Human Cognition, Behaviour, and Performance in an On-going Dynamic Task

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Abstract

Aim: This thesis aims to address a subset of questions within the broader context of understanding human cognition and performance in complex human-machine environments. The thesis forms part of a larger project focused on implications for military operations and examines basic aspects of human cognition and performance using a non-military participant pool and task. The study investigates general aspects of the elements of piloting an aircraft that were abstracted and investigated in a set of tasks embedded in an interactive driving simulation, a task selected as being more amenable to a non-specialist participant pool. In particular, hypothesises centred around the effects that track difficulty and visual occlusion characteristics (e.g., duration and predictability of onset) have on simulated driving speeds and errors, as well as, subjective cognitive workload. Research questions were positioned to evaluate if EMG and HRV data could be used as predictors of upcoming occlusion or errors, and whether the pairing of quantitative driving performance metrics and qualitative measures of expertise facilitate more robust acquisitions of individual performance.

Method: The interactive driving simulation was based on two race tracks, the first, a simple circuit track and the second, a more demanding track based on the Formula 1 Grand Prix track in Melbourne, Australia. Nine participants (5 males, 4 females) recruited from the general population in Australia were assessed on their performance as they drove the car simulator while experiencing varying levels of visual occlusion aimed to simulate predictable and unpredictable task interruptions. Both quantitative and qualitative measures of effect were analysed. The quantitative

aspect of the study was used to determine individual differences in skill attainment to inform the qualitative analyses to be undertaken.

Results: Hypotheses were partially supported. Both increased track difficulty and unpredictable occlusions led to reduction in driving speed but did not affect driving errors. Increases of visual occlusion intervals increased errors, particularly beyond 3 s. Analyses of HRV and EMG data to evaluate if these measures could be used to predict up-coming visual occlusions and errors reported null findings. Individual quantitative performance data was used to identify higher and lower performing participants to guide qualitative analyses of performance. Qualitative analyses suggested that participants who used more cognitive and psychomotor strategies to counter visual occlusions performed better on the driving task, particularly if they were able to apply their strategies effectively through superior skill execution.

Significance: The findings have implications for defence domains, proposing that when multitasking/task alternating within a human-in-the-loop dynamic environment, military personnel will experience large degradations in task performance if they disengage from one task for durations longer than 3 s. Moreover, these performance degradations remain consistent even if the individual can prepare to disengage from the task or not. The findings also have implications for the development of cognitive models of performance that can be applied to various fields of expertise. Employing a mixed-methods approach offers a robust methodology for analysing performance in interactive dynamic experimental environments. Quantitative performance measures alone do not provide an understanding of an individual's cognitive framework, but when quantitative measures are combined with qualitative analyses it may be possible to develop more targeted individual training and make better predictions regarding which individuals are more likely to succeed in their respective working domain.

Future Research: This thesis is part of a larger research program investigating the human factors associated with automation, multitasking, and performance identification. The current study was the first of three planned studies. Acting as a baseline, this study intended to set temporal parameters that govern one's cognitive capabilities to undertake a second dynamic task without impacting significantly on the primary dynamic task. The second study should aim to investigate the spatiotemporal parameters governing the ability to retrieve information from a briefly-presented text message, and the third study should combine the two dynamic tasks into a single experiment to test predictions regarding the cognitive, behavioural, and performance implications of undertaking two simultaneous dynamic tasks under different task priorities. Furthermore, it is imperative that future research continues to develop rigorous, but practical methods which have sufficient ecological validity to be used for applied work. Lastly, it is hopeful that this thesis will facilitate mixed methods research into being a standard approach for future research in this area.

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Declaration by Candidate

I declare that this thesis does not incorporate without acknowledgment any material previously submitted for a degree in any University, College of Advanced Education, or other educational institution, and that to the best of my knowledge and belief it does not contain any material previously published or written by another person except where due reference is made in the text. I further declare that the ethical principles and procedures specified by the Swinburne University Human Research Ethics Committee have been adhered to in the preparation of this report.

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Abbreviation list

Abbreviation	Explanation
DSTO	Defence Science and Technology Organisation
JOAD	Joint and Operations Analysis Division
AOD	Air Operations Division
RPAS	Remote Piloted Autonomous Systems
IVIS	In-vehicle information system
AI	Artificial Intelligence
PLATO	Portable Liquid crystal Apparatus for Tachistoscopic Occlusion
sEMG	Surface Electromyogram
HRV	Heart rate variability
ANOVA	Analysis of Variance
EP	Easy track with predictable visual occlusion sequence
EUP	Easy track with unpredictable visual occlusion sequence
HP	Hard track with predictable visual occlusion sequence
HUP	Hard track with unpredictable visual occlusion sequence
P 1; 2; 3; 4; 5; 6; 7; 8; 9	Participant (Identification number)
NASA-TLX	National Aeronautics and Space Administration Task Load Index
MD	NASA-TLX: Mental demand
PD	NASA-TLX: Physical demand
TD	NASA-TLX: Temporal demand
Pe	NASA-TLX: Performance
Fr	NASA-TLX: Frustration
EF	NASA-TLX: Effort

Chapter 1. Background

This thesis is part of a larger project funded by the Defence Science and Technology Organisation (DSTO)[1] investigating the human factors associated with automation, multitasking, and performance identification. The project was tasked by the Joint and Operations Analysis Division (JOAD) and Air Operations Division (AOD) to investigate what workload demands are placed on the human operator while interfacing with complex machine environments such as Remote Piloted Autonomous Systems (RPAS). This thesis aims to address a subset of questions within the broader context of understanding human cognition and performance in complex human-machine environments. While the larger project is focused on implications for military operations, this thesis examines basic aspects of human cognition and performance using a non-military participant pool and task, to set a benchmark that may be extrapolated into the defence environment. The task characteristics and performance requirements relate to aspects of human performance abstracted from the more demanding military operational domain.

Military air operations are by their nature hazardous, and training for such operations also involves exposure to risk on the part of both trainee and instructors. While some missions are routine, many missions have singular aspects that make demands on operators that they may not have exactly experienced previously. Furthermore, recent technological growth has facilitated the development of new vehicle types, instruments, control interfaces and increased automation, and there is uncertainty about the likely impact of these technologies on human performance (Cummings & Mitchell, 2008; Miller & Parasuraman, 2007).

Technological advances have now made available aircraft known as RPAS that are flown remotely by operators. RPASs are able to endure sustained and high g-forces and long duty periods, and these advantages, together with there being no airborne crew at risk, make RPASs an attractive alternative to manned aircraft in many aviation scenarios (Miller & Parasuraman, 2007). Typically in military

[1] Note that DSTO and AOD have been restructured and renamed since the funding for this project was awarded. DSTO is now Defence Science and Technology Group, and AOD is now Aerospace Division.

scenarios, RPAS crew undertake navigation or target search functions, with the flying itself often being automated (Cummings, Bruni, Mercier, & Mitchell, 2007; Cummings & Mitchell, 2008; Wasson, Liu, & Macchiarella, 2007). Automation of some of the more routine aspects of flying, such as maintaining flight and adherence to a flight plan, and the introduction of artificial intelligence (AI) agents to oversee these functions has been deemed desirable (Kaber & Endsley, 2004). However, the integration of AI into RPAS operation and determining a set of principles for the development of optimal operator interfaces has proven to be difficult (Fuchs, Borst, de Croon, Van Paassen, & Mulder, 2014; Ruff, Narayanan, & Draper, 2002; Wickens, Clegg, Vieane, & Sebok, 2015). While RPAS operator workload can be decreased by automating some related tasks (e.g. system failure monitoring) and by the use of AI, it has been realised that RPAS also have the potential to impose workload demands (e.g., navigating and monitoring for targets or system parameters) that exceed the cognitive capacity of a single operator (Dixon & Wickens, 2003).

A perceived need to reduce the sensory and cognitive demands of RPAS operators has been one of the drivers for increasing automation (Dixon, Wickens, & Chang, 2005; Levinthal & Wickens, 2006). In particular, crew can be assisted by automating tasks that commonly would require constant manual control (Cottrell & Barton, 2013). However, the level of task automation has been found to influence the behaviour and performance of operators (Endsley & Kaber, 1999). Highly automated systems, where the human operator has little control over the level of automation or the task itself, can result in operator complacency, such that if there is a system malfunction, errors might go unnoticed. Alternatively, inadequate automation, where the human operator is required to make decisions and initiate some actions with minimal assistance, can result in sensory and cognitive overload, leading to a commensurate decrement in performance. Therefore, understanding the nature of human performance (i.e., how humans behave while engaging in a task and why some individuals perform better than others should) provides directions for training and task automation guidelines, and in turn promote higher task performance. As Squire and Parasuraman (2010) state, a better understanding of human factors may enable more efficient operations, opening the possibility of operators controlling more RPAS than are presently feasible.

Squire and Parasuraman's (2010) recommendations are relevant to the aviation domain, as aircrew operate in dynamic multitasking environments with varying levels of task automation, giving rise to new sensory and cognitive demands that have not been thoroughly investigated. Therefore, it is important to investigate the capacity of human information processing and the limitations that it might impose on multitasking in dynamic environments. It is also important to identify the salient sensory and cognitive factors in successful multitasking, in order to offer additional insight into the nature of the expertise required for specific domains.

High level expertise has domain-specific elements, but also there are more generic elements of mastery that can be abstracted from specific domains. In the research reported in this thesis, theoretical aspects of the general elements of controlling a vehicle were abstracted from the aviation and RPAS domain and investigated in a set of tasks embedded in an interactive driving simulation. The type of simulation tool that was used in this research project, while not directly relatable to the air domain, is commonly used by pilot crew driving land-based autonomous systems with a human-in-the-loop in the Army context. Participants drove on two simulated race tracks, an 'ideal' simple circuit track, and a more demanding track based on the Formula One Grand Prix racing track in Melbourne, Australia. Visual occlusion spectacles were used to limit visual information available to the driver for varying visual occlusion intervals presented in either a predictable or unpredictable sequence. These visual occlusions were used to simulate task interruption, as a precursor to interleaving a secondary task (task switching) with the primary driving task. The research used a mixed methods approach involving quantitative and qualitative measures of effect to assist with the development of constructive models of military air operations, including future operations that may involve RPAS. The mixed methods approach aimed to develop a better understanding of new strategies of information processing that may warrant adoption in training regimes for military personnel in complex human-machine environments involving increasing automation and multiple entities.

The structure of the current thesis begins with a literature review covering previous research that investigated the cognitive and performance implications of task switching, multitasking, and imposed visual occlusions in driving situations, culminating with the aims for the research. This is followed by the "General

Methodology and Methods for the Experiment" chapter that explains the methodology of the study and describes the apparatus, materials, design, and procedure of the research. The "Results and Discussion" chapter reports the data acquired and analyses conducted. Due to the sequential nature of the mixed methods data analyses, each set of results is discussed briefly before proceeding to the next analysis. Lastly, the "General Discussion" chapter links the findings with previous research and presents the implications of the research for the field, along with suggesting directions for further research.

Chapter 2. Literature review: Capturing and modelling cognitive processing

Chapter Overview

The following sections describe previous experimental paradigms in task switching, current theories of mental workload, and relevant research involving visual occlusion. Each of the sections will address specific elements of the experimental framework of the current thesis. Firstly, the Task Switching section will address initial attempts to identify both the cognitive mechanisms and performance implications of engaging in various task switching scenarios. It will discuss the various paradigms and variable manipulations implemented and the theories proposed to explain their findings. The Cognitive Workload section will discuss how previous researchers have conceptualised workload and how increased workload demands lead to task performance decrements. The section will also address the task characteristics that allow humans to multitask effectively. The Visual Occlusion section will address how visual occlusion research has been used to investigate car driver distractions and the use of in-vehicle information systems during driving. The final section of this chapter will reiterate the aims of the research presented in this thesis and outline how these aims will be addressed.

Task switching paradigms

Jersild (1927) was the first to document performance implications of task switching through the employment of basic task alternation trials, which he termed mental shifts. He developed a number of experimental designs, directing participants to engage in a range of task alternations, varying in task type. For example, task types and their paired alternation included having participants read through a list of numbers and verbally add 6 to a number then subtract 3 from the following number, or verbally name the antonym of a word then name an associative object for a verb. Jersild noted that shifts between tasks incurred, added expenditure in both time and effort. In order to measure performance, Jersild used a stopwatch to record the time intervals taken to switch between tasks as well as the accuracy of responses. As expected, time interval variations and inaccuracies occurred during task switches and these were dependent on a number of factors such as task difficulty, task similarity and training.

Influenced by Jersild's (1927) mental shift experiments, further research into task switching has been conducted under more controlled experimental designs with the use of more objective measurement instruments (Altmann, 2007; Chevalier, Blaye, Dufau, & Lucenet, 2010; Rogers & Monsell, 1995). The original method used by Jersild was a paradigm that compared the trial completion time and accuracy between single task block trials and mixed task block trials (Kiesel et al., 2010). Single task block trials are those that repeat tasks (*AA* or *BB*), while mixed task block are trials that alternate between tasks (*ABA* or *BAB*). It was proposed that by using the trial completion times and errors recorded in the single block trials as a base performance level, it would be possible to identify task switching performance differences by the comparison of the trial completion times and errors with the mixed task block.

This alternative tasks paradigm was criticised due to its assumption that maintaining mental models for single task block trials requires the same cognitive demands as maintaining mental models for mixed task blocks (Rogers & Monsell, 1995). More specifically, participants undertaking a mixed task block trial had to remember the rules and goals of both tasks as compared with single task block trials where participants only need to remember one set of rules and goals (Logan, 2003). It was proposed that the requirement to remember multiple sets of rules could impose higher demands on memory. Therefore, this experimental design would potentially record performance differences as a consequence of memory load rather than the cognitive processing for task alternations. It was also postulated that participants in mixed task block trials were required to monitor their task position in the sequences in order to remember which task rules to employ. However, no such monitoring was required in single block trials. Further, the requirement for participants to monitor their task switching trial could cause higher cognitive demands that exaggerate the performance differences between mixed task blocks and single task block trials.

Rogers and Monsell (1995) developed the alternative runs paradigm as an improved task switching paradigm. This paradigm integrated the single task block repetition trials and mixed task block alternation trials to create a predictable sequence (a run). Therefore, rather than employing the alternative task method that evaluates performance through disjointed mixed task block (*ABAB*) and single task block (*AA*, *BB*), the alternative runs paradigm (*AABBAABB*) consists of one short predictable run containing of both task repetitions and alternations (Kiesel et al., 2010; Logan, 2003). The short predictable runs of the alternative runs paradigm addressed concerns surrounding increased memory loads during the alternative task paradigm (Logan, 2003). When participants engaged in an alternative runs task they incurred the same memory load and task-monitoring load during both task repetitions and alternations. Hence, while experiments employing the alternative runs paradigm also produced increased reaction times and errors during the task alternations compared to task repetitions, Rogers and Monsell postulated that the performance results were more indicative of task switch mechanisms than increased memory load.

Debate arose around what the cognitive mechanisms of task switching were and how these processes were responsible for the performance costs (Altmann, 2004; Logan, 2003) and new task switching paradigms were employed to investigate task switching implications across different laboratory settings. Meiran (1996) employed an adaptation of Shaffer's (1965) unpredictable task-cueing paradigm as a complement to Rogers and Monsell's (1995) alternative runs paradigm. Meiran acknowledged the concerns surrounding the alternative task paradigm but also questioned the alternative runs paradigm, citing potential effects of predictability of task alternation/task repetition sequence and consistent time durations between task alternations and task repetitions. Meiran addressed these considerations by firstly employing explicit cues to direct the participant either to repeat or alternate between tasks. The explicit cues that directed participants to either repeat or alternate between tasks were random, with the potential for trial runs to consist of task repetitions and task alternations in an unpredictable way. Meiran also manipulated the time period between the cue and target stimulus (cue-stimulus interval). Varied cue-stimulus intervals were used to evaluate the performance of preparation time for both task repetition and task alternation. Results supported the performance difference reported by research employing both the task alternating and alternative runs paradigms, with longer reaction time and more errors during task alternations than task repetitions (Meiran, 1996). Results also revealed that when cue-stimulus intervals are longer, reaction times are quicker and accuracy improves. However, the explicit cue paradigm has been criticised, as it has been postulated that additional performance costs occur when cognitively processing the cue for instructions (Logan & Bundesen, 2004). This suggests that using this paradigm records an exaggerated cognitive penalty of repeating or alternating between tasks. Hence, not capturing the distinctive cognitive processing requirements to alternate between tasks.

Rationale for task switching performance decrements

Research across numerous task switching experiments using various experimental designs consistently documents longer reaction times and poorer accuracy when alternating between two tasks in comparison to repeating a single task (Altmann, 2007; Hughes, Linck, Bowles, Koeth, & Bunting, 2014; Logan, 2003; Meiran, Chorev, & Sapir, 2000; Monsell, 2003; Rogers & Monsell, 1995; Strobach, Liepelt, Schubert, & Kiesel, 2012). These performance decrements were described as switch costs, and while the notion of switch costs has become widely used in task switching research (Wylie & Allport, 2000), debate has ensued pertaining to the underlying mechanisms giving rise to these performance decrements (Logan, 2003). Researchers have attempted to understand these underlying mechanisms with the aim of developing methods or systems that can reduce or eliminate task switching performance decrements (Braver, Reynolds, & Donaldson, 2003; Logan, 2003; Squire & Parasuraman, 2010).

Firstly, there is debate over whether the ability to switch between tasks is an executive control function (see for example Baddeley, 2012; Norman & Shallice, 1986, for models of executive control within working memory and attentional control respectively) or another cognitive process (Logan, 2003; Wylie, Javitt, & Foxe, 2003). Empirical research has supported both arguments. For example, task switching appears to require time to recalibrate to a new task, over and above the time required purely for task-scheduling that would be undertaken by an executive control function. This preparatory reconfiguration (Rubinstein, Meyer, & Evans, 2001) has been hypothesised to consist of two mechanisms (Dreisbach & Haider, 2006; Meiran, 1996; Meiran et al., 2000). The first mechanism pertains to goal activation, where declarative memory is updated to provide the individual with an understanding of the new task's objective and demands. The second mechanism pertains to rule activation, where procedural memory is updated to provide the individual with specific task instructions and the sequence of procedures that permit the individual to undertake the task competently. Previous research has supported this view in experiments that compare performance when the participant is allowed time to prepare for up-coming task alternations compared with when no preparatory time is allowed (Altmann, 2007; Meiran, 1996; Monsell, 2003). The preparation effect is evidenced by decreases in reaction time and increased accuracy when participants are provided with more time to prepare for a task switch. It is argued that by providing participants with preparation time, prior to the alternation of a task, they have sufficient processing time to select the alternate task and also to recalibrate for this new task's demands.

Alternative explanations of switch costs postulate theories with the absence of supervisory (unitary non-modality-specific) executive control (Allport, Styles, & Hsieh, 1994). Allport et al. (1994) conducted a number of experiments investigating the role of executive control during task alternations. They implemented adaptations of Jersild's (1927) alternative tasks, asking participants to alternate between one and two task features (Allport et al., 1994). In their experiment, participants were instructed to make two types of numerical judgements, identifying the parity (odd/even) or magnitude (more than or less than 5) of two types of stimulus dimensions (either the value of the number within the matrix (V) or the quantity of identical numbers within the matrix (G)). Participants were presented with a 3x3 matrix that could contain up to nine identical numbers ranging from 1-9 (excluding 5) but which were incongruent from each other. In other words, the quantity of identical numbers presented in the matrix was never the same as the number value. Participants were measured on the time taken to complete a list of seven matrices across a variety of conditions. These included a baseline when the participant repeated the task (V/Odd-V/Odd; G/Odd-G/Odd); a numerical judgement alternation while controlling for stimulus dimension (V/Odd-V/More); the alternation between stimulus dimensions while controlling for numerical judgment (V/Odd-G/Odd); and the alternation between both numerical judgement and stimulus dimension (V/Odd-G/More). It was hypothesised that, due to the previous descriptions from researchers (e.g., Baddeley, 1986; Norman & Shallice, 1986; Posner, 1982) advocating an executive control system that is unitary and limited in capacity, list completion times should be longer when alternating between two task features (e.g., numerical judgements and stimulus dimensions) in comparison to alternating between one task feature (Allport et al., 1994). However, results indicated that there was no difference between list completion times when alternating between one or two task features. Allport et al. suggested that perhaps switch costs were in fact not caused by preparatory reconfiguration but rather by proactive interference from the previous task set. Other empirical research has supported this finding, revealing that switch costs are larger when participants are required to switch from less practiced tasks to more practiced tasks (Logan, 2003; Minear & Shah, 2008). This is contrary to expectations as researchers predicted that the less practiced task should require more executive control processing to prepare for it, thereby increasing the duration to switch to it. This finding, labelled task set inertia, supports task switching in the absence of executive control (Gilbert & Shallice, 2002).

Summary

The above highlights salient experimental designs, findings and theories that provide direction for the current study's design. All experiments reveal longer response times and more errors when participants are required to switch tasks. Experimental manipulations, such as predictable sequences of task switches and directional task cues, were shown to influence task performance. However, most research uses simple discrete tasks with simple discrete cues to indicate what needs to be done next. While different task and cue configurations can create complex cognitive demands, the tasks themselves are not dynamic, ongoing tasks requiring extraction of relevant cues from the task environment. The major source of complexity in these task switching paradigms is in identifying from the predetermined cues which simple task is currently of highest priority. Therefore, it is not surprising that the role of the executive control mechanism responsible for planning and allocation of cognitive resources would be the focus of theorising and that explicit executive control is not required in practised tasks.

In regards to findings suggesting that switching from less-practiced tasks is more difficult than switching away from more-practiced tasks may suggest that the execution of more-practiced tasks does not require specific executive control functioning and relies on procedural memory. Meanwhile, execution of less-practiced tasks appears to rely on the executive control functioning and work with the procedural memory to ensure sufficient completion. The increased time required to disengage from less practiced tasks may be an outcome of the requirement to deactivate more cognitive mechanisms and store relevant parameters for task resumption in less-practiced tasks to then switch to more-practiced tasks.

The proposed cognitive mechanisms involved in task switching in these experiments are likely to be the same mechanisms used in more ecologically valid tasks requiring skilled performance in dynamic ongoing environments. In the real-world context, the executive control system would select and prioritise the sequence of task execution undertaken by procedural memory while ensuring that the task rules and goals are followed. For example, while driving a car on a suburban road, the executive control system would prioritise and regulate a number of sub-tasks for the procedural memory to complete in order to arrive safely at the desired destination. This may include directing the procedural memory to monitor and regulate speed to make sure the car remained within the specified speed parameters, as well as ensure that appropriate driving lines are maintained so the car is driven safely within the designated traffic lines. Therefore, the procedural memory's role would then be to execute the sub-tasks as effectively as possible under the constraints given and monitored by the executive system. This interplay between the two systems is an important consideration when evaluating performance, as good performance is likely to involve both superior regulation of task execution by the executive control system (e.g., monitoring outcomes and goal priorities within the constraints of the task) and greater proficiency of procedural memory in execution of the specific skills required to execute the task.

Experiencing Cognitive Workload

The task switching studies described above explored the mechanisms and performance costs associated with task alternations in simple tasks in static environments, but there are limitations in transferring findings to more ecologically valid dynamic task environments. Research into cognitive workload has explored performance implications that occur while engaging in more dynamic multitasking environments over longer periods of time (Wickens, 2008). This research identifies the task parameters and characteristics of simultaneous tasks that lead to greatest performance decrements and highest levels of cognitive workload, and addresses similar issues as the task switching literature, but often without direct reference to task switching *per se*.

Empirical research has shown that multi-tasking often incurs heavy workload demands for an individual, which are assessed through the overall performance outcomes and self-reported workload scales (e.g., NASA-TLX workload scale) (Diekfuss, Ward, & Raisbeck, 2016; Hart & Staveland, 1988; Sanjram, 2013). Workload in multi-tasking environments increases as tasks become more complex and tasks require intra-modal processing, for example, engaging in (and presumably switching between) two visual scanning tasks simultaneously (Wickens, 2002). If workload becomes too high, decrements in task performance occur. These performance decrements often occur in the form of increased reaction time to respond to one or more of the tasks or through committing task errors. Individuals can take two approaches to dealing with these performance decrements. The first is to continue multi-tasking while accepting performance decrements in each task. The second is to engage in one task by ignoring other tasks to ensure at least one of the tasks maintains error-free performance. These decisions by individuals are often directed from either the priorities associated with each task (e.g., one task is more important to maintain than another) or individuals' coping strategies (Calhoun, Ruff, Draper, & Wright, 2011). This is often seen in pilots of drones prioritising safe navigation over monitoring for targets of interest (Calhoun et al., 2011), which is in line with the explicitly-instructed aviation hierarchy of task prioritisation: aviate, navigate, communicate, administrate.

Cognitive resources

When attempting to conceptualise cognitive workload and cognitive resources, some researchers adopt the cognitive capacity approach (Kahneman, 1973; Wickens, 1980, 1984, 2002, 2008). Typically, they propose a cognitive processing system that requires cognitive or attentional resources to operate efficiently while undertaking tasks (Hirst & Kalmar, 1987). Depending on the theoretical framework adopted by researchers regarding cognitive processing systems, cognitive resources have been proposed to operate in different ways.

Kahneman (1973) popularised the cognitive capacity approach through his conceptualisation of a pool of attentional resources that could be expended in the form of mental effort. In Kahneman's view, an individual directs their mental effort to tasks for completion. However, there is a finite amount of mental effort, and its available capacity depends on both task demands and the arousal level of the individual. Kahneman suggests that mental effort is the interplay between task demands and arousal levels, in that together these two factors dictate the quantity of attentional resources that are available to complete the task. Firstly, the task's demands are presented and reveal how much attentional resources need to be made available for task completion. To then access the required attentional resources, an appropriate level of arousal must be met, with higher task demands requiring higher arousal. Together this cognitive process dictates how much mental effort can be applied to a task.

Following on with Kahneman's (1973) cognitive capacity approach, decrements or failures in performance occur due to high task demands that exceed the attentional resource capacity, and under or over arousal levels. As the cognitive system is proposed to have a finite amount of attentional resources, if task demands exceed the capacity of attentional resources available decrements in performance will occur. Similar performance decrements will occur in the case of under or over arousal levels. In cases of under arousal, it was suggested that individuals are unable to access the required attentional resources to fulfil the task demands, therefore not exerting enough mental effort to complete the task. Performance failures due to over arousal were proposed to be the consequence of the inability to control attention, leading to failure to fixate on relevant cues to guide actions. When completing simple tasks, Kahneman postulates that it is not possible to voluntarily direct more mental effort than the task demands. For example, an individual is unable to increase their mental effort when mentally rehearsing four numbers for ten seconds. Future attentional capacity theories distinguished mental effort from resources, with attentional resources being relabelled as cognitive resources and effort being reconceptualised as a motivation term (Gruszka, Matthews, & Szymura, 2012).

Multiple resource theory

Inspired by Kahneman's (1973) research into multitasking and its implications for human processing and task performance, Wickens (1980) developed multiple resource theory as a four-dimensional model of cognitive resources, expanding the single-channel attentional theories such as Kahneman's to a more comprehensive framework for studying the attentional and cognitive limitations in multi-tasking.

Wickens' intention for the multiple resource theory was to provide a practical and theoretical model that evaluates task performance during multi-tasking situations. From a practical perspective, the theory is intended to assist in predicting whether an individual will be successful in efficiently completing tasks in a multi-tasking environment (Wickens, 2002, 2008) and to assist in predicting what types of task interferences will occur while undertaking different multitasking situations (Wickens, 2002). Wickens proposes that the model constructs of multiple resource theory are analogous to the neurophysiological structures in the human brain that are responsible for task performance.

The four-dimensional multiple resource theory proposes that there are four fundamental categorical cognitive dimensions each with dichotomous levels that account for the variability in multitasking performance (Wickens, 2002). The four dimensions in the model are: *processing stages*, *perceptual modalities*, *visual channels*, and *processing codes* (Wickens, 2002). The levels of each dimension have access to their own reservoir of cognitive resources, used to complete the aspects of tasks that require processing in that level. Interferences that cause performance decrements arise when multiple tasks require simultaneous processing within the same level (e.g., simultaneously engaging in two visual scanning tasks). However, if multiple tasks require processing from different levels (e.g., simultaneously engaging in a visual scanning task while listening for verbal instructions), minimal to no performance decrements should occur (Wickens, 1984).

Processing stages

The stages dimension has three levels: *perception*, *cognition,* and *responding* (Wickens, 1984, 2002). The perception and cognition constructs act according to Baddeley's (2000) working memory model, with stimuli being directed through a stage of sensory processing for further perceptual and cognitive processing (Wickens, 2002). Cognitive resources are then consumed for perception and high-level cognitive processing of the stimuli. Once processing within that level is complete, cognitive resources from the responding level are then consumed in selecting and executing appropriate responses.

Empirical research by Liu and Wickens (1992) has supported interferences in simultaneous tasks requiring perception and cognitive processing. In this experiment participants were directed to simultaneously engage in a tracking task (perceptual) with either a *spatial decision* task (cognitive) or *verbal decision* task (cognitive). Both conditions were met with performance costs in both the tracking task and decision-making tasks. Therefore, these findings supported the argument that the perceptual and cognitive levels of the stages dimension share the same reservoir of cognitive resources. However, the responding level has its own pool of resources, thereby maintaining the dichotomous levels (Wickens, 2008).

Perceptual modalities

The perceptual modalities dimension concerns the processing of visual and auditory stimuli (Wickens, 1984), with the model postulating that the auditory and visual levels each have exclusive access to their own cognitive reservoir. Hence, individuals should be able to engage in two tasks simultaneously if one task is visually based and the other is auditorily based. For example, Parkes and Coleman (1990) conducted an experiment that directed participants to drive a car simulator while interfacing with an in-vehicle information system that presented information either in a visual or auditory format. Driving performance largely deteriorated when participants were interacting with information presented through a visual interface whereas there were minimal decrements in performance when participants interacted with an in-vehicle information system through an auditory interface. Wickens (1984, 2002) suggests that simultaneously engaging in intra-modal tasks (e.g., two visual tasks) causes interference in processing, as there is competition for the same cognitive resources for each task.

Wickens (2008) proposes that the advantage of bi-modal perceptual processing over intra-modal processing is not exclusively due to the utilisation of separate resources, but is also due to a reduction of structural interference between the tasks and their associated cues and stimuli. By structural interference, Wickens suggests that peripheral factors negatively impact on intra-modal processing. For example, when engaging in two visual tasks, additional processing costs will occur if visual stimuli are too dispersed and require visual scanning for location (Liu & Wickens, 1992). Conversely, when engaging in two visual or auditory tasks, if stimuli are presented too close together, confusion and masking (the inability to distinguish between stimuli) can occur. This suggests that there are numerous factors that contribute to the performance difference between intra-modal and bi-modal dynamic task switches.

Research by Murray, De Santis, Thut, and Wylie (2009) investigated how switch costs between task alternation requiring bi-modal processing differed from tasks requiring intra-modal processing. They found that switch costs were less in bi-modal alternations compared with intra-modal processing. However, Murray et al. utilised static tasks such as tone frequency detection and living versus man-made object categorisation. Therefore, while it might be expected that bi-modal processing will generate lower switch costs than intra-modal processing, the magnitude of differences between bi-modal and intra-modal processing for dynamic task alternations is not known.

Visual channels

The two levels of the visual channel in multiple resource theory are referred to as *focal vision* and *ambient vision* (Wickens, 1984, 2002, 2008). Focal vision involves the sensory receptor area (the fovea and para-foveal region of the retina) responsible for perceiving fine detail in visual stimuli resulting in pattern and object recognition. Ambient vision refers to the perception of the visual environment (predominantly through peripheral vision), and perceiving orientation and self-motion (Wickens, 2008). These two aspects of visual processing complement each other during multitasking situations, as they are functionally responsible for processing different kinds of information. Typically, switch cost studies have investigated task alternation in focal vision. While alternating between dynamic tasks, participants will typically be required to use both focal and ambient vision, which may impose additional performance decrements. Conversely, ambient vision could reduce switch costs as it could be used to maintain the location of important stimuli. This was also demonstrated by Posner's (1980) experiment, suggesting individuals can pick up movements in ambient vision when focally attending to a fixed point.

Codes

The codes dimension pertains to executing responses to stimuli (Wickens, 2008). The dichotomous levels of this dimension are analogue-spatial processing and categorical-symbolic (linguistic) processing. The analogue-spatial processing refers to responses to stimuli involving manual manipulations of an object (e.g., applying pressure to an accelerator in a vehicle). The categorical-symbolic processing refers to responding to stimuli with verbal output (e.g., verbally answering a question). Like all the dichotomous levels, the analogue-spatial processing and categorical-symbolic processing have their own distinct cognitive reservoirs and do not compete for cognitive resources. For example, research findings have revealed that participants experience no processing interferences when required to respond to stimuli manually and verbally concurrently (Wickens, 2002). However, interferences occur when individuals are required to respond to stimuli manually for two tasks (e.g., driving a vehicle while dialling a mobile phone), leading to failures to respond appropriately in one of the tasks.

These kinds of findings can help to identify when it might be appropriate or necessary to swap between spatial or verbal responses during multitasking situations in order to maintain higher performance levels across simultaneous tasks. For example, on the basis of these findings, it might be desirable to modify in-vehicle information systems to interchange the manual responses (touch command) with verbal responses (voice commands) in cars due to the already large spatial and manual response demands that are imposed on the users as they navigate (Lansdown, Burns, & Parkes, 2004). By removing the additional requirement to interface with an in-vehicle information system manually and replacing it with a voice command option, individuals should be able to maintain greater vigilance in navigation.

Cognitive and perceptual load

While Wickens (1984, 2002, 2008) was primarily researching in the applied cognition domain, Lavie (1995, 2005) extended research in the cognitive psychology domain proposing theories for perceptual and cognitive load. As aforementioned, Wickens (2008) modelled cognitive and perceptual processing under that same level in the processing stage, proposing that the two processes compete for cognitive resources. However, Lavie (1995) approached cognitive and perceptual processing as distinct functions, similar to Baddeley and Hitch’s (1974) working memory model. The cognitive component was suggested to be a processor of the executive control, responsible for decision-making and reasoning. The perceptual components were suggested to be processes from both the visuo-spatial sketchpad and phonological loop, each responsible for processing visual and auditory stimuli, respectively. Hence, Lavie (1995) investigated both the perceptual and cognitive processes independently.

Lavie (2005) conducted a literature review investigating the effect of high perceptual load and cognitive load on ignoring distractors and maintaining selective attention on specified visual stimuli. Perceptual load pertains to processing demands involved with perceiving and identifying stimuli. Typically, the processing demands for perceiving a single stimulus imposes low perceptual load on the individual. However, when required to attend to multiple stimuli, perceptual processing demands increase. The concept of perceptual load invites the assumption that there is a limited perceptual storage capacity and that high perceptual load is a consequence of reaching the limits of perceptual capacity. Experiments that measure perceptual load typically employ an experimental design that manipulates the quantity of task-relevant stimuli, and the complexity and features of these stimuli (Forster, Robertson, Jennings, Asherson, & Lavie, 2014; Sadeh & Bredemeier, 2011). Distractor stimuli are then paired with the task-relevant stimuli. Findings often reveal that as the quantity of task-relevant stimuli increases, attention to distractors decreases (Lavie, 2005). This has been argued to be a consequence of perceptual capacity overload, where the perceptual system is incapable of processing any more, which prevents attention being directed to the distractors (Lavie, 1995, 2005). This is similar to Kahneman's (1973) claims relating to mental effort, suggesting that when the mental effort has been exhausted, no other tasks can be attended to.

Cognitive load pertains to the processing demands on the executive control system within working memory that is involved in task planning and resource allocation (Lavie, 2005). Load on the executive control system can be generated through the engagement of tasks that require levels of problem solving (Sweller, 1988) and/or the need to remember stimuli (Lavie, Hirst, de Fockert, & Viding, 2004). Cognitive load is varied through the manipulation of task difficulty (e.g., simple or complex arithmetical questions) or through changes to the quantity of stimuli required for remembering. Experimental designs that have been employed to measure cognitive load typically use reaction times to respond to target stimuli in the presence of distractor(s). One popular experimental design employs a flanker task, where participants are directed to respond to basic stimuli (letters, numbers, arrows) in the presence of congruent and incongruent distractors (Lavie, 2005; Lavie et al., 2004; Lavie & de Fockert, 2005). Participants are then directed to remember unrelated stimuli for a task following the flanker task (e.g., remembering a set of numbers). Research that employs this design consistently reports that when participants are required to remember more stimuli (high cognitive load) they are slower to react to target stimuli within the flanker task than when required to remember fewer stimuli (low cognitive load). It is proposed that this is a consequence of an overloaded executive control that is unable to distinguish between the target stimuli and distractors (Lavie et al., 2004).

Criticisms of Lavie and colleagues'(1995, 2004, 2005) research into cognitive load suggest that the target stimuli in the flanker task often had similar properties to the stimuli that were to be remembered (e.g., pairing a target number in the flanking task with a set of numbers for rehearsal) (Park, Kim, & Chun, 2007). Therefore, it was suggested that cognitive load was a consequence of interference through the use of the same cognitive processing mechanisms rather than an interference from distractors. To counter this, subsequent experiments directed participants to remember stimuli that did not share the same characteristics as the target stimuli (Minamoto, Shipstead, Osaka, & Engle, 2015; Park et al., 2007; Robinson, Manzi, & Triesch, 2008). For example, Park et al. (2007) directed participants to remember a picture of a house while identifying whether two human faces on a screen were identical or not. They compared the reaction times with a following condition in which participants were directed to remember a human face while determining whether two human faces on a screen were identical or not. Results revealed slower reaction time in the decision making task when participants were required to remember a face rather than a house. This led Park et al. to suggest that these differences may be a consequence of intra-modal processing interferences rather than distractor processing.

Irrespective of whether the results of Lavie and colleagues (1995, 2004, 2005) are due to perceptual or cognitive aspects of stimulus processing (perceptual load) compared with executive control functions (cognitive load), the experiments provide a clean distinction of performance outcomes when dealing with high perceptual load (stimulus processing) and cognitive load (executive control and resource allocation) under controlled conditions. Experiments investigating perceptual load report that higher perceptual load prevents distractors or irrelevant stimuli from being perceived. Opposite effects are found when cognitive load is high, as individuals are more likely to attend to distractors as the executive control system has exceeded its processing limitations. However, completing tasks that exceed perceptual and cognitive capacity has severe performance implications for the real world as the penalties for failure may come at a high cost. Undertaking tasks in the real world are likely to impose higher demands, as task objectives would most likely contain multiple feature stimuli and have perceptual processing time constraints. For example, while controlled experiments consistently find that higher perceptual load leads to irrelevant stimuli being disregarded, in the real world this could lead to relevant task cues from simultaneous tasks or changes in task priority going unnoticed due to insufficient perceptual processing capacity. Therefore, in task situations where failures have high-cost penalties, it is important to account for the perceptual and cognitive task demands imposed on the cognitive system.

Behavioural indicators of cognitive workload

As delineated in the sports psychology literature, being able to identify indicators of physiological stressors and cognitive stressors can assist in evaluating how an individual is coping in a task. According to the Catastrophe theory, which is based on the Yerkes-Dodson U-shaped curve describing the relationship of arousal and performance (Yerkes & Dodson, 1908), performance outcomes can be predicted by somatic (physiological) arousal and cognitive anxiety (Hardy, 1990, 1996). Somatic arousal refers to physiological anxiety responses, such as sweating, being short of breath, and 'butterflies in the stomach'. In contrast, cognitive anxiety refers to feelings of anxiousness within a situation. Hardy (1990, 1996) postulated that as cognitive anxiety increases, and somatic arousal remains stable, individuals' performance increases. However, as this arousal exceeds a certain threshold that becomes overbearing for the individual, and the onset of the physiological responses of somatic arousal arise, drastic or "catastrophic" performance degradations occur. If the individual is able to manage their cognitive anxiety during the task and mitigate any somatic responses, then they theoretically should be able to manage a sustainable level of performance. Therefore, this theory suggests that biofeedback measures may be key to being able to predict when an individual's performance will be compromised through becoming cognitive overloaded.

Previous research has empirically demonstrated the interplay between increases in cognitive workload and increases in muscle tension activity (Bongers, Kremer, & ter Laak, 2002; Linton, 2000; Rissén, Melin, Sandsjö, Dohns, & Lundberg, 2000). More specifically, heightened cognitive load often results in increased muscle activity in the neck, shoulders, upper limbs, and handgrip tension ('activation') (Bongers et al., 2002; Linton, 2000; MacDonell & Keir, 2005; Schönpflug, 1985). This is argued to be a consequence of the combination of the stress imposed on the muscle area while it is being stabilised for appropriate posture and the incoming cognitive load (Lundberg et al., 1994). Roman-Liu, Grabarek, Bartuzi, and Choromański (2013) demonstrated the positive relationship between cognitive load and muscle activity in their study by examining the role that different levels of cognitive load played in muscle activity in the arms, forearms, shoulders, and neck. Participants were directed to undertake tasks that required different components of attention. For example, one task required participants to continuously focus their attention on a stimulus, while another task required participants to react to incoming stimuli. Using a surface electromyogram (EMG) to measure muscle activity during the trials, the researchers evaluated the muscle activation elicited during each task. The researchers found that there was a positive relationship between mental workload and muscle activity in the arms, shoulders and lesser extent forearms in both the sustained attention and vigilance tasks. However, the temporal properties of this relationship were not reported.

Other biofeedback measures, such as heart rate variability (HRV), galvanic skin response, and pupillometry have been used to indicate heightened levels of cognitive workload (Horrey, Lesch, Garabet, Simmons, & Maikala, 2017; Luque-Casado, Perales, Cárdenas, & Sanabria, 2016; Platten, Schwalm, Hülsmann, & Krems, 2014; Reimer & Mehler, 2011; Thayer, Hansen, Saus-Rose, & Johnsen, 2009). Simulator driving literature has supported the link between physiological arousal and increased workload, postulating that physiological measures are sensitive in identifying increased workload (Mehler, Reimer, & Coughlin, 2012; Mehler, Reimer, Coughlin, & Dusek, 2009; Nishimura, Murai, & Hayashi, 2011; Platten et al., 2014; Son et al., 2011; Tanaka, Murai, & Hayashi, 2014). Using galvanic skin response as a physiological measure to identify increases in cognitive load, researchers directed participants to drive a driving simulator while vocally recalling directed auditory stimuli (Son et al., 2011). Results revealed that as participants undertook more difficult variations of the recall task, the average skin conductance levels increased. Similarly, larger deviations in HRV were also recorded during periods of high cognitive load in marine pilot trainees while navigating a simulated ship (Tanaka et al., 2014). In this study, participants were required to navigate a ship across a number of simulated scenarios (e.g., turning, avoiding other ships, entering or leaving a port). During periods in which participants were required to steer the ship, increases in HRV was recorded. Moreover, the simulation requiring participants to enter or leave a port recorded the largest HRV average. This may have occurred due to the increased psychomotor requirements to dock the ship as well as increased cognitive demands to mentally map the participants' environment while doing so. Hence, both the galvanic skin response and HRV findings support the employment of some physiological measures to identify variations in cognitive workload.

Summary

The cognitive workload theories provide a convenient and understandable conceptualisation of what human cognition and performance implications arise during multitasking. Yet, the conceptualisation of cognitive workload, like theorising around working memory and attention, tends to be primarily data-driven, leading to potentially circular logic that results in models that describe and summarise observations within specific task domains rather than generating substantive theoretical explanations. The observations of multitasking are that task performance declines when multiple tasks are engaged in simultaneously, and that task performance decrements vary depending on task types. Directed by these observations, it was proposed that larger performance decrements are an indication of heavy cognitive workload and, therefore, heavy cognitive workload leads to larger performance decrements. Hence, this explanation describes the performance outcomes rather than the cognitive mechanism involved. These data are aligned with data on task switching in static environments, but do not identify whether multi-tasking performance decrements are due to (or include) the direct costs of switching between tasks, or are predominantly due to the requirements of resource-sharing of limited resources between multiple tasks undertaken simultaneously.

Other methods to measure cognitive workload levels have employed subjective workload self-reports. These self-report measures attempt to gain an understanding of what task characteristics participants perceive to be most loading on their cognitive systems. Participants are presented with items that are labelled with cognitive factors and brief descriptions of these factors, and are asked to rate on a Likert scale how much that item loaded on their cognition. While these scales can reveal perceived characteristics of *task demand*, they tend to be influenced by the perceived *task performance* (e.g., if the participant performed poorly on a task, they tend to perceive that it must have been heavily cognitively demanding). Subjective measures of cognitive workload may therefore also be indirect observations relating more to task performance rather than to cognitive workload.

The multiple resource theory shares the same limitations as the cognitive workload theories as its four dimensions and subsequent distinct levels were developed based on empirical data, rather than being tested by those data. While the theory is influenced by single-channel attentional theories and makes references to cognitive processes in its dimensions, it fails to explain the mechanisms that permit the processing to occur. Instead, the theory employs a cognitive resource approach in which finite resources are directed to levels in dimensions to enable processing to occur. Performance decrements in multitasking situations are then interpreted to mean that the tasks demand too many resources from the same level, consequently leading to insufficient resources to sustain sufficient performance in both tasks. Although this is easy to conceptualise, it still fails to provide an explanation of the cognitive mechanisms in the different levels and why and how they caused performance decrements. While there are some theoretical limitations to multiple resource theory, it nevertheless provides a useful framework for conducting experiments in the applied domain. It provides a useful guideline as to what type of tasks can be expected to cause interference in multitasking situations. Therefore, the multiple resource theory can assist in predicting performance outcomes of various multitasking situations.

Park et al.'s (2007) study of cognitive and perceptual load sided more with Wickens' (2008) model over Lavie's (1995, 2005) theories, suggesting that the perceptual and cognitive processing mechanisms were not distinct and that intra-modal interferences could occur. However, Lavie's (1995) finding on distractibility is particularly relevant to the applied domain. As lower perceptual load increases distractibility and the likelihood of attending irrelevant stimuli while high cognitive load interferes with the ability to maintain selective attention. Therefore, there is a need to create a balance of both perceptual and cognitive load, to promote optimal task performance.

Hardy's (1990, 1996) catastrophe theory postulates that combinations of cognitive anxiety and somatic arousal can assist in predicted future performance outcomes. It is theorised that increased levels of both cognitive anxiety and somatic arousal will cause large decrements in performance. Meanwhile, empirical research has demonstrated the positive relationship between increases in cognitive workload and muscle activation, particularly in the forearms, and shoulders (Bongers et al., 2002; Linton, 2000; Rissén et al., 2000). It has been argued that this response is the consequence of incoming cognitive load and muscle stability requirements imposed on the muscles while undertaking a task. Using various biofeedback tools (e.g., EMG, HRV, galvanic skin response), research has supported biofeedback as a sensitive measure to evaluate cognitive overload (Mehler et al., 2009; Mehler et al., 2012; Son et al., 2011; Tanaka et al., 2014). Hence, biofeedback tools may be useful in predicting future cognitive overload.

The Role of Visual Occlusions

A visual occlusion is the physical obstruction of information from specific regions of the visual field for a set period of time (Gelau & Krems, 2004). Visual occlusion research aims to identify cognitive and perceptual capacities of individuals as they engage in tasks within a dynamic on-going environment by looking at effects on performance of limiting visual input during key stages of specific tasks. For example, sport science research has employed visual occlusion techniques to study anticipatory skills of different sports athletes of different skill level (experts versus non-experts) (Dicks, Button, & Davids, 2010; Elliott, Zuberec, & Milgram, 1994; Rosalie & Müller, 2014). Theses studies aimed to evaluate what visual cues athletes attended to before deciding on and executing an action, and its consequential outcome, and ultimately, directing what information is important to attend to, in order to guide a following action. One study investigated what visual information goalkeepers in soccer attend to in penalty shoot-out situations, in order to prevent influences of deception from penalty shooters (Dicks et al., 2010). This was achieved by visually occluding the goalkeepers at different points as the penalty shooters moved towards the ball (e.g., 4 m from ball; right behind the ball). Deception was defined as the penalty-shooter behaving like they were to kick one way but kick the other (e.g., eye gazing towards the opposite side of the goals). By visually occluding the goalkeepers and preventing them from attending to different kinematic information, it was revealed that effects of deception decreased the later kinematic information was presented. In other words, the later the goal-keeper saw the penalty shooter moving towards the ball the less likely they were influenced from deceptions. Hence, this study was able to identify what useful anticipatory movements should be attended to in order to guide an effective counter-action.

Visual occlusion techniques have also been used in the context of driving a vehicle with the aims of simulating driver distractions, simulating the disengagement from a current task during task alternating or multitasking situations, or measuring the rate of information processing at different driving speeds or visual occlusion durations (Senders, Kristofferson, Levison, Dietrich, & Ward, 1967; van der Horst, 2004). There have been two types of metrics used to assess visual input required for adequate performance. One type is where the participants estimate the amount of time they believe they can be visually occluded to successfully complete a task without mistake. Participants will seek visual input only when required and will be visually occluded for the remainder of the task. The time interval spent unoccluded is assumed to correspond to the attentional demands of the task (Courage, Milgram, & Smiley, 2000; Lansdown et al., 2004; Senders et al., 1967). In other words, longer voluntary visual inspections are an indication of higher attentional demands. The other type of metric used is when the experimenter has control over the occlusion interval and gathers their data based on the accuracy and quality of individual's performance (Gelau & Krems, 2004).

Senders et al. (1967) were the first to employ visual occlusions. Their aim was to investigate the attentional demand a driver would be exposed to while driving across various track features at various speeds, with the aim of determining safe speed limits for different types of terrain. Using themselves as participants, their experimental design required them to drive a car on either a relatively straight highway (easy track) or a closed-circuit track that featured more curves (difficult track). During the trials, they wore a helmet with a mechanical shutter that could be activated to occlude their vision for specified intervals while driving a vehicle on these roads. There were four trial conditions that involved driving on each track while either experiencing fixed visual occlusion and visual inspection times while controlling their driving speed, or fixed driving speeds while controlling the onset of the visual occlusions. For the fixed visual occlusion and viewing time condition, visual occlusions intervals ranged from 1-9 s with Senders et al. measuring maximum speed. They concluded that as drivers had less opportunity to visually inspect the track, the maximum speed of the car decreased, especially on the more difficult track. For the conditions relating to fixed speeds with voluntary control of visual occlusions, Senders et al. investigated how long participants would voluntarily visually occlude themselves before feeling a need for updated visual information to guide their driving. As expected, their results revealed that the drivers occluded for shorter durations during faster driving speed trials, especially on the more difficult track and these findings led Senders et al. to postulate that their experimental design facilitated measuring the attentional demand of various driving situations. They suggested that the frequency of visual inspections undertaken during various track features (e.g., corners) provided a representation of how attentive the driver had to be at that point in time. Their work was used to identify the speed limits required for particular driving situations to allow adequate processing of relevant information.

The work by Senders et al. (1967) inspired a plethora of further research investigating the attentional demands of drivers in a pursuit to validate and expand on their work. Initial efforts were made to model vehicle control through quantitative metrics, such as voluntary inspection time, speed deviation and vehicle parameters (e.g., steering angles; pathline) (Godthelp, Blaauw, & Milgram, 1984; Godthelp, Milgram, & Blaauw, 1983, 1984). Other work aimed to further investigate the attentional demands of different driving situations and identify appropriate glance durations for visual occlusion research. For example, by using voluntary inspection times as an indicator of attentional demand, empirical research supported Sender et al.'s findings revealing that attentional demands increased as, driving speed increased, driving lane width decreased, and if the road had curves as opposed to straights (Courage et al., 2000). A further study investigating appropriate inspection times, tested participants in both real-world and simulated driving environments across various speeds (Chen & Milgram, 2011). By measuring voluntary visual occlusion duration and inspection time, their findings revealed that larger inspection times would allow for larger visual occlusion intervals, but only to an extent. In the real-world driving scenario, participants were asked to keep within a driving lane, and findings revealed that lower speeds allowed for longer visual occlusion durations and larger discrepancies between inspection times as compared to higher speeds. In other words, when travelling at 20 kph the inspection time/visual occlusion duration ratio was larger than if travelling at 100 kph. However, from 60 kph onwards the benefit of prolonged inspection time plateaus around 0.5-1 s, thereby, supporting Sender et al.'s findings. In the simulator driving scenario, participants were trialled in two conditions, 1) lane-keeping, and 2) following a simulated car. The findings revealed similar results to the real-world conditions, however, prolonged inspection time benefits plateaued around 1-1.5 s. Hence, these findings further assisted in setting parameters for future research.

More recent research using visual occlusions has extended into predicting secondary task performances (Gelau & Krems, 2004; Gray, Geri, Akhtar, & Covas, 2008). More specifically, visual occlusions were used as analogues of the redirection of attention to secondary tasks (Gelau, Henning, & Krems, 2009). The experimental designs involved participants undertaking a task (e.g., driving, visual scanning task) that involved no visual occlusions (as a baseline condition) and compared the dependent measures collected (e.g., speed, driving path line, task completion time) between the same tasks while the participants experienced visual occlusions (Noy, Lemoine, Klachan, & Burns, 2004). The differences between the baseline and visual occlusion conditions' dependent measures were suggested to be the *costs of interruption* for when attention is directed away from the task. "Safe driving" research typically employed this method, as research was interested in understanding the attentional demands associated with driving a vehicle while interfacing with an in-vehicle information system (IVIS) (Baumann, Keinath, Krems, & Bengler, 2004; Gelau & Krems, 2004). These studies often impose a 1.5-2 s inspection time followed by 3 s visual occlusion time on participants, as previous research has suggested it to be the maximum time tolerance ratio for taking your eyes off the road (Baumann et al., 2004; Gelau & Krems, 2004). While adjusting ratios for differing situations (e.g., track curvature, traffic congestion), if a task is able to be completed in the visual occlusion time, it was deemed safe to be engaged with.

Visual occlusion researchers acknowledge that visual occlusion techniques are not without their flaws. The ecological validity of the occlusion technique has been challenged with researchers arguing that, while it may simulate the visual demands of IVIS use during car driving, workload factors are not taken into consideration (Gelau et al., 2009; Lansdown et al., 2004). This is because during visual occlusions, the individual is still aiming to complete the current task, as opposed to completing an alternative task. Hence, by not accounting for cognitive load while employing the occlusion technique, the results could underestimate the performance costs that one would experience while driving and engaging in a secondary task (e.g., IVIS use) (Baumann et al., 2004). To combat this issue, cognitive workload measures (e.g., NASA-TLX scores; Hart & Staveland, 1988) are paired with the occlusion technique to acquire an understanding of the cognitive load differences between conditions (Noy et al., 2004).

Summary

Many fields of research have employed the visual occlusion technique with aims of addressing human performance capabilities in the absence of visual information. More specifically, research aims to identify the cognitive, perceptual, and psychomotor skills' implications while experiencing visual occlusion during a task. In sport science research, visual occlusions are employed to evaluate the anticipatory skills of athletes, in order to identify what visual cues are important to train athletes in. By visually occluding individuals at different time points during a sporting action, researchers are able to assess what part of an action needs to be attended to in order to maximise the chances of a successful response.

The visual occlusion technique has primarily been utilised in the driving literature. Initial research imposed visual occlusions as a measure of identifying the attentional demands of a road by recording how many times individuals actioned an inspection time following different visual occlusion durations, and at different driving speeds. The more times the individual actioned inspection times, the larger the attentional demand of the road was deemed to be. This research guided the following research parameters, where it was proposed that individuals required inspection times ranging between 0.5-1.5 s to adequately survey the environment and could endure a visual occlusion duration of 3 s before an inspection time is required.

Safe driving research has employed visual occlusions to investigate the performance implications of task interruptions with the desire to make accurate predictions of performance outcomes if a secondary visual task was paired with a primary task. Adopting the visual occlusion standard ratio of 0.5-1.5 s inspection time by 3 s visual occlusion time, researchers compared the task performance measures (e.g., speed, task completion time) between unoccluded trials and occluded trials. Broadly, if the performance measures did not deviate too greatly between conditions, it was deemed that the secondary task may be safe to undertake. However, visual occlusion research has acknowledged that visual occlusions do not measure the cognitive workload associated with a secondary task and that these factors must be included for more accurate performance prediction.

The Aims of the Present Study

The broad issue to be addressed in this thesis is to identify the cognitive, behavioural, and performance implications associated with a task alternating in a dynamic environment with ecological validity. The approach used was to employ an immersive interactive simulated task (a racing car simulation), which can act as an abstraction of some of the basic cognitive and performance factors that an individual might encounter when piloting a RPAS. While the experimental task does not in any sense simulate actual military operations, the simulated environment employs a navigational task in a spatio-temporally challenging environment. As such, it shares a basic similarity with the RPAS piloting scenario, but uses a task that is more familiar and accessible to non-specialised participants.

The research reported in this thesis is the first of three planned studies, which build upon each other. The current study investigated the cognitive, behavioural, and performance implications associated with task interruptions. Task interruptions were implemented by use of visual occlusion spectacles while undertaking a driving task in a simulated dynamic driving environment. Three aspects of task interruption were investigated in relation to the cognitive, behavioural, and performance implications: 1) the duration of visual occlusion interval; 2) the predictability of visual occlusion intervals; and 3) the difficulty of the driving task (easy versus hard track). This led to a number of hypotheses and research questions:

Hypothesis 1: As track difficulty increases and visual occlusion sequence becomes unpredictable, slower average speeds and more errors will be recorded.

Hypothesis 2: As visual occlusion interval increases, more errors will be recorded.

Hypothesis 3: As track difficulty increases and visual occlusion sequence type becomes unpredictable, larger NASA-TLX scores will be recorded.

Research question 1: Does track difficulty or visual occlusion sequence type have a larger effect of driving performance?

Research question 2: Can EMG and HRV data predict upcoming occlusion or errors?

Research question 3: Does the pairing of quantitative driving performance metrics and qualitative measures of expertise facilitate more robust acquisitions of individual performance?

These data will provide baseline temporal parameters governing the ability to undertake a second dynamic task without impacting significantly on the primary dynamic task. Moreover, this thesis intends to bridge the gap in the literature pertaining to the utilisation of mixed-methods designs to evaluate task performance. It is desired that through the convergence of quantitative and qualitative measures that more robust conceptualisations of high performance can be attained.

The second study aims to investigate the spatiotemporal parameters governing the ability to retrieve information from a briefly-presented text message, and the third study will combine the two dynamic tasks into a single experiment to test predictions regarding the cognitive, behavioural and performance implications of undertaking two simultaneous dynamic tasks under different task priorities. Studies 2 and 3 will not be presented within the current thesis, but provide the context and future direction of the research reported herein.

Chapter 3. General Methodology and Methods for the Experiment

Introduction

This chapter outlines the methodology and specific methods of the experiment reported in this thesis. This includes participant recruitment procedures, the apparatus and materials, experimental design, and the procedure of the experiment.

Methodology

The selection of participant pool and dynamic task environment was governed by a desire to explore generic aspects of cognitive and behavioural performance during dynamic tasks before considering performance implications for high-value participants undertaking expert skilled performance in specialised military operational tasks. Hence, a computer-based driving task was employed, as it would be familiar to participants and provided an accessible, generic task environment that imposes similar cognitive and psychomotor performance requirements as piloting an aerial vehicle (Engström, Johansson, & Östlund, 2005; Grácio, Wentink, Pais, van Paassen, & Mulder, 2011; Kemeny & Panerai, 2003; Redenbo & Lee, 2009). Using commercial off the shelf simulation programs is not foreign to defence, as these programs provide an affordable and high ecological fidelity simulator for individuals to operate within (Curry, Price, & Sabin, 2016; Schill et al., 2014). The computer-based driving task was delivered by a three-screen display and was paired with a car seat and steering wheel mounted on a motion-platform to become a low physical fidelity driving simulator. The purpose of the driving simulator was to make the task more engaging to participants rather than to simulate the properties and features of the real-world dynamic driving environment in high fidelity. The driving simulation provided a complex task with reasonable ecological validity and is one that required minimal participant training due to participants' previous driving training and experience in the real world. Moreover, the commercial off-the-shelf driving simulation software (rFactor) was selected on the basis that it included pre-configured software to control the motion platform and built-in performance metrics (MoTec) that could be utilised without the need for further software development costs.

The current study employed quantitative measures (speed and errors) to serve as initial basic performance indicators. Qualitative measures were used to attain an understanding of the phenomenology of increasing cognitive workload and alternative measures of performance (e.g., strategies employed). Biofeedback measures were used to assess if there were robust and accessible physiological measures that could be used as indicators of cognitive overload or imminent performance decrements outside of the laboratory. Muscle tension and HRV were selected due to the practicality of using the respective hardware during the trials. More specifically, measuring muscle tension, via surface electrodes, and HRV, via a finger sensor, did not interfere with the participants' ability to perform within the task. The surface electrodes were placed on the skin with the connecting cables led behind the participant. Similarly, the heart rate finger sensor was attached to the top of the index finger with the connecting cable led through the simulator's wood frame. Galvanic skin response and pupillometry measures were not employed, as it was deemed not practical to use. The galvanic skin response sensors would have had interference with the steering wheel and the unit would have obstructed the placement of the surface electrodes on the forearm. Due to the utilisation of the visual occlusion spectacles, use of pupillometry measures would not have been viable, as the visual occlusion spectacles would have repeatedly obstructed the eyes and prevented the appropriate data from being collected.

Methods

Participants

Ethics approval was granted from a Subcommittee of Swinburne University of Technology Human Research Ethics Committee (Appendix A: Ethics Letter of Clearance). Nine participants were recruited from the general public via on-campus advertising, online social media advertisements, and snowball sampling methods. Participants that were interested in participating in the study contacted the researcher to arrange an available date and time. Prior to finalising a date and time to participate, screening measures were conducted to confirm that the participant was above the age of 18, held a driver's license, and was physically fit to participate.

All participants had normal or corrected-to-normal vision. Participants that were recruited volunteered their time and were not paid. Both male and female participants were included as current defence directives show that male and female defence personnel will assume RPAS piloting roles in the future.

Screening procedure

Participants were required to be over the age of 18 and hold either a probationary or full driver's license. This was a requirement as this provided confidence that participants had a sound understanding of how to operate a car. Furthermore, this fundamental driving knowledge increased the likelihood that participants would transfer their driving knowledge and ability in the driving simulator, thereby, requiring minimal training. It also increased the likelihood that driving performance decrements, during the trials, were a consequence of the independent variable manipulations and not insufficient knowledge and practice of operating the driving simulator.

As the driving simulator caused motion during the trials, participants were required to answer a number of questions as to their general wellbeing to ensure safety during the trials. Participants were required to sign consent sheets (Appendix B: Consent Sheet) confirming that they were not pregnant, had not recently had surgery that still required recovery and that prevented normal functioning, were not wearing a cast and/or had injured bones, had no neck or back injuries, did not have high blood pressure or heart beat irregularities. Participants were also asked to confirm that they had no skin allergies to electrodes or Band-Aid placements, as they would be required to wear surface electrodes for the trials. If individuals met all the aforementioned conditions they were eligible to participate.

Apparatus and Materials

The apparatus and materials used in the current study include computer and simulator hardware, simulator and driving performance recording software, biofeedback hardware and software, human-video and screen capturing hardware and software, questionnaires and interviews, and miscellaneous software. As descriptions of the materials used are very technical and efforts were made not to disrupt the flow, pictures of the equipment were not included in the following section. However, these pictures of the equipment can be viewed in Appendix C: Materials.

The simulator

The driving simulator was comprised of a combination of computer hardware, sound effects, a 2-DOF motion platform and supporting external device structures, computer monitors and video game car controls.

Computer hardware

An Intel Core i7-3930K (Intel, California, United States) CPU @ 3.20 GHz with 16.0 GB of RAM on a 64-bit operating system was used to operate the hardware and software of the simulator and biofeedback tools. The system contained an AMD Radeon Graphics Processor (0x679a) (Advanced Micro Devices, California, United States), which exceeded the recommended requirements to smoothly run the simulator software. It contained eight USB ports that allowed the connection of external devices. A 4-port USB splitter was connected to one USB port to allow for additional external connections. Together, the aforementioned computer specifications provided an operating system powerful enough to run multiple software programs simultaneously, without lag time. The computer tower was positioned in front of the simulator and out of view of the participants.

Sound system

A Juster 3D/501 (Juster Co, Taipei, Taiwan) computer speaker was used to amplify in-game sounds, such as instructional signals, engine noises, tyre braking and crashing sounds emitted as part of the driving simulation. The loud speaker set contained a 130x105x230mm subwoofer and two 80x75x100mm speaker satellites. Complete with volume and bass variability controls, the speaker had a maximum power of 13.5W RMS. The subwoofer and one speaker satellite were positioned to the right corner of the simulator; the other speaker satellite was positioned in the left corner. The speaker set was connected to the computer via one USB port.

Motion platform and supporting device structure

A CKAS Thruxim, developed by CKAS Mechatronics (Melbourne, Australia), was used to provide motion and structural support for the simulator during the experiment. The CKAS Thruxim contains a CKAS T2s 2DOF motion system that provides the motion during the experiment, as well as an MDF rigid Thruxim framework hardware that supports additional simulator components. The dimension of the CKAS T2s 2DOF motion system were 800 mm width x 1180 mm length x 300 mm height and had built-in washout filter and acceleration onset cueing algorithms for a variety of simulator programs. Additionally, it had a high-speed 100 Hz motion controller which, together with the built in washout filter and acceleration onset cueing algorithms, provides smooth, motion responses.

Atop of the CKAS T2s 2DOF motion system was a large wooden structure, that contained a bench-top for vehicle controller placement, as well as a rigid steel screen monitor rail that held three 24 inch screen monitors. The platform also housed a universal seat bracket, which allows for the mounting of a Drift Blade automobile seat (Drift Performance Products, South Africa)

Computer monitors

The simulation was displayed across three 24 inch LCD monitors (Acer, Taipei, Taiwan) with a refresh rate of 60 Hz. The three monitors were mounted on the MDF rigid Thruxim framework screen monitor rail and positioned in a horizontal sequence in front of the participant, with a visual field of view of 115° horizontally and 24° vertically, thereby providing a simulated out-the-window view of the driving environment.

Video game driving controls

A Logitech G27 Racing Wheel (Romanel-sur-Morges, Switzerland) was centrally positioned atop the platform. It had a 900° steering rotation and built-in force feedback, that responded to the video game environment to provide the driver with a more realistic and engaging experience while driving the simulator. Steel paddle shifters were built into the steering wheel to allow the driver to change between drive and reverse should they be required to during the trials. Below the platform, a pedal box containing acceleration, brake and clutch pedals (which was not required for operation of the simulation program) was positioned centrally. The entire G27 Racing Wheel and pedal box were powered by an electrical power socket and connected to the simulator via a USB point.

Simulator and driving performance recording software

Simulator software SimCor (CKAS Mechatronics, Melbourne, Australia) and rFactor 2 (Build 1036, Image Space Incorporated, Michigan, United States) were used to provide the simulator experience and run the experiment. Motec i.2 pro (Version 1.18.0017, MoTeC, Melbourne, Australia) was the software used to record the driving performance in the trials.

SimCor

For the CKAS T2s 2DOF Motion System to elicit realistic motion during vehicle simulation, CKAS Mechatronics developed the simulation engine software SimCor (Melbourne, Australia). The SimCor software was developed to be compatible with various vehicle video games, operating in real time to calculate the physics in a virtual dynamic environment and cue the motion platform to respond appropriately. This software caused the motion platform to provide motion cues to simulate the turning angles and speed deviations an individual would experience while driving.

rFactor 2

rFactor 2 software was the software program used to simulate the dynamic driving environment. rFactor 2’s software engine, isiMotor (Version 2.5, Image Space Incorporated, Michigan, United States), allowed for the modification of vehicles and driving environments in the software to provide flexibility in the parameters used during the driving simulation. Note that the true fidelity of the simulated driving experience was not of concern in these experiments except insofar as the participant was able to understand the task requirements and perform the basic driving task with an appropriate level of task engagement and immersion. At the same time the experimenter was able to manipulate task difficulty and record performance data in a consistent and meaningful way.

During the trials, participants were provided with an in-vehicle field of view (Figure 1. In-game view of driving task) across the three computer monitors. The middle monitor presented a view that included a steering wheel, accompanied by virtual hands, and a front windscreen to view the track. It also contained an active speedometer that presented the car speed in real-time. The left and right monitor extended the view as if through a side window that could be used to see the sides of the tracks.

Figure 1. In-game view of driving task.

rFactor 2: Vehicle selection

rFactor 2 provided a large variety of cars for race selection. It was important to select a car that shared similar features to everyday street cars (steering power, acceleration power, etc.) and familiar for all participants to drive (Jenness, Lattanzio, O'Toole, & Taylor, 2002; Redenbo & Lee, 2009; Young, Mahfoud, Walker, Jenkins, & Stanton, 2008). It was important to select a car that was not too powerful (high horse power and torque) to control, as this would likely cause performance decrements and behaviours that are a consequence of poor vehicle control rather than the experimental manipulations of interest. A 2010 BMW Z4 sDRIVE35is (build 660) (Version 2.5, SimDream Development) was selected as the car that participants would drive in each of the experimental conditions. While it is on the higher end for performance of street cars, it is not as powerful as F1 and Rally cars. Hence, participants were able to become familiar with it after minimal training. The 2010 BMW Z4 sDRIVE35is specifications and dimensions are given in Table 1.

Table 1

2010 BMW Z4 sDrive Specifications and Dimensions

Engine
3.0-litre 16, DOHC, Turbocharged
Power: 340 hp @ 5900 rpm
Torque: 370 lb-ft @ 1400 rpm
Transmission
7-speed dual clutch sport automatic
Body
Curb Weight: 1525 kg
Wheelbase: 2496 mm
Length: 4244 mm
Width: 1790 mm
Height: 1284 mm

rFactor 2: Track selection

rFactor 2 provided a large range of real-world and fictitious racing tracks for selection. rFactor 2 tracks have a “real road” feature that evaluates, in real time, weather factors and road deterioration to produce a virtual road surface that would simulate the real-world interaction between environmental factors and the road.

It was important to identify and select two racetracks that participants would perceive as either easy or hard to navigate within. Limited, if any, previous literature using simulators has compared the findings of different track difficulties, with research typically using either prolonged straight tracks (Engström et al., 2005; He, McCarley, & Kramer, 2014; Marciano & Yeshurun, 2015; Redenbo & Lee, 2009) or tracks with a combination of curves and straights (Jenness et al., 2002; Senders et al., 1967; Young et al., 2008). Therefore, setting parameters to identify easy and hard tracks was guided by comparing track complexity (e.g., short/long straights; sharp/gradual turns). Easy tracks were categorised as those that contained long straights and gradual turns. In juxtaposition, hard tracks were categorised as those that contained both gradual and sharp turns as well as short and long straights. Moreover, easy tracks were typically shorter in distance than hard tracks. With the combination of shorter distance and simpler track design, individuals were able to become familiar with the easy track more quickly than the hard track.

rFactor 2: Easy track selection

Joesville Speedway (Version 1.0, Image Space Incorporated, Michigan, United States) (Figure 2: Joesville Speedway; Easy Track) was the easy track used in trials. It is a fictional oval track that is 660 m in length. It contains two long straights and two gradual turns, thereby meeting the requirements for an easy track. Additionally, this track had a bare surrounding environment that elicited low perceptual load to the participants as they navigated around the track.

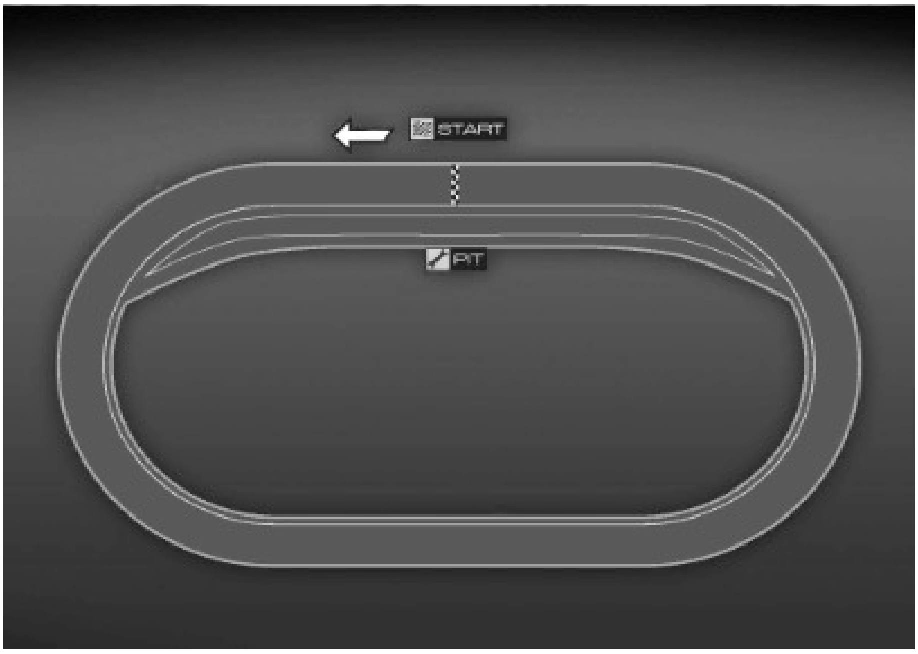

Figure 2. Joesville Speedway (Easy Track)

rFactor 2: Hard track selection

Melbourne Grand Prix Circuit (Version 0.25, Euroracers, Netherlands) was selected as the hard track (Figure 3: Melbourne Grand Prix Circuit; Hard Track). As the title indicates, this track was modelled on the real-world Melbourne Grand Prix track. It is 5.303 km long and contains combinations of long and short straights with gradual and sharp turns. This track contained more and larger radius of off-road areas in comparison with the easy track. Large buildings and in-game advertisements surrounded this track thereby imposing a higher perceptual load than the easy track, as participants navigated around it.

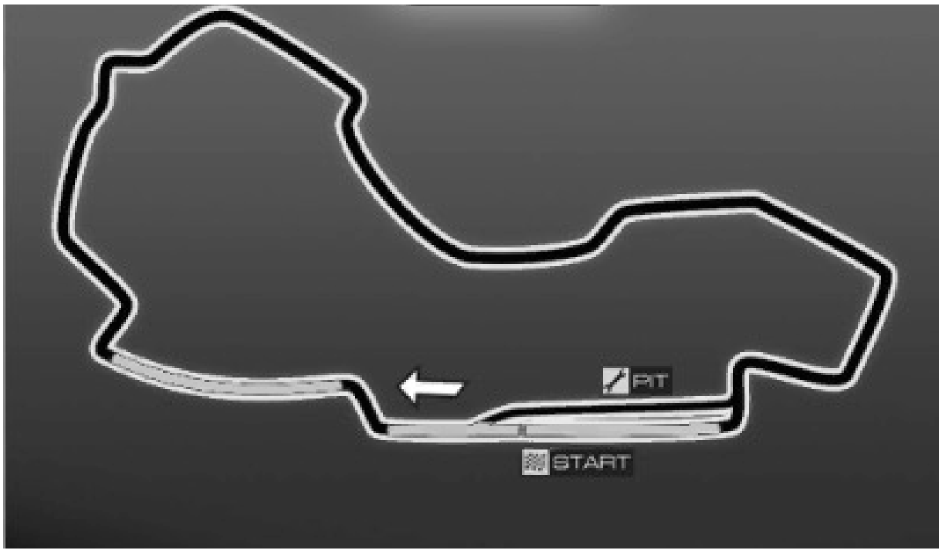

Figure 3. Melbourne Grand Prix (Hard Track)

rFactor 2: vehicle difficulty options

rFactor 2 contained various options that could be added to enhance the simulation. These permitted the experimenter to vary the difficulty of the task. To prevent the performance from trials to diminish as a result of car damage, the *invulnerability* feature was activated and *tyre wear*, *fuel usage* and *mechanical failures* were deactivated. These features protected the car from damage during crashes, prevented the tyres from wearing, and removed the need to refuel or to address any mechanical failures that occurred during a race. Moreover, *steering help, brake help*, *auto pit lane,* and *spin recovery* were disabled. *Steering help* is a feature that usually provides assistance to the driver in maintaining the correct path line on the track. *Brake help when activated* applies automatic brake pressure to the vehicle for the driver as they approach turns. These two functions were disabled as they would provide an excessive amount of assistance for participants during trials and would limit the ability to measure performance decrements in the driving task.

The *auto pit lane* feature is designed to take full control of the vehicle as it enters a pit lane. As invulnerability was enabled, there was no reason for participants to enter the pit lane. However, as visual perception and attention was diverted away from the driving simulator, participants could accidently steer into the pit lanes. By disabling the *auto pit lane* feature, it allowed participants to maintain control of the vehicle and further provided a free flowing driving experience. S*pin recovery* assisted the driver following a crash or "spin out" by automatically re-directing the vehicle towards the correct driving route. Similar to the rationale of the aforementioned disabled features, *spin recovery* was deactivated so that the data collected would provide a more reliable indication of how participants were coping with track difficulty and visual occlusions, visually scanning the environment and initiating their driving manoeuvres accordingly.

Opposite lock, auto shifting, and *auto clutch* were enabled during the trial conditions. Additionally, *stability control, anti-lock brakes,* and *traction control* were set on "high". *Opposite lock* assisted the driver when the vehicle began to "spin out", and locked the wheels in the opposite direction than the vehicle was spinning in order to regain stability. In reality, it is a manual technique, used commonly by professional rally car drivers, that involves the deliberate oversteering around corners to maintain high speeds. This was enabled because it provided minimal assistance that would not disrupt the participant's free flowing driving experience or interfere with how the participant was coping within a trial condition. While there was some level of automatic control, it did not provide enough assistance that would override the participant's control of the vehicle.

As is common in real street-cars, *auto shifting*, *auto clutch*, *stability control, anti-lock brakes,* and *traction control* were featured in the virtual vehicle. *Auto shifting* and *auto clutch* work together to provide the automatic shifting of gears. *Stability control* aided in keeping the car straight, minimising the risk of spinning out. *Anti-lock brakes* prevented the car from skidding during situations involving heavy braking; this was achieved by ensuring that the wheels maintained rotation. T*raction control* assisted in maintaining traction on roads. By doing so, this prevented the wheels from over-spinning, reducing the likelihood of skidding. These features are common in most modern cars and activation of these driving aids helped to provide a more familiar driving experience.

rFactor 2: Race session options and weather options

The trial's race session options were configured to allow the car to have a rolling start at the beginning of the trials as well as disabling AI drivers (simulated racing cars to provide computer-driven opponents on the track). The rolling start feature involved participants beginning the trial with their car on autopilot driving towards the starting line. Participants gained control of the car, after approximately 5 s as it drove through the starting line. In contrast to participants commencing the trials in a standing formation, the rolling start ensured that participants had time to sufficiently perceive their surroundings during the autopilot and cope with visual occlusions rather than be occluded just as they commence driving.

AI drivers were disabled to prevent them from interfering with an individual's performance during trials. The AI drivers had been developed for racing purposes and often do not factor in the user's car or the user's driving manoeuvres. This often leads to aggressive or unresponsive driving that cause the user and AI driver to crash into each other leading to further performance decrements.

The weather conditions of the race were configured to be a clear, sunny day with a 0% chance of rain. As the roads in rFactor 2 have high ecological fidelity, rain and extreme weather conditions could interfere with the track and influence the performance of the car.

MoTeC i2 Pro

MoTeC i2 Pro was the software used to collect the driving performance data and run analyses. This program enables the collection of a large battery of vehicle and track metrics, such as speed, steering angles and track positioning. Both professional car racing companies and military organisations have used this software as it provides an extensive number of analysis tools. For example, following the data acquisition, *MoTeC i2 Pro* allowed for the generation of a variety of time series graphs for the desired vehicle and track metrics to aid in analysis. These time series graphs could then be manipulated to analyse data to the millisecond and could manually mark time points of interest. The time series graphs could also be formatted to depict data overlays that pair numerous driving metrics in the same graph, thereby assisting in the visual recognition of data patterns. Moreover, driving performance data could be paired with video recording of trials. This permitted the viewing of the data on a time series graph to run simultaneously besides video recordings of the driver and the out-the-window view of the trial. Specifically, this feature assisted in undertaking mixed methods approaches, as the quantitative data (driving performance metrics) are able to be paired with qualitative data (video recordings).

Visual occlusion apparatus

Portable Liquid crystal Apparatus for Tachistoscopic Occlusion (PLATO) spectacles

The *Portable Liquid crystal Apparatus for Tachistoscopic Occlusion* (*PLATO*) shutter spectacles have been used in a variety of studies to occlude vision (Baumann et al., 2004; Chen & Milgram, 2011; Courage et al., 2000). The *PLATO* shutter spectacles were capable of being programmed to repeatedly occlude vision over extended periods of time.

The *PLATO* spectacles are large goggle-spectacles that fit onto the face conventionally. From the spectacles, a cable led to a *ToTaL Control System* (Translucent Technologies) to enable power to be delivered. *ToTal Control System* software was used to program the visual occlusion sequences. When programming the visual occlusion sequence, the software provided the flexible interface that permitted the independent programming for each lens. The software gave the user control over open- and closed-time duration in milliseconds and seconds, cycle period, onset delay, and the number of cycles per trial (Translucent Technologies, http://www.translucent.ca/products/total-control-system/). To load the visual occlusion sequences, the *ToTaL Control System* was connected to the computer via a USB port. Once the sequence had been programmed, the *PLATO* spectacles were activated via the *ToTaL Control* Software (Version 3. 0. 0. 18784, Translucent Technologies Inc., Toronto, Ontario, Canada) when connected to the computer, or manually by pressing an external activation button on the *ToTal Control System*. When activated, the spectacles had an approximately 3-4 ms delay when switching from open to closed, but there was no time delay from closed to open (Milgram, 1987).

The *PLATO* spectacles were used as the lens remained translucent but opaque when closed, permitting light to travel through it (Lansdown et al., 2004). This allowed the level of illuminance to remain constant between the spectacles open- and closed-state, minimising a change in pupillary response to the light following a visual occlusion (Lansdown et al., 2004; Milgram, 1987).

Miscellaneous Software: AutoHotKey

AutoHotKey (Version 1. 1. 22. 07, AutoHotKey Foundation LLC, Indiana, USA) is a free software program that was used to synchronise independent software and ensure data collection across a time period was consistent. This software permitted the user to script their own code and develop hotkeys to perform various functions. In the current study, the software programs used (e.g., *LabChart 7, rFactor 2*) were all independent programs that could not be started simultaneously, making it difficult to synchronise as each program would need to be manually activated to commence data recording. To resolve this issue, AutoHotKey was used to hotkey mouse-clicks that would start the software programs over a consistent period. This would ensure that each trial's time duration (that includes the time to start the data recording software and time for the driving trial) would be consistent across conditions and participants.

To ensure that the CPU polled all the mouse-clicks and key activations, all actions induced a 50 ms time lag; however, it should be noted that the movement of the cursor and the mouse-click were one action. Software program menus that required the cursor to move and click a start button were positioned on the viewing desktop screen in set locations to where the cursor would click.

The order in which the script was run (see Appendix D: Code for AutoHotKey) was, click the *LabChart 7* start button, click the *ToTaL Control* start button, click the *rFactor 2* shortcut on the toolbar, wait one second for *rFactor 2* to load, activate the hotkey that commenced the webcam to start recording, wait 3 s for webcam to load, click the "begin race" in the *rFactor 2* program, wait 3 min 36 s for the trial to finish, activate the hotkey to cease the webcam recording, activate the *escape* key to pause the driving trial, activate the *window* key and "D" key to minimise all menu windows, click the *LabChart 7* shortcut on the window's toolbar to display it on the desktop, click the "stop" button on the *LabChart 7* window.

Biofeedback Tools

A surface electromyogram (sEMG) and its software were used to record and analyse the participants' muscle contractions during trials. The purpose of the biofeedback tools was to investigate possible biometric markers that could be predictive of cognitive overload. However, pairing the PLATO spectacles and biofeedback tools together proved troublesome, with large amounts of contamination appearing in the data. Therefore, further analyses were abandoned.

A commercial off the shelf heart rate monitor was employed to capture heart rate variability of the participants throughout the different simulated driving conditions. It was employed in this study to evaluate if commercial off the shelf biofeedback tools would serve as an accurate and appropriate tool to utilise in the applied psychology fields. However, efforts to support this were futile, as the heart rate data was not robust or sufficiently reliable to draw any conclusions from. Details of the both the sEMG and heart rate monitor, and procedures used can be found in Appendix E: Difficulties in acquiring biofeedback measures.

Human behaviour and screen capturing hardware and software

Video recordings of the participants' behaviour during the trials were captured using a screen-mounted webcam and tripod-mounted video camera. Screen-capturing software was used to record the participants' driving behaviour and performance during the trial.

A *Logitech HD Webcam Pro C920* (Logitech, Romanel-sur-Morges, Switzerland) was used to capture the behaviour (i.e., facial changes, verbal expressions, body position adjustments) of participants as they drove the driving simulator. It recorded in full HD 1080p (up to 1920 x 1080 pixels) and contained built-in dual stereo microphones with automatic noise reduction. It was mounted, centrally above the middle LCD monitor with the camera facing the participant, connected to the computer via a USB port.

A *Canon Legria HFG10* (Canon Incorporated, Tokyo, Japan) portable video camera was used to video record participants' hand positions and adjustments on the steering wheel. It was mounted on a tripod and positioned at the left rear of the driving simulator, out of the view of the participants. The *Canon Legria HFG10* contained a 30 mm wide-angle lens and a *DIGIC III* (Canon Incorporated, Tokyo, Japan) image processor that provided high image quality and high resolution. Together, these features provided high definition recordings that were sufficient for subsequent analyses.

Human behaviour recording software

*Bandicam (*Version 2. 3. 3. 860, Bandisoft, South Korea) was the screen recording software used to record participants' in-game driving simulation trials. It recorded gameplay in high definition and was paired with webcams to record gameplay and the player simultaneously. This was a valuable feature as this permitted the acquisition of video that could be synchronised with the quantitative performance and biofeedback data. In particular, recordings of the participants' behaviour in-game and the driving simulation could be used to document participants' behaviour when they failed to cope with the tasks.

Questionnaires and Interviews

Demographic questionnaires, the NASA-TLX (Hart & Staveland, 1988) workload questionnaire, and semi-structured interviews were used to develop an insight into participants' driving and video game history, self-reported perceptions of workload, and strategies they used during the trials.

Demographic questionnaire

Demographics of the participant were recorded using a paper questionnaire (see Appendix F: Questionnaire on driving). This questionnaire invited participants to report their age and gender; the years that they have held a driver's licence; the average time they drove per week; the areas they normally drove in (e.g., inner city, freeway); if they had undertaken any advanced driving course; if they predominantly drove automatic, manual vehicles or both; if their vision was normal or corrected-to-normal; and their average racing car video game playing hours per week.

National Aeronautics and Space Administration Task Load Index

The National Aeronautics and Space Administration Task Load Index (NASA-TLX) (Hart & Staveland, 1988) questionnaire was used to gain an understanding of how participants rated and categorised their workload following each trial condition. The NASA-TLX is a multi-dimensional rating tool that contains a 6-item workload scale and a 15-item pairwise comparison. Its questions incorporated individuals' subjective feelings of physical effort, mental demand, and task performance following a recently performed task.

The items in the NASA-TLX questionnaire include *Mental Demand*, *Physical Demand*, *Temporal Demand*, *Performance*, *Effort*, and *Frustration* (Hart & Staveland, 1988).

- *Mental Demand*. The amount of mental and perceptual processing that was required to complete the task (e.g., thinking, deciding, calculating, remembering, looking, searching).
- *Physical Demand*. The amount of physical activity required to complete the task (e.g., pushing, pulling, turning, controlling).
- *Temporal Demand*. The time pressure individuals feel during a task due to the rate at which the task elements occurred.
- *Performance*. Individual's feeling of success in accomplishing the task.
- *Effort*. How hard an individual has to work (both mentally and physically) to reach their level of performance.
- *Frustration*. How stressed, discouraged, and annoyed an individual felt during the task.

When administering the NASA-TLX questionnaire, participants began with a 6-item workload rating scale (Appendix G: NASA-TLX) (Hart & Staveland, 1988). This involved participants quantifying the contribution of each item on a 20-interval response scale, ascending in intervals of 5; ranging from 0 (*very low*) to 100 (*very high*); or for the *Performance* item, 0 (*Perfect*) to 100 (*Failure*). Participants marked 'X' on the line of each item to indicate the level of contribution that item had in completing the task. Following completion of the workload scale, participants performed a 15-item pairwise comparison (Appendix G: NASA-TLX). This procedure involved participants being presented with cards that contained the names of two items from the workload rating scale. Participants marked one of the two items presented on the card to indicate the item that had a greatest magnitude of contribution to the task.

Upon completion of the NASA-TLX questionnaire, overall workload scores were calculated. This was achieved by identifying the location of the 'X' on each item's scale and assigning it the appropriate score, followed by tallying the items, selected on the cards, from the pairwise comparison. Each item's score from the workload rating scale was then multiplied by the number of times it was selected in the pairwise analyses (e.g., if *Mental Demand* was scored a 50 on the workload rating scale and was tallied 3 times in the pairwise comparisons, the adjusted rating would be 150). Once all the items have had an adjusted rating calculated, they were summed and then divided by 15 to provide a score out of 100 (100 being the highest workload). This final score was known as the overall workload.

The NASA-TLX was selected because it is a commonly used measure of workload in human factors research (Bezerra & Riberio, 2012; Stanton et al., 2013; Xiaoru, Damin, & Huan, 2014). The NASA-TLX (both modified and original) has been used in a range of studies involving simulation, driving, and training (Hart, 2006). It provided an appealing feature of evaluating how participants categorise their workload and permits the analyses of the sources-of-workload between the different conditions. The NASA-TLX questionnaire could be both administered online via a computer and in paper format; however, research has shown that this can produce difference in workload scores (Trujillo, 2011). In this experiment, the paper NASA-TLX questionnaire was chosen as it has been shown to minimise additional workload for participants interacting with a computer program that may incur following the experiment (Noyes & Bruneau, 2007).

Semi-structured interview

Semi-structured interviews were conducted with the intention of attaining an in-depth understanding of perceptual and cognitive aspects of the task. The interview structure and questions were developed following the recommendations of Stanton et al. (2013). Questions focused on participants' perceptions of their performance and workload during the trials, providing researchers with a better understanding of the strategies they used during the trials. While the questions had a sequential progression, the interview was semi-structured meaning that both the interviewer and participants were able to deviate from the script to clarify issues or explore themes that emerged during the interviews. Audio from the semi-structured interviews was recorded for post-analysis. The data collected was used to identify commonalities and differences between participants and trials, and also were used to investigate consistencies and inconsistencies between what the participants reported and their actual performance. The questions asked are as follows.

1. How do you think you performed during the drive and why?

2. Were there sections on the race track that you think you performed better in than other sections, and why?

3. Do you think being visually occluded during the race made it more difficult for you to maintain performance, and why?

4. Was there a certain time length after being visually occluded that you thought you could no longer perform the task?

5. Were there any driving situations that you found extremely difficult where you thought you could no longer maintain performance while being visually occluded?

6. If so, what made them difficult?

7.What strategies did you employ to cope with the visual occlusion in order to maintain performance during the drive and why?

8. Did you use different strategies for different situations during the drive?

Questions 1-2 were used to acquire data about participants' subjective perceptions of their performance. Questions 3-6 were asked to acquire data concerning participants' perception of their workload. Questions 7-8 were employed to acquire data focusing on the strategies participants' used to cope with the visual occlusions. Consistent with the general nature of semi-structured interviews, the order of the questions could change depending on the flow of the interview. Furthermore, participants may have been asked probing questions to further elaborate on a topic, or if they introduced a novel concept. The interviews lasted between 3-8 min, depending on the willingness of the participant to articulate their experience.

Design

A 4x2x2 repeated measures mixed methods experimental design was adopted. The independent variables were: visual occlusion interval (1, 2, 3 and 6 s Occlusion Intervals), visual occlusion sequence type (Predictable Sequence vs. Unpredictable Sequence), and track difficulty (Easy vs. Hard Track). There were three types of dependent variables: self-report measures, physiological recordings, and performance related variables (speed and errors).

Groups were partially counterbalanced with all participants starting on the easy track but randomly being allocated to do either the predictable or unpredictable visual occlusion sequence first (Figure 4; Repeated measures experimental design for the experiment). This was informed by an initial piloting process where the difficulty of the track was counterbalanced, however completion of the harder track first proved too difficult for many of the participants. This meant that the results would not have been scientifically valid and thus the researchers decided to not randomise this component of the research design. While participants had practice time for each track, it appeared that undertaking the easy track first provided participants with additional time to familiarise themselves with the simulated vehicle's settings and set expectations of how to handle visual occlusions while driving.

Average speed across track difficulty and occlusion sequence type were analysed for both aggregated and individual data by two-way Analysis of Variance (ANOVA). Errors for the different occlusion intervals were analysed using non-parametric Friedman's ANOVA. Speed data during each occlusion interval was not generated separately as the tracking would contribute to reduced average speed and increased variance and thus the errors themselves were deemed a more appropriate index of the effect of the different occlusion intervals.

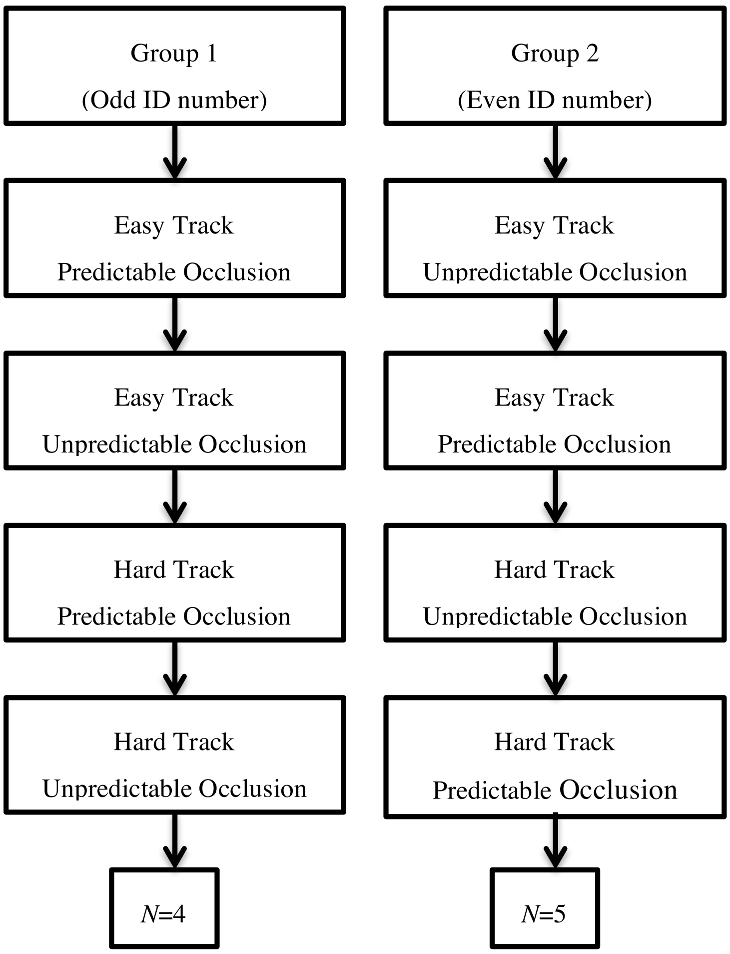

Figure 4. Repeated measures experimental design for the experiment.

Notes: N=Participants in each counterbalanced group; each trial contains all of the visual occlusion intervals

Independent variables

Visual occlusion intervals

During trials, participants experienced four different visual occlusion intervals. The different visual occlusion time intervals included 1, 2, 3 and 6 s. These visual occlusion durations were selected following direction from previous visual occlusion research (Chen & Milgram, 2011; Senders et al., 1967). While it is suggested that participants would need inspection times after 3 s, it was desired to measure participants' strategies and performance past that point. Visual occlusions lasting from 6 s onwards led to the largest decreases in performance, therefore maximum visual occlusion interval was set at 6 s (Senders et al., 1967). Moreover, in other domains such as military settings, it may not be feasible for personnel to return their visual attention to a task within a strict and short time duration, furthering the importance to investigate the consequences of larger visual occlusions.

Each visual occlusion interval was preceded by a visual inspection time, in which participants were not visually occluded and were able to view their virtual environment. Previous research has investigated “Glance Durations” and has reported that 500 ms to 1.5 s was ample time to perceptually process relevant driving information while driving at any speed following a visual occlusion (Chen & Milgram, 2011; Senders et al., 1967). Therefore, it was decided to allow participants a 2:1 inspection time to visual occlusion ratio (e.g. 6 s inspection time followed by 3 s visual occlusion). Moreover, participants were not notified of this ratio. The duration of the trials lasted 3 min 36 s, which were broken down into four 54 s time blocks. In each 54 s time block, a varied 18 s was visually occluded. This ensured that participants were visually occluded for the same total duration across conditions.

It should be noted that visual occlusion onsets were triggered via time periods and not events (e.g., visually occluded while steering around a corner), and this means that participants would be visually occluded at different points during the trials. However, as there were numerous visual occlusions, all participants were expected to experience similar events while visually occluded. In-game video analysis was used to track the participants’ event upon the onset of each visual occlusion across each condition. Events were separated into two categories; ‘visually occluded while steering straight’ and ‘visually occluded while turning’. Events were tracked by using the steering wheel’s position upon the onset of the visual occlusion as this provided the most objective indicator of how the vehicle was positioned on the track. Arguably, the categories used in the current study were more appropriate than alternatively identifying categories as visually occluded during straights and corners. This was due to the on-going nature of the trials as well as the characteristics of the roads. For example, participants could be visually occluded entering, during or leaving a turn in the road, however depending on the road characteristics, some corners permitted straight driving due to road width and curvature. Hence, visual occlusion during these events would be more representative of driving straight. Data pertaining to the percentages of the frequency of visual occlusion onsets by event type is further explained in the Results: Participants section.

Visual occlusion sequence type

Participants experienced either a predictable or an unpredictable visual occlusion sequence while undertaking the trials (Rogers & Monsell, 1995). By employing predictable and unpredictable visual occlusion sequence conditions, the current study was able to evaluate whether any similar benefits of predictability in terms of preparation for occlusion would occur in a more dynamic task environment.

Prior to the trial, participants were informed which type of visual occlusion sequence they would be undertaking. The total time length of the trial was 3 min 36 s, which consisted of 18 s of visual occlusion per 54 s. In the predictable visual occlusion sequence (Table 2: Predictable sequence), the duration of each visual occlusion and inspection time were executed consistently for 54 s. Following the end of each 54 s block, the time duration for each visual occlusion and inspection time would increase. For example, in the first 54 s of the trial there were 18 epochs consisting of 2 s visual inspection times followed by 1 s visual occlusion; in the following 54 s, there were nine epochs consisting of 4 s visual inspection times followed by 2 s visual occlusion, and so on. Participants were not externally cued before each occurrence of a visual occlusion during the trials, as the predictability of the sequence was cued by the duration for each visual occlusion and inspection time. Participants undertaking the predictable visual occlusion sequence were informed about the visual occlusion progressions (e.g., trials commencing with 1 s visual occlusions and progressing each 54 s time block). This further assisted the participants to prepare themselves in the trial, as they had received information concerning when a visual occlusion interval would occur.

Table 2

Predictable Sequence

Occlusion (Seconds)	Inspection (seconds)	Total Interval Period (seconds)	Repetitions	Total time (Seconds)
1	2	3	18	54
2	4	6	9	54
3	6	9	6	54
6	12	18	3	54

NB: Occlusion Spectacle program will elicit all repetitions before moving down to the following row

In the unpredictable visual occlusion sequence (Table 3: Unpredictable sequence) the visual occlusion intervals were pseudo-random making it difficult to predict the following visual occlusion. The visual occlusion software did not include a randomised visual occlusion feature, therefore visual occlusions and inspection times were manually programmed. Like the predictable visual occlusion sequence, the unpredictable visual occlusion sequence went for 3 min 36 s and in each 54 s time block 18 s was visually occluded. Each visual occlusion interval in the unpredictable sequence was preceded by the same inspection time interval as the predictable visual occlusion sequence (e.g., 4 s visual inspection followed by 2 s visual occlusion; 6 s visual inspection followed by 3 s visual occlusion). By imposing the same epoch intervals in both types of visual occlusion sequences, analyses can be conducted to evaluate the impact of predictable and unpredictable visual occlusion.

The programming of the unpredictable visual occlusion sequence slightly differed to the predictable visual occlusion sequence, but maintained many of the same aspects. In juxtaposition with the predictable visual occlusion sequence, the unpredictable visual occlusion sequence was programed to cycle through seven epochs continuously for 3 min 36 s, with each cycle indicating 54 s had elapsed. Therefore, each participant was subjected to the cycle four times.

Table 3

Unpredictable Sequence

	Occlusion (Seconds)	Inspection (seconds)	Total Interval Period (seconds)	Total time (Seconds)
	3	6	9	
	6	12	18	
	2	4	6	
	1	2	3	
	3	6	9	
	1	2	3	
	2	4	6	
Total				54

NB: Occlusion spectacle program will systematically sequence through rows for 216 s (3 min 36 s).

Track difficulty

Participants were required to drive an easy (Joesville Speedway) and hard track (Melbourne Grand Prix), the details of which are described in the proceeding chapters.

Dependent Variables

Self report measures

The self report measures pertained to the participants subjective workload and the strategies implemented across each condition.

Subjective workload

Participants' subjective overall workload was measured by the NASA-TLX questionnaire (Hart & Staveland, 1988) and via semi-structured interviews. Information about the NASA-TLX and semi-structured interviews can be located in the 'Questionnaire and Interviews' sections.

Strategies

Strategies refers to the cognitive and psychomotor techniques used by participants while being visually occluded in the different conditions. Cognitive strategies refer to perceptual and cognitive attention patterns that are employed to cope with the visual occlusions. Psychomotor strategies refer to vehicle manipulations. Strategies were extrapolated from thematic analyses of interview data, described in Chapter 4: Results and Discussion, section "Qualitative analysis"

Physiological recordings

The physiological recordings captured were the muscle activation, facial feedback, and hand positioning during the visual occlusions in the different conditions.

Muscle activation

Muscle activation of the upper trapeziums and flexor digitorum superficialis muscle was recorded by the sEMG.

Facial Feedback

A Webcam using *Bandicam* (Version 2. 3. 3. 860, Bandisoft South Korea) was used to capture and observe participants' bodily behaviours, (e.g. head movement, facial changes and postural alignments), during the different visual occlusion conditions.

Hand positioning

The Cannon Legria HFG10 video camera was focused on recording participant's hands with respect to the steering wheel during the different visual occlusion conditions.

Performance-related variables

Driving performance metrics were collected via *MoTeC i.2 pro* (Version 1.18.0017, MoTeC, Melbourne, Australia). Observable driving performance was captured via the screen capturing software *Bandicam* (Version 2. 3. 3. 860, Bandisoft, South Korea).

Driving performance metric

MoTeC i.2 pro was used to acquire data related to the virtual vehicle's speed deviations (km/h) for the different trials. It is important to note that there may be a driver skill - vehicle speed - track difficulty trade-off, suggesting that as one of these factors increases the other two factors decrease. However, in order to minimise this trade, prior to the experiment, pilot testing was conducted to identify target-driving speeds for the participants. The purpose of this was to ensure that participants did not reach speeds that would be considered dangerous to drive within and increase their likelihood to commit errors. Ultimately, participants were notified that the target speed was 80 kph, but could decrease their speed for precautionary measures.

Observable driving performance

Observable driving performance was monitored to provide context to the driving performance metrics during the different visual occlusions. Therefore, the screen capturing software *Bandicam* was used to capture the different facets of the observable driving performance for the various visual occlusion intervals during the trials. Such facets of the observable driving performance centred on periods in which participants were visually occluded and veered off-course or crashed into a wall. This was due to the interest in identifying if there were specific visual occlusion durations that caused these driving events. Together, these two facets were titled errors. Strayer et al. (2015), state that there is not a large literature that uses crash data as a measure of evaluating cognitive load, but expects a monotonic relationship between two (e.g., the longer the driver is distracted, the more likely they are to crash). However, previous research has postulated that driver distraction is the cause of 25% to 75% of all crashes and near crashes (Dingus et al., 2006; Ranney, Mazzae, Garrott, & Goodman, 2000). Hence, identifying the error rates of participants during visual occlusions may shed light into how long individuals are able to be distracted before incurring errors. Moreover, the observable driving performance recordings were also used to investigate the precision of execution of the strategies used that were identified during the interviews.

Procedure

Prior to a participant's arrival at the laboratory, the driving simulator was set up by running and formatting the software programs, *SimCor*, *rFactor 2*, *Bandicam*, *LabChart 7*, and *ToTaL Control System*. These software programs were then minimised. Upon arrival to the laboratory, the participant was also assigned an ID number for anonymity. Once the participant was assigned an ID number, they were presented with a Consent Information Statement (Appendix H: Consent information statement), providing them information about the importance, procedure, risks, and data analyses of the study. The participant was informed, both verbally and on the consent sheet, that if they had subsequent questions regarding the study to contact the researcher.

Once the participant had read the Consent Information Statement and any queries had been answered they completed a Consent Sheet. In particular, the participant was required to consent to questions pertaining to: the participation in the study; being free of medical conditions that could put them at risk; the data collection of video and audio recordings and biofeedback responses. This was a requirement as fully informed consent was essential. If participants answered "no" to any of the previous requests, they were informed that this was a requirement to participate and excluded from the study. However, participants were able to answer "no" to questions concerning their de-identified data and pictures being included in research papers and conference presentations. Upon completion of the Consent Sheet, participants were asked to complete a demographic/driving history questionnaire. Questions pertaining to their age and sex, driving history, vision acuity and video game history.

Following completion of the demographic/driving history questionnaire, participants were prepped for the placement of surface electrodes. Once participants had the surface electrodes attached over the skin where the muscles of interest were located, participants were seated in the driving simulator. Participants were asked to take a seat in the driving seat and it was adjusted until they were comfortable. The participants were instructed that the virtual vehicle they were to drive had automatic transmission and did not require use of the clutch or the gear stick to change gears. Instructions were given about the location of the acceleration and brake pedals. Participants were shown the paddles behind the steering wheel, and informed that if they required to put the vehicle in reverse during the trial, they would need to press the left paddle and then press the brake to reverse; pressing the right paddle would put the vehicle back into drive (gear 1). Participants were instructed that their objective was to drive as safely as possible, aiming for a target of 80 kph. However, they were notified that they were allowed to lower the speed limit if they believed it would benefit their safety or if the track required a lower speed.

Following the instructions, participants were permitted approximately 5 min of practice around Joesville Speedway. This was to provide participants time to become familiar with the vehicle, track, and rolling start feature. Participants were notified to alert the researcher if they had any questions during the practice and explicitly told to practice putting the car into reverse and reversing, as well as familiarising themselves with the rolling start feature. Upon concluding practice, participants were asked if they had any questions before they started the trials.

Final trial preparation followed any questions by the participants. This involved attaching the sEMG leads to the assigned surface electrodes; ensuring the webcam and video camera was viewing the participant correctly; and asking the participants to wear the PLATO spectacles. The sEMG was pretested with the participants to ensure that correct data was being recorded. This involved asking participants to voluntarily grip the steering wheel to see muscle activation from the flexor digitorum superficialis muscles, and asking participants to raise their shoulders to see muscle activations from the upper trapeziums. The webcam and video camera were set up accordingly to the neutral sitting and hand position of the participant, previewing each recording prior to recording.

Once all the final trial preparation was finished, the PLATO glasses were programmed with either the predictable or unpredictable visual occlusion sequence. The visual occlusion sequence that participants started with depended on their ID number: participants with an odd ID number were assigned to the predictable visual occlusion sequence first and participants with an even ID number were assigned to the unpredictable visual occlusion sequence first. Participants were asked if they had final questions before the trial started and when they were ready to start, to put on the PLATO glasses.

When participants had fitted the PLATO spectacles, the AutoHotKey script was activated. The video camera was manually activated to commence recording followed by the hotkey press to activate all the software programs together. Participants then began their first trial.

When the trial concluded, the video camera was manually deactivated. Participants had the sEMG cable leads removed and asked to take a seat at a desk. Participants were provided a NASA-TLX (Hart & Staveland, 1988) subjective workload questionnaire and its instructions. They were asked to read the instructions and ask the researcher if they had any questions. Once participants had finished the NASA-TLX questionnaire, a semi-structured interview was conducted and recorded. Participants were then directed to the driving simulator to commence the second condition.

In the second condition, participants commenced the opposite occlusion sequence type that they undertook in the first condition but maintain driving on the easy track. This follows the same experimental procedure and structure as the first condition, including when participants finished the trial, they were provided with the NASA-TLX (Hart & Staveland, 1988) questionnaire again, followed by the semi-structured interview.

Following the completion of the second condition, participants commenced the third condition, where they drove the hard track. Participants had approximately 10 min practice driving around the hard track and then commenced the occlusion sequence type they were assigned in their first condition. In order to promote familiarity around the hard track, participants had additional practice time, as the time duration to drive around the track was longer than the easy track. Following the trial, participants completed a NASA-TLX (Hart & Staveland, 1988) questionnaire and interviewed in the same format as conditions one and two.

Following the end of the third trial, participants commenced the fourth and last condition. In this trial, participants drove on the hard track paired with the occlusion sequence type they were assigned in the second condition. Again, this was followed by the NASA-TLX (Hart & Staveland, 1988) questionnaire and semi-structured interview. After the experiment, participants had the surface electrodes removed and were asked if they had any queries about the experiment or their participation.

Quantitative data analyses

All quantitative performance-related data were retrieved from MoTec, inspected and cleaned in Excel (Microsoft Corporation, USA). Statistical analyses were performed using SPSS statistical package for the social sciences (Version 23, IBM Corporation, Armonk. New York, U.S) software.

Within-subjects aggregated quantitative performance data

The data that was collected was aggregated for quantitative analysis.

Average speed

Data from individual participants pertaining to speed were collected at a sampling rate of 10 Hz, which led to over 2000 data points per condition. Individual participants' speed was averaged and those averages were used in the aggregated data analyses. Parametric tests of significance were then used to identify significant differences between participants' average speeds across conditions. Prior to the analyses, assumption testing was conducted. This included screening the data for outliers via boxplots and ensuring normality via Shapiro-Wilks tests. Alpha (α) levels were set at .05 for all analyses.

Errors

Errors were defined as *crashes* (where the vehicle hit an obstacle such as the outside wall of the racetrack circuit) or *off-road events* (where the vehicle left the defined race track, such as driving through dirt or track-side grass). Errors included each crash or off-road event that occurred during visual occlusions. If participants crashed and veered off-course in the same visual occlusion interval, only one error was scored. As there were different numbers of visual occlusion intervals (e.g., nine 2 s occlusions vs. six 3 s occlusions) errors were converted into percentages to permit comparisons between the errors made in different intervals. Consequently, as these particular data were percentages and classified as discrete, it would have been inappropriate to employ an ANOVA, as it violates the continuous data assumption. Therefore, the non-parametric test, Friedman's ANOVA by ranks, was used to identify significant differences in the participants' percentage of errors. Alpha levels were set at 0.05 for all analyses. As there are currently no non-parametric alternatives for a two-way ANOVA, two-way repeated measures ANOVAs were employed to reveal if there significant interactions between the independent variables.

NASA-TLX overall subjective workload

The initial NASA-TLX (Hart & Staveland, 1988) overall workload analysis was outlined in the previous section (see *Questionnaires and Interviews: National Aeronautics and Space Administration Task Load Index)*. When comparing NASA-TLX scores between participants, previous research often employs parametric analyses, such as ANOVA. However, employing ANOVA to compare workload differences between conditions is problematic as it violates the continuous data assumption as scores can only be rated out of 100. Moreover, the NASA-TLX data is ordinal at best, as differences in numerical scores between conditions are not necessarily equal between participants. For example, if two participants received workload scores of 45 for a condition and 50 for a following condition, there is no guarantee that these scores are conceptually identical for both participants. It may be that for one participant the increment of five was low, while the other participant may conceptually rate it medium to high, therefore making it inappropriate to use parametric statistics to compare for significant differences. In light of these conceptual issues, the non-parametric test, Friedman's ANOVA by ranks was used to identify significant differences between participants' subjective workloads across conditions. Alpha levels were set at .05 for all analyses.

Post hoc tests: Bonferroni technique

All post hoc tests were conducted after applying the Bonferroni correction. The Bonferroni correction was selected given its robust technique at minimising the risks of Type 1 errors (Mendenhall & Sincich, 2007). To achieve this, the technique adjusts the α level by dividing it by the number of pairwise comparisons to be conducted. All analyses that required post hoc tests contained six pairwise comparisons, hence, the pairwise α level were set at .008 (pairwise α level= .05/6).

Outliers

Given the dynamic nature of the task, large deviations in speed were anticipated and were observed. Consequently, numerous "outliers" were revealed when examining boxplots. Outliers are defined as data points that are subjectively suspicious to the experimenter (Dixon, 1950) however, in this experimental design, the outliers recorded were not suspicious, but instead represented data points in which participants' performance and behaviour were dramatically affected by experimental manipulations (e.g., sudden decrease in speed as a result of going off-track, or being subjected to a long or unpredicted occlusion). While previous literature has cautioned that the inclusion of outliers in parametric testing can increase Type I errors (Osborne & Overbay, 2004), the exclusion of such outliers in the analysis is not justifiable in the current study, as the data would no longer represent the true statistical variability of participants' performance (Orr, Sackett, & DuBois, 1991). Therefore, outliers were retained in the parametric analyses.

Individual performance data

Following the data analysis of the within-subjects aggregated data, analysis of individual case data was conducted. While the aggregated group data aimed to establish that various experimental manipulations created the expected effects on performance, the main focus of the research was to identify through detailed case studies matching qualitative and quantitative data for individual participants what factors led to some participants performing better than other participants.

Average speed

Individual participants' speed was collected at a sampling rate of 10 Hz, which resulted in over 2000 data points per condition speed. All data points were included in the parametric testing. The parametric tests employed were identical to the tests employed for the aggregated group data; however, a number of considerations were taken into account for the assumption tests.

F-statistics for single-case

While not common, previous research has demonstrated that ANOVA tests can be conducted for single-case research (Gentile, Roden, & Klein, 1972; Huitema, 1985, 1986b; Scruggs, Mastropieri, & Regan, 2006). The primary concern with conducting ANOVA tests on single participants is violations in the interdependence assumption, suggesting the test is prone to autocorrelation in the data (Scruggs et al., 2006). However, after analysing 441 single-case data displays, Huitema (1985, 1986b) supported the use of F-statistics on single-case data after finding near-normal distributions in histograms of within phase, lag one autocorrelations (data points that are correlated with each subsequent data point) with a mean near 0. Therefore, these findings installed confidence in conducting the ANOVA tests on the individual cases.

Skewed distribution

A violation of the assumption of normality does not greatly influence the risk of type I and II errors in large sample sizes (Glass, Peckham, & Sanders, 1972; Lix, Keselman, & Keselman, 1996). This is particularly true, as guided by the Central Limit Theorem (Mordkoff, 2000), as the sample size increases (*n*<30) "the sampling distribution of $\bar{X}$ is always approximately normal, regardless of the shape of the population distribution" (King, 2013, p.160). Therefore, given that there were over 2000 speed data points, violations of normality was unlikely to influence the parametric analyses.

Errors

Identical non-parametric tests employed for the aggregated data were also employed to identify statistically significant differences between individual participants' errors.

Individual NASA-TLX source and overall subjective workload

Individual NASA-TLX scores and weighted sources of workloads were assessed to identify how each participant cognitively rated each condition and which cognitive factors they believed to impose the most demand. Visual analyses were conducted to compare the overall subject workload and weighted source of workload between conditions for each participant. Variable width column graphs have been used to depict the sources of workloads. The x-axis depicts the magnitude that the source of workload played in the condition (e.g., wider bar widths indicate the weight of the source of workload). The y-axis depicts the rating given to each source of workload. Sources of workload that received weighting scores of 0 were omitted from the graphs.

Qualitative data

Using a general qualitative framework, individual qualitative data was collected and analysed to identify the strategies used, and driving behaviour elicited by the participants during the trials. More specifically, semi-structured interviews and video recordings were analysed. The data pertaining to the strategies in the semi-structured interviews were transcribed verbatim and then analysed using non-numerical repertory grids (see Appendix I: Example of non-numerical reporatory grids format). Grid templates had the ten semi-structured interview questions, including an 'Extras' grid (for answers of questions that did not fit into the interview structure), arranged horizontally across the top of the grids. Each participant's trial conditions were arranged vertically adjacent along the left hand side of the grid. Quotes and paraphrases of the responses of each question were then assigned to the relating trial conditions box in grid.

As per leading qualitative researchers Miles and Huberman (1994), transcripts were read numerous times and responses were initially coded by tagging similar responses and phrases, with similar content organized into preliminary categories. This allowed for large chunks of data to be easily represented by smaller fragments and easily stored and retrieved for further analysis (Punch, 2009). Initial descriptive codes were formed into pattern codes, which are inferential in nature and allow data to be separated into refined, meaningful categories. Overlapping categories were collapsed and final categories were expanded into themes.

Behavioural and biofeedback data

The behaviour of participants was observed in the video-recordings. Head movements, facial changes and postural alignments were observed to identify the differences across the four groups, and were evaluated following recommendations by Stanton et al. (2013). This involved tabulating an observation transcript (Appendix J: Observation Template, adaptation from Stanton et al., 2013) and reporting if any head movements, facial changes and postural alignments occurred prior to an error being committed. If any behavioural indicators occurred, the contextual situation was described. Muscle activation acquired from the surface electromyogram was initially evaluated via the identification of observable activation patterns on the *LabChart 7* graphs.

Chapter 4: Results and Discussion

Introduction

This chapter has four sections that cover: 1) within-subject aggregated quantitative performance data; 2) individual quantitative performance data; 3) qualitative data; and 4) behavioural and biofeedback data. The first section will establish that the experimental manipulations have an effect on performance across the group of participants, and that a speed-accuracy trade-off is evident as the driving conditions became more demanding. The second section will explore the differences between individuals on quantitative performance data, and will aim to identify characteristics of better and poorer performance within the normal range. The third section explores qualitative data with the aim of understanding the cognitive and psychomotor strategies employed by participants to aid performance across different conditions. The fourth section reports behavioural and biofeedback data collected to assist in understanding possible predictors and indicators of impending performance degradation. Given that the data analyses were performed sequentially in the same sequence as the sections in this chapter, findings will be discussed in as much as they guided the next stage of data analysis.

Participants

Nine adults (four women and five men) aged between 18 and 35 years old (M=24.33, SD=4.12) participated in the experiment. It was initially envisaged that the participant pool would consist of up to 30 participants (see Appendix K: Intended participant sample size on Ethics application). However, the decision to analyse full sets of data from 8 participants was driven by the primary focus of the current study to combine qualitative and quantitative data to understand human cognitive factors contributing to dynamic task performance and not relying purely on quantitative results. Eight participants were considered sufficient to demonstrate clear quantitative differences in performance across experimental conditions (e.g., see Chen & Milgram, 2011; Godthelp et al., 1984) while providing the capacity to analyse the extensive qualitative data as well.

Participants from the general population were used in this project as it was considered likely to resemble new recruits for the Australian Department of Defence who will not have had previous highly specialised training in simulation modalities. Although the participants in this study did not have military training, assessing the range of cognitive and psychomotor strategies and performance of such participants on a relatively familiar fast-paced, dynamic task should provide insight into the appropriate progression of skills training required for multi-tasking in more specialised complex dynamic task environments. Additionally, from an ethical perspective, it was important not to burden skilled expert performers by involving them in experiments in highly specialised environments prior to investigating the phenomena of interest in more a generic context, particularly when research participation carries the risk of interfering with current training.

All participants had normal or corrected-to-normal vision and were screened to ensure that they were physically fit to participate. All participants had held (a probationary or full) driver's licence for between 1 and 17 years (*M*=5.44, *SD*=4.67). Seven participants exclusively drove with automatic transmission only, no participants exclusively drove manual, and two participants drove both manual and automatic transmission. On average, participants drove between 1 and 20 hours (*M*=9.67, *SD*=6.40) per week. The most common driving areas participants reported driving in was on inner city roads. Two participants reported that they had undertaken advanced driving courses, which included Defensive Driving Course level 1 and 2. Two participants reported playing racing car videos, although only one had current gaming experience, and reported playing on average 8 hours per week. Participants were randomly assigned to a group that was presented with either a predictable or an unpredictable occlusion condition first.

As can be seen, participants were all sufficiently familiar with the task environment and had the basic skills to complete the task. Although eight participants were recruited initially, one participant was not presented with all the occlusions in a few trials owing to an equipment fault. Therefore, this participant was not included in the omnibus analyses, as they did not sufficiently complete the conditions. However, because this participant had extensive video game experience, his data were included in the individual case studies and qualitative data analyses. An extra participant was recruited (making nine in total) to ensure that there were eight participants in the aggregated quantitative data analysis.

In order to verify that participants were imposed with visual occlusions while experiencing different events (driving straight or turning), in-game video observations were conducted to track the events where the visual occlusion onsets occurred. The frequency of visual occlusion onsets for both event types across all conditions for each participant were converted to percentages to promote relativity between participants (See Table 4). Across the easy track with a predictable visual occlusion, participants' percentages of visual occlusion onset while steering straight ranged between 48-61% (*M*= 54%), while visual occlusion onset while turning ranged between 39-52% (*M*= 46%). When undertaking the easy track with an unpredictable visual occlusion sequence, participants' percentages of visual occlusion onset while steering straight ranged between 36-69% (*M*=43%), while visual occlusion onset while turning ranged between 31-64% (*M*=57%). For the hard track with a predictable visual occlusion, participants' percentages of visual occlusion onset while steering straight ranged between 56-77% (*M*=48%), while visual occlusion onset while turning ranged between 23-44% (*M*=52%). Across the hard track with an unpredictable visual occlusion, participants' percentages of visual occlusion onset while steering straight ranged between 58-71% (*M*=63%), while visual occlusion onset while turning ranged between 29-42% (*M*=37%) between participants. Although there are were some differences between the percentages of the frequency of visual occlusions across the two events types there appeared to be no extreme cases across condition. In other words, there were no trials where participants exclusively experienced visual occlusions on straights or around corners.

Table 4

Percentages of event type upon visual occlusion onset across conditions by participant

Simulated Driving Conditions				
	Easy Predictable	Easy Unpredictable	Hard Predictable	Hard Unpredictable
	Straight/Turning (%)	Straight/Turning (%)	Straight/Turning (%)	Straight/Turning (%)
Participant 1	50/50	43/57	68/32	67/33
Participant 2	50/50	48/52	77/23	67/33
Participant 3	42/58	58/42	72/28	63/37
Participant 4	44/56	36/64	57/43	58/42
Participant 5	39/61	69/31	69/31	71/29
Participant 6	44/56	46/54	64/36	67/33
Participant 7	42/58	37/63	58/42	52/48
Participant 8	37/63	52/48	56/44	61/39
Participant 9	36/64	46/54	64/36	59/41

Within-subjects aggregated quantitative performance analyses

This section presents the quantitative analyses of aggregated data on performance for eight participants to establish performance characteristics under occlusion and to ensure that the experimental manipulations were having the intended effects on performance. The approach taken has been to report mean data in tabular form, and to present the data in graphical form with standard error bars to depict the trends in the data and highlight the likely sources of significant effect.

Average Speed

Mean group speed across simulated driving conditions

The mean group speeds and standard deviations across driving conditions presented in Table 5 and Figure 5 show that, as expected, participants tend to slow down as the driving conditions become more difficult. While the harder track caused an obvious decrease in speed for the unpredictable occlusion sequence, speed appeared to be less affected on the easy track.

Table 5

Means and standard deviations of group speed (km/h) across simulated driving conditions

	Simulated Driving Conditions			
	Easy Predictable	Easy Unpredictable	Hard Predictable	Hard Unpredictable
Average Speed (km/h)	82.56 (3.25)	80.91 (7.18)	73.74 (7.49)	67.28 (5.54)

n= 8

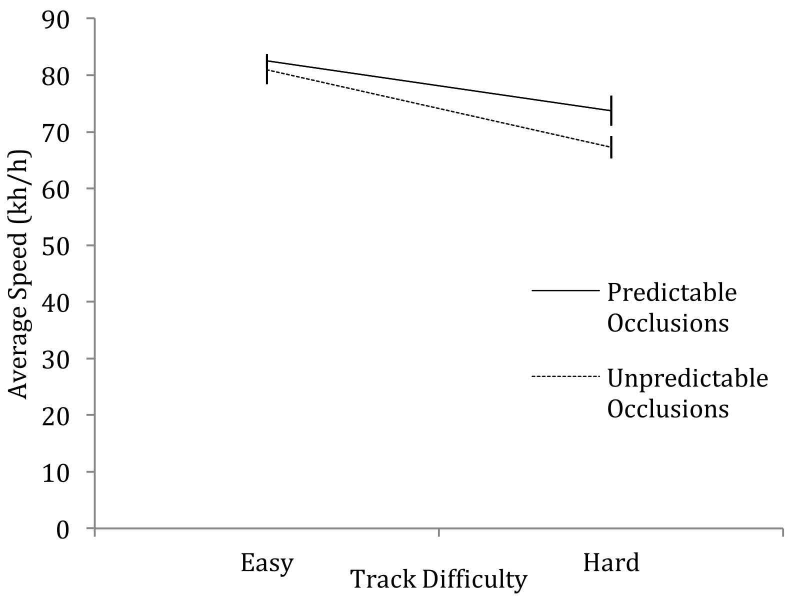

Figure 5. Means and standard error bars of group average speed across simulated driving conditions.

A two-way (Track Difficulty: Hard/Easy x Occlusion Sequence (Predictable/Unpredictable) repeated measures ANOVA was conducted to test whether the observed differences were significant. Shapiro-Wilk tests conducted on the studentized residuals of the simulated driving conditions, for the easy track with predictable visual occlusion sequence (EP) (ρ=.382), easy track with unpredictable visual occlusion sequence (EUP) (ρ=.195), hard track with predictable visual occlusion sequence (HP) (ρ.607), and hard track with unpredictable sequence (HUP)

(ρ=.589) showed that they were normally distributed. Following inspection of the boxplots of the studentized residuals of the simulated driving conditions, there were no outliers found. Mauchly's test of sphericity indicated that the assumption of sphericity had been met ($\chi^2(5)$=.387, ρ=.372). As there are two levels of the factors in the analyses, there is no deviation from sphericity (Hinton, Brownlow, & McMurray, 2004). Hence, the assumption of sphericity was met.

A significant main effect of track difficulty ($F(3,21)$=19.752, ρ<.003) confirmed that average driving speed was significantly slower on the hard track (*M*=70.51, *SD*=7.18) compared with the easy track (*M*=81.73, *SD*=5.45). A significant main effect of predictability of the occlusion sequence confirmed that driving speed was significantly reduced during the unpredictable occlusion sequences (*M*=74.02, *SD*=9.40) compared with the predictable sequences (*M*=78.14, *SD*=7.12). There was no significant interaction effect.

The analysis of mean speed across conditions supports the fact that participants reduce speed as the track becomes harder, and also reduce speed as the occlusion sequence is less predictable. Both experimental manipulations appeared to affect performance in the expected direction. While there appeared to be a trend for the combined effect of harder track and unpredictable occlusion sequence to deliver a greater reduction in speed than either effect alone, this interaction did not reach statistical significance.

Errors

The second performance metric of interest was the number of errors, comprising a count of the number of times a participant veered off track or crashed into the wall. Errors were identified by the experimenter through post-hoc visual analysis of the Bandicam screen recordings of each trial. The errors recorded during each occlusion interval were normalised to a percentage score of errors/occlusion as the number of occlusions were different for each occlusion duration condition. Note that all errors occurred during intervals of occlusion except for two errors that occurred at the beginning of a trial while the participant was gaining control of the car. These errors were not included in the analyses.

Error score across simulated driving conditions

Means and standard deviations of the error scores across simulated driving conditions are presented in Table 6 and Figure 6. It appeared that approximately one third of occlusion intervals resulted in errors across all conditions. A Friedman's ANOVA, $\chi^2(3)$=1.282, ρ=.733, confirmed that there were no significant differences between the conditions.

Table 6

Means and standard deviations of the error scores (% errors/occlusions interval) across simulated driving conditions

	Simulated Driving Conditions			
	Easy Predictable	Easy Unpredictable	Hard Predictable	Hard Unpredictable
Errors (%)	38.37 (40.98)	37.63 (34.78)	34.87 (35.59)	33.34 (38.54)

n= 8

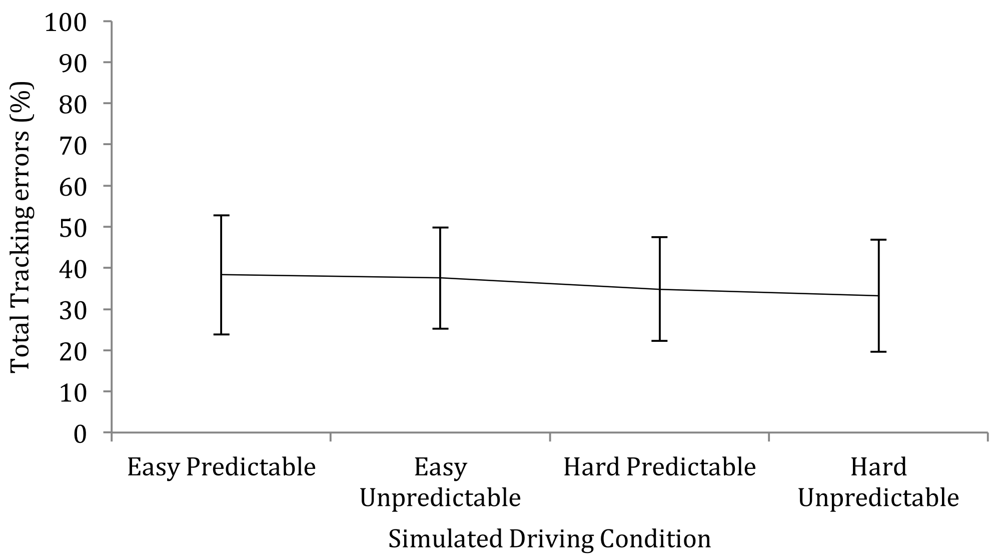

Figure 6. Means and standard error bars of errors across conditions.

Error scores across visual occlusion intervals

Means and standard deviations for error scores across visual occlusion intervals are given in Table 7 and Figure 7. As can be seen from Figure 7, the error scores increase monotonically as the length of occlusion increases, and a Friedman's ANOVA by ranks indicated that there were significant differences in error scores between visual occlusion intervals, $\chi^2(3)=83.510$, $\rho<.001$.

Table 7

Means and standard deviations of error scores (% errors/occlusion) across visual occlusion intervals

	Visual Occlusion Interval			
	1 second	2 second	3 second	6 second
Errors (%)	1.69 (3.50)	14.78 (14.39)	37.00 (20.27)	90.75 (15.90)

n= 8

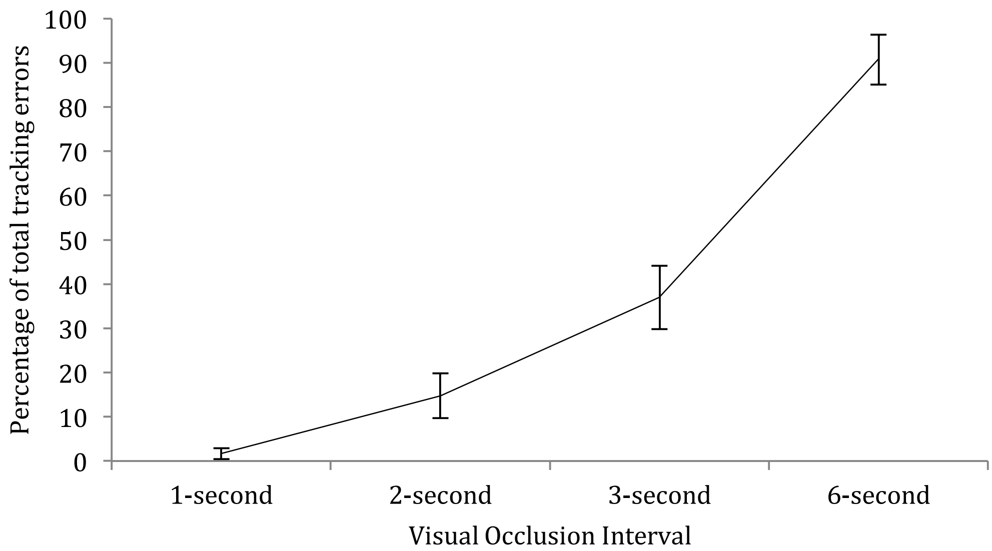

Figure 7. Means and standard error bars of error across visual occlusion intervals.

Six post-hoc pairwise comparisons (SPSS Statistics, Version 23, IBM Corporation, Armonk. New York, U.S) with Bonferroni corrections were employed to investigate the effects between the percentages of errors across each visual occlusion interval. Statistical significance was accepted at the $\rho<.008$ level. All pairwise comparisons reached significance except for the difference in errors between the 1 s and 2 s occlusion intervals, confirming that, as occlusion interval increased beyond 2 s, errors increased. To investigate the contributions of track difficulty and predictability of occlusion on error scores, further analyses were conducted.

Percentage of errors across visual occlusion intervals by track difficulty

Mean and standard deviations for percentage of errors across track difficulty and visual occlusion interval are given in Table 8 and Figure 8. Unexpectedly, these data suggest a trend towards fewer errors in the more difficult track conditions for 2 s and 3 s occlusions, however a 4 (visual occlusion interval [1, 2, 3, 6 s]) x 2 (track difficulty [easy track; hard track]) repeated measures ANOVA did not reveal any significant differences between these conditions, $F(3,45)=0.863$, $\rho=.467$, $\eta^2=0.054$.

Table 8

Means and standard deviations of the percentage of errors across visual occlusion intervals by track difficulty

	Visual Occlusion Interval			
Track difficulty	1 second	2 second	3 second	6 second
Easy Track	1.19 (3.49)	17.00 (16.83)	41.63 (19.69)	92.19 (15.05)
Hard Track	2.19 (3.54)	12.56 (11.58)	32.38 (20.40)	89.31 (17.07)

n=8

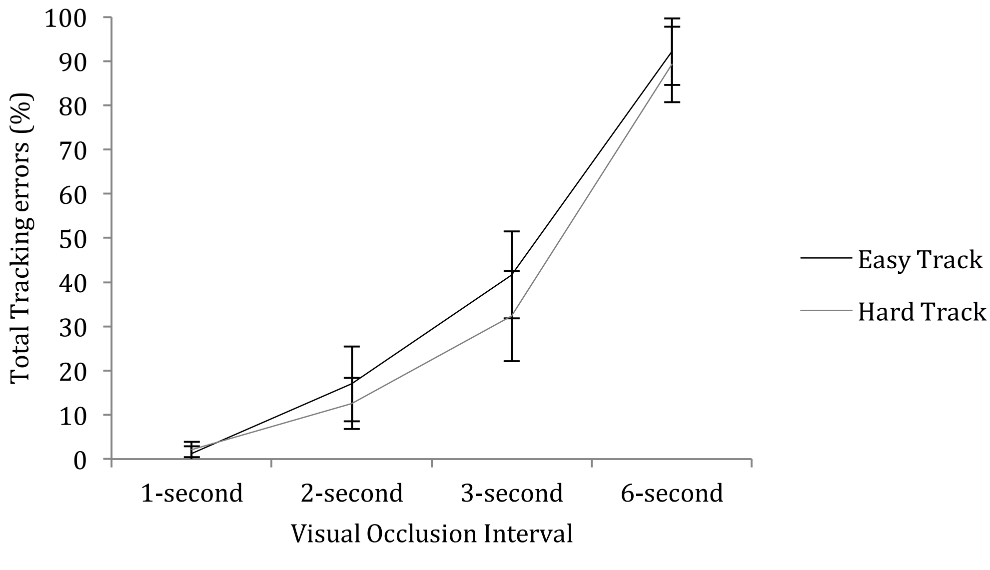

Figure 8. Means and standard error bars of percentage of errors across visual occlusion intervals by track difficulty.

Percentage of errors across visual occlusion intervals by occlusion sequence predictability

Mean and standard deviations for percentage of errors across visual occlusion sequence type and visual occlusion interval are given in Table 9 and Figure 9. A 4 (visual occlusion interval [1, 2, 3, 6 s]) x 2 (visual occlusion sequence type [predictable; unpredictable]) repeated measures ANOVA confirmed that there was no significant interaction between visual occlusion intervals and visual occlusion sequence type on the mean percentage of errors ($F(3,45)=0.692$, $\rho=.562$, $\eta^2=0.044$).

Table 9

Means and standard deviations of the percentage of errors across visual occlusion intervals by visual occlusion sequence type

	Visual Occlusion Interval			
Visual occlusion sequence type	1 second	2 second	3 second	6 second
Predictable occlusion sequence	2.56 (3.61)	14.50 (13.06)	35.44 (21.89)	94.00 (12.90)
Unpredictable occlusion sequence	0.81 (3.25)	15.06 (16.03)	38.56 (19.11)	87.50 (18.26)

n=8

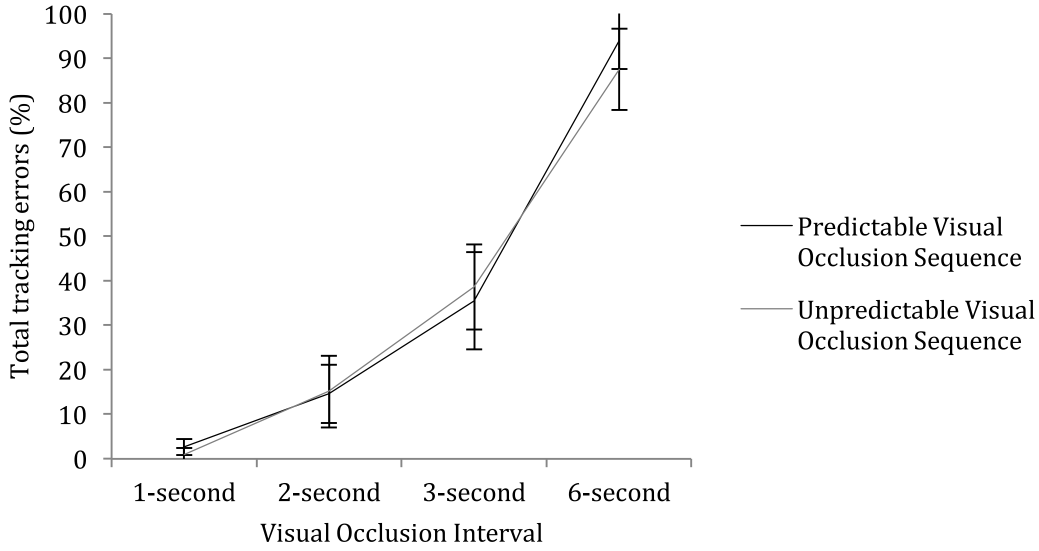

Figure 9. Means and standard error bars of percentage of errors across visual occlusion interval by visual occlusion sequence type.

Summary of error score data

It should be noted that there were inherent problems in determining the appropriate error metric. Only one error was recorded per occlusion period due to the nature of errors committed and the time taken to recover from an error. However this meant that there was more opportunity for accruing errors in the shorter occlusion conditions because they had more periods of occlusion. For example, as per Table 2 in Chapter 3, there were 18 occlusion periods during the 1 s occlusion condition (offering a maximum of 18 errors in this condition) whereas there were only 3 occlusion periods during the 6 s occlusion condition (offering a maximum of 3 errors). The normalised error scores presented in this section generated a percentage error score (the percentage of occlusion intervals incurring an error per condition), however the granularity of the error score differs across conditions.

Despite these issues with determining an appropriate error metric, the overall data support the expectation that errors would increase as occlusion interval increased. The effects on performance observed across other manipulations were most evident in the speed data, suggesting, as per instructions to participants, a speed accuracy trade-off was employed to maintain performance so far as possible.

NASA-TLX subjective workload scores

NASA-TLX workload scores were employed as a measure to gain insight into participants' cognitive workload during each condition. NASA-TLX workload scores were aggregated across participants to evaluate for significant difference between conditions. Means and standard deviations for NASA-TLX workload scores across simulated driving conditions are depicted in Table 10 and Figure 10. As can be seen in Figure 10 the workload scores increases monotonically as the visual occlusion sequence becomes unpredictable and the track difficulty increases. A Friedman's ANOVA by ranks indicated that there were significant differences in NASA-TLX workload scores between the simulated driving conditions, $\chi^2(3)=13.385$, $\rho<.004$.

Table 10

Means and standard deviations of aggregated NASA-TLX workload scores across simulated driving conditions

	Simulated Driving Conditions			
	Easy Predictable	Easy Unpredictable	Hard Predictable	Hard Unpredictable
NASA-TLX workload score	70.75 (17.41)	74.25 (11.23)	76.88 (12.92)	84.88 (9.85)

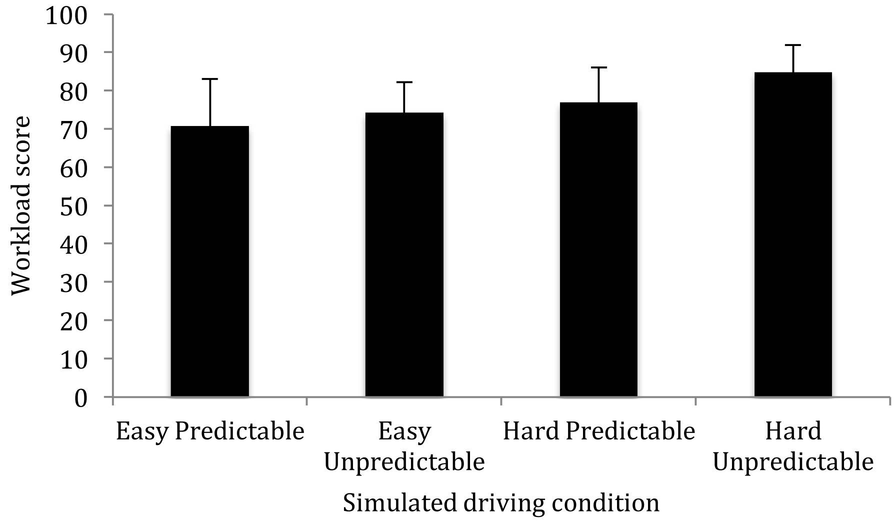

Figure 10. Bar chart of aggregated overall workload across simulated driving conditions.

Six post-hoc pairwise comparisons (SPSS Statistics, Version 23, IBM Corporation, Armonk. New York, U.S) with Bonferroni corrections were employed to investigate the effects between the NASA-TLX workload scores across each simulated driving condition. Statistical significance was accepted at the $\rho<.008$ level. Tests revealed that there were statistically significant differences between the EP and the HUP conditions ($\rho=.001$) and the EUP and the HUP conditions ($\rho<.004$). No other pairwise comparisons revealed to be significantly different from each other.

Individual quantitative performance analyses

Aggregated data presented in the previous section provided evidence that, in general, the experimental manipulations produced the expected effects on performance. Speed decreased and number of errors increased as conditions became more difficult (harder track, unpredictable occlusions, increased occlusion interval). The major focus of this thesis was to determine the differences in performance between individual participants, all of whom had sufficient skill to perform the assigned tasks but differed in their level of performance while operating within reasonable performance parameters. In this section, the differences between performances of individuals across conditions are highlighted.

Participants were categorised into higher performing participants and lower performing participants based on their error data. Participant in the higher performing group were those who committed the least number of errors across visual occlusion intervals. Participants' total number of errors were ranked for each visual occlusion intervals. The ranking scores attained for each visual occlusion interval were added to form an overall participant ranking. A median split of ranking scores resulted in five higher performing participants and four lower performing participants (see Table 11). It should be emphasised that, while participants are classified as higher performing and lower performing on the basis of their error data, all participants were sufficiently skilled to perform the driving task at an acceptable level.

Table 11

Participant grouping based on driving performance error data across simulated conditions

Higher and lower performing participants	
Higher performing participants	**Lower performing participants**
Participant 8 (Rank 1)	Participant 6 (Rank 6.5)
Participant 5 (Rank 2)	Participant 7 (Rank 6.5)
Participant 3 (Rank 3)	Participant 4 (Rank 8)
Participant 1 (Rank 4)	Participant 9 (Rank 9)
Participant 2 (Rank 5)	

The breakdown of quantitative performance data sought to identify for each participant which factors influenced their performance the most. For example, if track difficulty generated the most impact on performance, it could be argued that the limiting factor in performance was primarily psychomotor skill level. In contrast, if predictability of occlusion generated the most impact on performance, it could be argued that cognitive skills (anticipating and preparing for potential occlusion, dealing with uncertainty) are the limiting factor in performance. The ability to deal with longer occlusion intervals may be indicative of better mental models of the driving task and better strategies for maintaining performance or might be purely a function of psychomotor skill level. Speed and error data for each participant are summarised in Figures 11 and 12. These data will be discussed in detail for each participant.

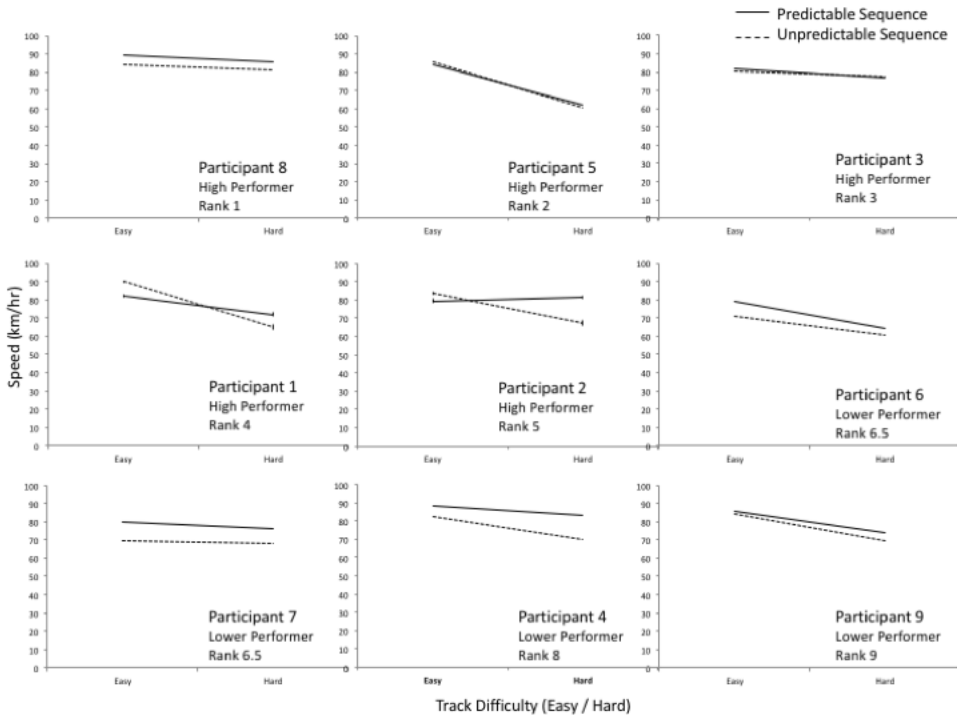

Figure 11. Mean speed and standard error bars for all participants ordered by rank for track difficulty and predictability of sequence.

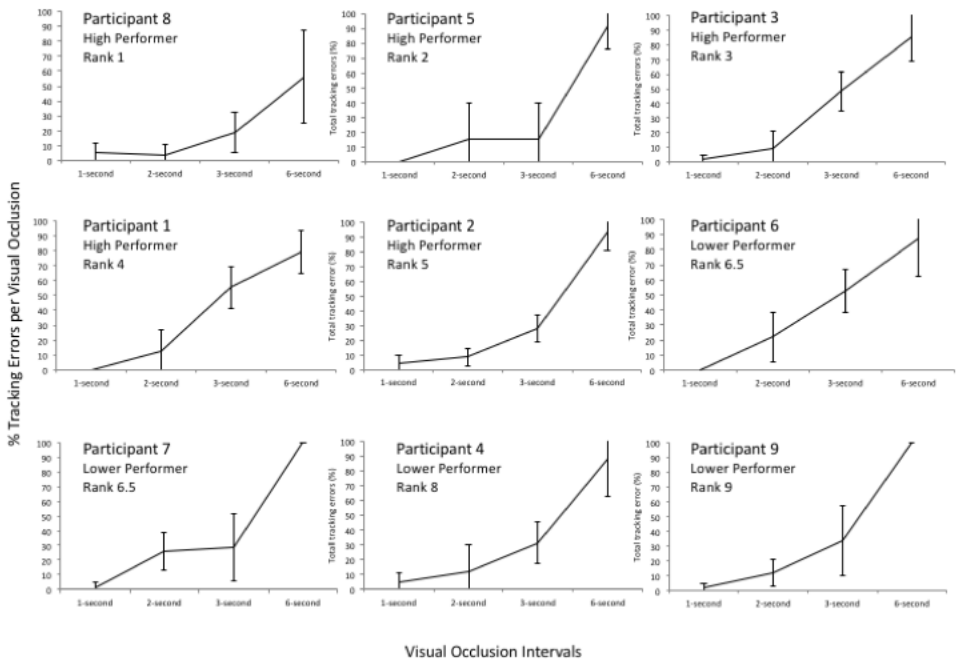

Figure 12. Mean percentage of errors and standard error bars for all participants ordered by rank errors across visual occlusion intervals.

In the following sections, demographic data are presented for each participant, along with a breakdown of their quantitative performance data and the NASA-TLX data. The paper version of the NASA-TLX was chosen over using the computer input version as Noyes and Bruneau (2007) have previously demonstrated that when participants were required to answer the NASA-TLX via computer input, their absolute and relative workload scores were significantly higher than when required to answer it via paper. The increase in workload for computer-based NASA-TLX was rationalised to occur as a consequence of the increased cognitive demands associated with processing information from computers (Noyes & Bruneau, 2007; Wästlund, Reinikka, Norlander, & Archer, 2005). Therefore, the paper NASA-TLX questionnaire was chosen for this experiment to minimise any additional workload that may be incurred by doing the experiment.

While the NASA-TLX provides numerical scores, the data are ordinal at best and comparison of scores across participants is problematic. For this reason the NASA-TLX data have only been included in the individual analyses. The presentation of individual quantitative data is followed by a qualitative analysis of interview data to identify strategies used to maximise task performance across higher and lower performing participants. Note that odd-numbered participants except for Participant 9 (Participants, 1, 3, 5, 7) received the easy predictable condition first, whereas even-numbered participants (2, 4, 6, 8) received the easy unpredictable condition first. Participant 9, who replaced Participant 8 in the aggregated data analysis received the easy unpredictable condition first to maintain the counter-balancing in the aggregated data analysis.

High performing participants

Participant 8 (P8)

Participant 8 was a 22-year-old male who had held a driver's license for 1 year. Participant 8 had not undertaken any extra driving training and on average drives 1 hour per week with an automatic transmission car, typically around the inner city. Participant 8 reported that he was experienced in racing video car games, playing, on average, 8 hours per week. During three of the four trials for participant 8, the code responsible for terminating the simulation and data collection software after 3 min 36 s malfunctioned, which resulted in shorter trials (3 min 20 s). The data for this participant were not included in the aggregated data analysis, but because this participant had extensive experience in racing car video games and was a high performer on the experimental task, his data was analysed at the individual level. In order to keep trial time consistent, data collected after 3 min 20 s for the trial that ran for the appropriate time length was ignored. Participant 8 experienced the unpredictable visual occlusion sequence first.

Average speed (km/h) across simulated driving conditions

Means and standard deviations of Participant 8's speed across simulated driving conditions are presented in Table 12 and in the combined data of Figure 11. It can be seen from these data that both the harder track and the unpredictable occlusion sequence resulted in reduced speed.

Table 12

Means and standard deviations of Participant 8's speed (km/h) across simulated driving conditions

	Simulated Driving Conditions			
	Easy Predictable	Easy Unpredictable	Hard Predictable	Hard Unpredictable
Average Speed (km/h)	89.20 (4.27)	83.88 (20.80)	85.53 (20.94)	80.90 (19.82)

A two-way (Track Difficulty x Predictability) repeated measures ANOVA confirmed that mean driving speed on the easy track (M=86.54, SD=15.24) was faster than on the harder track (M=83.21, SD=20.52), $F(1, 2006) = 57.249$, $\rho<.001$, and that mean driving speed in the unpredictable condition (M=82.39, SD=20.37) was slower than in the predictable condition (M=87.36, SD=15.22), $F(1, 2006) = 186.835$, $\rho<.001$. There was no significant interaction effect.

Percentage of errors made per visual occlusion interval

The means and standard deviations of Participant 8's errors across visual occlusion intervals are presented in Table 13 and Figure 12. It can be seen from these data that errors were highest for the longer occlusion intervals.

Table 13

Means and standard deviations for Participant 8's error per occlusion (%) across visual occlusion intervals

	Visual Occlusion Interval			
	1 second	2 second	3 second	6 second
% Errors / occlusion	5 (6.63)	3.5 (7.00)	18.75 (13.72)	56.25 (31.46)

A Friedman's ANOVA by ranks supported a significant difference in the percentage of errors/occlusion across the visual occlusion intervals, $\chi^2(3)=8.250$, $\rho=.041$. Pairwise Friedman's tests ($\rho<.05$) showed that the 6 s occlusion interval had a significantly higher error score than both the 1 s and 2 s intervals, but no other pairwise comparisons were significantly different from each other.

NASA-TLX (Hart & Staveland, 1988) source and overall workload across individual and aggregated simulated driving conditions

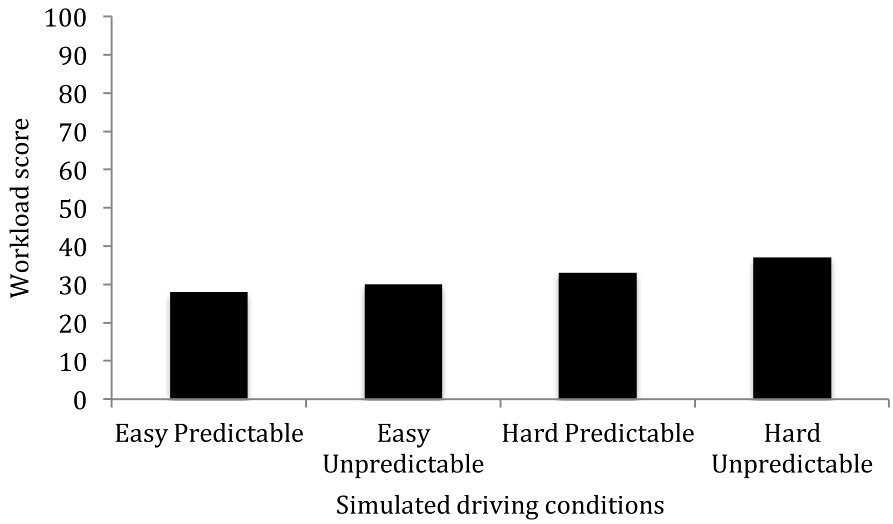

Figure 13. Bar chart of Participant 8's overall workload across the simulated driving conditions.

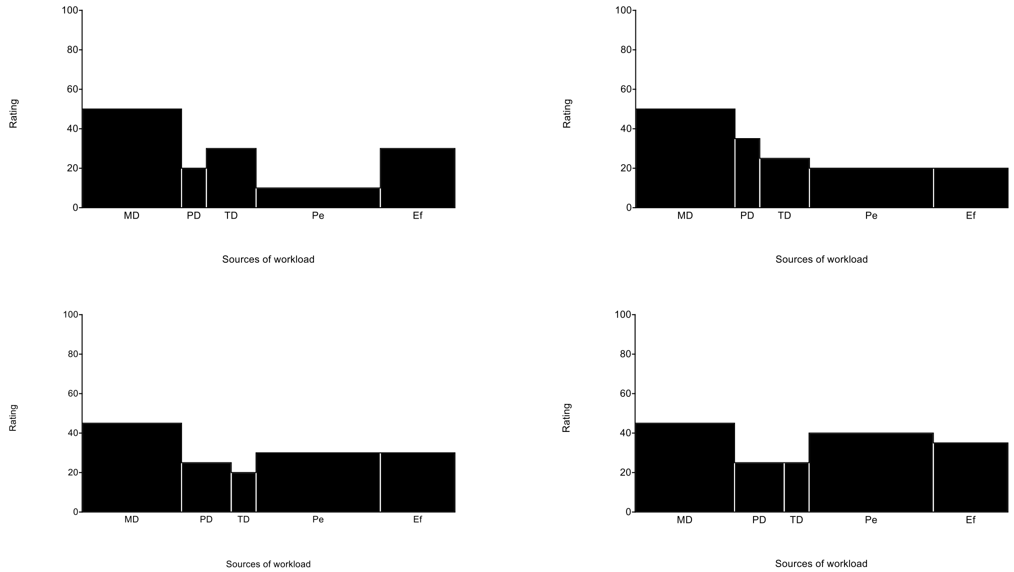

Figure 14. Variable width column chart of Participant 8's NASA-TLX (Hart & Staveland, 1988) sources of workload and respective ratings.

Figures 13 and 14 present the data for Participant 8's NASA-TLX workload scores. Figure 13 shows the overall workload for each simulated driving condition, suggesting a slight increase in perceived workload as driving conditions become more difficult. Figure 14 shows the weights and ratings of each source of workload that was selected, across conditions. While performance, mental demand, and effort contributed the most to overall workload, the notable differences between conditions were in perceived physical and temporal workload between easy and hard track. Moreover, the rating of each source of workload remained relatively stable, except for performance that increased as the track became more difficult and the visual occlusion sequence became unpredictable. Participant 8 did not indicate any frustration for any of the conditions.

Participant 5 (P5)

Participant 5 was a 22-year-old male. Participant 5 had held a driver's license for 4 years and had undertaken Defensive Driving Course level 1 and level 2. On average he drives 20 hours a week, typically in the suburbs and has been trained with both manual and automatic transmission cars. Participant 5 reported that he did not have experience in racing video car games. Participant 5 experienced the predictable visual occlusion sequence first.

Average speed (km/h) across simulated driving conditions

Means and standard deviations of Participant 5's speed across simulated driving conditions are presented in Table 14 and in the combined data of Figure 11. It can be seen from these data that while the harder track resulted in a greater speed reduction, the unpredictable occlusion sequence did not have as much effect.

Table 14

Means and standard deviations of Participant 5's speed (km/h) across simulated driving conditions

	Simulated Driving Conditions			
	Easy Predictable	Easy Unpredictable	Hard Predictable	Hard Unpredictable
Average Speed (km/h)	84.25 (9.27)	86.01 (9.15)	62.11 (22.87)	60.42 (20.36)

A two-way (Track Difficulty x Predictability) repeated measures ANOVA confirmed that mean driving speed on the easy track (M=86.54, SD=15.24) was faster than on the harder track (M=85.13, SD=9.25), $F(1, 2160) = 3826.979$, $\rho<.001$, but there was no main effect of predictability (M=73.18, SD=20.67 compared with M=73.21, SD=20.32 for predictable versus unpredictable respectively). However, there was a significant interaction effect, $F(1,2160)=6399.915$, $\rho<.001$.

To identify significant differences between simulated driving conditions six post-hoc pairwise comparisons were conducted (SPSS Statistics, Version 23, IBM Corporation, Armonk. New York, U.S) with Bonferroni corrections. Statistical significance was accepted at the $\rho<.008$ level. The post-hoc analysis revealed that there was a significant increase in the mean speed (M=1.75, 95% CI [1.04, 2.46] km/h, $\rho<.001$) from the Easy Predictable (EP) condition (M=84.25, SD=9.27 km/h) to the Easy Unpredictable (EUP) condition (M=86.01, SD=9.15 km/h). The post-hoc test indicated that there was a significant decrease in mean speed (M=22.15, 95% CI [21.00, 23.30] km/h, $\rho<.001$) from the EP condition (M=84.25, SD=9.27 km/h) to the Hard Predictable (HP) condition (M=62.11, SD=22.89 km/h). The pairwise comparisons test revealed a significant decrease in mean speed (M=23.84, 95% CI

[22.72, 24.96] km/h, ρ<.001) from the EP condition (*M*=84.25, *SD*=9.27 km/h) to the Hard Unpredictable (HUP) condition (*M*=60.42, *SD*=20.36 km/h). The post-hoc analysis indicated that there was a significant decrease in the mean speed (*M*=23.90, 95% CI [22.56, 25.232] km/h, ρ<.001) from the EUP condition (*M*=86.01, *SD*=9.15 km/h) to the HP condition (*M*=62.11, *SD*=22.89 km/h). The pairwise comparison post-hoc test revealed that there was a significant decrease in mean speed (*M*=25.59, 95% CI [24.36, 26.81] km/h, ρ<.001) from the EUP condition (*M*=86.01, *SD*=9.15 km/h) to the HUP (*M*=60.42, *SD*=20.36 km/h). The post-hoc test indicated that there was a significant increase in mean speed (*M*=1.69, 95% CI [.594, 2.79] km/h, ρ<.001) from the HP condition (*M*=62.11, *SD*=22.89 km/h) to the HUP condition (*M*=60.42, *SD*=20.36 km/h).

The increase in speed in the EUP condition compared with the EP condition may be due to the practice effects as this participant began with the EP condition and appears to be driving the interaction effect.

Percentage of errors made per visual occlusion interval

The means and standard deviations of Participant 5's errors across visual occlusion intervals are presented in Table 15 and Figure 12.

Table 15

Means and standard deviations for Participant 5's percentage of errors per occlusion (%) across visual occlusion intervals

	Visual Occlusion Interval			
	1 second	2 second	3 second	6 second
Errors (%)	0 (0.0)	15.75 (23.64)	15.75 (23.64)	92.00 (16.00)

A Friedman's ANOVA by ranks supported a significant difference in the percentage of errors/occlusion across the visual occlusion intervals, $\chi^2(3)$=10.80, ρ=.013. Pairwise Friedman's tests (ρ<.05) showed that the 6 s occlusion interval had a significantly higher error score than the 1 s interval although these differences were close to significance (ρ=.055) for both the 2 s and 3 s intervals when compared with the 6 s interval.

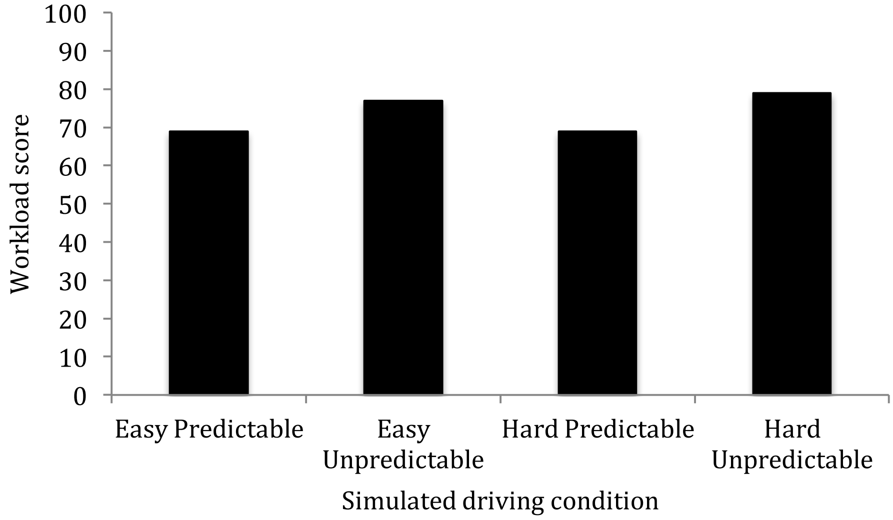

Figure 15. Bar chart of Participant 5's overall workload score across the simulated driving conditions.

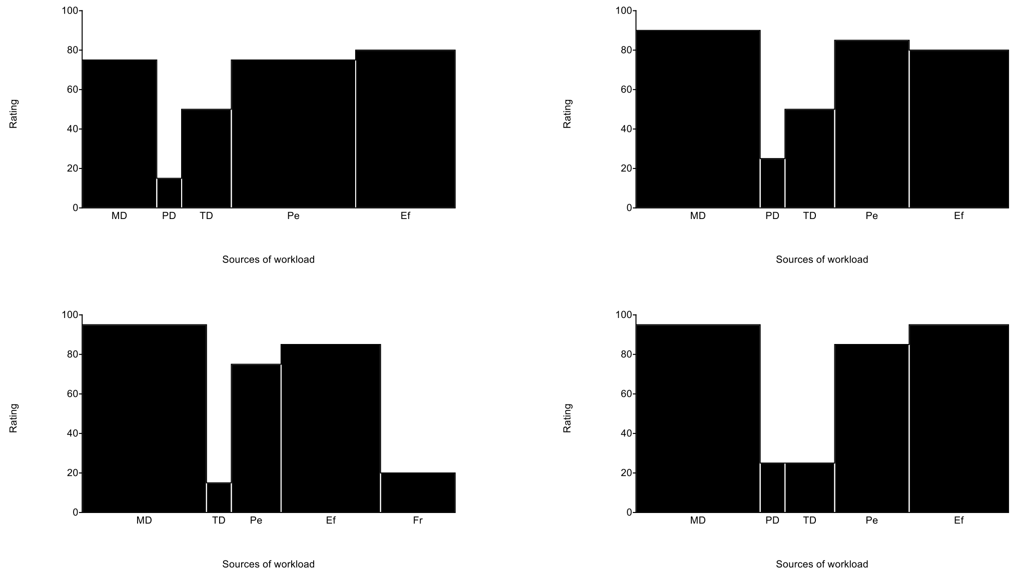

Figure 16. Variable width column chart of Participant 5’s NASA-TLX (Hart & Staveland, 1988) sources of workload and respective ratings.

Figures 15 and 16 present the data for Participant 5’s NASA-TLX workload scores. Figure 15 shows the overall workload for each simulated driving condition, suggesting that for this participant, predictability of the occlusion incurred the greatest change in workload.

Figure 16 shows the weights and ratings of each source of workload that was selected, across conditions. Mental demand and effort contributed the most to overall workload. The most noticeable differences in perceived workload across conditions were for the EP condition performance workload, which was the largest contributor to workload, and was the first condition encountered by this participant. Subsequently, the performance workload appeared to decrease, while the mental demand increased, suggesting that performance workload in the EP condition may have been due to the novelty of the task. Frustration was noted during the HP condition, presumably as the participant adjusted to the more difficult track conditions. Rating of each source of workload all increased from the EP condition. However, from the EUP condition to the HP and HUP conditions, the sources of workload ratings plateau or decrease. This may suggest outcomes of practice effects.

Participant 3 (P3)

Participant 3 was a male and was the oldest (35 years old). Participant 3 had held a driver's license for 17 years and within that time had undertaken an advanced driving program titled "Defensive Driving Course Level 1". On average participant 3 drives 10 hours a week, typically around inner city roads, and can drive both automatic and manual cars. Participant 3 reported no history of engagement with car-racing video games. Participant 3 experienced the predictable visual occlusion sequence first.

Average speed (km/h) across simulated driving conditions

Means and standard deviations of Participant 3's speed across simulated driving conditions are presented in Table 16 and in the combined data of Figure 11. It can be seen from these data that the harder track resulted in reduced speed. However, while the unpredictable occlusion sequence had the effect of reducing speed on the easy track, there was, if anything, a slight increase in speed in the unpredictable condition on the hard track.

Table 16

Means and standard deviations of Participant 3's speed (km/h) across simulated driving conditions

	Simulated Driving Conditions			
	Easy Predictable	Easy Unpredictable	Hard Predictable	Hard Unpredictable
Average Speed (km/h)	81.82 (13.58)	80.39 (8.95)	76.97 (15.24)	77.24 (19.79)

A two-way (Track Difficulty x Predictability) repeated measures ANOVA confirmed that mean driving speed on the easy track (M=81.11, SD=11.59) was faster than on the harder track (M=77.10, SD=17.66), $F(1, 2160) = 134.919$, $\rho<.001$, there was no main effect of occlusion predictability (M=79.40, SD=14.63 and M=78.81, SD=15.44, for the predictable and unpredictable conditions respectively). There was, however, a significant interaction effect, $F(1, 2160)=1584.357$, $\rho<.001$.

Six post-hoc analyses with bonferroni corrections were employed to investigate the significant differences in mean speed across the four simulated driving conditions. Statistical significance was accepted at the $\rho<.008$ level. The first post-hoc test revealed a significant mean decrease in speed (M=1.44, 95% CI [.50, 2.38] km/h, $\rho<.001$) from the EP (M=81.20, SD=13.58 km/h) to the EUP (M=80.39, SD=8.95 km/h) condition. The second post-hoc analysis indicated that there was a significant mean decrease in speed (M=4.86, 95% CI [3.77, 5.94] km/h, $\rho<.001$) from the EP (M=81.20, SD=13.58 km/h) to the HP (M=76.97, 15.24 km/h) condition. The third post-hoc test revealed a significant mean decrease in speed (M=4.58, 95% CI [3.21, 5.96] km/h, $\rho<.001$) from the EP (M=81.20, SD=13.58 km/h) to the HUP (M=77.24, SD= 19.79 km/h) condition. The fourth post-hoc analysis revealed a significant mean decrease in the speed (M=3.42 km/h, 95% CI [2.41, 4.43], $\rho<.001$) from the EUP (M=80.39, SD=8.95 km/h) to the HP (M=76.97, 15.24 km/h) condition. The fifth post-hoc test revealed a significant mean decrease in speed (M=3.14, 95% CI [2.0, 4.29] km/h, $\rho<.001$) from the EUP (M=80.39, SD=8.95 km/h) to HUP (M=77.24, SD= 19.79 km/h) condition. The sixth post-hoc test indicated that there was no significant difference in speed from the HP (*M*=76.97, 15.24 km/h) to HUP (*M*=77.24, *SD*= 19.79 km/h) condition (ρ=1.0).

The interaction effect was driven by the lack of significant difference between the occlusion sequences for the hard track due to the fact that the participant slowed significantly in the HP condition.

Percentage of errors made per visual occlusion interval

Means and standard deviations of Participant 3’s errors across visual occlusion intervals are presented in Table 17. Mean and standard error bars (set to 2 standard errors) of the errors across visual occlusion intervals are depicted in Figure 12.

Table 17

Means and standard deviations for Participant 3's percentage of errors per occlusion (%) across visual occlusion intervals

	Visual Occlusion Interval			
	1 second	2 second	3 second	6 second
Errors (%)	1.50 (3.00)	9.00 (11.86)	48.25 (13.72)	85.75 (16.70)

A Friedman’s ANOVA by ranks supported a significant difference in the percentage of errors/occlusion across the visual occlusion intervals, $\chi^2(3)$= 11.68, ρ=.009. Pairwise Friedman's tests (ρ<.05) showed that the 6 s occlusion interval had a significantly higher error score than both the 1 s and 2 s intervals, but no other pairwise comparisons were significantly different from each other.

NASA-TLX (Hart & Staveland, 1988) source of workload and overall workload across the simulated driving conditions

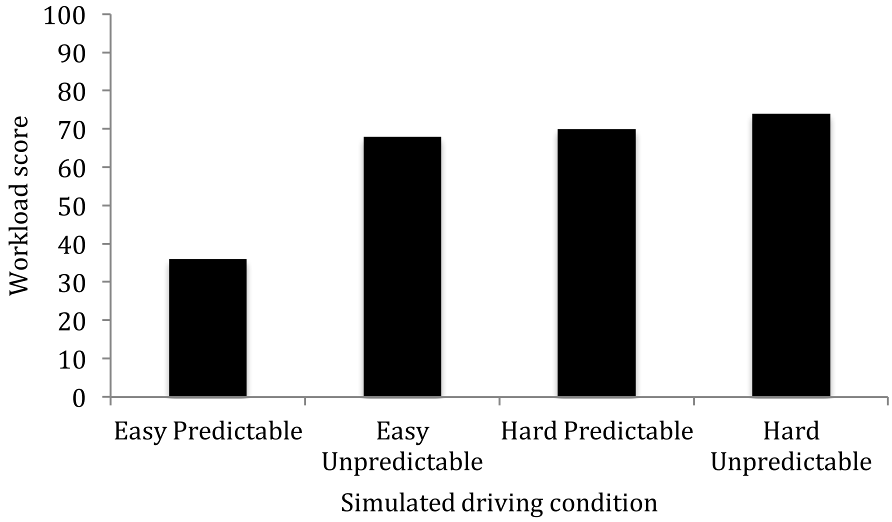

Figure 17. Bar chart of Participant 3's overall workload across the simulated driving conditions.

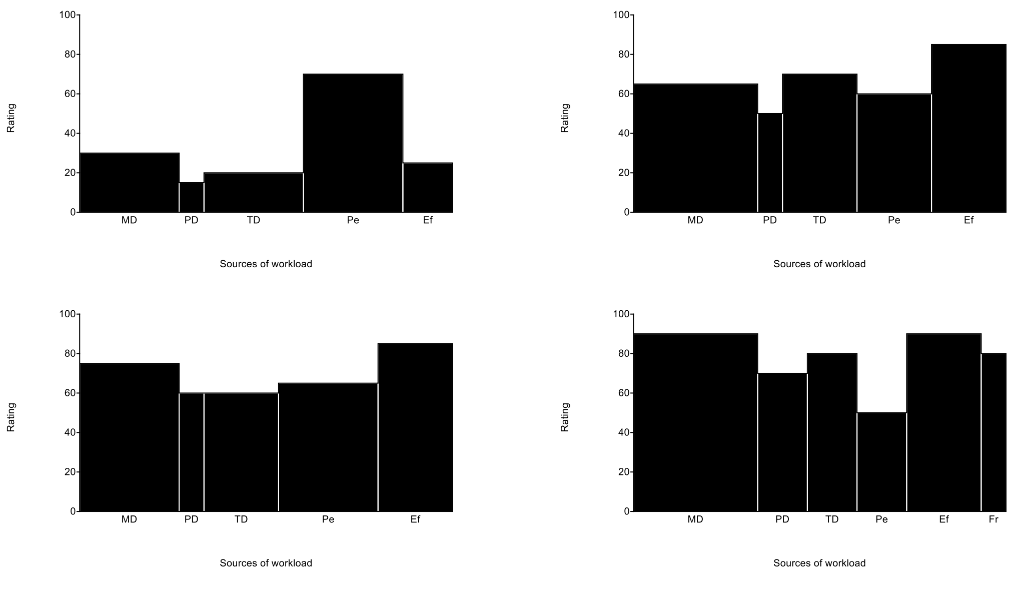

Figure 18. Variable width column chart of Participant 3’s NASA-TLX (Hart & Staveland, 1988) sources of workload and respective ratings.

Figures 17 and 18 present the data for Participant 3’s NASA-TLX workload scores. Figure 17 shows the overall workload for each simulated driving condition, suggesting a slight increase in perceived workload as driving conditions become more difficult.

Figure 18 shows weights and ratings of each source of workload that was selected, across conditions. While mental demand was perceived to be the greatest contributor to workload, and was perceived to be higher for the two unpredictable occlusion conditions, the predictable occlusion sequence was perceived to exert greater performance demand than the unpredictable sequences. The unpredictable occlusion sequence on the hard track incurred the most physical demand and was the only condition to incur frustration for this participant. As the track became difficult and the visual occlusion sequence type became unpredictable, the source of workload ratings appeared to increase. However, from the EUP to the HP condition, temporal demand decreased, which suggests that the participant was more comfortable dealing with the predictable visual occlusion sequence demands than the unpredictable visual occlusion sequence demands. Moreover, performance was rated lowest in the HUP condition, indicating practice effects.

Participant 1 (P1)

Participant 1 was a 23-year-old female that had held a driver's license for 2 years. Participant 1 had not experienced any extra driving training and on average drives 2 hours per week with an automatic transmission car. She typically drives in the inner city and reported that she had no experience in racing video car games. Participant 1 undertook the predictable visual occlusion sequence first.

Average speed (km/h) across simulated driving conditions

Means and standard deviations of participant 1's speed across simulated driving conditions are presented in Table 18 and in the combined data of Figure 11. It can be seen from these data that the harder track resulted in reduced speed, however while the unpredictable condition reduced speed for the hard track, there was an increase in speed for this condition on the easy track.

Table 18

Means and standard deviations of Participant 1's speed (km/h) across simulated driving conditions

	Simulated Driving Condition			
	Easy Predictable	Easy Unpredictable	Hard Predictable	Hard Unpredictable
Average Speed (km/h)	82.05 (22.79)	89.84 (8.73)	72.00 (29.15)	64.96 (32.38)

A two-way (Track Difficulty x Predictability) repeated measures ANOVA confirmed that mean driving speed on the easy track (M=85.94, SD=17.69) was faster than on the harder track (M=68.48, SD=31.00), $F(1, 2160) = 916.825$, ρ<.001, but there was no main effect of predictability (M=77.02, SD=26.64 compared with M=77.40, SD=26.78 for predictable versus unpredictable respectively). However, the analysis confirmed that there was a significant interaction effect, $F(1, 2160)$=165.051, ρ<.001.

Six post-hoc pairwise comparisons were conducted with Bonferroni corrections. Statistical significance was accepted at the ρ<.008 level. The post-hoc analysis revealed a significant increase in mean speed (M=7.79, 95% CI [6.38, 9.19] km/h, ρ<.001) from the EP condition (M=82.05, SD=22.79 km/h) to the EUP condition (M=89.84, SD=8.73 km/h). The post-hoc test indicated that there was a significant decrease in mean speed (M=10.05, 95% CI [7.72, 12.38] km/h, ρ<.001) from the EP condition (M=82.05, SD=22.79 km/h) to the HP condition (M=72.00, SD=29.15 km/h). The pairwise comparisons test revealed a significant decrease in mean speed (M=17.09, 95% CI [14.75, 19.42] km/h, ρ<.001) from the EP condition (M=82.05, SD=22.79 km/h) to the HUP condition (M=64.96, SD=26.71 km/h). The post-hoc analysis indicated a significant decrease in mean speed (M=17.84, 95% CI [16.17, 19.51] km/h, ρ<.001) from the EUP condition (M=89.84, SD=8.73 km/h) to the HP condition (M=72.00, SD=29.15 km/h). The pairwise comparison post-hoc test indicated a significant decrease in mean speed (M=24.88, 95% CI [22.91, 26.84] km/h ρ<.001) from the EUP condition (M=89.84, SD=8.73 km/h) to the HUP condition (M=64.96, SD=26.71 km/h). The post-hoc test indicated that there was a significant decrease in mean speed (*M*=7.04, 95% CI [4.53, 9.54] km/h, ρ<.001) from the HP (*M*=72.00, *SD*=29.15) to the HUP (*M*=64.96, *SD*=26.71 km/h) (ρ<.001).

As was the case for Participant 5, the increase in speed shown in the EUP condition compared with the EP condition may be due to the practice effects as this participant began with the EP condition.

Percentage of errors made per visual occlusion interval

The means and standard deviations of Participant 1's errors across visual occlusion intervals are presented in Table 19. The mean and standard error bars (set to 2 standard errors) of the errors across visual occlusion intervals are depicted in Figure 12.

Table 19

Means and standard deviations for Participant 1's percentage of errors per occlusion (%) across visual occlusion intervals

	Visual Occlusion Interval			
	1 second	2 second	3 second	6 second
Errors (%)	0.0 (0.0)	12.50 (14.64)	55.50 (14.15)	79.25 (14.34)

A Friedman's ANOVA by ranks supported a significant difference in the percentage of errors/occlusion across the visual occlusion intervals, $\chi^2(3)$=11.432, ρ=.010. Pairwise Friedman's tests (ρ<.05) showed that the 6 s occlusion interval had a significantly higher error score than both the 1 s and 2 s intervals, and the 3 s intervals had a significantly higher error score than the 1 s intervals, but the other pairwise comparisons were not significantly different from each other.

NASA-TLX (Hart & Staveland, 1988) source and overall workload across individual and aggregated simulated driving conditions

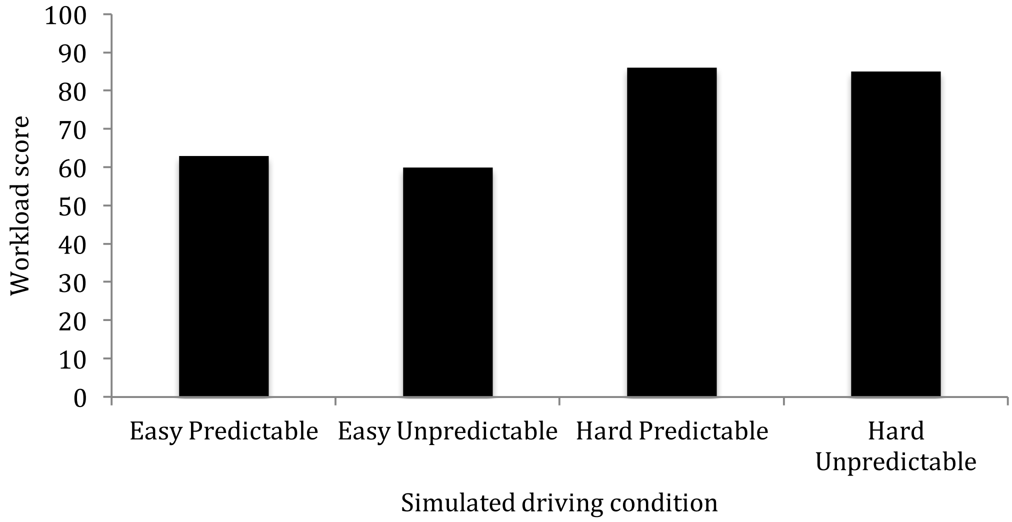

Figure 19. Bar chart of Participant 1's overall workload across the simulated driving conditions.

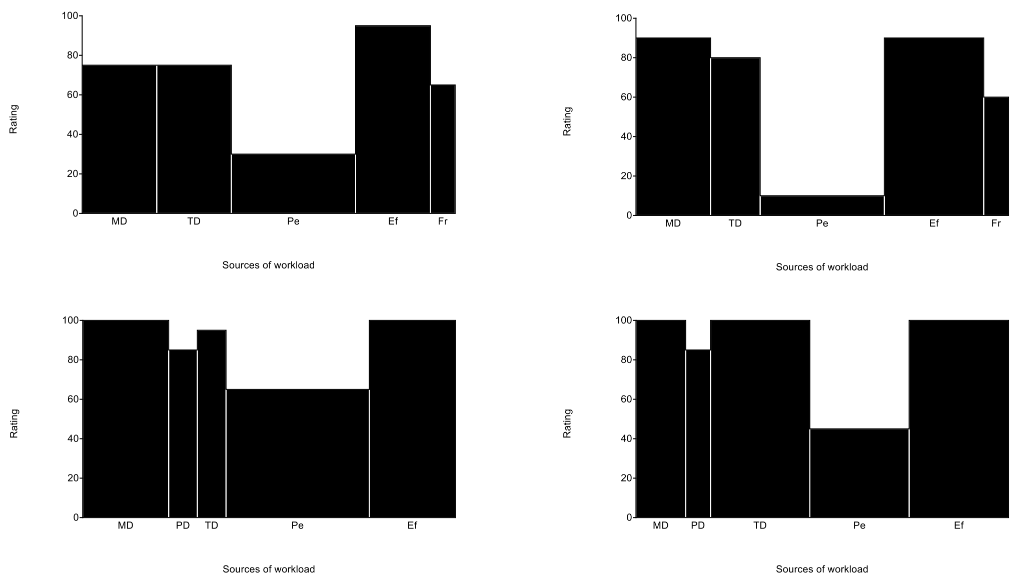

Figure 20. Variable width column chart of Participant 1's NASA-TLX (Hart & Staveland, 1988) sources of workload and respective ratings.

Figures 19 and 20 present the data for Participant 1's NASA-TLX workload scores. Figure 19 shows the overall workload for each simulated driving condition, suggesting a slight increase in perceived workload for the hard track compared with the easier track.

Figure 20 shows the weights and ratings of each source of workload that was selected, across conditions. This participant rated performance demands as generating more perceived workload than mental demands, and the unpredictable occlusion sequence as requiring more effort. This participant experienced some frustration in all conditions except for the HUP, during which she also rated mental and performance demands as lower than for other conditions. Barring the performance demand, the ratings of the sources of workload increased across conditions. Meanwhile, the performance demand was higher for the predictable sequences than the unpredictable. However, this may be a consequence of practice effects as Participant 1 undertook the predictable visual occlusion sequence before the unpredictable one. In other words, upon trialling the easy and hard track for the first time, Participant 1 would experience the predictable visual occlusion sequence. This would facilitate Participant 1's ability to learn the track for the up-coming trial with the unpredictable visual occlusion, leading to lower performance demand ratings.

Participant 2 (P2)

Participant 2 was a 22-year-old female who had held a driver's license for 3 years. Participant 2 had not experienced any extra driving training and on average drives 5 hours per week with an automatic transmission car. She typically drives in suburban areas and reported that she had no experience in racing video car games. Participant 2 experienced the unpredictable visual occlusion sequence first.

Average speed (km/h) across simulated driving conditions

Means and standard deviations of Participant 2's speed across simulated driving conditions are presented in Table 20 and in the combined data of Figure 11. It can be seen from these data that the combination of harder track and the unpredictable occlusion sequence resulted in greatly reduced speed for this participant, whereas the predictable occlusion sequence did not seem to affect speed. Given that this participant experienced the EUP condition first, it may be that she reduced speed to improve accuracy in later conditions.

Table 20

Means and standard deviations of Participant 2's speed (km/h) across simulated driving conditions

	Simulated Driving Condition			
	Easy Predictable	Easy Unpredictable	Hard Predictable	Hard Unpredictable
Average Speed (km/h)	79.35 (27.04)	83.74 (12.14)	81.35 (22.05)	67.45 (30.86)

A two-way (Track Difficulty x Predictability) repeated measures ANOVA confirmed that mean driving speed on the easy track (*M*=81.54, *SD*=21.07) was faster than on the harder track (*M*=71.40, *SD*=27.70), $F(1, 2160) = 136.454$, $p<.001$, and that mean driving speed in the unpredictable condition (*M*=75.59, *SD*=24.82) was slower than in the predictable condition (*M*=80.35, *SD*=24.69), $F(1, 2160) = 88.722$, $p<.001$. However, the analysis confirmed that there was also a significant interaction effect, $F(1,2160)=651.741$, $p<.001$.

Six post-hoc pairwise comparisons were conducted with Bonferroni corrections. Statistical significance was accepted at the $p<.008$ level. The post-hoc analysis revealed a significant increase in mean speed (4.39, 95% CI [2.64, 6.14] km/h, $p<.001$) from the EP condition (*M*=79.35, *SD*=27.04 km/h) to the EUP condition (*M*=83.74, 12.14 km/h). The post-hoc test indicated that there was no significant difference in mean speed (*M*=2.00, 95% CI [.18, 3.81] km/h, $p=.022$) from the EP (*M*=79.35, *SD*=27.04 km/h) to the HP (*M*=81.35, *SD*=22.05 km/h). The pairwise comparisons test revealed a significant decrease in mean speed (*M*=11.90, 95% CI [9.39, 14.40] km/h, $p<.001$) from the EP condition (*M*=79.35, *SD*=27.04 km/h) to the HUP (*M*=67.45, *SD*=30.86 km/h). The post-hoc analysis revealed a significant decrease in mean speed (*M*=2.39, 95% CI [.81, 3.97] km/h, $p<.001$) from the EUP condition (*M*=83.74, 12.14 km/h) to the HP condition (*M*=81.35, *SD*=22.05 km/h). The pairwise comparison post-hoc test indicated that there was a significant decrease in mean speed (*M*=16.29, 95% CI [14.36, 18.21] km/h, $p<.001$) from the EUP condition (*M*=83.74, 12.14 km/h) to the HUP condition (*M*=67.45, *SD*=30.86

km/h). The post-hoc test indicated that there was a significant decrease in mean speed (M=13.90, 95% CI [12.39, 15.40], ρ<.001) from the HP condition (M=81.35, SD=22.05 km/h) to the HUP condition (M=67.45, SD=30.86 km/h).

The lack of significant difference in the predictable occlusion condition from EP to HP may have been due to the participant being the only one to commit errors in the EP condition which would have slowed her speed. It can be seen in Figure 21 (Workload Scores) that the EP condition for this participant was perceived as the most frustrating condition, presumably due to committing errors.

Percentage of errors made per visual occlusion interval

The means and standard deviations of Participant 2’s errors across visual occlusion intervals are presented in Table 21 and Figure 12.

Table 21

Means and standard deviations for Participant 2's percentage of errors per occlusion (%) across visual occlusion intervals

	Visual Occlusion Interval			
	1 second	2 second	3 second	6 second
Errors (%)	4.25 (5.32)	8.75 (5.91)	28.25 (9.22)	93.75 (12.50)

A Friedman’s ANOVA by ranks supported a significant difference in the percentage of errors/occlusion across the visual occlusion intervals, $\chi^2(3)$=11.684, ρ=.009. Pairwise Friedman's tests (ρ<.05) showed that the 6 s occlusion interval had a significantly higher error score than both the 1 s and 2 s intervals, but no other pairwise comparisons were significantly different from each other.

NASA-TLX source and overall workload across individual and aggregated simulated driving conditions.

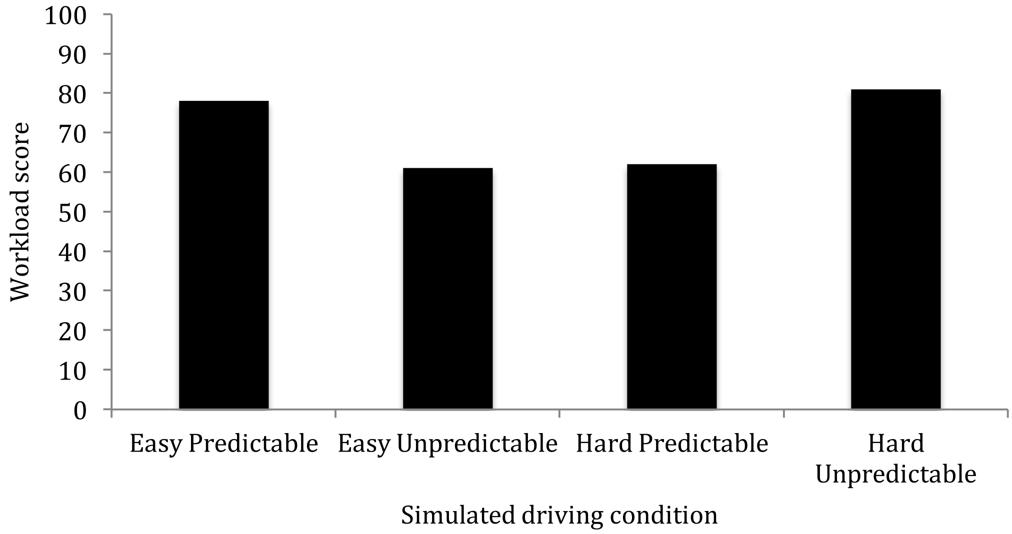

Figure 21. Bar chart of Participant 2's overall workload across the simulated driving conditions.

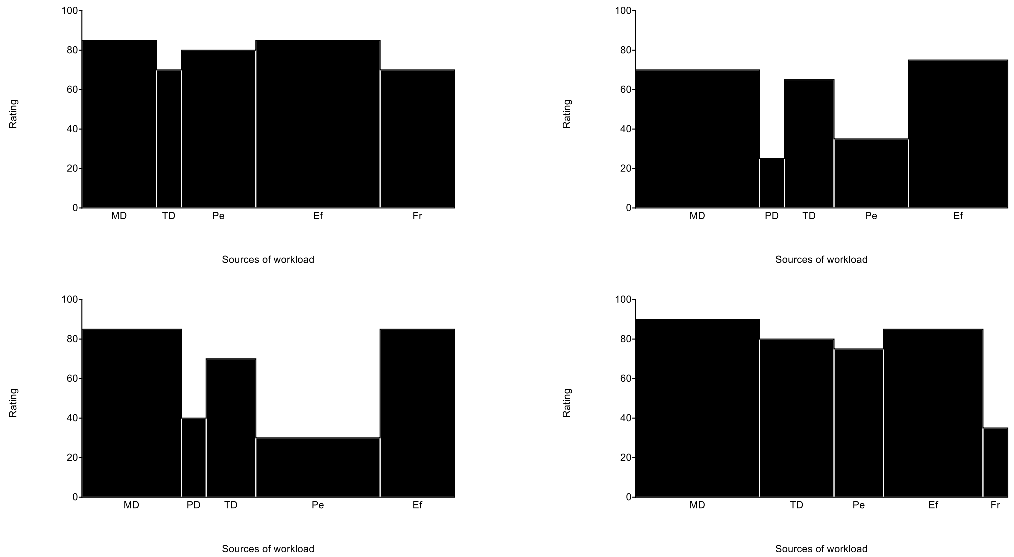

Figure 22. Variable width column chart of Participant 2's NASA-TLX (Hart & Staveland, 1988) sources of workload and respective ratings.

Figures 21 and 22 present the data for Participant 2's NASA-TLX workload scores. Figure 21 shows the overall workload for each simulated driving condition, showing the highest perceived workload for the EP and the HUP.

Figure 22 shows the weights and ratings of each source of workload that was selected, across conditions. It can be seen that mental demand and effort contributed to the workloads across conditions. Notably, frustration appears in the EP and HUP conditions, with high ratings in the EP condition. This assists in understanding why the EP condition may have received higher overall workload scores than the EUP and HP conditions. In the EUP and HP conditions, Participant 2 may have begun to become familiar with the simulator mechanics and experienced less frustration as a result. However, when undertaking the HUP condition, higher ratings across the sources of workload were reported which may indicate that the task became to demanding and led the participant to becoming frustrated.

Lower performing participants

Participant 6 (P6)

Participant 6 was a 25-year-old female who had held a driver's license for 6 years. Participant 6 had not experienced any extra driving training and on average drives 7 hours per week with an automatic transmission car. She typically drives in suburban areas and freeways, and reported that she had no experience in racing video car games. Participant 6 experienced the predictable visual occlusion sequence first.

Average speed (km/h) across simulated driving conditions

Means and standard deviations of Participant 6's speed across simulated driving conditions are presented in Table 22 and in the combined data of Figure 11. It can be seen from these data that both the harder track and the unpredictable occlusion sequence resulted in reduced speed. The reduction of speed was greater in the unpredictable occlusion sequence, but this seemed to be due to the participant only being able to maintain the target speed of 80 km/h in the EP condition.

Table 22

Means and standard deviations of Participant 6's speed (km/h) across simulated driving conditions

	Simulated Driving Condition			
	Easy Predictable	Easy Unpredictable	Hard Predictable	Hard Unpredictable
Average Speed (km/h)	79.16 (8.14)	70.84 (16.94)	64.30 (23.47)	60.26 (25.15)

A two-way (Track Difficulty x Predictability) repeated measures ANOVA confirmed that mean driving speed on the easy track (M=75.00, SD=13.92) was faster than on the harder track (M=62.28, SD=224.40), $F(1, 2160) = 1003.706$, $\rho<.001$, and that mean driving speed in the unpredictable condition (M=65.55, SD=22.08) was slower than in the predictable condition (M=71.73, SD=19.07), $F(1, 2160) = 206.302$, $\rho<.001$. The analysis confirmed that there was also a significant interaction effect, $F(1,2160)=43.349$, $\rho<.001$.

Six post-hoc pairwise comparisons with Bonferroni corrections were conducted to identify significant differences between the simulated driving conditions. Statistical significance was accepted at the $\rho<.008$ level. The post-hoc analysis revealed significant decrease in mean speed (M=8.32, 95% CI [7.42, 9.22] km/h, $\rho<.001$) from the EP condition (M=79.16, SD=8.14 km/h) to the EUP condition (M=70.84, SD=16.94 km/h) ($\rho<.001$). The post-hoc test indicated that there was a significant decrease in mean speed (M=14.86, 95% CI [13.58, 16.14] km/h, $\rho<.001$) from the EP condition (M=79.16, SD=8.14 km/h) to the HP condition (M=64.30, SD=23.47 km/h). The pairwise comparisons test revealed a significant decrease in mean speed (M=18.89, 95% CI [17.43, 20.36] km/h, $\rho<.001$) from the EP condition (M=79.16, SD=8.14 km/h) to the HUP condition (M=60.27, SD=25.15 km/h). The post-hoc analysis revealed a significant decrease in mean speed (M=6.54, 95% CI [4.90, 8.17] km/h, $\rho<.001$) from the EUP condition (M=70.84, SD=16.94 km/h) to the HP condition (M=64.30, SD=23.47 km/h). The pairwise comparison post-hoc test indicated that there was a significant decrease in mean speed (M=10.57, 95% CI

[9.13, 12.02] km/h, $\rho<.001$) from the EUP condition (M=70.84, SD=16.94 km/h) to the HUP condition (M=60.27, SD=25.15 km/h). The post-hoc test indicated that there was a significant decrease in mean speed (M=4.03, 95% CI [2.23, 12.02] km/h, $\rho<.001$) from the HP condition (M=64.30, SD=23.47 km/h) to the HUP condition (M=60.27, SD=25.15 km/h).

While all pairwise comparisons were significantly different, there was a larger track difficulty over predictability of the occlusion sequence due to large decrease in speed in the HP condition to cope with the more difficult track. This increase in speed in the EP condition may be due to practice effects as this participant began with the EUP condition and may have found the EP condition to be much easier by comparison.

Percentage of errors made per visual occlusion interval

The means and standard deviations of Participant 6’s errors across visual occlusion intervals are presented in Table 23 and depicted in Figure 12.

Table 23

Means and standard deviations for Participant 6's percentage of errors per occlusion (%) across visual occlusion intervals

	Visual Occlusion Interval			
	1 second	2 second	3 second	6 second
Errors (%)	0.00 (0.00)	22.00 (16.08)	52.25 (14.22)	87.50 (25.00)

A Friedman’s ANOVA by ranks supported a significant difference in the percentage of errors/occlusion across the visual occlusion intervals, $\chi^2(3)$= 10.846, ρ=.013. Pairwise Friedman's tests ($\rho<.05$) showed that the 6 s occlusion interval had a significantly higher error score than both the 1 s and 2 s intervals, and that the 3 s occlusion interval also had a significantly higher error score than the 1 s interval, but no other pairwise comparisons were significantly different from each other.

NASA-TLX (Hart & Staveland, 1988) source and overall workload across individual and aggregated simulated driving conditions

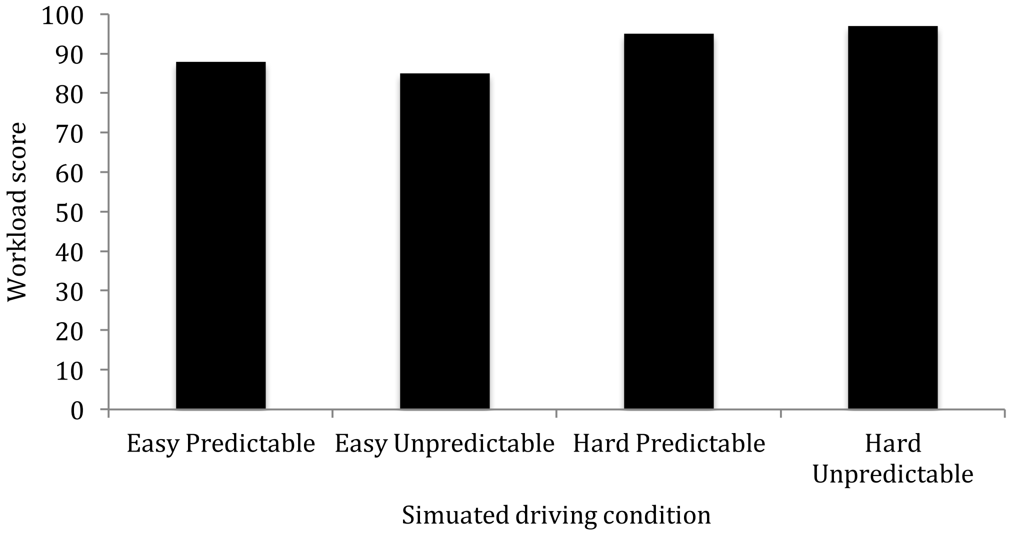

Figure 23. Bar chart of Participant 6's overall workload across the simulated driving conditions.

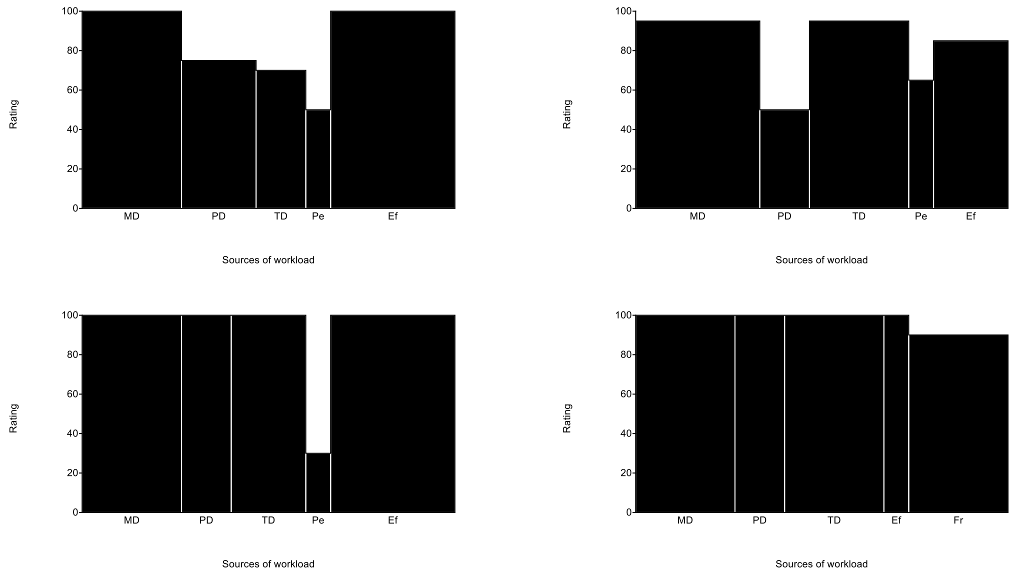

Figure 24. Variable width column chart of Participant 6’s NASA-TLX (Hart & Staveland, 1988) sources of workload and respective ratings.

Figures 23 and 24 present the data for Participant 8's NASA-TLX workload scores. Figure 23 shows the overall workload for each simulated driving condition, across conditions with few differences apparent across conditions.

Figure 24 shows the weights and ratings of each source of workload that was selected. While the mental demand of each condition was uniformly high, perceived effort was high in the predictable conditions, whereas perceived temporal demand was higher in the unpredictable conditions. The HUP condition was the only condition that was perceived as generating significant frustration. In addition, the participant rated each source of workload extremely high, with many sources of workload receiving ratings of 100. This suggests that the task may have been too difficult for the participant.

Participant 7 (P7)

Participant 7 was a 23-year-old male who had held a driver's license for 5 years and had no extra driving training. On average he drives 13 hours a week, typically in the inner city and exclusively drives automatic transmission cars. Participant 7 reported that he did not have experience in racing video car games. Participant 7 experienced the predictable visual occlusion sequence first.

Average speed (km/h) across simulated driving conditions

Means and standard deviations of Participant 7's speed across simulated driving conditions are presented in Table 24 and in the combined data of Figure 11. It can be seen from these data that the unpredictable occlusion sequence and, to a lesser extent, track difficulty, resulted in reduced speed.

Table 24

Means and standard deviations of Participant 7's speed (km/h) across simulated driving conditions

	Simulated Driving Condition			
	Easy Predictable	Easy Unpredictable	Hard Predictable	Hard Unpredictable
Average Speed (km/h)	79.87 (8.93)	69.45 (22.77)	76.16 (21.46)	68.17 (26.18)

A two-way (Track Difficulty x Predictability) repeated measures ANOVA confirmed that mean driving speed on the easy track (*M*=74.66, *SD*=18.06) was faster than on the harder track (*M*=72.17, *SD*=24.26), $F(1, 2160) = 32.863$, $\rho<.001$, and that mean driving speed in the unpredictable condition (*M*=68.81, *SD*=24.54) was slower than in the predictable condition (*M*=78.02, *SD*=16.54), $F(1, 2160) = 186.835$, $\rho<.001$. However, there was also a significant interaction effect, $F(1,2160)=6399.915$, $\rho<.001$.

Six post-hoc pairwise comparisons were conducted with Bonferroni corrections to identify significant differences in speed between the simulated driving conditions. Statistical significance was accepted at the $\rho<.008$ level. The post-hoc analysis indicated a significant decrease in mean speed (*M*=10.43, 95% CI [8.98, 11.87] km/h, $\rho<.001$) from the EP condition (*M*=79.87, *SD*=8.93 km/h) to the EUP condition (*M*=69.45, *SD*=22.77 km/h). The post-hoc test indicated that there was a significant decrease in mean speed (*M*=3.71, 95% CI [2.40, 5.02] km/h, $\rho<.001$) from the EP condition (*M*=79.87, *SD*=8.93 km/h) to the HP condition (*M*=76.16, *SD*=21.46 km/h). The pairwise comparisons test revealed a significant decrease in mean speed (M=11.70, 95% CI [10.16, 13.24] km/h, $\rho<.001$) from the EP condition (*M*=79.87, *SD*=8.93 km/h) to the HUP condition (*M*=68.17, *SD*=26.18). The post-hoc analysis indicated that there was a significant increase in mean speed (*M*=6.71, 95% CI [4.79, 8.65] km/h, $\rho<.001$) from EUP condition (*M*=69.45, *SD*=22.77 km/h) to the HP condition (*M*=76.16, *SD*=21.46 km/h). The pairwise comparison post-hoc test indicated that there was no significant difference in mean speed between the EUP condition (*M*=69.45, *SD*=22.77 km/h) and the HUP (*M*=68.17, *SD*=26.18) ($\rho=.349$). The post-hoc test indicated that there was a significant decrease in mean speed (*M*=7.99, 95% CI [6.07, 9.89] km/h, $\rho<.001$) from the HP condition (*M*=76.16, *SD*=21.46 km/h) to the HUP condition (*M*=68.17, *SD*=26.18) ($\rho<.001$). These post-hoc pairwise analyses revealed that there was no significant differences in speed on the easy versus hard track in the unpredictable condition, while all other comparisons were significantly different.

Percentage of errors made per visual occlusion interval

The means and standard deviations of Participant 7's errors across visual occlusion intervals are presented in Table 25 and in Figure 12.

Table 25

Means and standard deviations for Participant 7's percentage of errors per occlusion (%) across visual occlusion intervals

	Visual Occlusion Interval			
	1 second	2 second	3 second	6 second
Errors (%)	1.5 (3.0)	26.00 (13.08)	28.75 (23.13)	100.00 (0.0)

A Friedman's ANOVA by ranks supported a significant difference in the percentage of errors/occlusion across the visual occlusion intervals, $\chi^2(3)= 11.154$, $\rho=.011$. Pairwise Friedman's tests ($\rho<.05$) showed that the 6 s occlusion interval had a significantly higher error score than the 1 s interval, but no other pairwise comparisons were significantly different from each other.

NASA-TLX (Hart & Staveland, 1988) source and overall workload across individual and aggregated simulated driving conditions

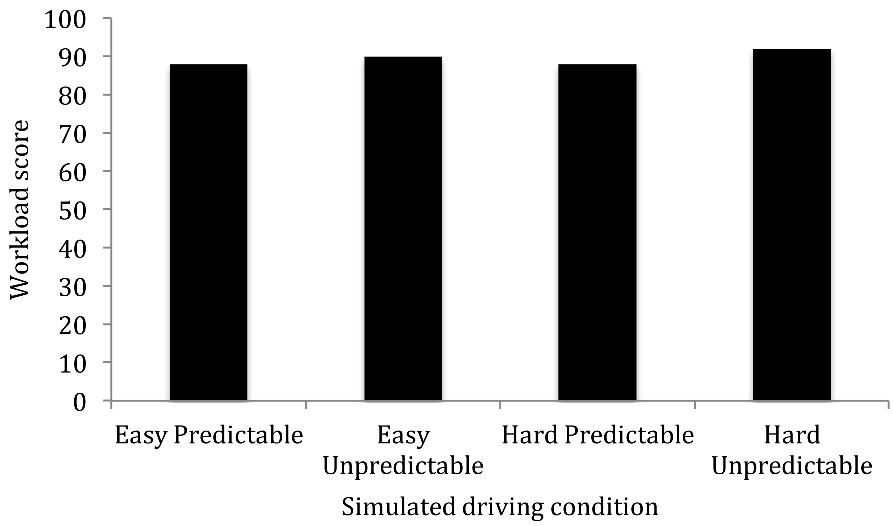

Figure 25. Bar chart Participant 7's overall workload across the simulated driving conditions.

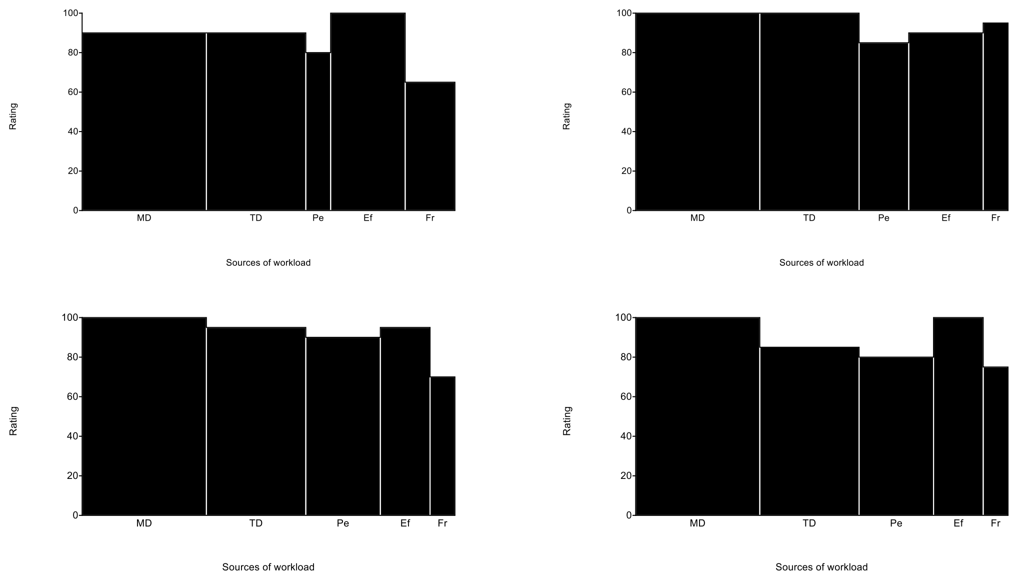

Figure 26. Variable width column chart of Participant 7's NASA-TLX (Hart & Staveland, 1988) sources of workload and respective ratings.

Figures 25 and 26 present the data for Participant 7's NASA-TLX workload scores. Figure 25 shows the overall workload for each simulated driving condition, with no obvious differences in perceived workload being evident across driving conditions.

Figure 26 shows the weights and ratings of each source of workload that was selected, across conditions. Weightings of performance demands appeared to be offset by effort, with less workload in terms of effort for conditions for which performance was demanding. Frustration was perceived across all conditions, but more in the EP condition where performance was perceived to be non-influential. The ratings show that Participant 7 felt extremely burdened by mental and temporal demands over the conditions. Notably, frustration starts off strong for the EP condition but declines throughout the conditions, indicating practice effects.

Participant 4 (P4)

Participant 4 was a 24-year-old male who had held a driver's license for 6 years and had not undertaken any advanced driving training. On average Participant 4 drives 15 hours a week, typically on freeways with only automatic transmission cars. Participant 4 reported that while he no longer plays car-racing games, when he was younger he used to play them for an average of 5 hours per week. Participant 4 experienced the unpredictable visual occlusion sequence first.

Average speed (km/h) across simulated driving conditions

Means and standard deviations of Participant 4's speed across simulated driving conditions are presented in Table 26 and in the combined data of Figure 11. It can be seen from these data that both the harder track and the unpredictable occlusion sequence resulted in reduced speed although the unpredictable occlusion sequence appeared to exert more effect in the hard track condition.

Table 26

Means and standard deviation of Participant 4's speed (km/h) across simulated driving conditions

	Simulated Driving Condition			
	Easy Predictable	Easy Unpredictable	Hard Predictable	Hard Unpredictable
Average Speed (km/h)	88.00 (5.15)	82.78 (10.11)	83.26 (19.44)	70.25 (30.14)

A two-way (Track Difficulty x Predictability) repeated measures ANOVA confirmed that mean driving speed on the easy track (M=85.44, SD=8.39) was faster than on the harder track (M=76.76, SD=26.81), $F(1, 2160) = 57.249$, $\rho<.001$, and that mean driving speed in the unpredictable condition (M=76.56, SD=23.34) was slower than in the predictable condition (M=85.63, SD=14.41), $F(1, 2160) = 186.835$, $\rho<.001$. There was also a significant interaction effect, $F(1{,}2160)=6399.915$, $\rho<.001$, supporting the contention that the unpredictable sequence had a greater effect in the hard track condition.

In order to test for significant differences between the conditions, six post-hoc pairwise comparison tests were conducted with Bonferroni corrections. Statistical significance was accepted at the $\rho<.008$ level. The post-hoc analysis revealed that there was significant decrease in mean speed (M=5.23, 95% CI [4.57, 5.89], $\rho<.001$) from the EP condition (M=88, SD=5.15 km/h) to the EUP condition (M=82.78, SD=10.11 km/h). The post-hoc test indicated that there was a significant decrease in mean speed (M=4.74, 95% CI [3.59, 5.894], ρ<.001) from the EP (M=88, SD=5.15 km/h) to the HP condition (M=83.26, SD=19.44 km/h). The pairwise comparisons post-hoc test revealed a significant decrease in mean speed (M=17.75, 95% CI [15.95, 19.55], ρ<.001) from the EP condition (M=88, SD=5.15 km/h) to the HUP condition (M=70.25, SD=30.14). The post-hoc test indicated that there was no significant difference in mean speed between the EUP (M=82.78, SD=10.11 km/h) and the HP condition (M=83.26, SD=19.44 km/h) (ρ=1.00). The pairwise comparison post-hoc test revealed that there was a significant decrease in mean speed (M=12.53, 95% CI [10.87, 14.19], ρ<.001) from the EUP (M=82.78, SD=10.11 km/h) to the HUP condition (M=70.25, SD=30.14). The post-hoc test indicated that there was a significant decrease in the means speed (M=13.01, 95% CI[11.38, 14.64], ρ<.001) from the HP condition (M=83.26, SD=19.44 km/h) to the HUP condition (M=70.25, SD=30.14).

The pairwise comparisons suggest that the effect of harder track or unpredictable occlusion sequence are similar (no significant difference between HP and EUP conditions), but that the combination of hard track and unpredictable occlusion sequence is greater than either effect alone.

Percentage of errors made per visual occlusion interval

The means and standard deviations of Participant 4's errors across visual occlusion intervals are presented in Table 27 and in Figure 12.

Table 27

Means and standard deviations for Participant 4's percentage of errors per occlusion (%) across visual occlusion intervals

	Visual Occlusion Interval			
	1 second	2 second	3 second	6 second
Errors (%)	4.75 (6.19)	12.25 (17.93)	31.25 (14.10)	87.50 (25.00)

A Friedman's ANOVA by ranks supported a significant difference in the percentage of errors/occlusion across the visual occlusion intervals, $\chi^2(3)$= 11.154, ρ=.011. Pairwise Friedman's tests (ρ<.05) showed that the 6 s occlusion interval had a significantly higher error score than both the 1 s and 2 s intervals, but no other pairwise comparisons were significantly different from each other.

NASA-TLX (Hart & Staveland, 1988) source of workload and overall workload across individual and aggregated simulated driving conditions

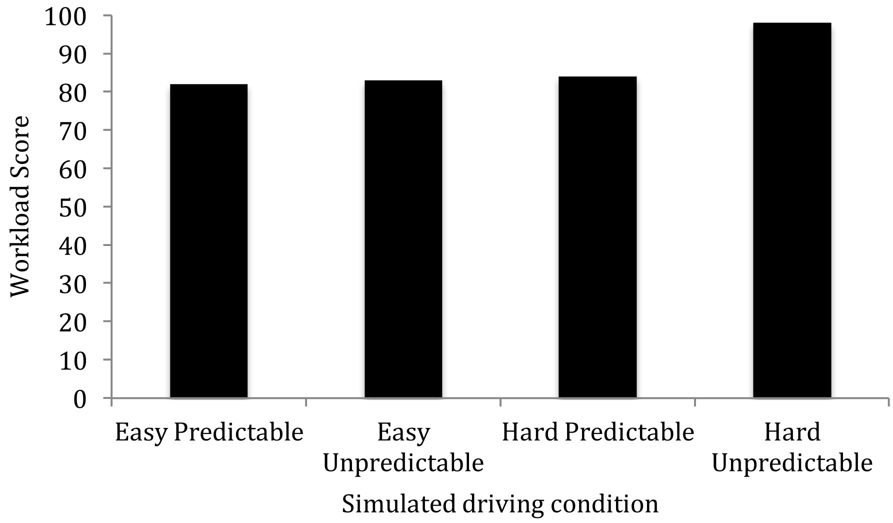

Figure 27. Bar chart of Participant 4's overall workload across the simulated driving conditions.

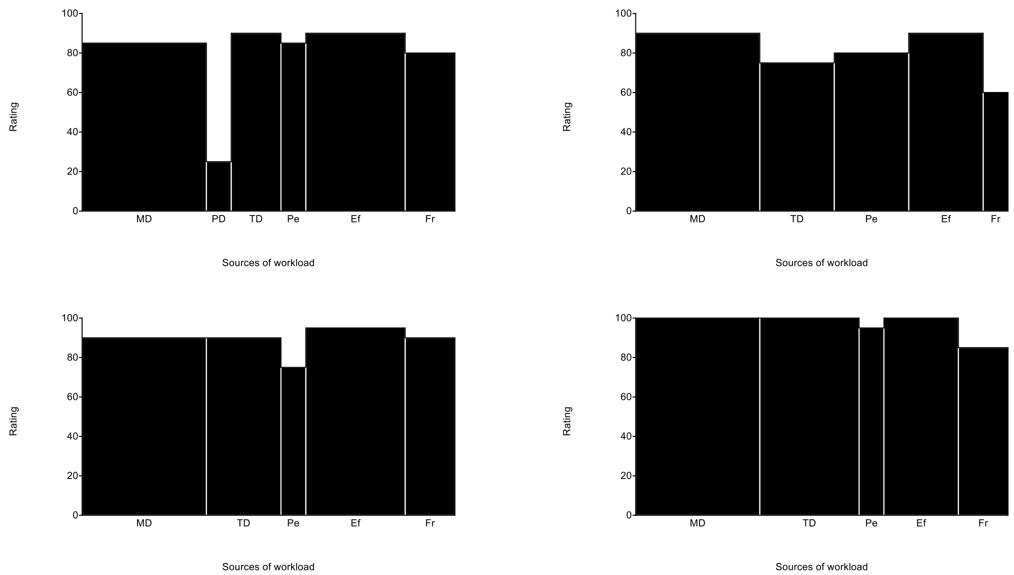

Figure 28. Variable width column chart of Participant 4’s NASA-TLX (Hart & Staveland, 1988) sources of workload and respective ratings.

Figures 27 and 28 present the data for Participant 4's NASA-TLX workload scores. Figure 27 shows the overall workload for each simulated driving condition, suggesting an increase in perceived workload only for the combination of hard track and unpredictable occlusion sequence.

Figure 28 shows the weights and ratings of each source of workload that was selected, across conditions. While mental demand contributed the most to overall workload, effort and temporal demand also incurred high workload in most conditions. Participant 4 appeared to show less frustration in the condition reported as incurring the highest performance load. The sources of workload ratings increased as the track became difficult and the visual occlusion sequence became unpredictable. In particular, the always perceived high mental and temporal demands from the tasks.

Participant 9 (P9)

Participant 9 was a 22-year-old female who had held a driver's license for 5 years. Participant 9 had not experienced any extra driving training and on average drives 4 hours per week with an automatic transmission car. She typically drives in the inner city and on freeways. Participant 9 reported that she had no experience in racing video car games. Participant 9 experienced the predictable visual occlusion sequence first.

Average speed (km/h) across simulated driving conditions

Means and standard deviations of Participant 9's speed across simulated driving conditions are presented in Table 28 and in the combined data of Figure 11. It can be seen from these data that both the harder track and the unpredictable occlusion sequence resulted in reduced speed, with a slightly greater effect of occlusion sequence in the hard track condition.

Table 28

Means and standard deviations of Participant 9's speed (km/h) across simulated driving conditions

	Simulated Driving Condition			
	Easy Predictable	Easy Unpredictable	Hard Predictable	Hard Unpredictable
Average Speed (km/h)	85.97 (8.62)	84.10 (7.80)	73.73 (19.64)	69.44 (19.38)

A two-way (Track Difficulty x Predictability) repeated measures ANOVA confirmed that mean driving speed on the easy track (M=85.04, SD=8.27) was faster than on the harder track (M=71.59, SD=19.63), $F(1, 2160) = 1591.580$, $\rho<.001$, and that mean driving speed in the unpredictable condition (M=65.55, SD=22.08) was slower than in the predictable condition (M=71.73, SD=19.07), $F(1, 2160) = 104.595$, $\rho<.001$. The analysis confirmed that there was also a significant interaction effect, $F(1,2160)=25.141$, $\rho<.001$.

Six post-hoc pairwise comparisons with Bonferroni corrections were conducted to identify significant differences between the simulated driving conditions. Statistical significance was accepted at the $\rho<.008$ level. The post-hoc analysis revealed significant decrease in mean speed (M= 1.87, 95% CI [1.19, 2.55] km/h, $\rho<.001$) from the EP condition (M=85.97, SD=8.62 km/h) to the EUP condition (M=84.10, SD=7.80 km/h). The post-hoc test indicated that there was a significant decrease in mean speed (M=12.24, 95% CI [11.07, 13.40] km/h, $\rho<.001$) from the EP condition (M=85.97, SD=8.62 km/h) to the HP condition (M=73.73, SD=19.46 km/h). The pairwise comparisons test revealed a significant decrease in mean speed (M=16.53, 95% CI [15.29, 17.77] km/h, $\rho<.001$) from the EP condition (M=85.97, SD=8.62 km/h) to the HUP condition (M=69.44, 19.38 km/h). The post-hoc analysis indicated a significant decrease in mean speed (M=10.37, 95% CI [9.22, 11.51] km/h, $\rho<.001$) from the EUP condition (M=84.10, SD=7.80 km/h) to the HP (M=73.73, SD=19.46 km/h). The pairwise comparison post-hoc test revealed a significant decrease in mean speed (M=14.66, 95% CI [13.64, 15.68] km/h, $\rho<.001$) from the

EUP condition (*M*=84.10, *SD*=7.80 km/h) to the HUP condition (*M*=69.44, 19.38 km/h). The post-hoc test indicated that there was a significant decrease in mean speed (*M*=4.26, 95% CI [13.64, 15.68] km/h, ρ<.001) from the HP condition (*M*=73.73, *SD*=19.46 km/h) to the HUP condition (*M*=69.44, 19.38 km/h).

The post-hoc pairwise comparisons confirm that all differences were significant supporting the contention that the effect of track was greater than the effect of occlusion sequence, but the combined effect in the two manipulations was significantly greater in the HUP condition.

Percentage of errors made per visual occlusion interval

The means and standard deviations of Participant 9's errors across visual occlusion intervals are presented in Table 29 and in Figure 12.

Table 29

Means and standard deviations for Participant 9's percentage of errors per occlusion (%) across visual occlusion intervals

	Visual Occlusion Interval			
	1 second	2 second	3 second	6 second
Errors (%)	1.5 (3.0)	12.00 (9.06)	33.25 (23.57)	100.00 (0.00)

A Friedman's ANOVA by ranks supported a significant difference in the percentage of errors/occlusion across the visual occlusion intervals, $\chi^2(3)= 9.308$, ρ=.025. Pairwise Friedman's tests (ρ<.05) showed that the 6 s occlusion interval had a significantly higher error score than both the 1 s and 2 s intervals, but no other pairwise comparisons were significantly different from each other.

NASA-TLX (Hart & Staveland, 1988) source and overall workload across individual and aggregated simulated driving conditions

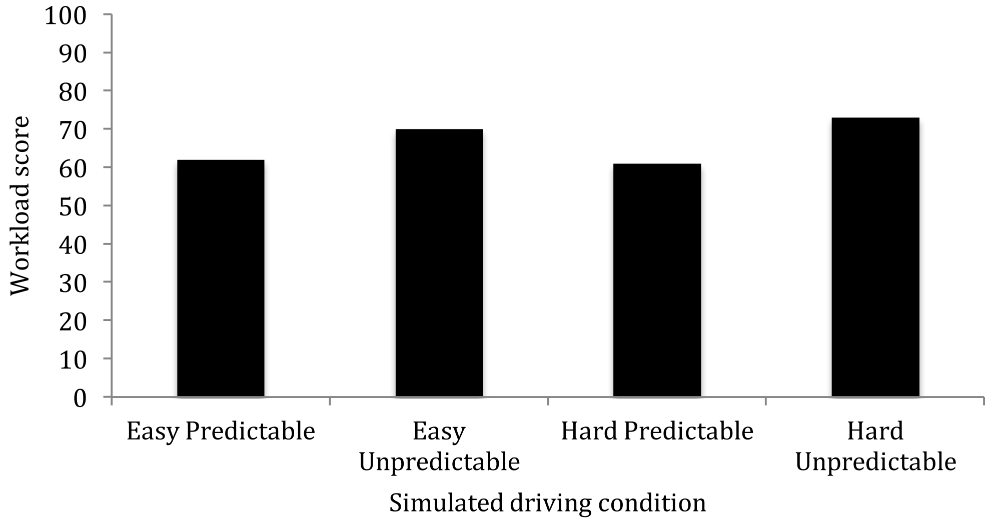

Figure 29. Bar chart of Participant 9's overall workload across the simulated driving conditions.

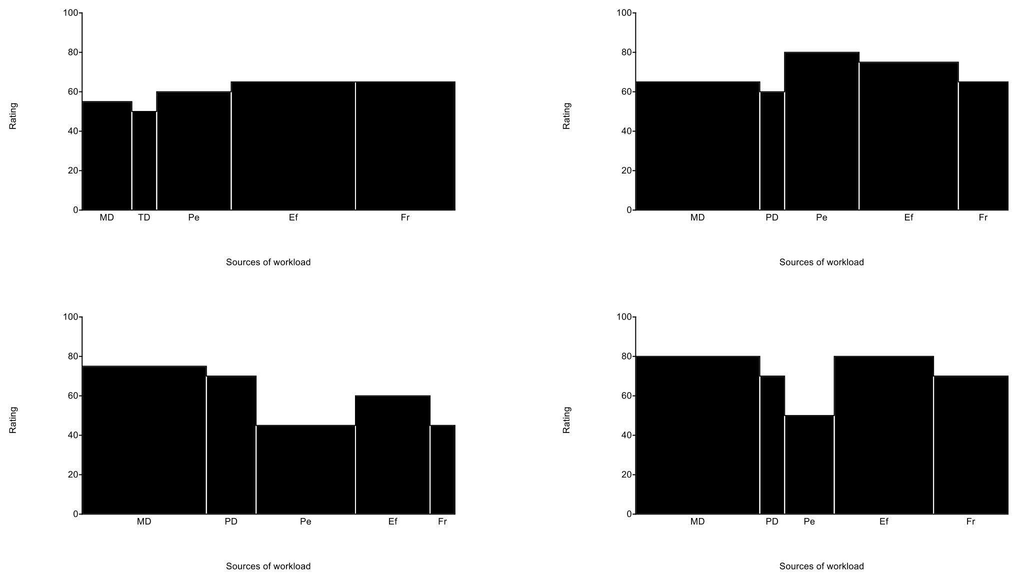

Figure 30. Variable width column chart of Participant 9's NASA-TLX (Hart & Staveland, 1988) sources of workload and respective ratings.

Figures 29 and 30 present the data for Participant 9's NASA-TLX workload scores. Figure 29 shows the overall workload for each simulated driving condition, suggesting a slight increase in perceived workload as for the unpredictable occlusion sequences

Figure 30 shows the weights and ratings of each source of workload that was selected, across conditions. While performance, mental demand, and effort contributed the most to overall workload, Participant 9 showed the highest level of frustration of all participants, indicating frustration across the conditions. The ratings show performance demands drop throughout conditions, suggesting that the participant begun to feel comfortable undertaking the tasks. However, this was met with increased mental demands and effort, which may suggest that this participant believed that they were identifying and regulating their workload efficiently.

Qualitative analyses

In the preceding section, the individual quantitative data across participants have been presented as case studies, and show that there are different patterns of performance across individuals, despite a consistent trend for track difficulty and predictability of occlusion sequence to incur performance decrements. In the next section, qualitative data are explored to try to gain further insight into whether specific cognitive or behavioural strategies may be driving the different patterns of performance across participants. Details of the method of qualitative analysis were presented in Chapter 3, and Appendix H and I.

Themes and sub-themes of strategies

Repertory grids relating to the semi-structured interview questions were used to identify strategies employed by participants to manage their performance across different experimental conditions. Strategies, to be described in the following section, appeared to have fallen into two overarching themes, *psychomotor* and *cognitive* strategies. Psychomotor strategies were those that involved vehicle manipulation to maintain performance and resulted in observable behaviours. Cognitive strategies were those that involved perceptual and cognitive attention patterns that are not directly observable in behaviour. One aim of the current research was to identify whether these strategies may have observable correlates in terms of biofeedback data (e.g., EMG, HRV) or subtle aspects of observable behaviour. Altogether, five psychomotor strategy sub-themes and six cognitive strategy sub-themes were identified. The psychomotor strategy's sub-themes included, *anticipatory manoeuvring*, *decrease speed*, *maintaining vehicle parameters*, *controlled errors*, and *vehicle positioning*. The cognitive strategy's sub-themes included, *self-talk*, *scanning environment*, *external sensory feedback*, *counting visual occlusion internal (VOI) duration*, *mental mapping*, and *anticipating visual occlusions*. These sub-themes, including their definitions and codes are given in the tables that follow. Table 30 articulates the psychomotor strategy sub-themes, while Table 31 describes the cognitive strategy sub-themes.

Table 30

Psychomotor strategy's sub-themes

Theme	Sub-theme	Definition	Examples of coded responses
Psychomotor strategy	Anticipatory Manoeuvring	Strategies that predicted both steering angles and speed adjustments during visual occlusions.	"Corners were- yeah, just taking an educated guess as to where I think the car needed to turn" "Just kind of like predicting the speed and like when I would have to turn and stuff like that"
	Decrease speed	Strategies that actively sought to lower vehicles speed via the brakes or release of the accelerator during visual occlusions.	"The longer they [visual occlusions] went the more I um went um just lined off the accelerator." "Just being a little bit more cautious with my speed when I black out [visually occluded]"
	Maintain vehicle parameters	Strategies that maintained a consistent speed and steering angle during visual occlusions.	"During the shorter occlusions, I just maintained my- my input and tried to last it out."
	Controlled errors	Strategies that intentionally caused small errors to prevent severe errors or identify track location during visual occlusions.	"I just tried to stay close to the wall because I knew if I hit the wall I could just keep bumping it and keep going…"
	Vehicle positioning	Strategies that aligned the vehicle on the track in a position that would assist in maintaining performance during an up-coming visual occlusion.	"I felt they [visual occlusions] were coming just as I was approaching a corner. So to actively try and position myself….I'm always trying to find the best lines".

Table 31

Cognitive strategy's sub-themes

Theme	Sub-theme	Definition	Example of coded responses
Cognitive Strategy	Self-talk	Actively encouraging, focusing, and/or calming themselves during or before trials to improve performance.	"It's ok if you hit something." "I guess I would just tell myself that it's going to be over soon so just try and like stay on track...."
	Scanning environment	Either looking ahead in the track or attending to the dynamic map prior to a visual occlusion to prepare for up-coming track changes.	"Tracking what was coming up, so looking um at the left screen to know how far the corner…was still there, like still to go."
	External sensory feedback	Executing vehicle adjustments via auditory and haptic feedback from the car and track during visual occlusions.	"Started listening, you could sort of hear if you were going near the grass or anything like that." "I was able to use the sound of the car to um determine how fast I was going."
	Counting VOI duration	Cognitively counting the seconds of a visual occlusion.	"When the blocks [visual occlusions] would come, I actually timed it, so it helped me a lot."
	Mental mapping	Creating mental images of the track and track location during visual occlusions.	"When the visual occlusions [occurred], trying to visualise the track…"
	Anticipating visual occlusions	Predicting the occurrence of up-coming visual occlusions.	"Trying to get that pattern of occlusion… right".

Strategy mind maps

'Mind maps' are tools used to visually organise information in a hierarchical format. Mind maps commence with a topic or theme, which are deconstructed into sub-themes in order to depict quick visualisation of their constructive make-up. Strategy mind maps were developed to enable a clear visualisation of which sub-themes were present during each trial. The strategy mind maps allowed comparisons between higher and lower performing participants, and directed the student investigator to the behaviours and strategies to be investigated via the participant trial video recordings. Participants' strategy mind maps are presented based on the higher and lower performers, identified on the basis of their quantitative performances, as well as the effectiveness of their strategies. The questions asked were developed with predetermined themes. For example the question: "What strategies did you employ to cope with the visual occlusion in order to maintain performance during the drive and why?", was developed to elicit the theme "Strategy". This permitted development of sub-themes. This was achieved by coding quotes and phrases of the responses based on their similarities and differences. Following the establishment of sub-themes for each participant, participant 'mind maps' were developed to enable comparisons between the participants. Together, the quantitative performance data, strategy mind maps, and interviews data converged to distinguish new groups. Four groups were identified and titled: "higher performing participants with diverse strategies"; "higher performing participants with limited strategies"; "lower performing participants with diverse strategies"; and "lower performing participants with limited strategies". Following the identifications of the differences between each groups' strategies, video-recordings of participants' trials were examined to see where the strategic differences were located during the trials.

Higher performing participants with diverse strategies

As depicted in the strategy mind maps (Figures 31: Participant 8's strategy mind map; Figure 32: Participant 5's strategy mind map; Figure; 33: Participant 3's strategy mind map), higher performers reported that they employed a diverse range of psychomotor strategies across the trial conditions. While the three highest performing participants did not always adopt the same psychomotor strategies for the same trial conditions, they all reported implementing the same four psychomotor strategies (vehicle positioning, anticipatory manoeuvring, maintaining vehicle parameters, and decreasing speed) during driving situations in their trials. Similar to the psychomotor strategies, the higher performing participants implemented a diverse range of cognitive strategies that often overlapped with one another.

When the higher performing participants were describing how they implemented their strategies during the trial conditions, they often mentioned using a complementary combination of cognitive and psychomotor strategies. The cognitive strategies would often be employed with the intention of being able to execute the psychomotor strategy effectively. For example, this was evident when questioning Participant 3 about his preparation and strategies to cope with a visual occlusion. He commented that by predicting the visual occlusion sequence, he could position the vehicle on the track that would provide him with “a lot more margin of error both ways”:

> Participant 3: “…try to get that pattern of occlusion… right, so I knew how I was going to get through, but sort of really work hard to stay in the middle of the track rather than trying to do the inside corners”.

Similarly, Participant 5 also commented on the combination of employing cognitive and psychomotor strategies to cope with visual occlusions, stating that “you sort of would look ahead and think, ok, it’s [visual occlusion] gonna come and then… I need to do this…” This was followed with further comments concerning the strategies he employed to cope with the visual occlusions:

> Participant 5: “… slowed down. …’Cause they were semi-predictable [visual occlusions] sort of assess ahead when I thought it was coming… yeah, sort of pre-empting [correct driving manoeuvres]…”

Two of the higher performing participants revealed specialised knowledge that lesser performers either did not consider or did not disclose. More specifically, they commented on being knowledgeable on and identifying correct driving lines to improve their performance. For example, when responding to whether they used different strategies for different driving situations, Participant 3 commented that:

Participant 3: “the longer it [visual occlusions] got the less preparation I was able to do. So, I was more concerned with actually getting back on the track… and getting the line right and speed right…”

Moreover, Participant 8 was the most knowledgeable of driving lines to improve performance, referencing his racing video-game experience:

Participant 8: “… because I play these racing games as racing games, I’m always trying to find the best lines, trying to complete it in the best times… I will always try and find the best position to start turning from. And what I mean by line, I mean driving line…”

Participant 8 elaborated on this in a further interview, suggesting that, “I would give the same answer as any racing driver would give, find the best line and best speed to minimise your lap time.” These comments from both participants provided support that they had well-established understandings on how to appropriately integrate and employ cognitive and psychomotor strategies to efficiently execute navigating the vehicle on a performance enhancing driving line.

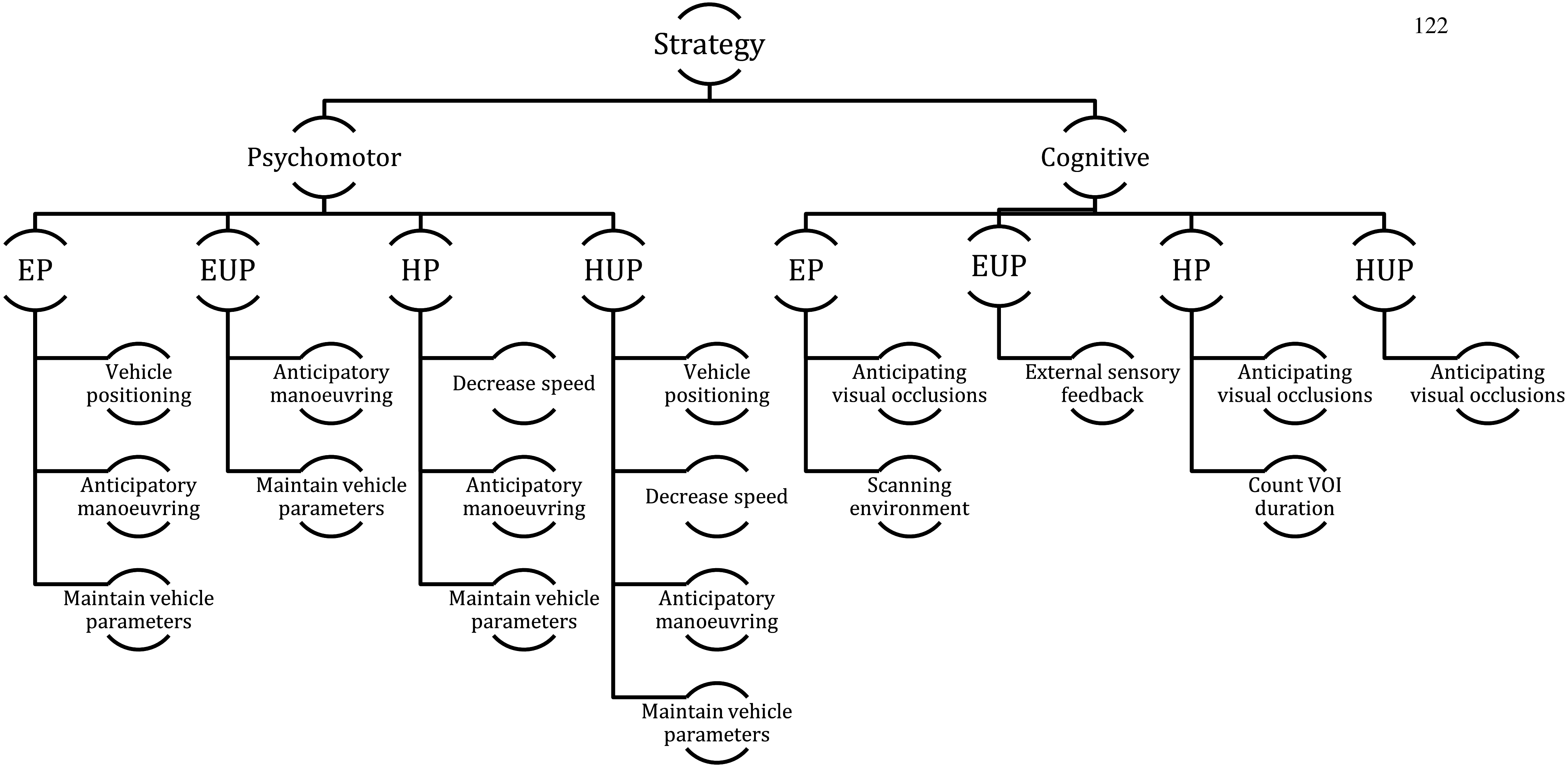

Figure 31. Participant 8's strategy mind map.

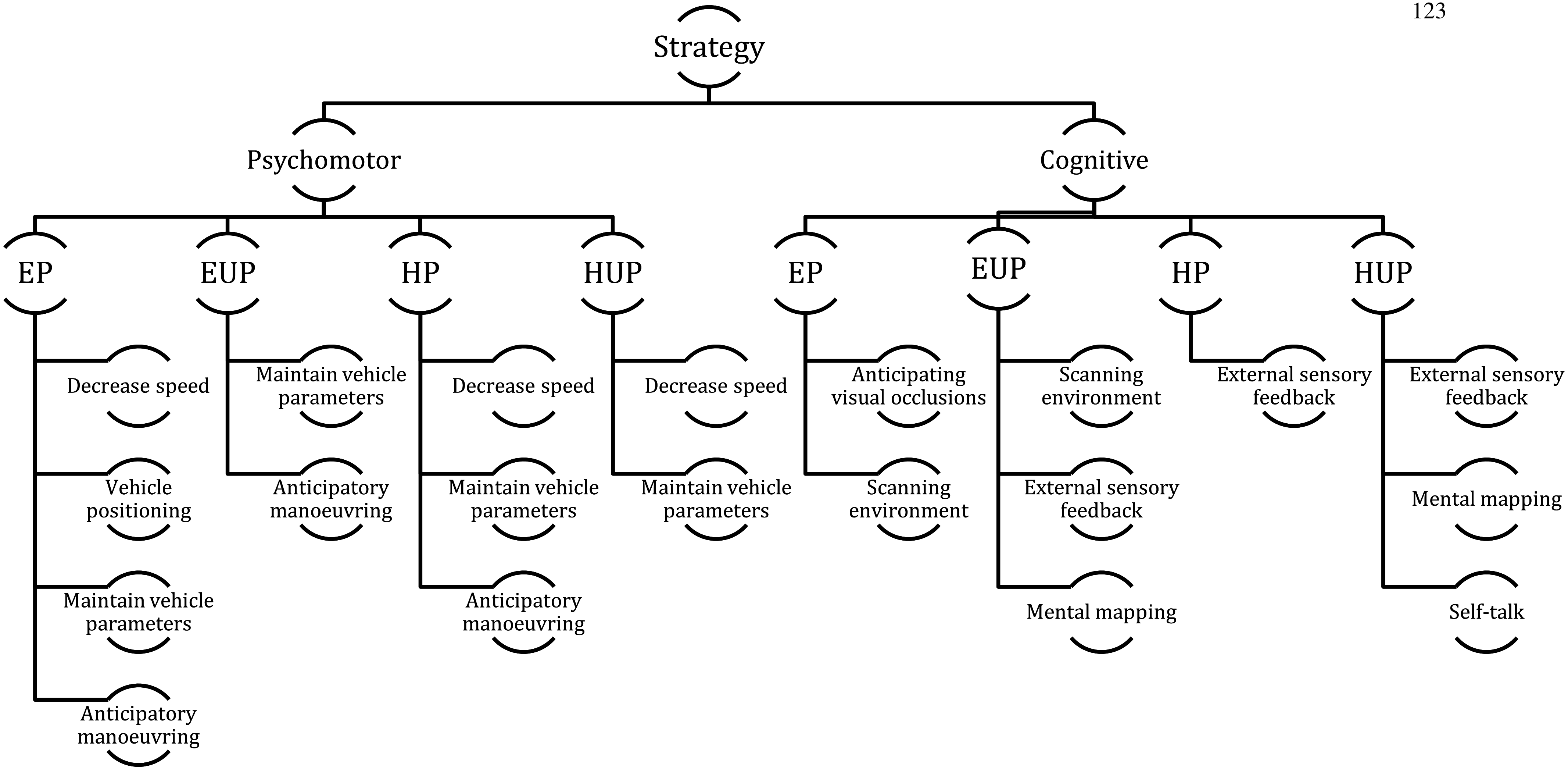

Figure 32. Participant 5's strategy mind map.

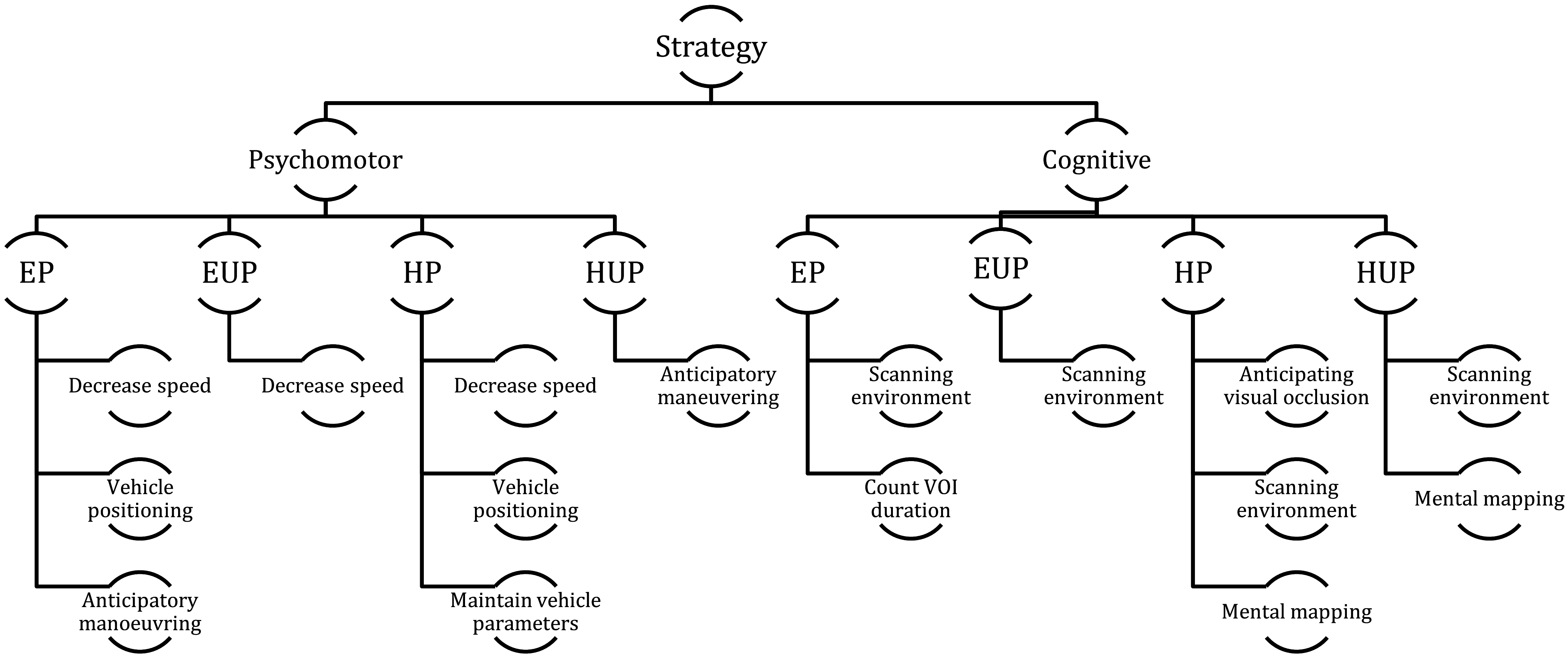

Figure 33. Participant 3's strategy mind map.

Higher performing participants with limited strategies

As depicted in the strategy mind maps (Figure 34: Participant 1's strategy mind map; Figure 35: Participant 2's strategy mind map), higher performers with limited strategies employed basic psychomotor strategies and minimal cognitive strategies. More specifically, the two participants that were categorised in this group were revealed to implement similar combinations of psychomotor strategies to cope with the visual occlusions and either did not disclose or employ such a diverse range of strategies for different driving situations as did the highest performers. Moreover, these two participants commented on the difficulty of the task and the importance of being calm during the trials. For example, when questioning Participant 2 on her frustration following the HUP condition, she commented that she had learnt from a previous trial that if she did not stay calm during the trial her performance would decline:

> Participant 2: “I’m not feeling as… frustrated as I was the one before [previous trial]. That one really affected me, whereas this one…it [bad performance] was definitely still playing on my mind and it was a bit irritating… and I thought it [trial condition] was difficult but… yeah, I guess I like kind of learnt from the one before to kind of, you know, once… you’re not calm and like not composed it’s a lot harder, so I just keep it in mind.”

This learned response, pertaining to poor performance as a result of not staying calm in trials, was also evident in Participant 1’s comment:

> Participant 1: “I tried to stay calm and I tried… to stay calm compared to the… previous one [trial] with that track… and tried not to be so frustrated...”

Unlike the higher performing participants with diverse strategies, the higher performing participants with limited strategies did not or rarely commented on employing any integration of psychomotor and cognitive strategies. For example, only once when questioned on the strategies employed to cope with the visual occlusions, Participant 2 commented:

> Participant 2: “Just looking at the track, looking ahead… kind of thinking about… how much the… car would move…depending…how much I turned the wheel.”

Participant 1 did not refer to any situation in which she employed both psychomotor and cognitive strategies to cope with the visual occlusions. Both participants appeared to have good psychomotor skill execution to support their driving

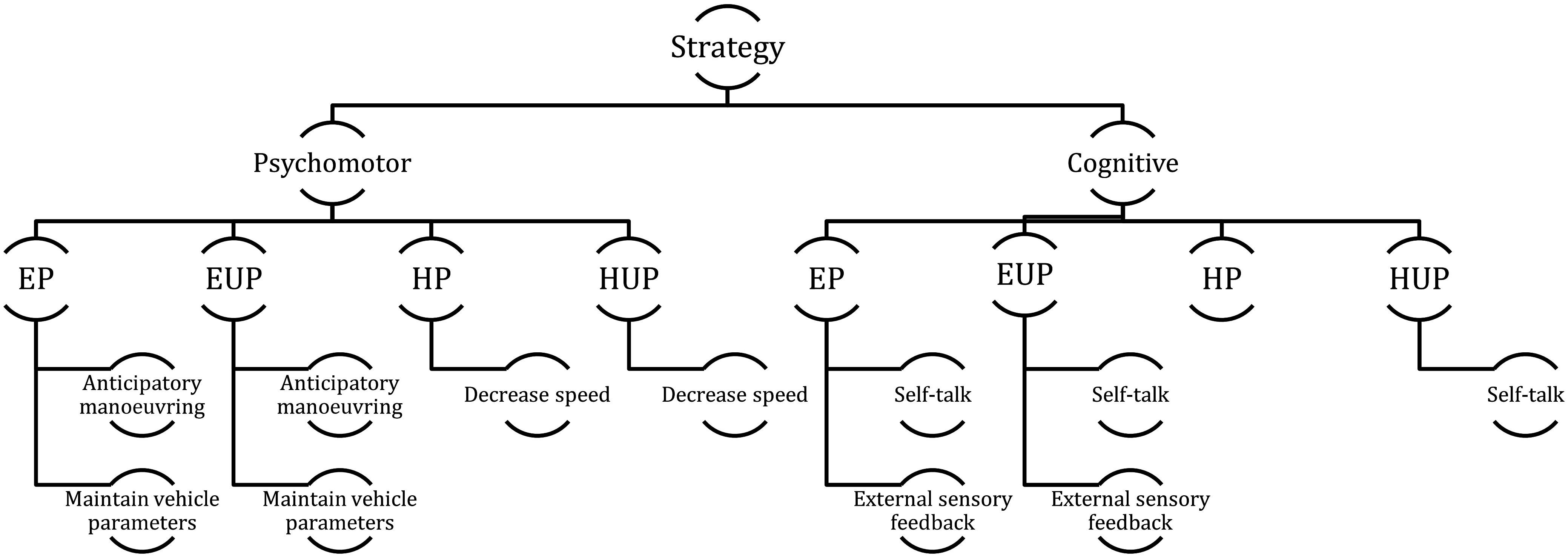

Figure 34. Participant 1's strategy mind map.

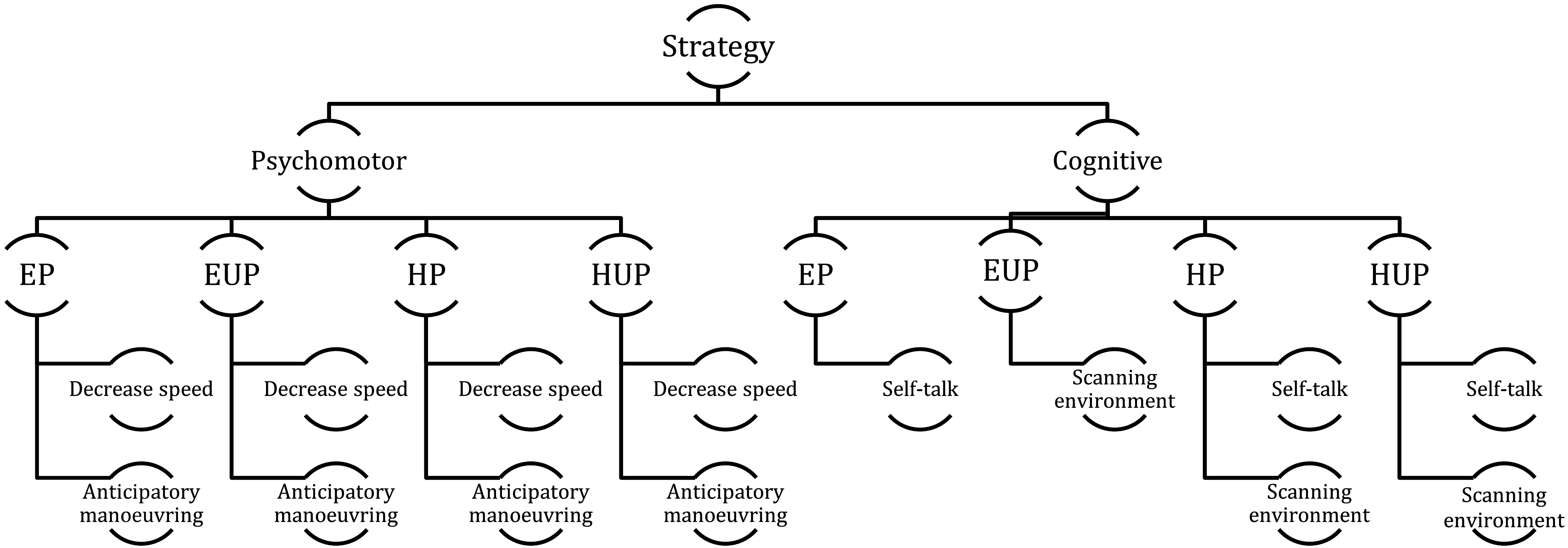

Figure 35. Participant 2's strategy mind map.

Lower performing participants with diverse strategies

As shown in the strategy mind maps (Figure 36: Participant 6's strategy mind map; Figure 37: Participant 7's strategy mind map), lower performing participants with diverse strategies disclosed using more sophisticated cognitive strategies than the higher performing participants with limited strategies. However, they did not disclose using a similar number of psychomotor strategies as reported by the higher performing participants with diverse strategies. Moreover, these participants appeared to employ the detrimental performance strategy and controlled errors. Both Participant 6 and Participant 7 commented on how they would intentionally cause minor errors to prevent major errors that could cause further errors. For example, when questioned on the strategies employed to cope with visual occlusions, Participant 6 commented:

> Participant 6: "… I would just hope that I'd go on the grass and then I could correct it."
>
> *I*: "Ok, so you were aiming for the grass or?"
>
> Participant 6: "Rather than the wall, 'cause every time it, my vision, went out when I was on a bend… I knew I was going to crash because it was just too difficult for me to control it."
>
> *I*: "And why did the grass help you?"
>
> Participant 6: "Cause I could hear the grass and it also means that I wouldn't have like crashed into a wall for example, so it would be easy for me to correct where I was driving… to get back to the road."

Participant 7 echoed Participant 6's concern about preventing major crashes by intentionally committing minor errors, stating:

> Participant 7: "I just tried to stay close to the wall because I knew if I hit the wall I could just keep bumping it and keep going like that and eventually it [vision] would come back or less likely to spin out."

Participants implementing a diverse integration of psychomotor and cognitive strategies were evident following their interviews, often expressing similar strategy integrations as the higher performers with diverse strategies. For example, when questioned on the strategies employed to cope with the visual occlusions, participant 7 commented:

> Participant 7: "… I guess I look forward to try and see what's coming up and then at one point I found myself counting, like how long it would take me to get to a point. So then I knew that when it would come the next time, I'd go 1, 2, 3 alright now is probably a good time to start hanging a turn and try and, you know, be a bit more aware of what I was doing."

Note that higher and lower performing participants were identified through a median split on quantitative error data, so the strategy of harm minimisation by committing recoverable errors in the context of the task would not have been revealed without further qualitative investigations. This is discussed further in Section "Poor strategy masking higher performer" on behavioural data.

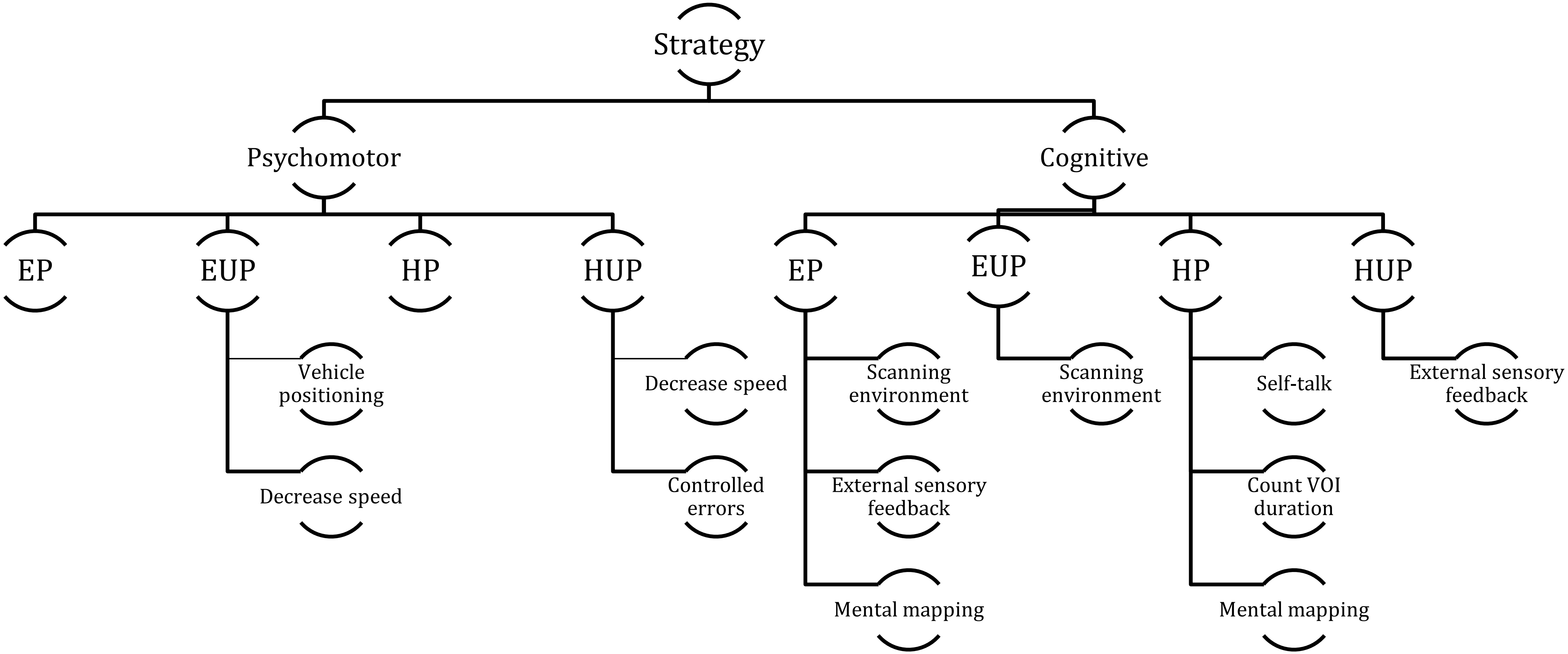

Figure 36. Participant 6's strategy mind map.

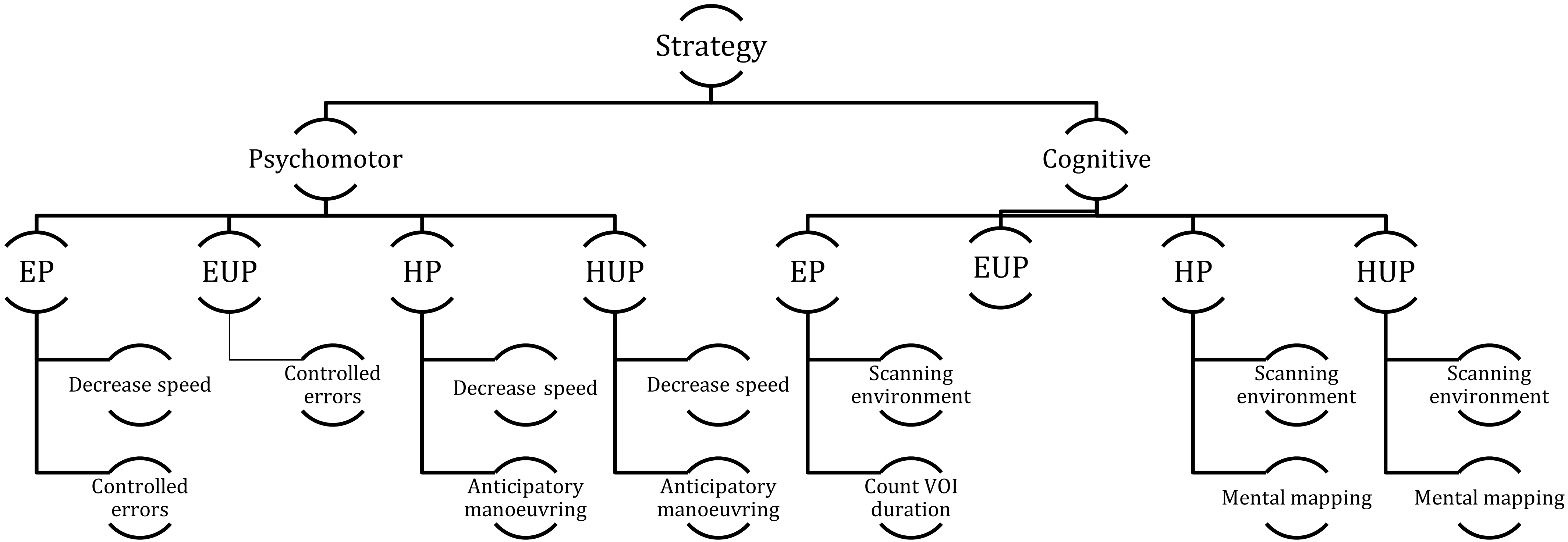

Figure 37. Participant 7's strategy mind map.

Lower performing participants with limited strategies

As given in the strategy mind maps (Figure 38: Participant 4's strategy mind map; Figure 39: Participant 9's strategy mind map) the lower performing participants with limited strategies employed a limited range of psychomotor and cognitive strategies. Participant 4 and participant 9 both lacked diverse strategies and either did not or rarely disclosed or employed integrated cognitive and psychomotor strategies. However, arguments can be made that the strategies used by them do not differ greatly from the higher performing participants with limited strategies. For example, participant 9 commented on visually inspecting the track environment to assist her in making appropriate driving manoeuvres:

> Participant 9: "… I was always anticipating what was coming next and making sure I knew if there was a turn coming up or not…"

These performance differences of Participant 4 and Participant 9 - between the higher performing participants with limited strategies - may be the outcome of the ability to execute the manoeuvring efficiently rather than the strategies employed.

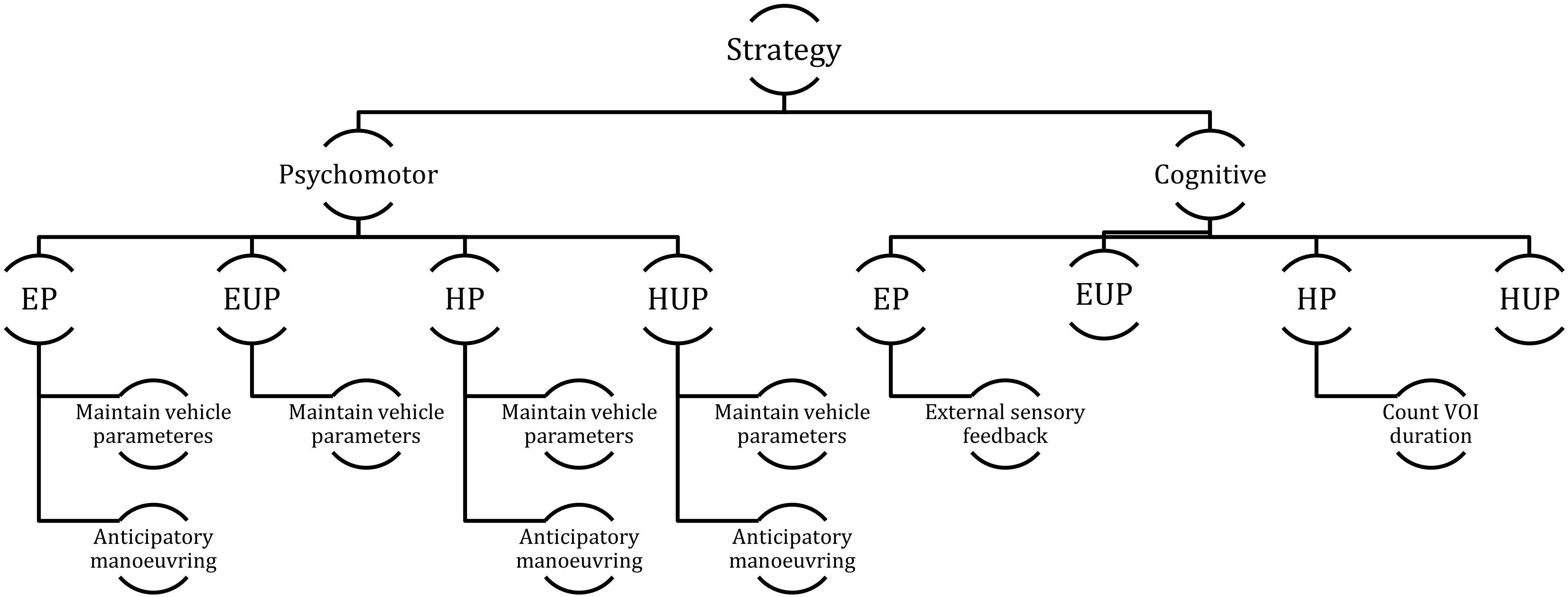

Figure 38. Participant 4's strategy mind map.

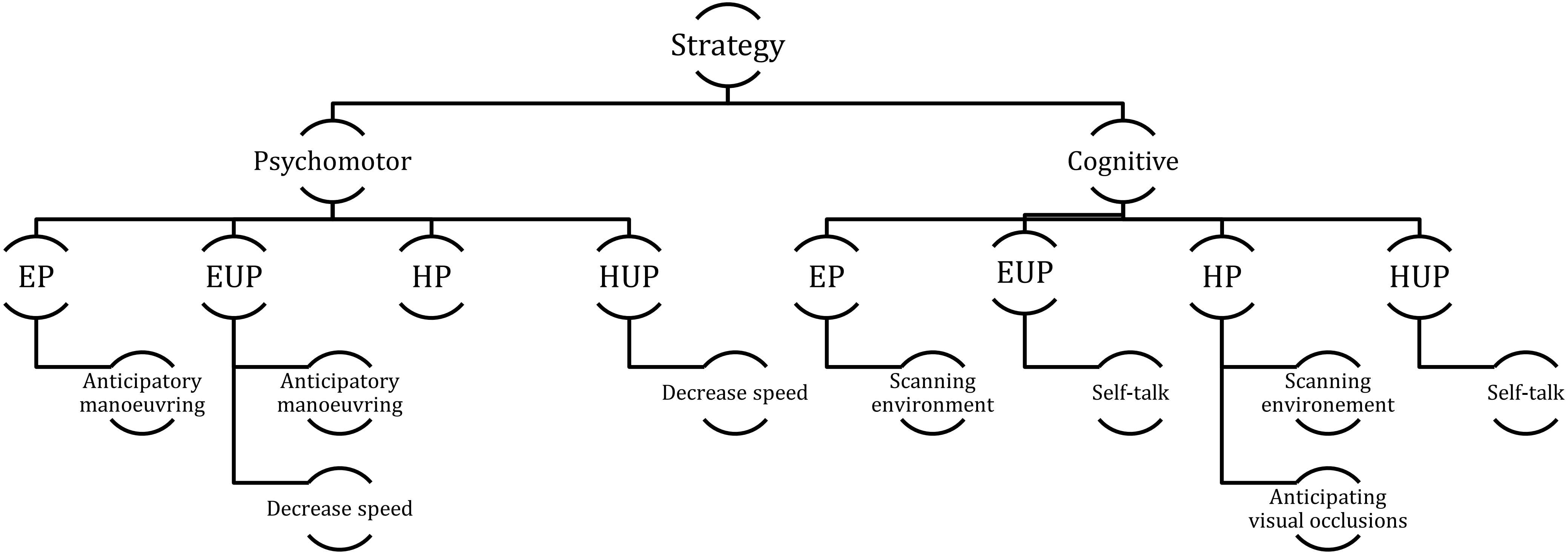

Figure 39. Participant 9's strategy mind map.

Participant trial video-recordings

Video-recordings of the observable driving behaviour of participant's trials were used to identify whether the disclosed strategies the participants employed led to observable behaviours. The video-recordings permitted comparison between participants, and evaluation of the execution of strategies. The following sections presents sequences of pictures attained from the video-recordings of the trials.

Diversity of strategies

Higher performing participants with diverse strategies disclosed utilising a more diverse range of strategies to maintain performance than the lower performing participants. It is possible that lower preforming participants had used similar strategies to the higher performing participants, and had not disclosed them in interviews; however, the video-recordings have provided observable support for a lack of psychomotor strategies being implemented by those lower performing participants.

Evidence of a difference between the diversity of psychomotor strategies is depicted in Figure 40 (Higher performing participant with diverse strategy executes vehicle position, anticipatory manoeuvring, and maintain vehicle parameters efficiently) and Figure 41 (Lower performing participant with limited strategy executes anticipatory manoeuvring inefficiently). In Figure 40, the higher performing participant with diverse strategies is visually occluded for a 6 s visual occlusion in the EP condition. This participant mentioned the use of three psychomotor strategies and two cognitive strategies in this condition. Firstly, the participant disclosed that he was anticipating the onset of visual occlusions and visually scanned the up-coming track prior to the visual occlusion (cognitive strategies). Moreover, the participant disclosed that he was always aiming to position the vehicle on a driving line that would maintain their performance (psychomotor strategy). This can be seen in the first picture of the sequence in Figure 40, where the participant has aligned the vehicle along a driving line on the inside of the track. The participant commented on how he aimed to identify appropriate steering angles and speeds while navigating around the track (psychomotor strategy). This is evident in the following of the sequence of pictures in Figure 40, as the participant stabilises and maintains his steering angle and speed within the driving lane leading into the corner. The participant then begins to anticipate the turning angle (cognitive strategy) and lowers the speed around the corner (psychomotor strategy). The participant maintains the steering angle and speed (psychomotor strategy) around the corner until vision is returned. It appears that through the integration of these strategies, the participant is unaffected by the long visual occlusion and was able to maintain performance until vision of the track returned.

In contrast with Figure 40 of the higher performing participant with diverse strategies, Figure 41 depicts an identical situation of a lower performing participant with limited strategies. Similar to the higher performing participant with diverse strategies, the lower performing participant was visually occluded for 6 s in the EP condition. In this condition, the participant exhibited the use of only one psychomotor strategy and one cognitive strategy. The lower performing participant with limited strategies, disclosed that they would visually scan (cognitive strategy) the environment to become aware of the upcoming track should they become visually occluded. Compared to the higher preforming participant with diverse strategies, this participant did not disclose nor appear to identify driving lines to improve performance. The absence of this strategy is evident in the first picture of Figure 41, as the vehicle is positioned over the top of the inside line and too far inside the track. Moreover, as depicted in the following sequence of pictures in Figure 41, this participant incorrectly anticipates the corner as she begins steering too late for the corner. This delay in steering resulted in the vehicle crashing against the wall, with a lack of diverse integration of strategies having contributed to the participant making an error.

Figure 40. Higher performing participant with diverse strategy executes vehicle position, anticipatory manoeuvring, and maintain vehicle parameters efficiently.

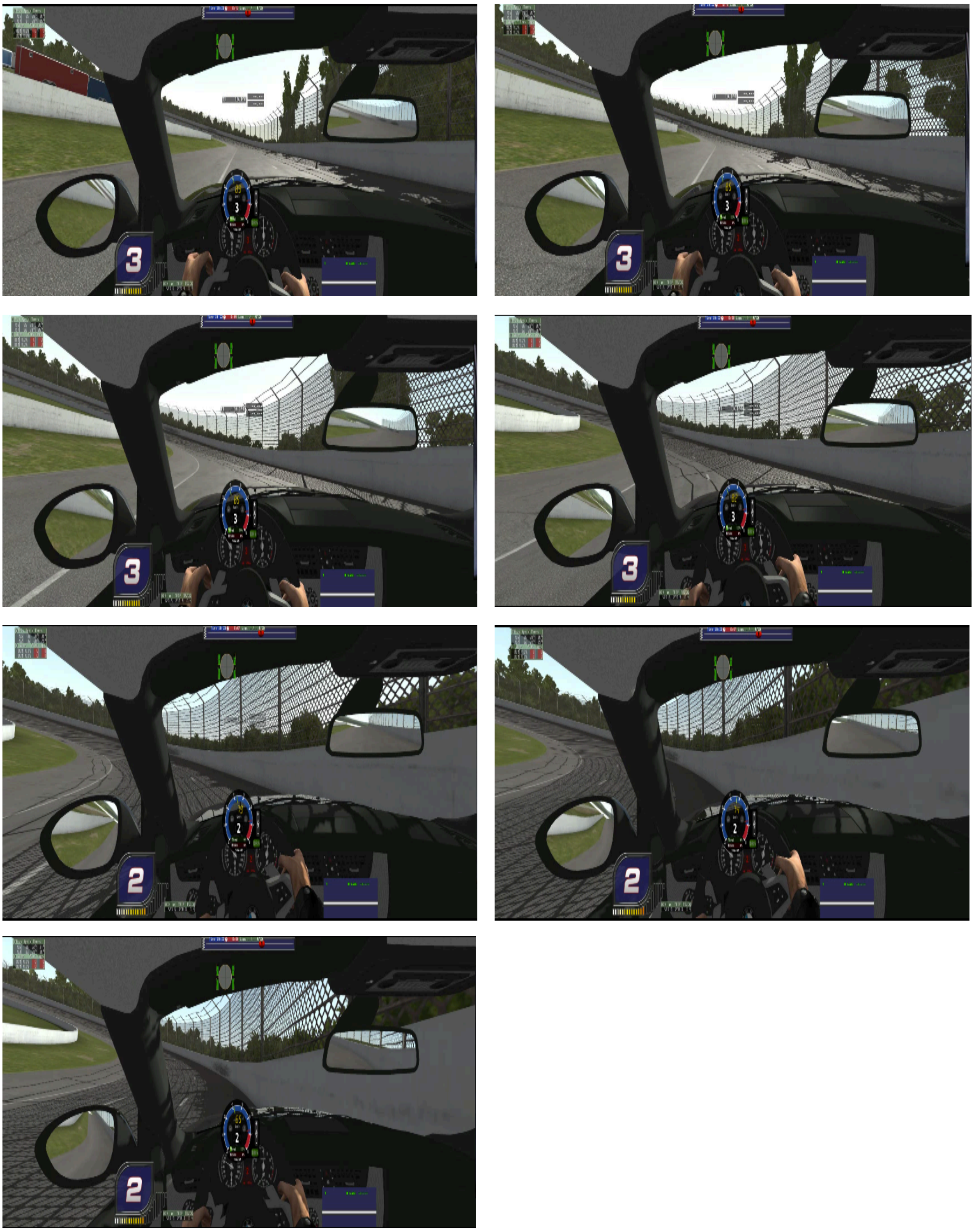

Figure 41. Lower performing participant with limited strategy executes anticipatory manoeuvring inefficiently.

Execution of strategies

Video recordings provided support for differences between the executions of similar psychomotor strategies of the groups. While all participants from the four groups committed errors during their trials, video-recording data suggests that higher performing participants were more regularly able to execute their psychomotor strategies efficiently to avoid errors. The difference in the execution of psychomotor strategies may have been a consequence of either more diverse or appropriate cognitive strategy integration and/or higher skill in manually manipulating the steering and speed of the vehicle.

Video recording evidence of the difference in the execution between higher performing participants and lower performing participants is presented in Figure 42 (Higher performing participant with limited strategy executes the maintain vehicle parameters strategy efficiently) and Figure 43 (Lower performing participant with limited strategy executes the maintain vehicle parameters strategy inefficiently). Both Figures show similar situations within the HUP condition. Both participants experienced a 3 s visual occlusion on a long straight and appeared to employ a strategy to stabilise their steering angle and speed (psychomotor strategy). The participants in Figure 42 and 43 differed in their quantitative performance scores but both disclosed a lack of diverse strategies. As can be viewed in the sequence of frames in Figure 42, the higher performing participant became visually occluded in the centre of the track. While the higher performing participant drifted both left and right off the centre, these are minimal and the participant is able to avoid error. However, as depicted in the sequence of pictures in Figure 43, the lower performing participant also became visually occluded in the centre of the track but began to drift too far right and consequently crashed into the track barrier. Hence, the difference in execution shown in Figure 42 and Figure 43 provides an example that higher performing participants are able to execute strategies more efficiently than the lower performing participants to minimise the risk of committing errors.

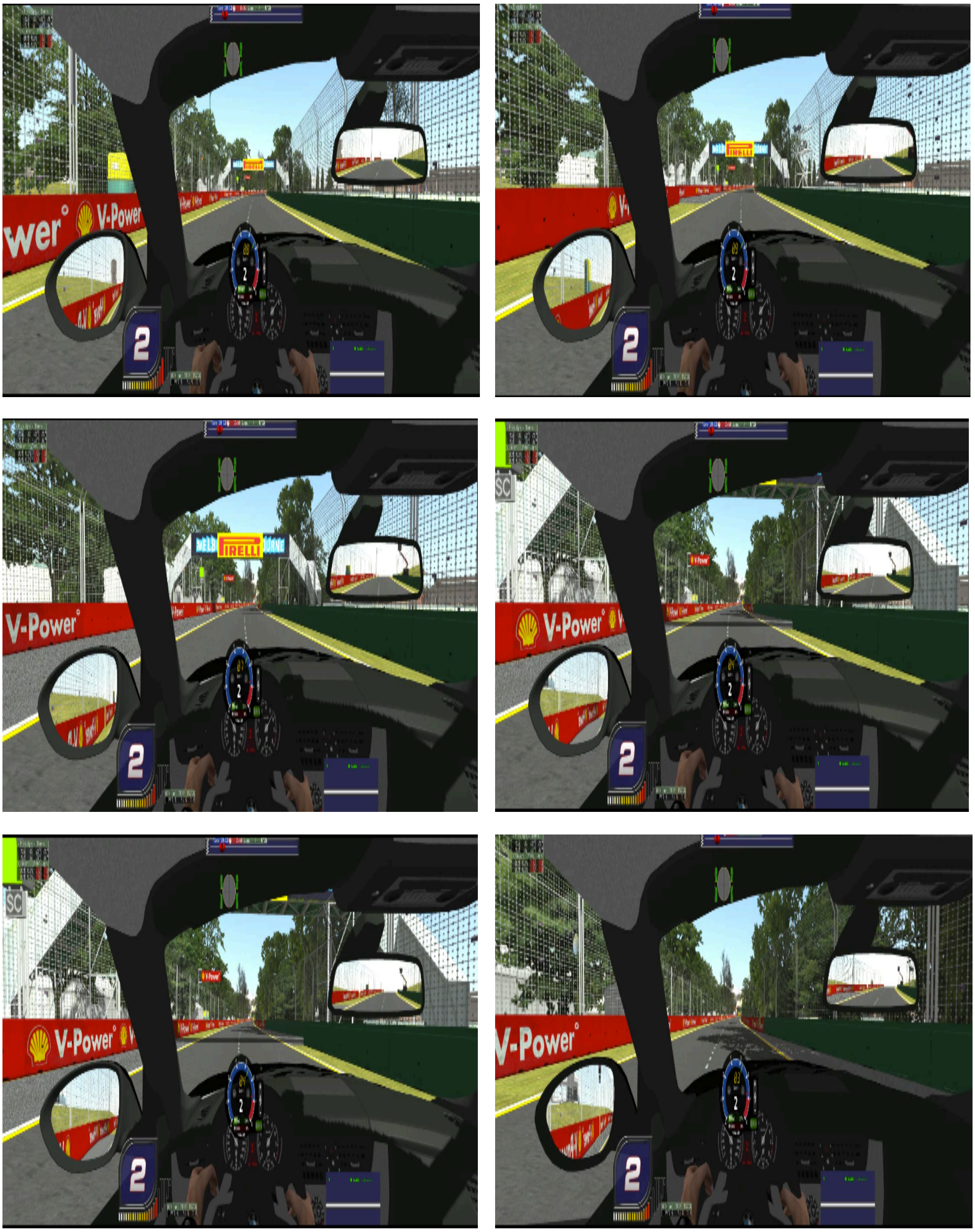

Figure 42. Higher performing participant with limited strategy executes the maintain vehicle parameters strategy efficiently.

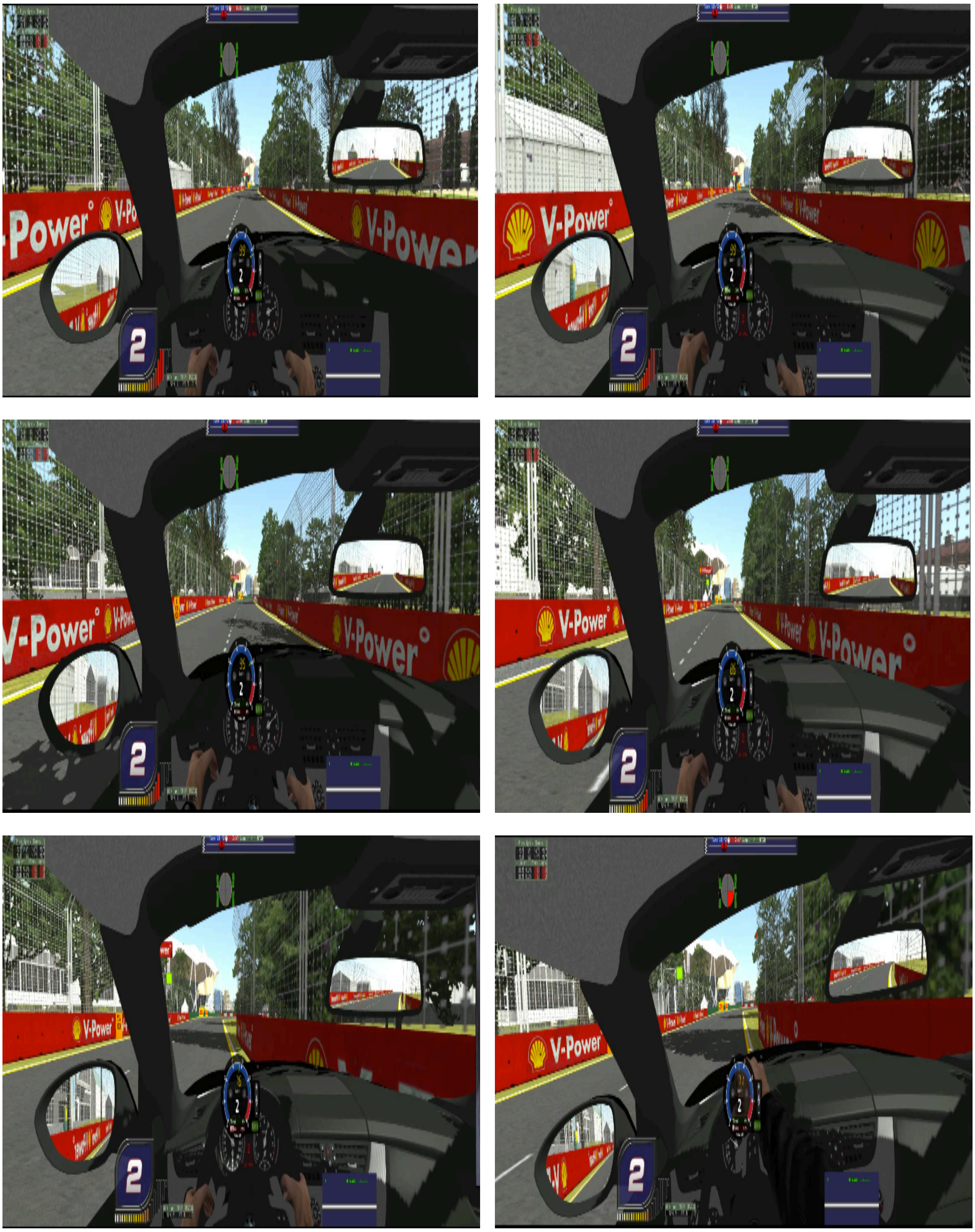

Figure 43. Lower performing participant with limited strategy executes the maintain vehicle parameters strategy inefficiently.

Poor strategy masking higher performing participants

Video recordings identified those participants that employed strategies to cause controlled errors. As depicted in the first picture of the sequence in Figure 44 (Lower performing participant with diverse strategy executes the controlled error strategy), the participant became visually occluded while navigating around the corner. The participant reduced the steering angle and straightened up towards the wall. The participant made contact with the wall in the third frame of Figure 44, and proceeded to grind against it at a consistent speed until vision returned. This action is classified as an error in the quantitative data; however following the interview and video recording observation this intentional action of grinding against the wall appears to have permitted the participant to identify his location during the visual occlusion. Moreover, the strategy also appeared to prevent an error that would cause excessive disruption to his performance and require longer recovery times once he was no longer visually occluded.

The lower performing participants that employed the controlled error strategy disclosed utilising more diverse strategies than the other lower performing participants that did not. Video recordings were examined to identify how the lower performing participants that employed the controlled error strategy executed their strategies during visual occlusions that were free of errors. While these participants still made errors that appeared unintentional, they also executed a number of strategies efficiently. As depicted in Figure 45 (Lower performing participant with diverse strategy that employs the controlled error strategy executes anticipatory manoeuvring efficiently) the participant became visually occluded leading into a sharp corner. In the second frame of the sequence in Figure 45, the participant began to make anticipatory steering manoeuvres and narrowly avoided navigating off-road. The participant then straightened the vehicle briefly before making further anticipatory manoeuvres until he was no longer visually occluded. These actions are all executed without the participants veering off-road. The sequence of frames in Figure 44, provides an example of how participants that employed the controlled errors strategy may actually have similar performance abilities to the higher performing participants but have their abilities masked by the utilisation of performance decrementing strategies.

Figure 44. Lower performing participant with diverse strategy executes the controlled error strategy.

Figure 45. Lower performing participant with diverse strategy that employs the controlled error strategy executes anticipatory manoeuvring efficiently.

Observed Driver Behaviour and Biofeedback

Observable behaviour on the data

The observations and evaluation of participants' non-driving behaviour (e.g., facial expression, posture, grip of steering wheel), suggested that there were no significant differences across conditions or between groups. Participants more often exhibited facial expressions overhead movements and postural realignments. Some participants would tense the muscles around their mouths, bite their lips or frown during longer visual occlusions. These facial expressions appear to be an implicit behavioural reaction to concentrating and trying to perform the task. However, these facial expressions did not appear to be an indicator as to when a participant was about to commit an error, as these expressions were observed during periods of good performance. Moreover, participants often exhibited facial expressions more following an error than during a visual occlusion. For example, some participants would laugh or smile after a crash, while some would sigh or intentionally exhale. The participants that smiled or laughed following an error may have had this response due to the novelty of driving the car simulator while being visually occluded and/or enjoying participating in the trials, or as a release of arousal. Participants who sighed or intentionally exhaled may have reacted this way due to feelings of frustration with committing an error.

There was only one case of a participant engaging in a postural realignment. This occurred when the participant navigated the vehicle into a wall barrier resulting in a large crash that caused the simulator to vibrate rigorously. The participant may have realigned his posture in the seat as he may have been shaken into an uncomfortable position or as a symbolic gesture to forget the crash and 'mentally reset' the task and continue the trial. Moreover, participants' hand positioning on the steering wheel did not alter during visual occlusions or during errors.

Muscles activation and heart rate variability

To reiterate from the Method section; attempts were made to acquire clean biofeedback data, however the data was contaminated by external artefacts that could not be filtered out. Further analyses using these data would be inappropriate, as the data would not reveal any significant information. Moreover, the heart rate variability data, acquired from the commercial off the shelf heart monitor, was not robust or reliable enough to reveal any significant conclusions. Ultimately, the biofeedback analyses revealed null findings. See Appendix E, for further information regarding the biofeedback tools and procedures.

Chapter 5. General Discussion

The research reported here was directed towards gaining a better understanding of some of the more general aspects of mastery of skilled performance in a dynamic, interactive task. The genesis of this research has been numerous theoretical and practical issues that have arisen during the development of training and standard operating procedures for military RPAS operations. For the current research, a driving simulation was used in conjunction with visual occlusion technology to generate task interruptions. These task interruptions manipulate the demand of the dynamic driving task in ways consistent with interleaving other concurrent dynamic tasks. Multiple converging measures of effect were gathered with the aim of performing both quantitative and qualitative analysis of participants' performance and the cognitive factors relating to their behaviour. The aggregated quantitative analyses served to confirm that the experimental manipulations affected driver performance in the ways predicted. The individual case studies were the focus of the research, which explored factors that affect individual differences in performance, to identify critical factors in selection and training of future military personnel operating in complex and dynamic human-machine environments, and in other challenging like domains.

Developing a model of cognition

The surface level of expertise: Aggregated data on performance

In this section, the aggregated quantitative data on performance are summarised and discussed. Across the different conditions, the visual occlusions were found to have similar effects on the quantitative measures of performance as previous empirical visual occlusion literature has reported (Chen & Milgram, 2011; Senders et al., 1967). These finding show that the manipulations of the independent variables (track difficulty, predictability of visual occlusion, and visual occlusion duration) were having the expected effects on performance.

Easy versus Hard track: Speed

The current study's findings confirmed that, as expected, when the track became more complex and the visual occlusions became unpredictable, average speed decreased. More specifically, when the speed was aggregated across track difficulty, significant differences of up to 11 km/h were recorded from driving on the easy track to the hard track. This finding was also consistent with previous research. For example, Senders et al. (1967) reported that when the roads became more complex and there was less time to inspect the roads between visual occlusions, participants would decrease the speed of the vehicle. The participants in Senders et al.'s experiment had control over visual occlusion and were able to seek visual information when required. While Senders et al. do not report on mean speed for the more complex track, they report that participants on the complex track are not able to drive safely as fast as they can drive on the less complex track. They proposed that this was more a consequence of the distance travelled rather than speed per se and that because there were more curves and uncertainty about the up-coming track, participants required more inspection time to cope. While the participants in the current study did not have control of the visual occlusions and thus could not voluntarily seek further visual information, by lowering the driving speed, less distance was travelled during the visual occlusions and thus the participants had more opportunities to view and process the track features. By reducing speed, this would reduce the task’s perceptual-cognitive processing load, facilitating their ability to maintain and update an accurate mental model of the track in their memory and safely navigate the track using it as a reference.

Predictable versus Unpredictable visual occlusion sequence: Speed

When speed was aggregated across the visual occlusion sequence types, differences of up to 4 km/h were recorded. The impact of unpredictable visual occlusions on speed has not previously been reported, but the decrease in speed confirmed expectations that this manipulation would increase the perceived task demand and affect performance. It appears that in the predictable visual occlusion sequence, participants had a level of understanding of how much of the track they needed to remember to ensure sufficient performance during a visual occlusion. However, given that in the unpredictable visual occlusion sequence participants were not aware of when the visual occlusions would occur or their durations, participants were unable to predict how much of the track they were required to remember.

This is consistent with previous switch cost literature. For example, Meiran (1996) reported that engaging in tasks that have unpredictable onsets are prone to inaccuracies and longer completion times as a consequence of a preparation effect (Monsell, 2003). If individuals were able to prepare themselves for a task before undertaking it they were more inclined to complete the task more quickly and more accurately.

Chen and Milgram (2011) showed that visual inspections times (glance durations) of 0.5 s up to 1.5 s are sufficient to support driving performance for the next 1.5-2.5 s of visual occlusion. However as visual inspection times increase beyond 1.5 s, the visual information can only support approximately 2.5 s of visual occlusion. In these studies, the onset of the visual inspection opportunities were under the control of the participants, allowing them to direct their attention specifically to the information required to maintain driving performance for as long as possible. In the current study, visual inspection times were twice the duration of the upcoming occlusion interval, and performance decrements occurred as occlusion periods increased beyond 1.5-2.5 s of occlusion, consistent with Chen and Milgram's data. While participants in the current study had more than adequate visual inspection time to support driving (with the briefest inspection time of 2 s in the 1 s occlusion condition), they were unsure of when the onset of a visual occlusion would occur, and thus had less information about how to focus visual attention to maintain driving performance. In Chen and Milgram's study, the participant triggered visual inspection opportunities, and thus they could simultaneously tune their visual attention to prioritise visual information guiding their driving task. It seems that most participants in the current study lowered their speed to reduce the distance travelled on the track during visual occlusions, therefore, limiting the distance required to manually navigate while visually occluded. This is consistent with the findings of Senders et al. (1967), who suggested that the major factor leading to increased inspection times of the environment is the distance travelled rather than the speed of the vehicle.

From a cognitive processing and memory point of view, dealing with the unpredictable visual occlusion intervals would increase the cognitive demands of the task, as participants would be required to consistently prepare themselves for the next visual occlusion and be overly vigilant. Chen and Milgram (2011) demonstrated that visual information acquired during shorter glance durations support smaller windows of visual occlusion, and it is an open question as to whether the shorter glance durations trigger different visual information processing strategies or simply result in less information. The unpredictability of visual occlusions in the current study appeared to increase cognitive workload, as the participants did not know what attentional strategies would maximise their capacity to memorise the amount of track required for a possible upcoming occlusion.

Lavie (2005) proposed that increased cognitive workload increases the risk of processing distractors while increased perceptual load facilitates more selective attention. As noted above, in a dynamic driving environment with unpredictable visual occlusions, the distinction between relevant stimuli and distractors becomes more difficult to determine if you do not know how far in advance you need to prepare for. For normal driving with ongoing visual information, the task priority is driving on the track and things that are not on the road are perceptual distractors. It is worth noting that if there is a chance of driving off the track (errors during occlusion) then avoiding obstacles off the track becomes a priority and the so-called perceptual distractors become important visual information. Preparing for a possible occlusion would require increased processing of both on-track and off-track features.

Errors

Findings in this study indicated that there was no significant difference between the total group percentages of errors committed across the different track conditions. On average, approximately one third of errors were committed in each condition. This was contrary to expectations, as it was thought that due to the increasing complexity of the track and unpredictability of the visual occlusions, participants would be more prone to committing errors in the hard track/unpredictable occlusion condition. However, this finding may simply be a reflection of a speed-accuracy trade-off, due to the decreases in speed seen as the conditions became more difficult. The lower average speeds recorded in the difficult track and/or unpredictable visual occlusion sequence mitigated the errors that would have occurred had they maintained similar speeds in the conditions of the easy track and predictable visual occlusion sequence. While the research was designed with a view that the number of errors would be a sensitive metric, the lack of sensitivity observed suggests that there may not have been sufficient difference in track difficulty. Nevertheless, the speed-accuracy trade-off suggests that participants were following the instructions to prioritise safety over maintaining the target speed of 80 km/hr.

A prominent pattern that emerged in the data was the monotonic increase in the average errors committed across visual occlusion intervals. While no significant differences in the percentage of errors committed were identified between being visually occluded for 1 s and 2 s, significant differences were found between these shorter intervals and the longer 3 s and 6 s intervals. Manipulations of task difficulty can be accommodated by adjusting speed for visual occlusions of up to 2–3 s. The increases in the average percentages of errors committed between visual occlusions intervals was considerable, with an increase of 22% of errors committed from being visually occluded for 2-3 s, and 54% increase from 3-6 s. Track difficulty and visual occlusion sequence type appeared to have no effect on the average percentage errors committed across visual occlusion intervals. This suggests that errors were committed on the basis of how long individuals lost visual information of their surrounding, regardless of the difficulty of the track or whether or not they were aware of when the onset of a visual occlusion would occur. In other words, long visual occlusions override all other effects, and the duration of occlusion that can be safely negotiated (around 2-3 s) is consistent with previous research (e.g., Chen & Milgram, 2011).

These findings provide an insight into how long individuals can safely navigate through a dynamic environment in the absence of updated visual information. Errors were not caused by insufficient inspection time prior to a visual occlusion, but rather, by the fact that visual information held prior to the occlusion became out-dated. As previous research has shown, an approximate visual inspection time of 500 ms to 1.5 s was sufficient to support safe driving performance for up to 3 s of visual occlusion irrespective of driving speed (Chen & Milgram, 2011; Sender et al., 1967). The current study's findings are in line with previous research with the severity of performance degradation increasing the longer participants were visually occluded. The current study also supports the idea that attentional strategies for processing visual information to support an upcoming occlusion may need to be triggered selectively, so that uncertainty with respect to the timing of occlusions may leave a participant unprepared, despite having sufficient inspection time available.

The aggregated data suggest that individuals are able to maintain mental models of their dynamic environment accurately for around 2-3 s before the accuracy of their mental models diminish. However, this time window may vary slightly, as, participants' failure to execute steering manoeuvres precisely (psychomotor skill) may contaminate their mental model of the track (cognitive skill). An important question is whether individual differences in psychomotor or cognitive capacity or the types of strategies employed by participants are instrumental in determining which participants can sustain good levels of performance during longer visual occlusion intervals.

Beyond the surface level of expertise: Individual differences in performance

The previous section confirmed that the current study's task manipulations worked as expected and the diversity in performance was within expected ranges based on previous literature. This section discusses the individual quantitative and qualitative data that are the primary interest of the thesis. This section interprets how the demographics of the participants affected their performance based on their previous experience and training in a similar task domain. It will be argued that the evaluation of cognitive and psychomotor skills is critical for understanding performance. Findings from mental workload and behavioural measures will be discussed including the limitations of some of these approaches, particularly in the context of providing methods to assess workload in real-world domains. The benefits of converging quantitative and qualitative measures when evaluating individual performance are also highlighted.

Demographics

Individual differences were observed across participants when evaluating both the percentage of errors across visual occlusion sequence types, and speed across conditions. When evaluating the demographic details of the higher performers, the top three performers had significant advantages in external experience or training over the other participants. Participant 8 was a self-reported car racing video game player who spent up to 8 hours a week playing. Participant 3 and Participant 5 reported undertaking defensive driving courses. It is possible that the additional experience in racing video games for Participant 8 and real-world driving training for Participants 3 and 5 had provided them with more advanced cognitive skills (e.g., strategies; proficient visual scanning of the environment) and psychomotor skills (e.g., efficient steering manoeuvre execution) over the other participants. Specifically, the defensive driving courses focus on maintaining vigilance and planning for the unexpected. Both video games and defensive driving training will also provide opportunities to practise recovering from unusual situations.

By using the methods in the current study, an understanding could be attained as to why these participants performed well and employed the strategies that they did. For example, Participant 8, who had experience in racing video games, reported low NASA-TLX workload scores and was capable of completing the conditions at over 80 km/h, while committing the lowest percentage of errors across visual occlusion intervals. The goal of many racing games is to navigate around the track as quickly and efficiently as possible. Therefore, by having consistently engaged in these types of environments, Participant 8 may have developed the appropriate skill set to execute steering manoeuvres at higher speeds around a track proficiently. Moreover, while the simulator aimed to provide a highly engaging experience for the user, it did not provide high fidelity haptic stimulation that would be present in a real vehicle, and it is reasonable to speculate that Participant 8 developed the skills to operate efficiently within virtual worlds, while participants with limited to no experience of simulators require time to learn the discrepancies between the real-world and the physics engines used in simulated environments.

Participant 3 and 5 self-reported that they had undertaken advanced real-world driving courses. Unlike engaging in racing video games, these driving courses emphasise the requirements to drive safely in the real world, emphasising speed reductions in the speed-accuracy trade-off along with identification of safe driving lines to mitigate errors. This would support the cognitive framework reported by Participant 5, who stressed the importance of lowering speed during visual occlusions to ensure safety. This was also evident in the performance data, especially in harder track conditions where Participant 5 drove at very low speeds compared to other participants. However, this was an effective strategy as this participant recorded the lowest error rate during the 3 second visual occlusions. Therefore, it appears that the additional real-world driving training received provided Participant 5 with a different set of equally effective strategies to Participant 8, and facilitated the lower percentage of errors committed across visual occlusion intervals. These differences also offer an insight into some of the differences in outcome between training in simulators in a virtual world and training for driving in an actual vehicle on public roads in the real world.

Contrary to expectation, Participant 4 was classified as a poor performer despite having previous experience in racing video games. However, Participant 4 revealed that his video game experiences were during his childhood. Therefore, lower performance may be due to the participant's absence from racing video games for a long time and forgetting strategies previously used. As Participant 4 stated that he was in his childhood when he used to play racing video games, the video games he would have played are out-dated as gaming technology graphics and game play has improved. Therefore, the strategies employed by the participant may have been unsuitable. It is also possible that the participant was actually never proficient at racing video games and never learnt successful strategies to achieve high performance and that this lack of success may have influenced his lack of recent video game play.

Cognitive versus psychomotor abilities

The higher performing participants often recorded fewer errors in the 2 s and 3 s visual occlusion intervals compared to the lower participants. The qualitative data assisted in understanding and explaining how and why the higher performing participants were able to perform at a higher level than the lower performing participants. Participants' ability to employ more diverse strategies and to execute the strategies efficiently appeared to be a major factor. Those participants who revealed using more diverse strategies reflected having higher cognitive skills. This was demonstrated as these participants used complementary strategies together that would promote driving performance during visual occlusions. By employing more sophisticated strategies, the participants were able to channel their attentional resources more efficiently which would assist with their ability to avoid processing irrelevant track features. This is consistent with the work of Lavie (1995, 2005), as participants with more skilled cognitive systems were able to employ more sophisticated strategies that promote using cognitive resources efficiently, to assist in regulating in-coming cognitive workload. This, in turn, would keep the overall cognitive workload at a sustainable level and mitigate the likelihood of attending irrelevant information. Therefore, the strategies would most likely aim to load their visual-perceptual systems to a threshold that permits only task-relevant information being attended, and irrelevant information ignored.

Those that are more cognitively skilled would be able to apply strategies that should facilitate in the development of accurate and sophisticated mental models of their track position and any obstacles in close proximity. This combination of employing appropriate strategies that promote the development of sophisticated mental models of their surroundings could direct participants to engage in the task from a more top-down approach rather than bottom- up. While there would still be an interplay between both approaches, if participants were able to transition from reacting to the track environment once inspection time commenced (bottom-up) to predominately anticipating the track with accuracy during visual occlusions (top-down), participants would be able to prepare for up-coming visual occlusions faster and better. For example, the requirement to react to the environment upon inspection time would be minimised for the highly cognitively skilled participants', as the discrepancies between the real world environment and their mental models should be minimal. This would allow them to spend more of their inspection time to employ strategies rather than react to ill-anticipated scenarios (e.g., unforeseen obstacles, large steering corrections). This would ultimately provide these participants with an advantage over those that were not cognitively skilled as the low cognitively skilled participants would need the initial moments of the inspection time to identify their track position and their immediate surroundings before making adjustments for the onset of a following visual occlusion.

The ability to successfully execute a strategy is a reflection of high psychomotor skills. These participants excelled at driving in the simulator and were able to maintain driving lines and make effective steering and speed adjustments around the track. This allowed them to execute steering manoeuvres more implicitly and not have to direct more resources for steering corrections.

Depending on the task, the combination of both cognitive and psychomotor skills should be emphasised by recruiters. For example, severely lacking in one of the skills can cause much larger inconsistencies in performance. An individual with high cognitive skills but poor psychomotor skills will be able to plan and strategise for a task but will risk failure if the task requires a level of psychomotor proficiency. Hence, the inability to perform at a required psychomotor skill level could lead to participants minimising their cognitive skills' potential as they would have to employ more basic strategies to compensate for their short-comings. Therefore, these individuals would be better suited to roles that require direction rather than action (e.g., air traffic controller, sports coach). Conversely, individuals with high psychomotor skills but poor cognitive skills should be able to execute actions with precision but will put the task success rate at risk, if they are unable to strategise or adapt appropriately. These individuals will actually constrain their psychomotor abilities if they fail to initiate strategies that depend on their highly skilled psychomotor skills. This can be seen in sports, such as American Football, where athletes are required to learn extensive game plans, code words and movements. Many athletes are recruited for their athletic prowess that enables them to be technically flawless. However, players often fail because of their inability to learn the game plan and all of its nuances. Hence, despite exhibiting high psychomotor skills and the ability to execute technically demanding movements, poor cognitive skills limit the ability to anticipate the appropriate situation for specific skill execution. This cognitive limitation is sometimes described as a lack of situational awareness (e.g., Endsley, 1995)

The influential three-level construct of Situational Awareness developed by Endsley (1995, 2015a, 2015b) provides a useful descriptive framework for applied research in specific task domains, however similar to Wicken's (2002, 2008) Multiple Resource Theory, it does not provide a sufficiently robust conceptual framework for understanding the cognitive processes and mechanisms that support it. Without an adequate theoretical and conceptual foundation, neither Multiple Resource Theory nor Situational Awareness provides sufficient insight into the implications on cognition and performance of future technology environments. While distributed systems approaches such as those of Stanton, Salmon and colleagues (Stanton et al., 2006; Stanton, Salmon & Walker, 2015) among others (e.g., Chiappe, Rorie, Moran, & Vu, 2012; Chiappe, Strybel, & Vu, 2015; Chiappe, Vu, & Strybel, 2012; Fioratou, Flin, Glavin, & Patey, 2010; Gutwin & Greenberg, 2001; Hollan, Hutchins, & Kirsh, 2000; Hutchins, 1995) may provide more substantive theoretical foundations for future technology systems, current human factors models of distributed cognition and distributed situation awareness are similarly grounded in specified task environments and systems.The qualitative data presented in this thesis demonstrate that quantitative performance metrics alone would not be sensitive enough to distinguish between participants with diverse strategies but poor execution and those with limited strategies but high execution. By pairing the *surface level* performance quantitative data with the qualitative data we are able to develop richer frameworks for evaluating and predicting high performance in training and operations. By employing converging measures, the current study identified that the differences in performance were the outcome of cognitive and psychomotor skills, with the best performers exhibiting high levels of both. Although aggregated group data may set appropriate criteria for recruitment of trainees and the assessment of their performance in relatively generic tasks, individualised performance profiles including qualitative data are recommended in domains requiring individuals to undertake demanding tasks in complex and dynamic environments.

Workload

No meaningful data patterns emerged when evaluating the NASA-TLX workload scores across conditions or between participants. The workload scores were used to identify what participants found to be the most challenging conditions. When contrasting the aggregated workload scores across the different simulated driving conditions, only the HUP condition was found to be significantly different from any of the other simulated driving conditions (the EP and EUP conditions). This suggests that the EP, EUP, and HP conditions were not as cognitively demanding from one another. Further evaluation into individual NASA-TLX scores and their sources of workload assisted in explaining this. While it was expected that participants would rate the EP condition as the easiest, this was not always the case. Six of the nine participants reported workload scores for some conditions that were lower than the workload scores reported for the EP conditions. For the participants that commenced the EP condition first, this may be because they had previously nothing to compare the task to. Another potential factor causing higher workload scores in the EP conditions may be related to practice effects. For example, participants may have become more comfortable with the visual occlusions or the simulator's interface in the later trials, therefore leading to a lower perceived workload in those trials. For participants that undertook the EP condition second, they may have become more aware of their performance errors or may have failed to reach their own performance expectations set based on previous conditions. This may have led to participants reporting workload scores that actually reflected their perceived performance (inability to meet performance goals), rather than the workload they were actually experiencing during the conditions (e.g., they performed poorly, therefore, the task must have been hard). These data highlight the inherent subjectivity and relativity involved in completing the NASA-TLX. It should be emphasised that these workload measures provide ordinal data at best and are not useful for comparisons between participants. As described above, the scores may not even be reliable across multiple experimental conditions, with the interpretation only straightforward in pairwise comparisons of task components or conditions.

The difference in workload between the EUP and HP condition should have indicated whether participants perceived higher workloads as a consequence of the unpredictability of the visual occlusion intervals or the increased psychomotor demands of the track, but no real pattern emerged: neither the EUP nor HP conditions were reported as more demanding in terms of participants' workload. Moreover, there were no clear differences between higher and lower participants in their self-perceived workload demands between the two conditions. This may have been due to practice effects across conditions, or the fact that the workload was very high across all conditions, with the more difficult and unpredictable conditions incurring greater performance decrement due to the inherent task difficulty rather than the cognitive demands per se. It is also possible that participants could not voluntarily allocate more perceptuo-motor attention to the driving task in the EP condition (as in Kahneman, 1974 and Lavie, 1995) and thus were more likely to be distracted by extraneous information and therefore occasionally less-prepared than they could have been for occlusions. As the conditions became more difficult, they would have been able to allocate all their attention to meeting task demands.

Nearly all participants reported the HUP condition caused the highest workload. This was to be expected as this condition imposed the highest combination of cognitive and psychomotor demand. Only participant 1 reported that the HP condition imposed a higher perceived workload than the HUP. Overall, the NASA-

TLX results added little to the understanding of the interplay between expertise and the task demands due to the lack of sensitivity and consistency of the measures.

Regulating arousal

From an analysis of interview data, it was proposed that higher performers with limited strategies used basic psychomotor strategies, and did not report employing a vast range of cognitive strategies. However, these participants emphasised remaining calm during the trials to prevent them from becoming flustered during or after visual occlusions. Participant 1 stated that she would tell herself that it was ok if she crashed, and to keep going with the task. While this would not be ideal for real-world driving situations, the calmness most likely allowed her not to dwell on the mistakes and focus her attention on the ongoing task. This self-regulation of emotional arousal is consistent with attentional resource theory, whereby the participant is conserving cognitive resources by ignoring the previous errors, thereby permitting maximal attentional resources to be applied to the task itself.

This interpretation of behaviour is also consistent with the *Catastrophe model* in sport psychology (Hardy, 1990, 1996). According to this theory, as psychological arousal increases, performance increases. However, as this arousal exceeds a certain threshold that becomes overwhelming for the individual, catastrophic performance degradations occur. While individual differences are likely to influence the threshold level and how much arousal is needed for optimal performance, some participants reported actively aiming to manage their arousal levels by deliberately disregarding the errors committed and focusing on the remainder of the trial.

The catastrophe model also provides insight into the experience of cognitive workload (anticipating and planning for upcoming occlusions) separate from cognitive anxiety. Up to a certain level, it seems that participants can cope with increasing workload without a perception of impending overload. However, at a certain critical level when both track difficulty and occlusion uncertainty increased, most participants appeared to become overwhelmed by the task demands, with a catastrophic drop in performance rather than a graceful degradation.

Masking higher performers as lower performers

Given that the lower performing participants with diverse strategies employed better pairing of strategies than the higher performing participants with limited strategies, the question arose as to why they did not perform as well. It seemed that the lower performing participants with diverse strategies employed a strategy in which they would intentionally commit minor errors (e.g., grinding against the wall) to prevent bigger errors during visual occlusions. By employing this strategy, participants had an accurate reference of their track location and maintained their driving direction (grinding the wall stopped them spinning around or losing orientation as they would if they ran off the track) while visually occluded. For example, Participant 7 said he would grind along the wall during visual occlusions, as when vision returned he would be able to keep navigating around the track. This finding is important for two reasons. This highlights the limitations of evaluating performance based only on quantitative metrics without observation of behaviour. It also highlights the issues in task selection. While the driving task has some level of ecological validity, the settings selected to ensure reasonably consistent task performance (i.e., minimising the impact of the vehicle crashing), allowed for strategies that would have different consequences in the real world task being simulated. If performance were just evaluated on crash statistics, these participants would be categorised as poor performers who were unsuitable for further training in the task. However, the strategy selected could be considered an innovative and successful strategy for the simulator task and required a level of psychomotor skill to execute.

Difficulties with behavioural and biofeedback performance indicators

The current study did not identify significant predictors of future performance decrements through video observation of facial expressions and upper body movement of the driver. It appeared that participants tended to react with facial tension following errors but not in the lead up to them.

The muscle tension data were contaminated with an electronic-noise artefact produced by the occlusion spectacles during the occlusion window, masking the period of greatest interest (during occlusion). It was not possible to filter the artefact without filtering out actual muscle tension data as well. Similar issues with using sEMG with visual occlusion glasses have been experienced by Milgram (personal communication, March 1, 2015). Therefore, no physiological predictors were able to be identified that would indicate when the task was becoming too difficult and an error might be about to occur.

These findings demonstrate some of the difficulties of acquiring clean behavioural and biofeedback data in on-going dynamic environments. It appears that, at least for the task used in this study, individuals tended to respond with facial expressions once an error was committed rather than in the lead up to the error, and therefore facial expressions did not provide good markers for impending cognitive overload. The possibility that facial expressions might also be indicative of near-misses was not explored, although this might be a useful indicator of strategies used to prevent actual errors. In the current study, video analysis of facial expressions was only undertaken in the window around previously identified errors, limited practically by the sheer volume of video data. While motion capture data were considered as a quantitative method of analysing facial expressions, the use of occlusion glasses was not compatible with motion capture technology.

Recording artefacts observed in the current study are also likely to affect biofeedback recordings in dynamic real-world scenarios, especially in high-technology context. Unless biofeedback tools can be developed to only capture the desired data and include real-time data processing, then utilisation of these tools may have limited benefit in current real-world operations.

The benefits of converging measures

The combination of tools used in the current study captured a rich representation of performance that would not have been possible with stand-alone measures. The sequence of analysis undertaken guided the systematic conceptualisation of each participant's performance level. Aggregating the quantitative data permitted the initial confirmation that the independent variable manipulations caused the intended effect. Assessing the quantitative data, at the individual level directed the grouping of higher and lower performing participants. By conducting semi-structured interviews, insights were gained relating to the skill level differences between higher and lower performers, and assisted in interpreting the patterns in the quantitative data. Analysis of video recordings of the participants' performance permitted observation of the psychomotor strategies employed and evaluation of their level of execution; and was thus able to confirm the content in the interviews. Hence, it has only been by converging quantitative and qualitative results that human performance could be properly evaluated.

Summary of findings and implications

This research used a driving simulation test in conjunction with visual occlusion in a novel approach to probe expertise in a task analogous to the parent problem with piloting RPAS, and the associated variation in the task demand. It was found that high performing participants could sustain visual interruption of 2-3 s without a performance decrement while engaging in an immersive dynamic task. While this did not affect error rates adversely, it did affect average speeds, but longer periods of occlusion resulted in increased errors.

As well as performance measures, participants' observable behaviour and utterances were recorded. In addition, physiological responses relating to overt behaviour were gathered with an expectation that variations would be related to the degree of difficulty experienced, but this line of enquiry was not pursued due to a recording artefact. The NASA-TLX workload scales were also analysed but the results were also not very informative. Although used routinely in simulation studies, the utility of this particular test was not confirmed in this study.

Much effort was expended gathering verbal protocols from participants immediately following simulation sessions. A semi-structured technique was used that ensured uniformity across participants while enabling the experimenter to pursue issues of interest mentioned during the interviews. The interviews, in conjunction with performance data were central in identifying the strategies used by each participant, adding meaning to the quantitative performance data of individuals. This is important for evaluating performance in tasks situated in a dynamic environment, as there are often many different ways to achieve a goal, compared with tasks in more static environments (Navarro, Newell, & Schulze, 2016). Ultimately, it was found that higher performers had a more developed and sophisticated understanding of the task and how to complete it, enabling them to develop more advanced strategies to complete the task and execute it with proficiency.

The methodology of this research and the pattern of results offer a model for investigating human performance and cognition in immersive, dynamic, interactive experimental environments. The more individualised approach adopted enabled the elicitation of a richer representation of an individual's ability to complete a challenging task competently. Separating performance characteristics into cognitive and psychomotor ability can assist in both recruitment and training programs for different operations. Identifying individuals' cognitive abilities (e.g., decision making; strategy implementation) can initially assist in assessing whether an individual has the cognitive ability to perform tasks and whether they will benefit from further training. Meanwhile, assessing psychomotor abilities (e.g., manual action execution) can reveal whether the individual will be capable in proficiently executing strategies to achieve future task goals. However, the required ability level for both characteristics is task-dependent and also governed by the available recruitment population, and therefore should be varied accordingly.

The approach used in this study could be used to address real-world problems that arise in training, such as potentially lowering the attrition rate of pilots nearing completion of their training. As this can be costly for trainers and trainees, developing better methods to identify individuals with both psychomotor and cognitive skills is needed for success in such domains. Competency-based training that simply requires trainees to pass performance criteria is therefore not supported by these findings. If trainers in these challenging domains moved away from relying solely on performance metrics and added qualitative evaluation, it is possible that this method could give trainers more insight into a trainee's cognition and attrition rates may be attenuated.

Another related area of work that might benefit from using this broad method of mixed methods research is building better constructive (mathematical) models of humans performing challenging dynamic tasks, such as those encountered in military operations, particularly air operations. The "holy grail" of modelling air combat, for example, has been the idiosyncratic techniques that distinguish exceptional pilots ("A" category) from the rest. If this type of attribute could be better understood and more easily characterised, such models would have a higher predictive value.

It should be acknowledged that during this thesis, other research commenced employing visual occlusions to simulate the alternation of a task, much like the rational for the current study. For example, Kujala, Mäkelä, Kotilainen, and Tokkonen (2015) used visual occlusions in driving tasks as an analogue to interfacing with in-vehicle information systems (IVISs). By employing visual occlusions, those researchers aimed to identify time intervals in which individuals are able to be non-attentive to an on-going task (e.g., driving), maintaining a desired level of performance while engaging in another task (e.g., safe driving).

Future directions and limitations

The current study was the first of three planned studies. Acting as a baseline, this study intended to set temporal parameters that govern one's cognitive capabilities to undertake a second dynamic task without impacting significantly on the primary dynamic task. The second study should aim to investigate the spatiotemporal parameters governing the ability to retrieve information from a briefly-presented text message, and the third study should combine the two dynamic tasks into a single experiment to test predictions regarding the cognitive, behavioural, and performance implications of undertaking two simultaneous dynamic tasks under different task priorities. Furthermore, it is imperative that future research continues to develop rigorous, but practical methods which have sufficient ecological validity to be used for applied work. Lastly, it is hopeful that this thesis will facilitate mixed methods research into being a standard approach for future research in this area.

While the study aimed to employ a dynamic environment, there are many limitations to the use of a simulator. For example, participants' behaviour and performance may have been influenced by the absence of real-world penalty cost for errors. Had a participant been navigating a physical vehicle, human performance and behaviour outputs may have been modified. While it appears that individuals have a 2-3 s time window to interleave a secondary task while undertaking a task in a dynamic environment, the visual occlusions do not require the individual to update their procedural memory in-between visual occlusions. Therefore, future studies planned as part of this program of research seek to identify what other dynamic tasks can be successfully interleaved in 2-3 s intervals without impacting safety and performance on either task. Further research needs to be directed towards determining what task information should be retained when alternating between tasks with the aim of achieving more efficient task switching.

While all participants experienced being visually occluded while driving straight and turning around corners, arguments can be made towards the unequal distribution between participants. While the percentage ratio between participants did not vary in extremes, future studies should look to impose an event-triggered visual occlusion rather than interval-based triggers. While the interval-based triggers were useful to remain consistent across trial times and permit different visual occlusion time durations within trials, the event-trigger visual occlusions would ensure that all participants experienced visual occlusions while undertaking the same events. However, given the dynamic nature of the experiment, event-triggered visual occlusions may lead to larger trial times on the simulator which could promote varied cognitive fatigue levels between participants and effect performance. In other words, higher-performing participants would complete the trials more quickly than lower performing participants and not be required to sustain attention for longer periods of time.

It should be highlighted that the simulated vehicle was a left hand-drive car, while the participants, all from Australia, were right hand-drive orientated. Although the external features of the simulator (e.g., pedals) were set up as a right hand-drive vehicle, this may have influenced some of the poor vehicle positioning during the trials (Saito, Murata, Takayama, & Sato, 2012). Saito et al. (2012) found that when right hand-drive oriented individuals drove the left hand-drive cars in a simulator they had a tendency to cross lanes, suggesting a failure to recognise their vehicle position within the driving lines on the road. However, it is believed that this effect would not dramatically influence the results as participants were not being evaluated on their line positioning. In other words, participants could position their vehicle on the track however they desired. Nevertheless, future driving simulator studies should take this into consideration in order to mitigate this effect.

It should be noted that there is a large amount of literature describing driver distraction (Young, Regan, & Hammer, 2003), and the implications drawn from this body of evidence aims to impose legislative limits to reduce driver distraction (e.g., do not text and drive). In contrast, the aim of the current research takes the opposite direction, seeking to identify the best strategies for performing multiple dynamic tasks simultaneously without compromising task performance or safety. It is clear that this approach will be increasingly relevant in high technology environments of the future both in military operations and normal everyday life.

Conclusion

This program of research was generated by the challenges experienced by those responsible for the development of training of RPAS operators. However, the findings relate not only to this parent problem, but also to other related training domains, particularly in the aviation and military system. The findings have particular relevance to areas of operational research making use of constructive models. While the findings themselves are of primary interest, the methodology also strikes new ground with the quantitative data used as probes for the qualitative analysis that followed. It is to be hoped that this mixed-methods approach will become a standard method for future research in this area.

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Appendices

Appendix A –Ethics Letter of Clearance

SHR Project 2015/311 - Ethics clearance - Inbox

Message

Delete Reply Reply All Forward Move Ru... Junk Unread Categorize Follow Up

SHR Project 2015/311 - Ethics clearance

Astrid Nordmann

Sent: Monday, 11 January 2016 11:42 am
To: Lisa Wise
Cc: RES Ethics; Jason Skues; Lucy Parrington; Luke Crameri

To: Dr Lisa Wise, FHAD

Dear Lisa.

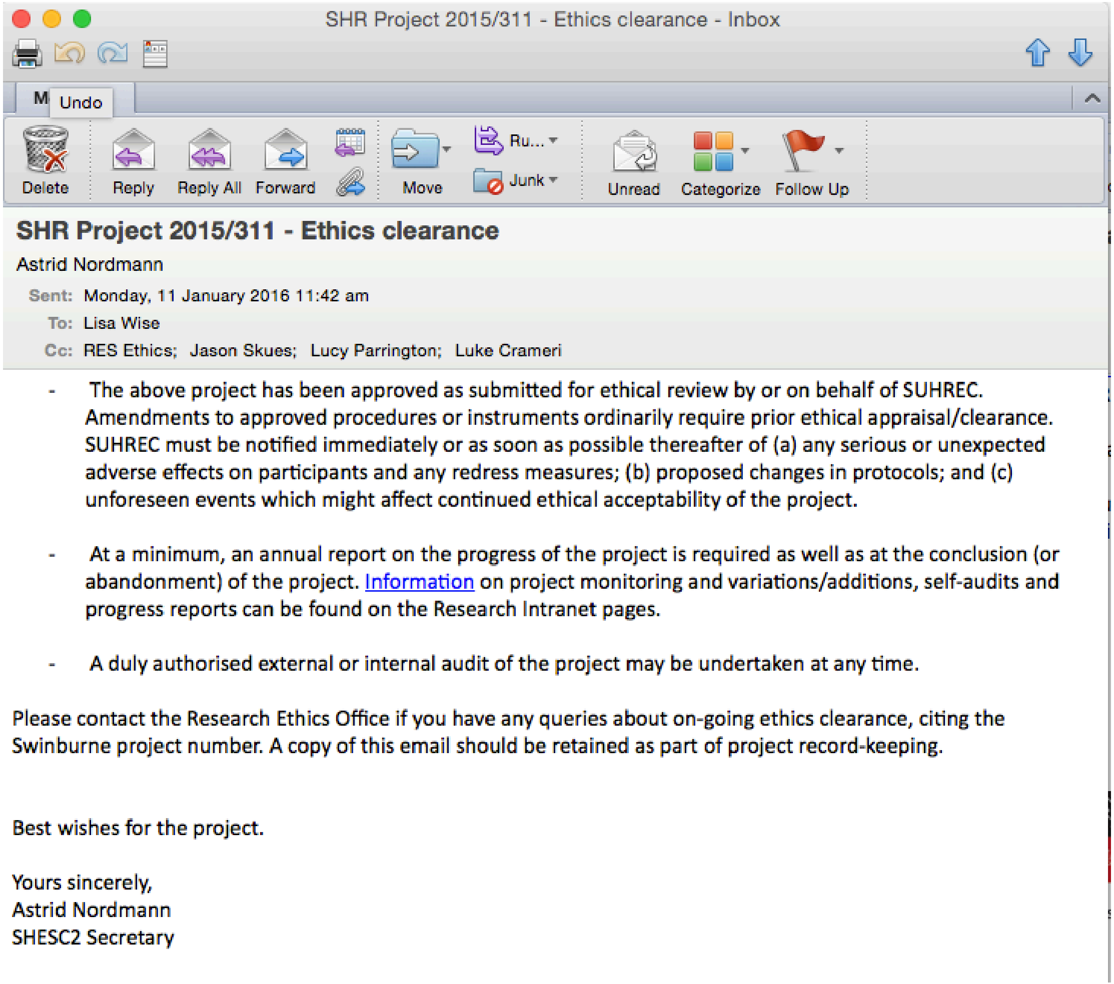
SHR Project 2015/311 – Human behaviour and performance implications in dynamic task alternations
Dr Lisa Wise, Mr Luke Crameri (Student), Dr Jason Skues, Dr Lucy Parrington, Ignacio Bruhn - FHAD
Approved duration: 11-01-2016 to 20-02-2017 [adjusted]

I refer to the ethical review of the above project by a Subcommittee (SHESC2) of Swinburne's Human Research Ethics Committee (SUHREC). Your responses to the review as emailed on 11 January 2016 were put to the Subcommittee delegate for consideration.

I am pleased to advise that, as submitted to date, ethics clearance has been given for the above project to proceed in line with standard on-going ethics clearance conditions outlined below.

- All human research activity undertaken under Swinburne auspices must conform to Swinburne and external regulatory standards, including the *National Statement on Ethical Conduct in Human Research* and with respect to secure data use, retention and disposal.

- The named Swinburne Chief Investigator/Supervisor remains responsible for any personnel appointed to or associated with the project being made aware of ethics clearance conditions, including research and consent procedures or instruments approved. Any change in chief investigator/supervisor requires timely notification and SUHREC endorsement.



SHR Project 2015/311 - Ethics clearance - Inbox

Undo

Delete Reply Reply All Forward Move Ru... Junk Unread Categorize Follow Up

SHR Project 2015/311 - Ethics clearance

Astrid Nordmann

Sent: Monday, 11 January 2016 11:42 am

To: Lisa Wise

Cc: RES Ethics; Jason Skues; Lucy Parrington; Luke Crameri

- The above project has been approved as submitted for ethical review by or on behalf of SUHREC. Amendments to approved procedures or instruments ordinarily require prior ethical appraisal/clearance. SUHREC must be notified immediately or as soon as possible thereafter of (a) any serious or unexpected adverse effects on participants and any redress measures; (b) proposed changes in protocols; and (c) unforeseen events which might affect continued ethical acceptability of the project.

- At a minimum, an annual report on the progress of the project is required as well as at the conclusion (or abandonment) of the project. Information on project monitoring and variations/additions, self-audits and progress reports can be found on the Research Intranet pages.

- A duly authorised external or internal audit of the project may be undertaken at any time.

Please contact the Research Ethics Office if you have any queries about on-going ethics clearance, citing the Swinburne project number. A copy of this email should be retained as part of project record-keeping.

Best wishes for the project.

Yours sincerely,
Astrid Nordmann
SHESC2 Secretary

Appendix B – Consent Sheet

FACULTY OF HEALTH, ARTS AND DESIGN, HAWTHORN

SWINBURNE UNIVERSITY OF TECHNOLOGY

Consent Sheet

PROJECT TITLE: Human Behaviour and Performance Implications in Dynamic Task Alternations

INVESTIGATORS: Mr. Luke Crameri, Masters by Research (Arts) student

Dr. Lisa Wise, Senior Lecturer in Psychology

Dr. Jason Skues Senior Lecturer in Psychology

Mr. Ignacio Bruhn, Research and Technical Support

1. I consent to participate in the project named above. I have been provided a copy of the project consent information statement to which this consent form relates and any questions I have asked have been answered to my satisfaction.

Yes / No

In relation to this project, please circle your response to the following:

2. I agree to allow my participation in the study to include video and picture footage captured web and video camera, and understand that while experimenters may identify me during data analysis, no identifiable data will be published or shared.

Yes / No

3. I agree to allow my participation in the study to include recordings of my muscle activation via a surface electromyogram.

Yes / No

4. I agree to allow my participation in the study to include recordings of my heart rate monitored via the emWave sensor.

Yes / No

5. I agree to have my interviews audio recorded via a portable audio recording device.

Yes / No

6. I confirm that at this time, I am fit to take part in the study and do not have any of the following:

- Am pregnant
- Have recently had surgery that is still in the recovery phase and have not yet returned to normal functioning
- Have a cast and/or injured bones
- Have neck and/or back injuries
- Have high blood pressure
- Have heart beat problems that include structural or functional abnormalities of the heart, or of the blood vessels supplying the heart.

Have skin allergies (e.g. allergic skin reactions to electrode/ Band-Aid placements)

Yes / No

If you have answered "No" to any of the above you will not be eligible to participate in the experiment.

7. I agree to allow my de-identified data to be used in a student thesis, research publications and conference presentations.

Yes / No

8. I agree to allow my de-identified images to be used in a student thesis, research publications and conference presentations.

Yes / No

I acknowledge that:

(a) My participation is voluntary and that I am free to withdraw from the project at any time without explanation;

(b) The Swinburne project is for the purpose of research and not for profit;

(c) any identifiable information about me which is gathered in the course of and as the result of my participating in this project will be (i) collected and retained for the purpose of this project and (ii) accessed and analyzed by the researcher(s) for the purpose of conducting this project;

(d) My anonymity is preserved and I will not be identified in publications or otherwise without my express written consent.

By signing this document I agree to participate in this project.

Name of Participant: **Signature & Date:**

Appendix C – Materials

1. PLATO Spectacles

PLATO spectacles closed (vision occluded)

PLATO spectacles open

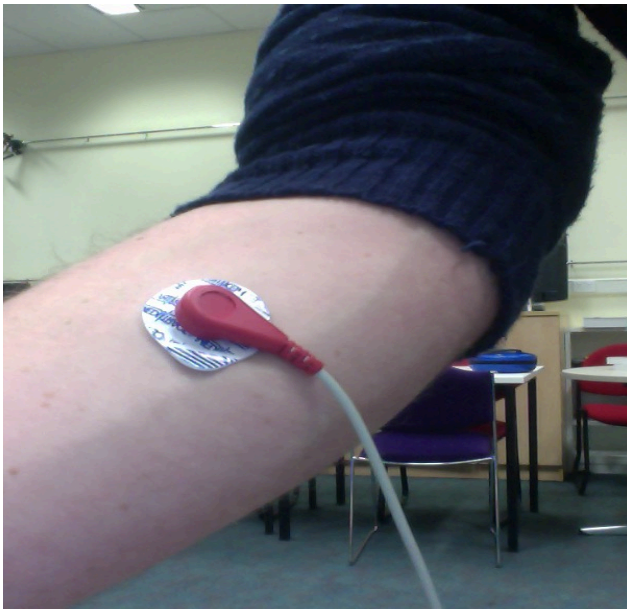
2. CKAS T20 Motion Platform

3. Steering Wheel

4. Web camera

5. Surface Electromyogram

6. Surface electrode placement



7. Cannon Legria HFG10Video Camera

Appendix D – Code for AutoHotKey

```
#NoEnv  ; Recommended for performance and compatibility with future AutoHotkey releases.
; #Warn  ; Enable warnings to assist with detecting common errors.
SendMode Input  ; Recommended for new scripts due to its superior speed and reliability.
SetWorkingDir %A_ScriptDir%  ; Ensures a consistent starting directory.


#InstallKeybdHook ; initalise basic function
#UseHook On ; initialise basic function
SetMouseDelay 0
Coordmode, Mouse, Screen ; initalise basic hardware

$F10:: ;Run As administrator
 MouseClick(0.28,0.7499)  ; Start Powerlab
 MouseClick(0.4580,0.7295) ; Start emWave
 MouseClick(0.7840,0.7495) ; Start Plato

 MouseClick(0.052,0.98)  ; Start rFactor 2
 Sleep, 1000   ; Time it take to open Rfactor 2 from side bar
 SendFancy("F12") ;press F12  ; Start Bandicam
 Sleep, 2000   ; Bandicam loadtime
 MouseClick(0.62,0.72)  ; Start Race

 Sleep, 222000 ; After 3:39 shut down program
 SendFancy("esc")  ; Pause rFactor
 SendFancy("F12") ;press F12  ; End Bandicam
 Send, #d   ; Minimise rFactor
 Sleep, 1000
 MouseClick(0.487,0.7295)  ; End Powerlab
 MouseClick(0.4650,0.7295) ; End emWave
 return

 SendFancy(key) ; Setting up key
{
 Send {%key% down}
 Sleep, 50
 send {%key% up}
 Sleep, 50
}

 MouseClick(x,y)
{
 Mousemove, 6004*x, 1080*y ;screen resolution
 Sleep, 50
 Click, Down
 Sleep, 50
 Click, Up
 Sleep, 50
}

return
```

Appendix E –Difficulties in acquiring biofeedback measures

The following details the materials and procedure employed in attempting to acquire clean biofeedback data during each trial. This is followed by the results we attained and a comparison of the supposed muscle activation acquired during a trial and that of a volunteer in a relaxed state wearing the PLATO spectacles.

Surface electromyogram hardware

A *PowerLab 4/25t* sEMG (ADInstruments, Sydney, Australia) was used to measure participants' muscle contractions during the trials. The use of a sEMG to record muscle contraction in participants was selected given its practicality over the traditional needle-electromyogram (EMG) (Moraes, Cunha, Bezerra, Cunha, & Silva, 2012). The *PowerLab 4/25t* provided an amplification input range of ±20 μ V to ±50 mV, input impedance ~1M Ω , and EMG signals were amplified with a Common Mode Rejection Ratio (CMRR) > 96 dB @50 Hz. It featured one Bio Amp input point that permitted two channels for measurements of isolated muscle contractions. A *Dual Bio Amp/Simulator* (ADInstruments, Sydney, Australia) was connected to the Powerlab 4/25t sEMG to provide two additional differential channels for further simultaneous measurements of isolated muscle contractions. The *Dual Bio Amp/Simulator* was powered via the *Powerlab 4/25t* and mimics its features to acquire muscle contraction data. The *Powerlab 4/25t* and *Dual Bio Amp/Simulator* was connected to the computer via a USB connector.

Connected to each of the Bio Amp inputs on the Powerlab 4/25t and Dual Bio Amp/Simulator was a 5-lead Bio Amp cable. These type of cables have two sets of bipolar electrode sources and a shared ground source. Connected to each lead a disposable AG/AgCl surface electrode (Kendall Medi-Trace Mini 130 Foam ECG Electrodes, Neurotronics, Randwick, NSW, Australia) was attached. These foam surface electrodes have a recording diameter of 10 millimetres and were accompanied by conductive adhesive hydrogel that assisted in secure skin to surface electrode adhesion.

Surface electromyogram software

LabChart 7 (Version 7.3.7, ADInstruments, Sydney, Australia) was the software used with *Powerlab 4/25t* (ADInstruments, Sydney, Australia) to start the data acquisition and analyses. It provided a number of features such as fully customisable simulator control, a number of signal analysis tools and hotkey mapping. *LabChart 7* was set to enable a sampling rate of 1000 Hz per channel and was band pass filtered from 10 to 1000 Hz. A 50 Hz notch and main filters were activated to prevent external noise signals from being recorded during trials (Ekstrom, Soderberg, & Donatelli, 2004; MacDonell & Keir, 2007; Winter, Rau, Kadefors, Broman, & Luca, 1980).

Surface EMG sensor placement

Surface EMG sensors were placed over the top of the upper trapezium area (upper shoulder area) and over the top of the flexor digitorum superficialis muscle (partly responsible for handgrip activation).

The *PowerLab 4/25t* (ADInstruments, Sydney, Australia) was responsible for recording the muscle activation of the left side of the body and *Dual Bio Amp/Simulator* (ADInstruments, Sydney, Australia) was responsible for recording the muscle activation of the right side of the body. Following the guidelines set by Surface Electromyography for Non-Invasive Assessment of Muscles (SENIAM), participants were prepped using alcohol wipes to clean the area of the skin where the electrodes were placed. Earth sensors were placed on the Pisiform bone on the side of both wrists. Two sensors were placed approximately 2 cm apart over the belly of the flexor digitorum superficialis muscle and two sensors were placed approximately 2 cm over the belly of the upper trapezium muscle.

Supposed muscles activation

Activation in the flexor digitorum superficialis muscle and the upper trapezium muscle were recorded and initially assessed via visual inspection of the *LabChart 7* graphs. These graphs depicted a timeline window for each muscle region being recorded. Due to the set times of each visual occlusion during the trials, the aim was to assess muscle activation, before and during each visual occlusion interval. Visual inspections of the data sought to evaluate notable muscle activation patterns during these visual occlusion blocks, and it appeared that there was significant muscle activation during visual occlusions for all the participants for every occlusion. Muscle activation appeared to be elicited on the onset of a visual occlusion and consistently maintain its activation until the visual occlusion ended. However, it was predicted that muscle tension would increase prior to occlusion, particularly in the predictable condition, as the threat of the incoming visual occlusion would cause stress, resulting in heightened muscle tension. Meanwhile muscle tension would dissipate if a catastrophic error (e.g. a crash during occlusion) occurred, as they would no longer be required to worry about committing an error (Lundberg et al., 1994). It was also predicted that muscle tension would increase during harder track conditions for less skilled participants. The apparent muscles activations only and always during visual occlusion did not appear to depict an accurate representation of the participants' muscle activations during the trials (Figure 46: Participant 4's supposed muscle activations in their flexor digitorum superficialis muscle (top) and the upper trapezium muscle (bottom) during the EP condition) and was more likely an artefact generated by the PLATO occlusion spectacles during occlusion.

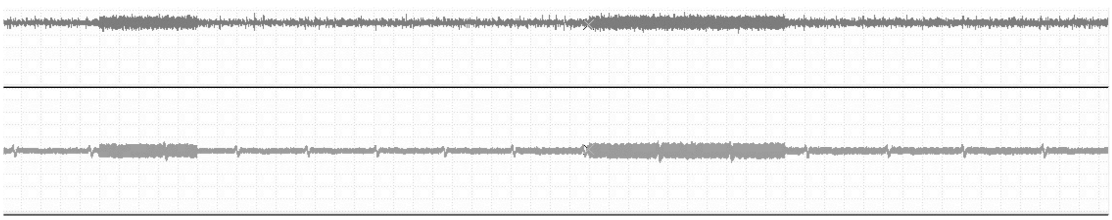


Figure 46. Participant 4's supposed muscle activation in their flexor digitorum superficialis muscle (top) and the upper trapezium muscle (bottom) during the EP condition

To test this hypothesis, surface electrodes were applied over the top of a volunteer's flexor digitorum superficialis muscle and the upper trapezium muscle on the left side of their body, the *PLATO* spectacles were then set to the predictable sequence and recorded the muscle activity while the volunteer maintained a relaxed steady position with their hands lightly gripping the steering wheel. Upon the completion of the visual occlusion sequence, the *Labchart 7* graphs were inspected, and revealed similar muscle activation patterns to the participants. The volunteers's muscle activation (Figure 47: External artefacts captured in the volunteer's relaxed trial) showed an almost identical pattern to the muscle activation of the participants in the trial (Figure 46; 48: Participant 6's supposed muscle activations in their flexor digitorum superficialis muscle (top) and the upper trapezium muscle (bottom) during the EP condition). Therefore, it was concluded that the *PLATO* spectacles were generating the external artefact. It was not possible to filter the artefact as it swamped any potential muscle tension signal and it was confirmed by Milgram (personal communication) that he has not been able to record EMG at the same time as using the occlusion glasses. Hence, further analysis of these data was abandoned. These null data are reported in this thesis to emphasise that the recording of physiological signals and biofeedback data are difficult in live technology-rich dynamic environments due to the possibility of interference and artefacts, and care must be taken in interpreting data in such situations. Failure to report such null findings may lead to other researchers committing the same errors.

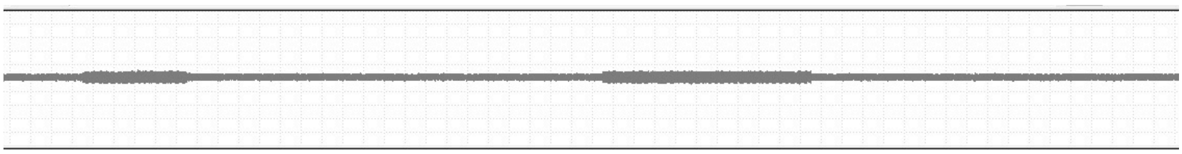


Figure 47. External artefacts captured in the volunteer's relaxed trial.

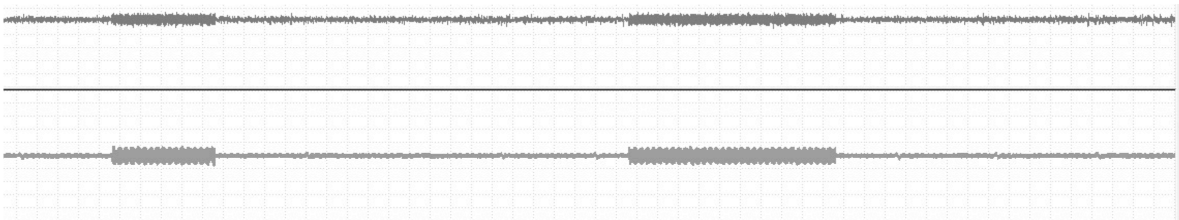


Figure 48. Participant 6's supposed muscle activations in their flexor digitorum superficialis muscle (top) and the upper trapezium muscle (bottom) during the EP condition.

Heart rate variability hardware and software

An *emWave Finger Sensor* (HeartMath, United States) and *emWave pro* (Version 3.5.0.9520, HeartMath, United States) was used to record the heart rate variability (HRV) of participants during trials. The finger sensor is attached by placing the sensor at the tip of a finger. Once connected, the *emWave pro* program can be activated to collect data. The raw data are collected from the pulse, which is then automatically converted into heat rhythms. The *emWave Finger Sensor* was connected via a USB port.

Appendix F– Questionnaire on driving

SWINBURNE UNIVERSITY OF TECHNOLOGY

FACULTY OF HEALTH, ARTS AND DESIGN, HAWTHORN

SWINBURNE UNIVERSITY OF TECHNOLOGY

Driver History

Please fill in the following questions to provide us with an overview of your drive experience. Your provision of information is entirely voluntary and you do not have to complete all questions in order to participate further in the study.

1. AGE (years) ___________________ 2. GENDER: M / F

3. Time holding a driver's license (years)__________________

4. On average, how many hours per week do you drive? ___________________

5. In what road environments do you normally drive (inner city, free way, country roads)?

____

6. Have you undertaken any advanced driving training programs?

YES NO

7. If yes, what ones and how many?

____

8. Do you predominantly drive automatic, manual or both? A / M / B

9. Do you have normal or corrected to normal vision (via contacts or glasses)?

YES NO

10. Do/did you play car racing video games, and if so, on average, how much time a week (hours/minutes)?

____

Appendix G – NASA-TLX

NASA-TLX

Rating Scale Definitions

TITLE	*ENDPOINTS*	*DESCRIPTIONS*
MENTAL DEMAND	LOW/HIGH	How much mental and perceptual activity was required (e.g. thinking deciding, calculating, remembering, looking, searching, etc.)? Was the task easy or demanding; simple or complex; exacting or forgiving?
PHYSICAL DEMAND	LOW/HIGH	How much physical activity was required (e.g. pushing, pulling, turning, controlling, activating, etc.)? Was the task easy or demanding; slow or brisk; slack or strenuous; restful or laborious?
TEMPORAL DEMAND	LOW/HIGH	How much time pressure did you feel due to the the rate or pace at which the tasks or task elements occurred? Was the pace slow and leisurely or rapid and frantic?
PERFORMANCE	GOOD/POOR	How successful do you think you were in accomplishing the goals of the task set by the experimenter (or yourself)? How satisfied were you with your performance in accomplishing these goals?
EFFORT	LOW/HIGH	How hard did you have to work (mentally and physically) to accomplish your level of performance?
FRUSTRATION LEVEL	LOW/HIGH	How insecure, discouraged, irritated, stressed, and annoyed versus secure, gratified, content, relaxed and complacent did you feel during the task?

NASA Task Load Index

Hart and Staveland's NASA Task Load Index (TLX) method assesses work load on five 7-point scales. Increments of high, medium and low estimates for each point result in 21 gradations on the scales.

Name	Task	Date

Mental Demand — How mentally demanding was the task?

Very Low — Very High

Physical Demand — How physically demanding was the task?

Very Low — Very High

Temporal Demand — How hurried or rushed was the pace of the task?

Very Low — Very High

Performance — How successful were you in accomplishing what you were asked to do?

Perfect — Failure

Effort — How hard did you have to work to accomplish your level of performance?

Very Low — Very High

Frustration — How insecure, discouraged, irritated, stressed, and annoyed wereyou?

Very Low — Very High

Appendix H – Consent information statement

FACULTY OF HEALTH, ARTS AND DESIGN, HAWTHORN

SWINBURNE UNIVERSITY OF TECHNOLOGY

Consent Information Statement

PROJECT TITLE: Human Behaviour and Performance Implications in Dynamic Task Alternations

INVESTIGATORS: Mr. Luke Crameri, Masters by Research (Arts) student

Dr. Lisa Wise, Senior Lecturer in Psychology

Dr. Jason Skues Senior Lecturer in Psychology

Mr. Ignacio Bruhn, Research and Technical Support

WHAT IS THE STUDY ABOUT? / WHY IS THE STUDY IMPORTANT?

There has been minimal research investigating how we apply our attention when alternating between tasks/multitasking in a dynamic environment. Dynamic tasks are tasks within an on-going environment that often require perceptual and cognitive processing used in everyday life, such as driving a vehicle. When alternating between tasks/multitasking we will usually experience a loss of vision and sound from non-attended tasks and are required to interchange between the rules and objectives of each task we engage in. Together, these processing demands are the cause of why we may experience difficulty while engaging in task alternating/multitasking situations. This study intends to act as a baseline of task alternations/multitasking situations by investigating the attentional implications of visual occlusions during a dynamic task. This study aims to investigate the cognitive and behavioural implications of vision loss during a dynamic task.

WHAT DOES THE STUDY INVOLVE?

During this study, you will be asked to complete a brief series of questions about your experience driving cars. You will then have non-invasive surface electrodes applied to your skin above your forearms and upper trapezium and wear a pulse monitor around your index finger in order to measure your heart rate variability. Your task is to drive a car simulator, as safely and quickly around two tracks while wearing visually occluding glasses. These are glasses that can occlude vision for different time intervals. Your vision will be occluded in either a predictable or unpredictable sequence. Your behaviour will be recorded using a web camera and driving performance recorded via computer software. Following each trial, you will be asked to complete a questionnaire about how difficult you found the trial and briefly interviewed about the strategies you used during the trial and if there were any notable situations in the drive that you found easy or hard.

Participation in this study is entirely voluntary. You are free to omit any questions you do not wish to answer and you may withdraw from the study at any time without question or explanation.

WHAT IS THE TIME COMMITMENT?

The experiment will be conducted in just one session and the total time needed to participate in the study is expected to be approximately 45-60 minutes.

WILL ALL DATA PROVIDED BE CONFIDENTIAL?

All individual and/or identifying data will be confidential.

Will THERE BE ANY RISKS?

Due to the simulator being attached to a motion platform, there is a possibility that you may feel motion sickness during the experiment. However, this normally occurs through prolonged use of the simulator and experimental trials will last approximately 10 minutes followed by a break. This should minimise your chances to feeling motion sick. If you do feel motion sickness during the experiment, you are free to stop immediately and withdraw from the study.

HOW WILL THE DATA BE USED?

Your data, alongside other participant data will be analyzed as anonymous individual and grouped data. Findings from this project may be published in academic journals or presented at research forums or conferences. Although the results of the study may later be published, there will be no way to attach you personally to your responses or task performance.

ADDITIONAL QUESTIONS ABOUT THE STUDY

If you have any questions regarding the project at any stage, please contact the investigators:

Mr. Luke Crameri

Email: lcrameri@swin.edu.au

Dr. Jason Skues

Email: jskues@swin.edu.au

Dr Lisa Wise

Email: lwise@swin.edu.au

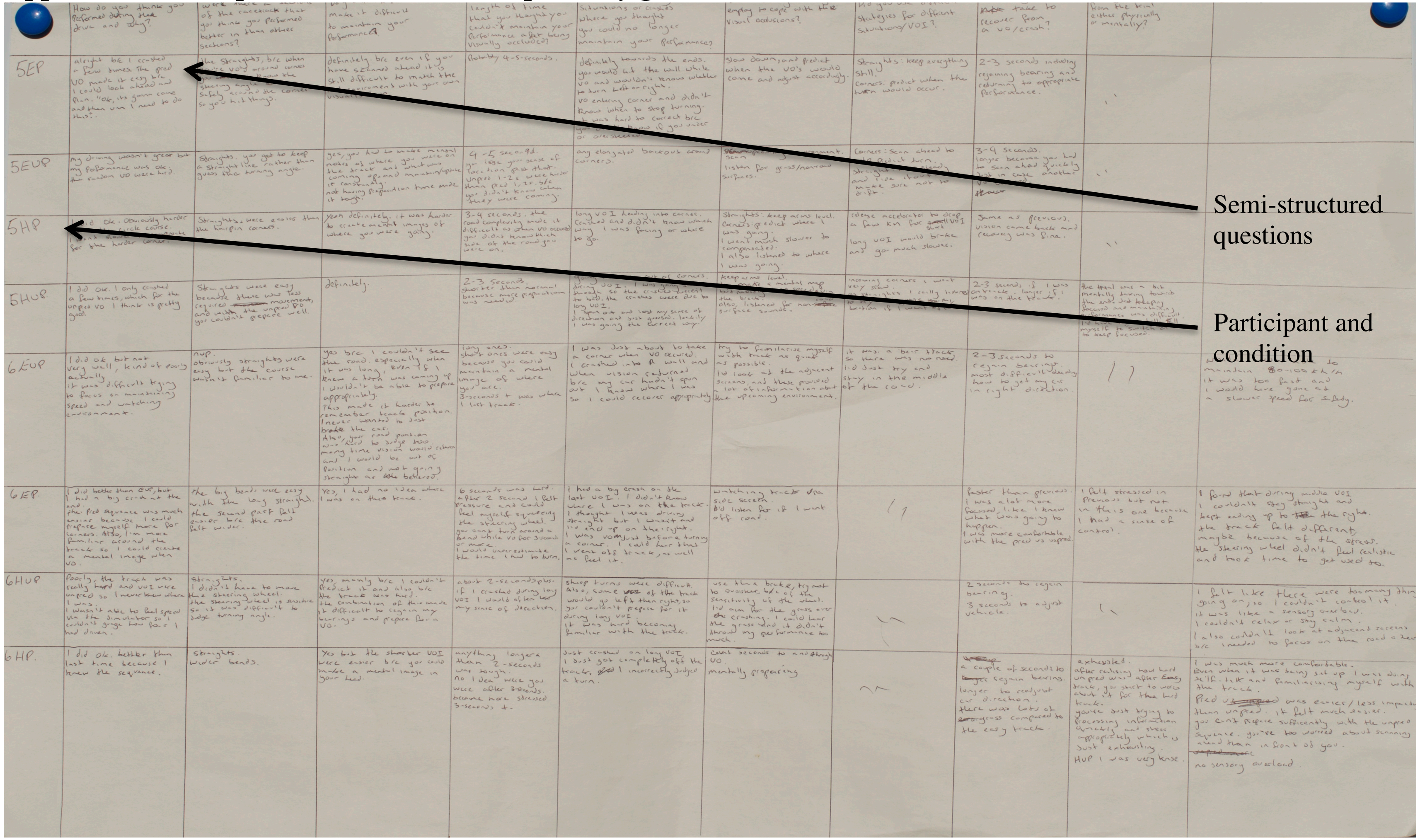
This project has been approved by or on behalf of Swinburne's Human Research Ethics Committee (SUHREC) in line with the *National Statement on Ethical Conduct in*

Research Involving Humans. If you have any concerns or complaints about the conduct of this project, you can contact:

Research Ethics Officer, Swinburne Research (H68),

Swinburne University of Technology, P O Box 218, HAWTHORN VIC 3122. Ph. (03) 9214 521

Appendix I –Example of non-numerical reporatory grids format



Appendix J - Observation Template, adaptation from Stanton et al. (2013)

Time (min)	Occlusion (s)	EP Event	EP Observed behaviour	EP Context
0.05	1			
0.08	1			
0.11	1			
0.14	1			
0.17	1			
0.2	1			
0.23	1			
0.26	1			
0.29	1			
0.32	1			
0.35	1			
0.38	1			
0.41	1			
0.44	1			
0.47	1			
0.5	1			
0.53	1			
0.56	1			
1.01	2			
1.07	2			
1.13	2			
1.19	2			
1.25	2			
1.31	2			
1.37	2			
1.43	2			
1.49	2			
1.57	3			
2.06	3			
2.15	3			
2.24	3			
2.33	3			
2.42	3			
2.57	6			
3.15	6			
3.33	6			

Time (min)	Occlusion (s)	EUP Event	EUP Observed behaviour	EUP Context
0.09	3			
0.24	6			
0.34	2			
0.38	1			
0.45	3			
0.5	1			
0.55	2			
1.03	3			
1.18	6			
1.28	2			
1.32	1			
1.39	3			
1.44	1			
1.49	2			
1.57	3			
2.12	6			
2.22	2			
2.26	1			
2.33	3			
2.38	1			
2.43	2			
2.51	3			
3.06	6			
3.15	2			
3.19	1			
3.26	3			
3.31	1			
3.36	2			

NB: Observation templates have been adjusted to fit page format.

'Event' refers to the driving situation where the behaviour was observed.

'Observable behaviour' refers to the behaviour (e.g., Facial tension, postural realignment) elicited by the participants prior to an error being committed.

Context refers to the student researchers interpretations of the event and behaviour.

Appendix K – Intended participant sample size on ethics application

SECTION C: PARTICIPANT DETAILS

C1 PARTICIPANT DETAILS

The composition of the participant group may, in some circumstances, distort and invalidate an outcome, and risks may arise through the composition of the participant group.

How many individual participants will be involved? (*Number/number ranges for which approval is sought*)

Males: 15 Females: 15 Total participants 30

Over what range of ages?

From (youngest): 18 To (Oldest): N/A

If there is a gender or age imbalance in the number of participants please explain why.

Since this is an exploratory study employing a mixed methods, the literature has provided no consensus on a required minimum sample size. Guest, Bunce and Johnson (2006) suggest that when conducting interviews, 12 or more participants should be interviewed in order to maximise the chances of establishing meaningful codes and useful interpretations. Moreover, numerous studies employing quantitative methods via the use of simulators use between 12-32 participants to find statistically significant results (Brookhuis & Waard, 2010; Dijksterhuis, Brookhuis & Waard, 2011; Gibbons, Mullen, Weaver, Reguly & Be´dard, 2014; Young, Mahfound, Walker, Jenkins & Stanton, 2008).

Therefore, consistent with research that has been published in leading peer-reviewed journals in this discipline area, the current study will aim to recruit 30 participants in order to maximise chances of establishing meaningful codes and useful interpretations through interviews, as well as to investigate patterns in the quantitative data.