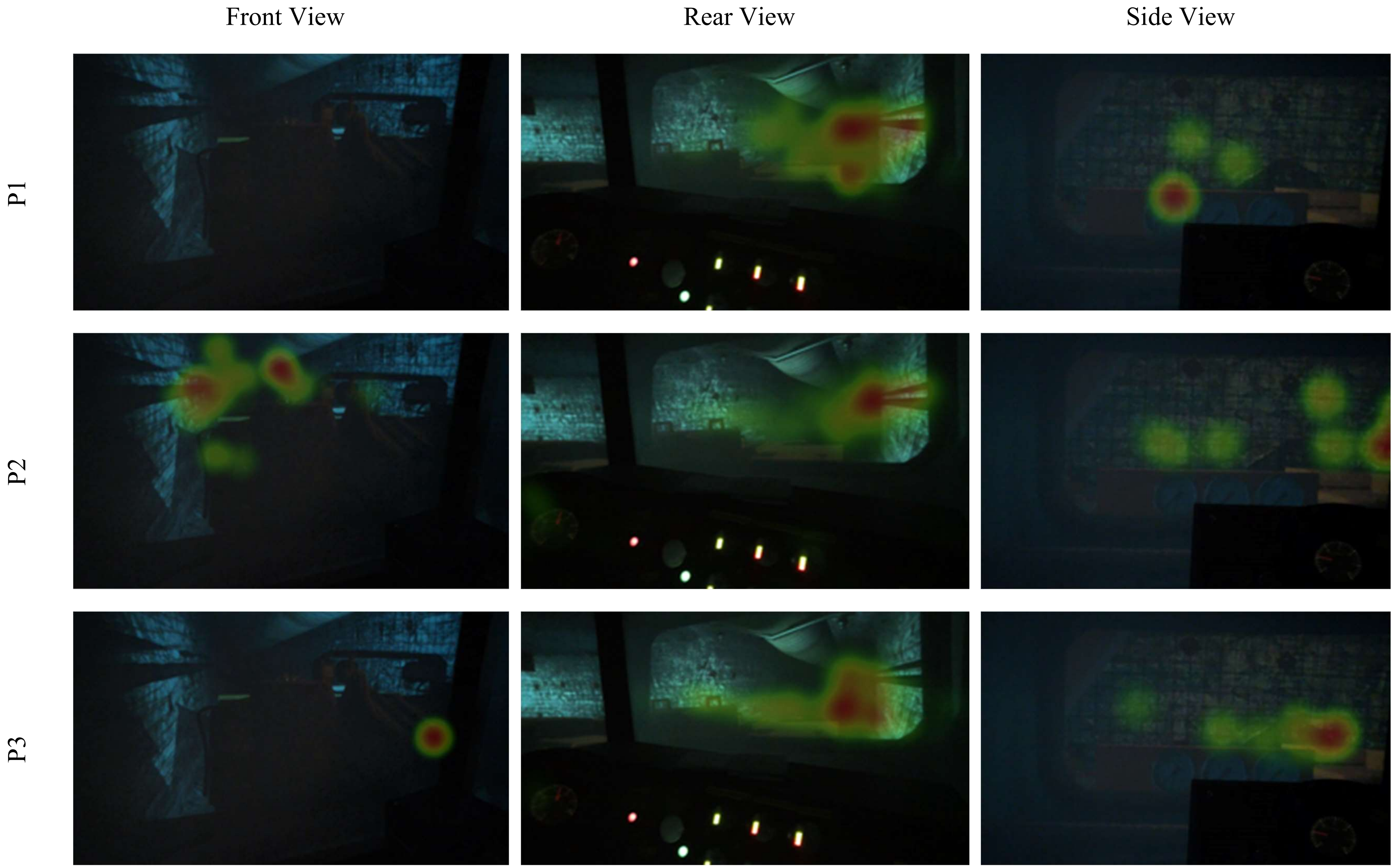

P4
P5
P6

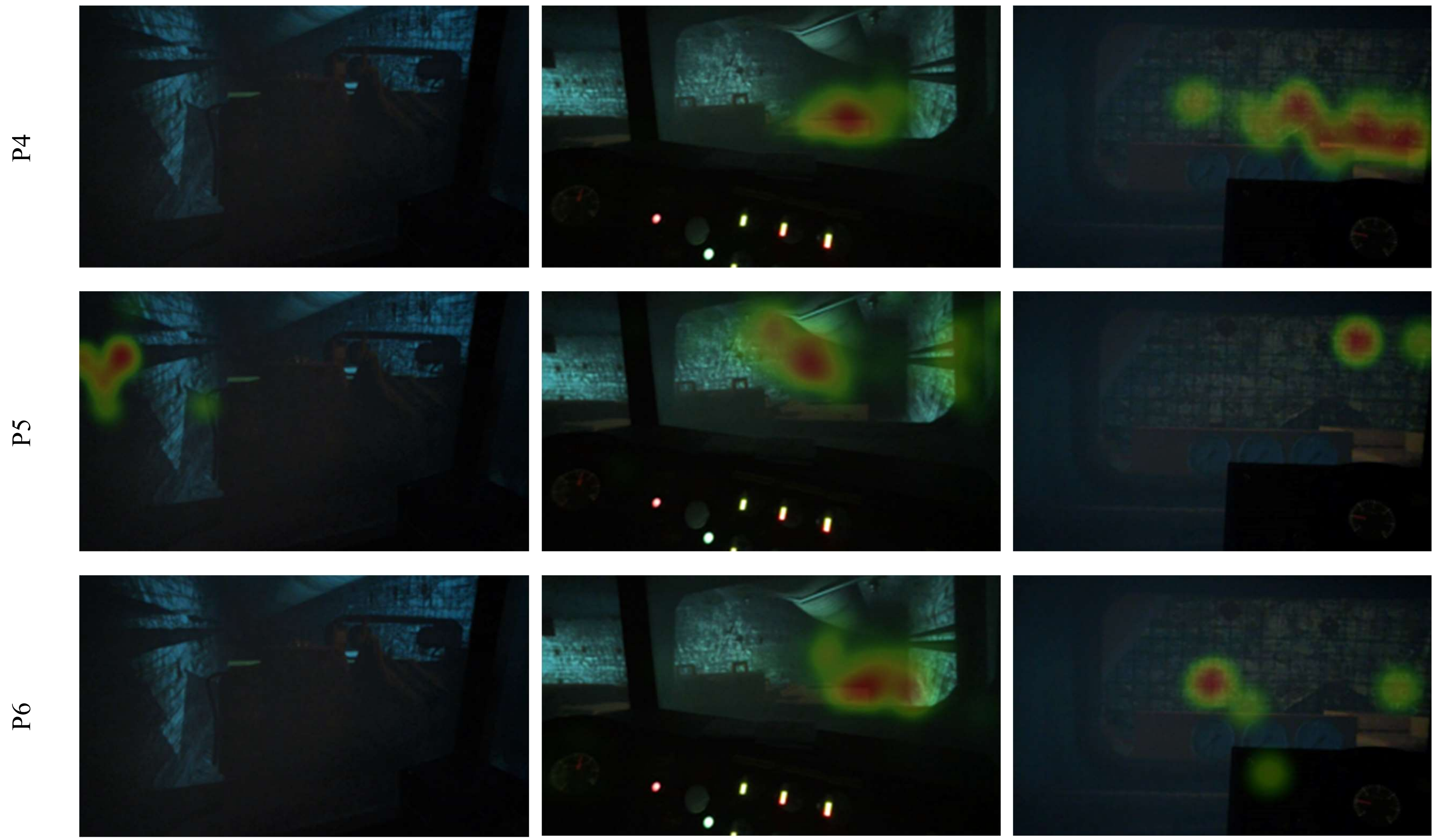
P7

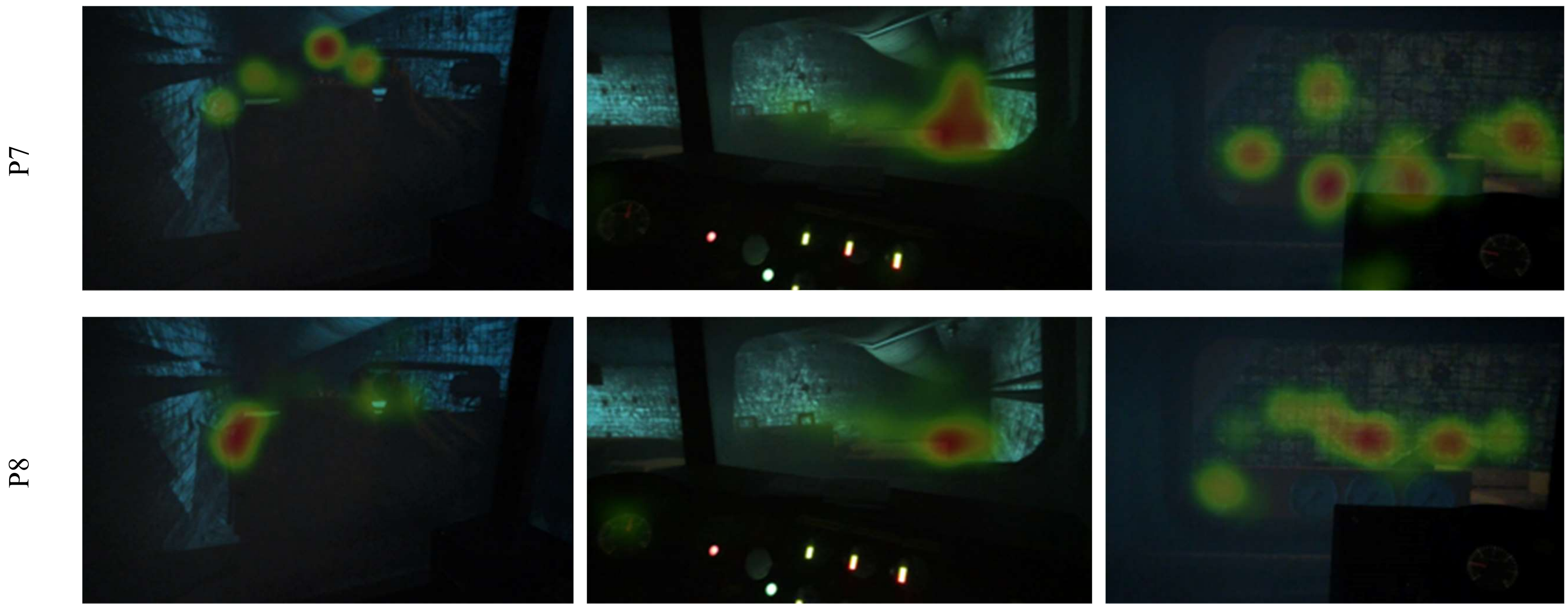
P8



REARWARD




P4
P5
P6


P7
P8

Appendix L: Gaze maps of novice operator’s gaze behaviour while driving the LHD forwards and rearwards on day four of training.

FORWARD

Front View | Rear View | Side View

P1

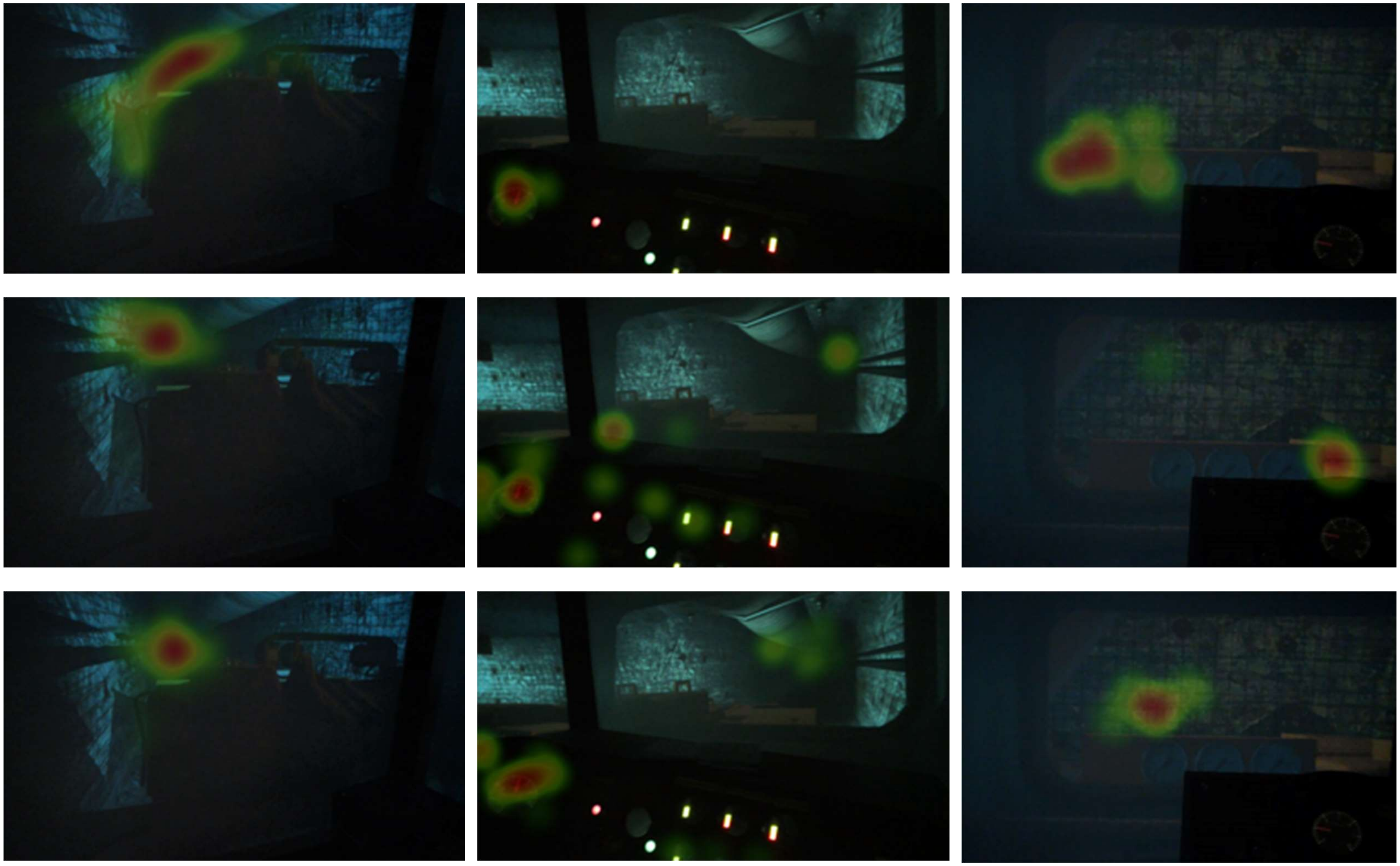
P2

P3

P4

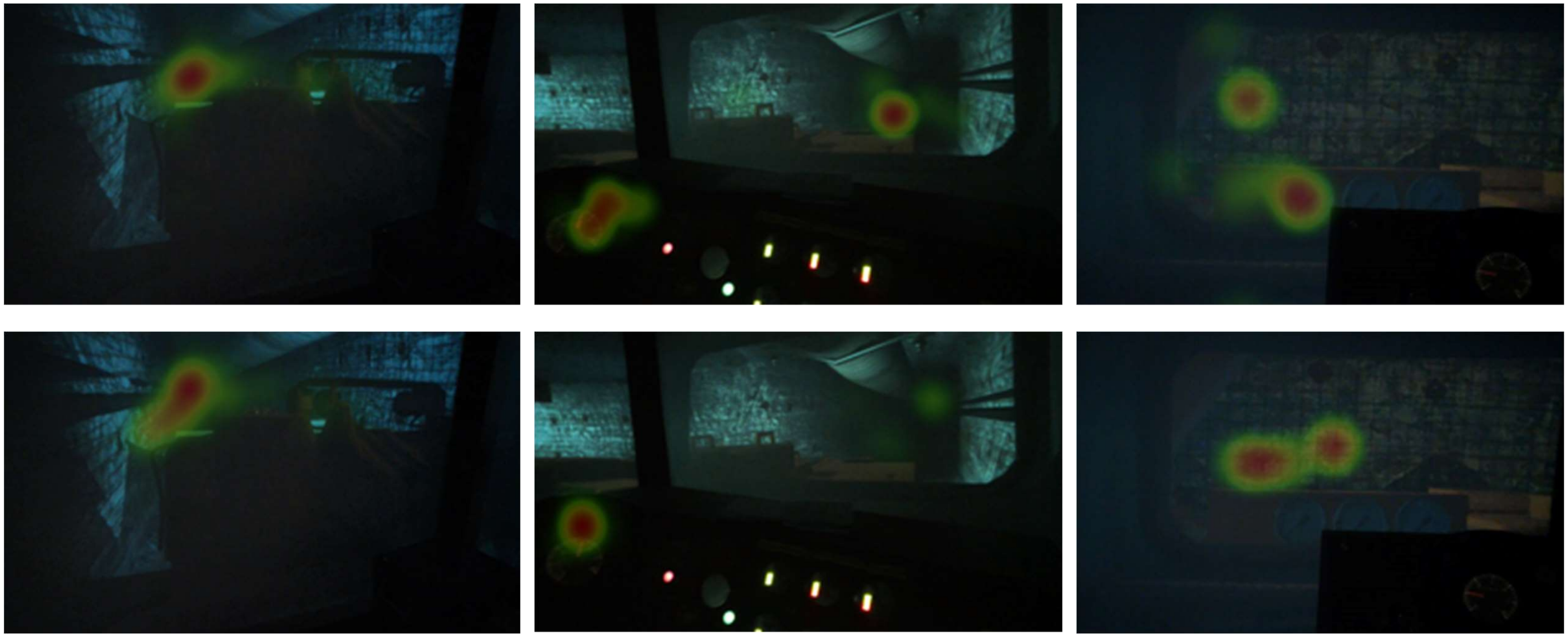
P5

P6



P7

P8



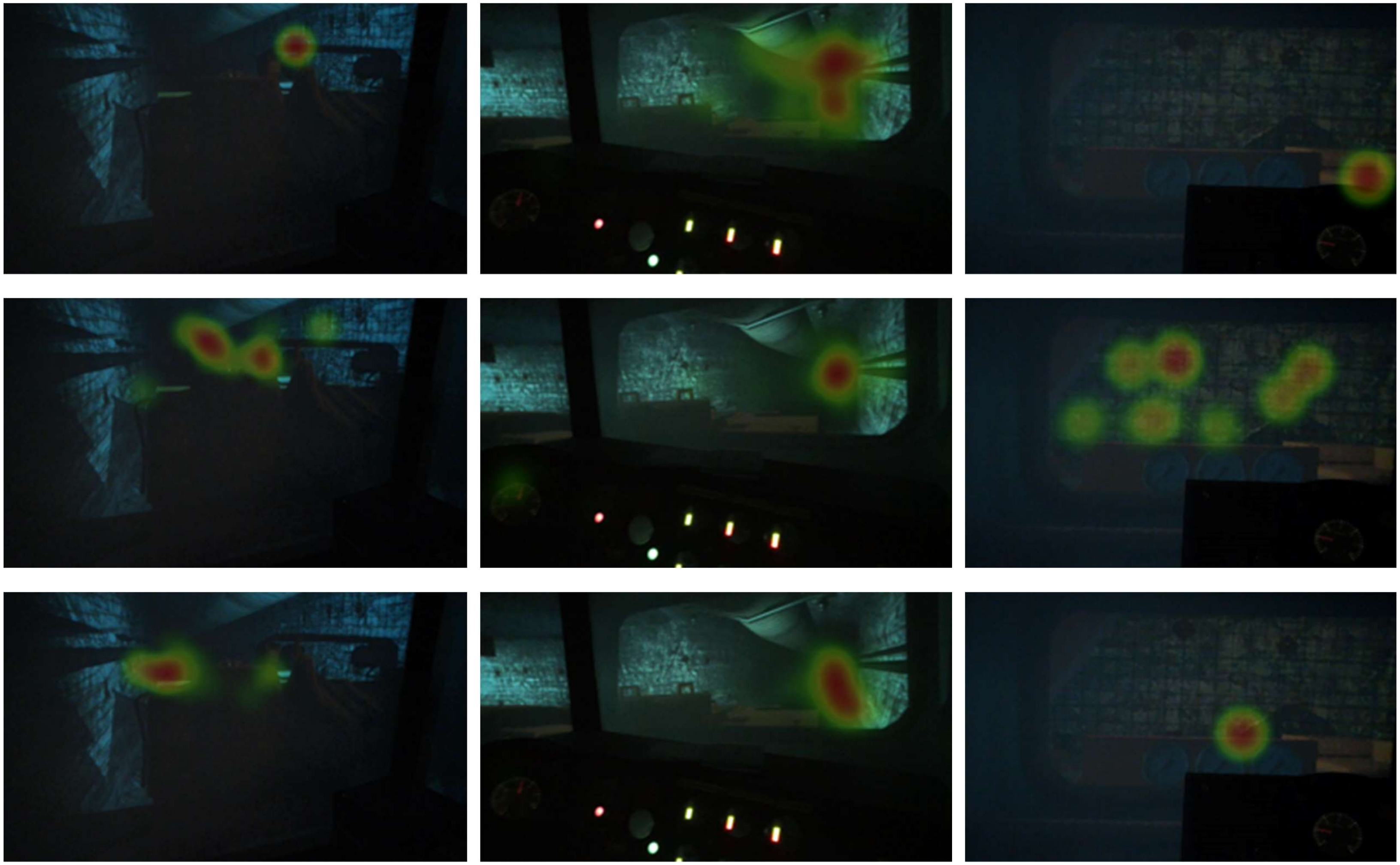
REARWARD

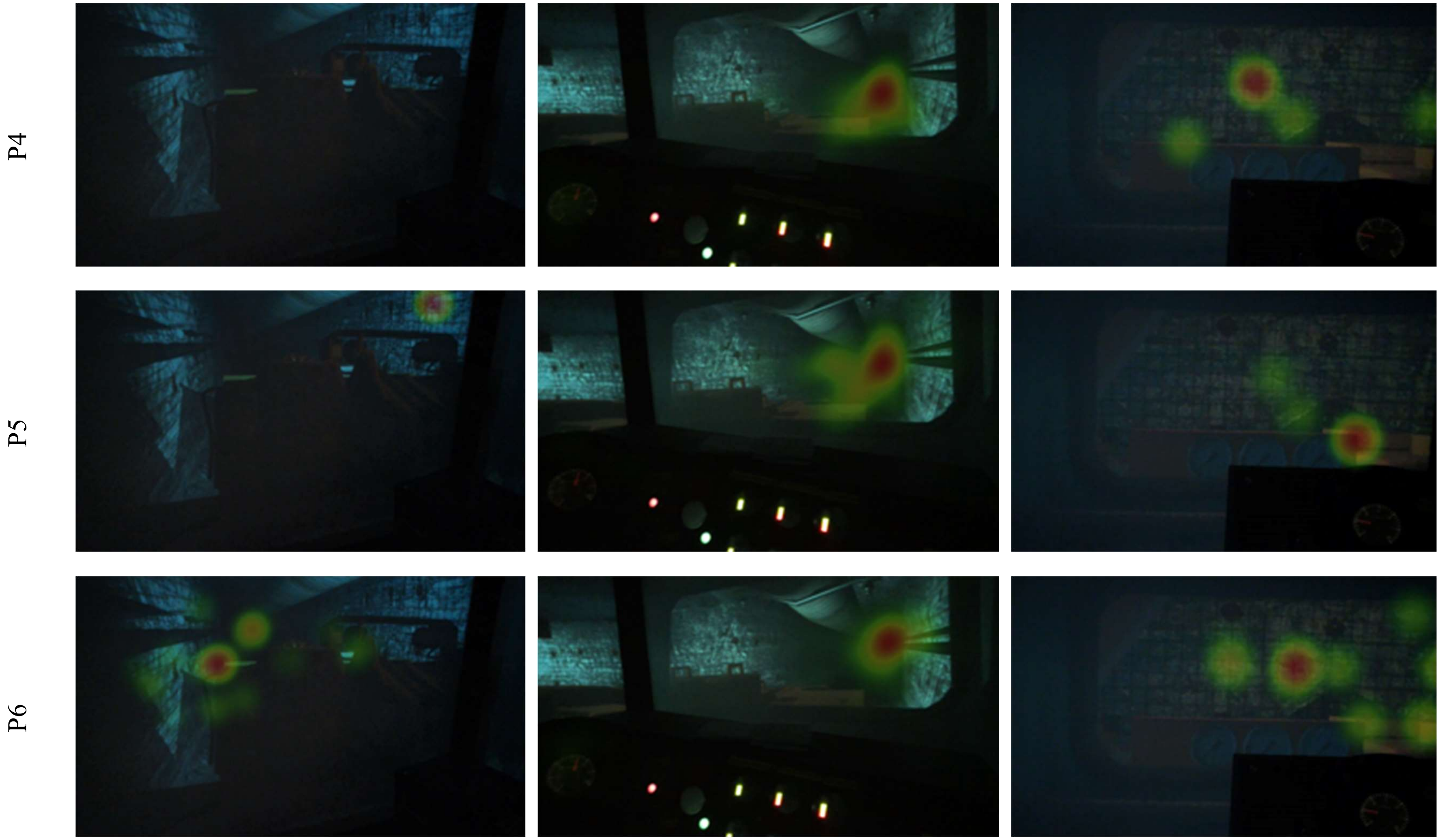
Front View | Rear View | Side View

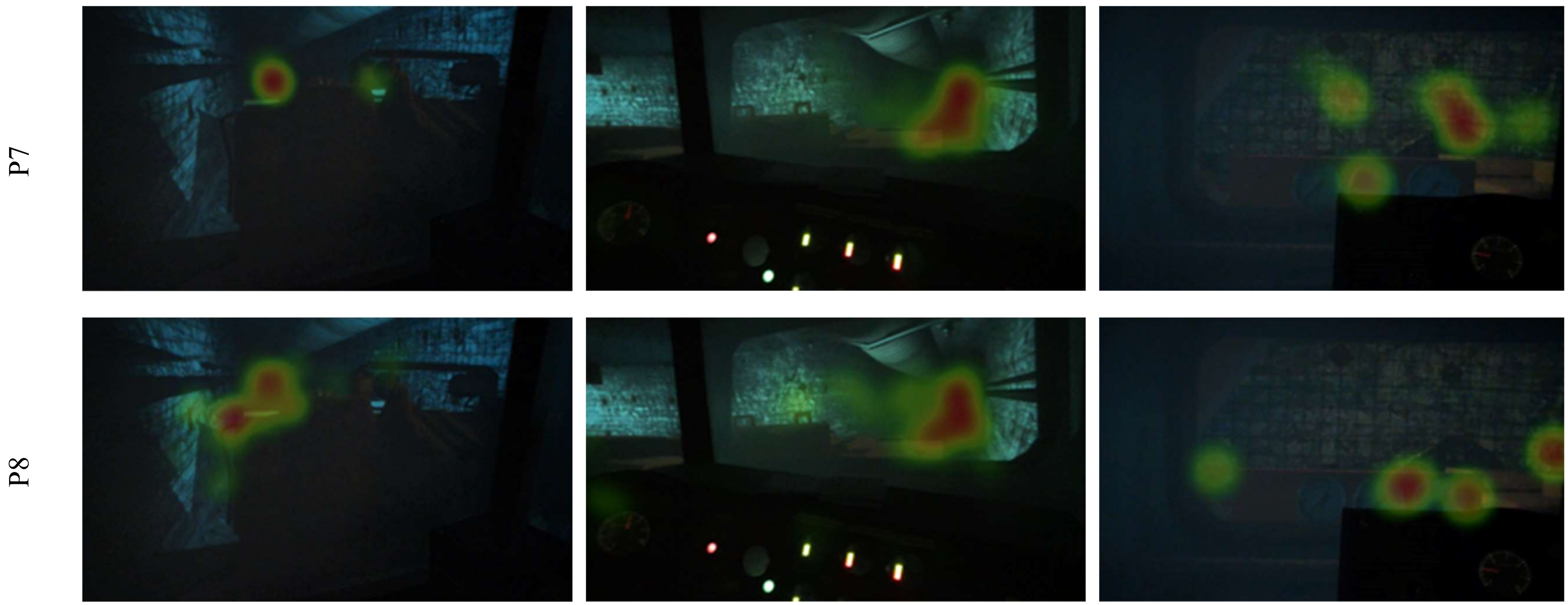
P1

P2

P3




P4
P5
P6


P7
P8