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Hysteresis Effects In Driving

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HYSTERESIS EFFECTS IN DRIVING

by

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ABSTRACT

This dissertation presents two studies examining the interaction between workload history and driver mental workload. The first experiment focuses on testing for the presence of a hysteresis effect in the driving task. The second experiment examines the proposition that cueing impending periods of higher task demand can reduce the impact of any such potential hysteresis effects. Thirty-two licensed drivers served as participants and all served in both studies. Using the directions provided by a Heads-Up-Display navigation system, participants followed a pre-set route in the simulated environment. At specified points within the drive, the navigation system would purposefully fail which required drivers to relay a ten digit alphanumeric error code to a remote operator in order to reset the system. Results indicated that this increase in task demand from the navigation system's failure leads to a significant increase in perceived mental workload as compared to pre-failure periods. This increase in driver mental workload was not significantly reduced by the time the drive ended, indicating the presence of a hysteresis effect. In the second experiment, the navigation system provided a completely reliable visual warning before failure. Results indicate that cueing had neither an effect on perceived mental workload, nor any ameliorating effect on the hysteretic type effect seen in mental workload recovery. The conclusion of these findings being that the overall safety and efficiency of the surface transportation system would likely improve by designs which accommodate the periods immediately following a reduction in stress. Whether from leaving high demand areas such as work zones or in the period immediately after using a in-car information device such as a GPS or a cell phone, these post-high workload periods are associated with increased variability in driver inputs and levels of mental workload.

For my friends and family,

I am nothing without their love and support.

ACKNOWLEDGMENTS

This work, and my education, would not be possible without the efforts and encouragement of some wonderful individuals. To Drs. Hancock, Mouloua, Szalma, and Edwards: thank you for encouraging me to think. To Dr. Tal Oron-Gilad, thank you for your constant insight and guidance.

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LIST OF ABBREVIATIONS

ACT-R	Adaptive Control of Thought- Rational
DCQ	Driver Coping Questionnaire
DSI	Driver Stress Inventory
FARS	Fatality Analysis Reporting System
GPS	Global Positioning System
HUD	Heads-Up-Display
IRB	Institutional Review Board
MRT	Multiple Resource Theory
NASA	National Aeronautics and Space Administration
NHTSA	National Highway Traffic Safety Administration
SSQ	Simulator Sickness Questionnaire
SWAT	Subjective Workload Analysis Technique
S-SWAT	Simplified Subjective Workload Analysis Technique
TLX	Task Load Index

CHAPTER ONE: INTRODUCTION

Mental workload is a concept that has been studied in many operational domains, in the context of both applied and theoretical investigations (Moray, 1979; Gopher & Donchin, 1986; Kantowitz, 1987; Hancock & Meshkati, 1988). Although the examination of mental workload within the driving domain has been predicted upon both the continuous nature of driving and the extreme degree of variability encountered in seemingly "normal" driving (Fuller & Santos, 2002), one area in which driver mental workload research is comparably sparse is in workload transitions (Huey & Wickens, 1993). This relative lack of attention to these frequent transitions involved in driver mental workload has immediate practical implications for the motoring public in terms of the number of accidents, financial savings, and highway efficiency (Evans, 2004).

The concept of mental workload itself began to gain importance in the middle part of the previous century with early theories of attention and human capacity limitations such as that proposed by Broadbent (1958). Broadbent himself offered a model of attention with filtered information being manipulated and used by channels with limited capacity. Early understanding of mental workload may be viewed as the inverse of the capacity within such a system (Kantowitz, 1987). Mental workload represents the amount of loading on the human as an operator. Also key to this relationship between the concept of mental workload and spare capacity within the operator is the idea of task demand (Kahneman, 1973). Task demand may be viewed as the requirements which the operator's task is placing upon the operator at any singular moment in time (Kantowitz, 1987). Demand may also be defined as the goal which must be attained through performance on the task (DeWaard, 1996). Therefore, the major aspects which we must examine in order to determine workload are at what level the operator's capacity is being tapped; and by what level of demand from the task.

One extension of the research being performed in mental workload evaluation is the hysteresis effect. Defined as performance deteriorations during the transition from high demand levels to lower demand levels (Farrell, 1999), the hysteresis effect may be demonstrated in a variety of tasks. Early researchers focused on simple shadowing and memory-based tasks (Cumming & Croft, 1968), while later the effect was demonstrated in the more complex tracking environments which typified the work of Pilots and the Air Traffic Controllers (Hancock, Williams, Manning, & Miyake, 1995; Smolensky, 1990). Although the hysteresis effect has been demonstrated in these experimental tasks and settings, the effect has yet to be demonstrated or explained within the driving domain.

Perhaps the only instance of the effect being described in driving research is the study reported by Chamberlain (1968), who noted the difference in accident rates for vehicles leaving versus entering an intersection. Although the high demand of entering an intersection (with the accompanying estimations required, such as gap acceptance, see Morgan & Hancock, 2008) was reduced, accident rates were greater upon exiting the intersection. This real-world epidemiological evidence gives credence to the idea of hysteresis in on-road driving, but as yet no such effect has been demonstrated within realms of experimental control. It is therefore the purpose of this dissertation to examine whether or not a hysteresis performance/task demand interaction effect may be observed in the driving simulation, and if so, by which hypothesized mechanism such effect is driven.

The impact of such an effect has the potential to positively affect the driver/vehicle/roadway system in terms of safety by helping us better understand how the driver's own attentional capacities are moderated by workload history (see also Shinar, 1978). Although the driver's individual characteristics and perceptual abilities are constantly monitoring the environment and the automobile's own display systems, increases in driver workload may eventually manifest as a failure (in some form of collision or accident). Besides the more proximal impact of workload history and hysteresis on safety, there exists the possibility to enhance driver education and training. Although driving is a skill in which most of the adult population of any developed country has already established abilities in (Hancock & Scallen, 1999), the situations and scenarios encountered by drivers are constantly changing and requiring exposure to maintain the driver's abilities and knowledge (Groeger, 2000). However, workload history may present interference in the learning or maintenance of such skills. The possibility of training to help ameliorate any hysteresis effects present has the distinct possibility of increasing the effectiveness and efficiency of all driver training.

The exploration of the hysteresis effect, in the form of workload history, has the potential to be an informative area within the driving domain. The proposed experiments present a course which will demonstrate if such an effect is present in a common driving task, and if so to what degree it may be offset through cueing. Additionally, the impacts of hysteresis on driver performance are examined. These experiments seek to provide an overall view of the hysteresis effect within driving, and suggest courses of future research in driver mental workload and driver safety.

CHAPTER TWO: REVIEW OF LITERATURE

Information Processing

From the birth of cognitive psychology, attempts were made to generate a both useful and theoretically valid analogy for the workings of the mind. One of the more commonly used metaphors to emerge from this period was that of the human as a computer, or information processor (Shannon, 1948). This, and the Information Processing domain that arose, proved to be a robust metaphor for the explanation of human behavior and reactions for years to come. Information Processing refers to the processes within the person which allow for the intake, manipulation, and output of information relevant to a task within their environment, much as a computer takes input from the user, manipulates it, and produces some output. These theories also attempt to account for the limits of the human in terms of task performance which was noted by researchers of the time (Miller, 1956).

Over time, multiple theories have been proposed to describe or to quantify in practice the operations of human information processing system. One of the earliest was presented by Broadbent (1958) whose filter theory attempted to explain the phenomena of how some information seems to pass through to consciousness and other discrete pieces of information are filtered out. This is accomplished in Broadbent's model by having information filtering occur before information processing. Attention serves as a selective channel which allows only one discrete stream of information to enter short term memory and be processed.

Another theory of derived from Broadbent's early work was that of Treisman (1960, 1964), who pointed out many pragmatic issues and concerns with Broadbent's (single) filter theory such as evidence suggesting that the meaning of information could affect processing.

Using tasks similar to those used by Broadbent and his predecessors, Treisman found that people were able to attend to certain aspects of multiple channels of information. Broadbent's early selection single filter theory could not adequately explain these findings. Treisman's resulting model suggested that filtering occurs after the information had been attended to. Recent neuropsychological research has provided stronger support for attenuation type theories of attention (summarized in Driver, 2001).

Triesman's theory was expanded by Deutsch and Deutsch (1963) and Norman (1968), resulting in models of attention wherein almost all ambient information is processed, and filtering occurs by attending only to pertinent stimuli. Such pertinent information can include such things as personally or professionally relevant information. Hence, a more robust explanation for the "cocktail party effect" first noted by Cherry (1953). Even though such models of attention and information processing did describe the limited nature of human abilities, they only approached the matter in an implicit nature. One of the first models to explicitly describe limited capacities in the human information processor was Knowles (1963), who describe attention as a pool of attentional resource reserves. Knowles's model is unique for being one of the first such models able to veridically describe dual-task processing; this conceptualization allowed for distributed resources and the ideas of multiple, and separate, capacities which evolved from it.

Multiple Capacities and Resources

Kahneman (1973) extended the idea of attentional resources by stating that a single resource pool existed which allows for multiple tasks to share the same resources. This was later refined by researchers such as Navon and Gopher (1979) and Wickens (1980) to include task-specific pools of attention. Navon and Gopher's conceptualization of resource pools assumed that dual tasks were processed in a parallel fashion. This allowed for two tasks not requiring the same cognitive capacities to be completed in a parallel, simultaneous, fashion. Wickens's implementation of the theory better allowed for explanations of dual task performance when varying sensory modalities are in use, such as performance two auditory tasks versus an auditory task with a visual task (See Figure 1).

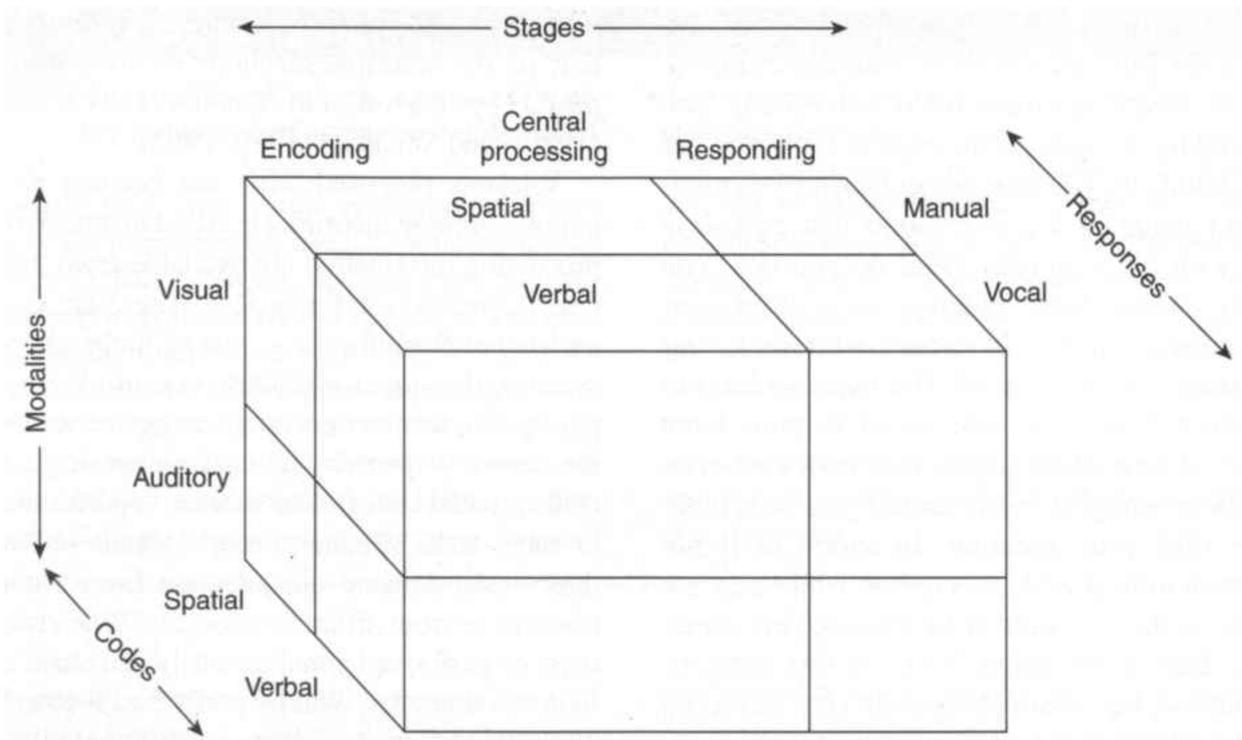

Figure 1. Wickens's Multiple Resource Theory. (Wickens, 1980)

Later refinements of the Multiple Resource Theory of attentional processes (Wickens, 2002), viewed attention as part of an overall finite Multiple Resource Theory. This MRT system differentiates between types of input information (auditory, visual) and response modality (verbal, manual). Thus, the demand on a system, i.e. the interference, is in part modulated by the relationship between the task and response modality. However, the modalities and task difficulty are not the only moderating factors. For instance, such systems may be regulated by one's own emotional states and expectations regarding the scenario (Hancock, Szalma, & Oron-Gilad, 2005). These moderating factors within the model lead to limits in the human's capacities, especially in response to such continuous control, variable demand, tasks like driving.

Limited Mental Resources and Driving

This produces the conclusion that although information processing abilities are limited and often divided, the functional limits of human capacities are rarely encountered and even more rarely exceeded. Thus, the question changes from being how driver performance is affected at the limits to how the driving performance of the human is affected by the dynamic nature of the individual task loadings which are present. The driver is not just engaged in control of an automobile, but frequently in navigation, signal detection, communication, and several other tasks also which impart some degree of stress on the driver (Ward, Hancock, Ganey, Mouloua, & Szalma, 2003). As these stressors are modulated, either by conscious choice on the part of the driver or by the environment, the driver's performance on the primary task of safely routing the automobile is likely to be affected (Verway, 1993). This, along with the theories expressing the discrete and sparing nature of attentional resources in relation to the dynamic and variable tasks associated with driving accords directly with the idea of satisficing proposed by Simon (1969).

Simon's hypothesis advances the notion that individuals perform at a level well enough to avoid collision but not at their maximal level of performance which may well exhaust the driver's cognitive capacities and present subsequent risk of vigilance decrement type failures of detection (Hancock & Scallen, 1999). In fact, other studies have demonstrated that the information which humans seek to better inform their decision making process may not always be necessary (that is, that small samples of information may produce above threshold contingencies in which the benefits to satisficing outweighs the disadvantage of increased false alarms (and see Fiedler & Kareev, 2006). This has also been demonstrated by Fu and Gray

(2006), who modeled a satisficing process within the ACT-R (Adaptive Control of Thought – Rational; Anderson, Bothell, Byrne, Douglass, Lebiere, & Qin, 2004) programming language and found that the tradeoff between the cost and utility of increased information tends to produce a consistently “good” level of performance.

Satisficing provides an interesting concept which complements hysteresis theory. One of the major theories proposed to explain the mechanism by which hysteresis occurs is the perseverance of expectations regarding workload (Cumming & Croft, 1973). The operator, according to Cumming and Croft’s hypothesis, continues to operate under the assumption of continuing the immediately preceding level of task loading. This results in a reduced level of performance as the operator persists with a non-optimal strategy for the task. Viewing this hypothesis though the concept of satisficing leads to the conclusion that the operator is attempting to perform at a satisficed level in order to continue their level of performance on multiple tasks. In this manner, satisficing may be viewed as a special state case of workload history and transitioning.

Stress and Driving

A multitude of variables exert an influence over task demand, and thus the perceived workload of the driver. One of the most predominant is the condition of the driver, in terms of level of arousal, driver training, and prior experience (Fuller & Santos, 2002). The driver operates a vehicle which provides its own sources of demand such as control difficulty and instrumentation features. The driving environment also provides sources of demand (Senders, Kristofferson, Levison, Dietrich, & Ward, 1967). Among these are factors which drivers encounter during daily commutes such as speed, visibility, road markings and signals, and road features such as curves and turns. The presence of other drivers traveling on the road also interacts with these variables. Of these factors, the driver has the ability to exert some control over their own status and that of their vehicle. To a lesser extent, the driver can select which times of day to drive and on what category of road. However, other drivers and the unknowns encountered on a roadway, which may present perhaps the greatest sources of task demand, are not under the driver's control.

Ecological Psychology and Driving

Gibson and Crooks (1938) introduced the concept of a field of safe travel to surface transportation research. In the Gibson and Crooks paradigm drivers operate a vehicle in spatial field and react to objects which intrude upon the immediately perceived safe area. This area which may be directly and safely traversed is the field of safe travel. Objects intruding or otherwise affecting the field have a negative valence, or subtract from the field. This idea has allowed for the assessment of driver behavior in terms of the relationship between the driver, the vehicle, and the environment. This paradigm also provides a useful way in which to examine driver reactions using driving simulators which primarily rely upon the visual sensory channel (and see Denton, 1966). The Gibson and Crooks theory allows for a driver to adjust an envelope of space and time through which he or she will be immediately traveling for any potential hazard identified. Thus, the paradigm of a field of safe travel provides a robust framework from which to examine obstacle avoidance, driver estimation, and emergency responses.

The idea of a field of safe travel is unique in that it allows for the selective attention to stimuli within the environment. When drivers are processing information in active (dynamic) situations, there is no such thing as a discrete stimulus. Gibson (1950) eloquently summarized this idea as a *flowing array of stimulus energy*. This flowing array is not any one individual stimulus, but stimuli in relation to other stimuli and distracters, all in relation to the driver's own motion through the environment. Just as a common criticism of laboratory studies is that a static observer in front of stimuli is of questionable ecological validity, one must view what the driver perceives and processes as an active, continuous, stream of information instead of discrete packets presented to a passive observer.

Models such as Sheridan's Control Theory Framework of driving (Sheridan, 2004) implies that the driver experiences a zone of situation awareness surrounding his or her vehicle. This idea may be viewed as an evolution of Gibson and Crook's (1938) field of safe travel in that both provide for some area of immediate perception on the driver's part which delimits the spatial areas where the driver may safety travel. However, Sheridan expands on the field of safe travel concept by providing a model of the factors (see Figure 2) which contribute to the field, or in this case, the zone.

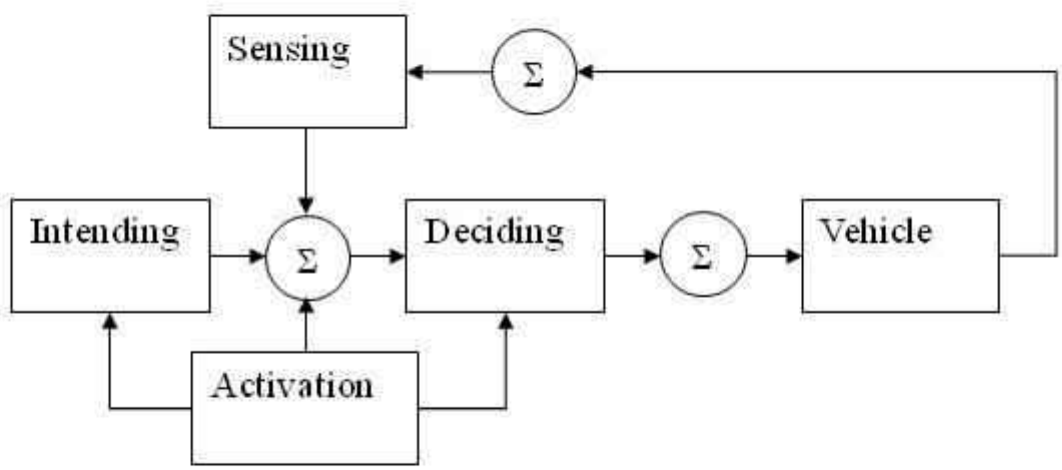

Figure 2. Sheridan's Control Theory Framework of Driver Behavior. For clarity of the model, the disturbances for each factor and the sensory/deciding secondary motor loop have been excluded from this representation. Adapted from Sheridan (2004).

The Sheridan model includes five factors which drive the model: Sensing, Intending, Activation, Deciding, and the Vehicle. Sensing includes the actual state of both the vehicle and environment, Intending is the goal of the driver, Activation is the motivational forces within the person, Deciding is a response to the aforementioned factors (Sensing, Intending, and Activation), and finally Vehicle, which describes the vehicle's state in relation to the operating environment. These factors are assumed to be both mutually exclusive and comprehensive for the purpose of explaining driver behavior from a control standpoint. From an ecological psychology perspective, this theory helps enumerate the factors which influence both the driver's own decisions regarding the spatial envelope surrounding the vehicle as well as the future direction (field of safe travel, or zone of situation awareness) in which the vehicle will be sent.

Driver Limited Capacities and Attentional Control

To successfully operate an automobile drivers must engage in a sampling of the environment for critical control cues (Senders, Kristofferson, Levison, Dietrich, & Ward, 1967). Most often, these are logical and predictable inferences drawn from known and well-learned circumstances. Occasionally such demands are sudden, urgent, and unpredictable, as well as source of very strong threat. Each of these event sequences, both ordinary and exceptional, require the driver to engage in a spectrum of estimations as to what is currently happening in their driving environment and what is liable to happen in the immediate future. The model of driving proposed by Senders et al. (1967) is one of sampling information from the roadway over time, with the driver's level of uncertainty regarding the road and potential sources of threat on the road increasing until a new sample of information is collected.

Their conceptualization of driving treats the driver as an information processor and the roadway as an information source, with components such as curvature of the roadway and other traffic increasing the amount (bits) of information contained. One could view the function generated by this model as time plotted against driver uncertainty, with the level of uncertainty reaching an asymptotic peak at which point the driver would resample the roadway. Bounding the time between samples is the roadway bandwidth and the driver's own capacities, which may be limited or intruded upon by other competing sources of information. Thus, driving becomes a task dictated by human information processing and the limited capacities which come along with it. This, and the limits of the driver's own focused attention, is what Senders and colleagues conceptualized as leading to accidents and other driving infractions.

Driver Distraction

Another source of cognitive loading in the driving task is distraction. Driver distraction is possible due to a multitude of sources, however many of these sources are under the direct control of the driver (Summala, 2002). Among these sources are in-vehicle entertainment from audio and video players, navigation, and communications devices. These sources have been found to be a contributor in a number of traffic accidents (Goodman, Bents, Tijerina, Wierwille, Lerner, & Benel, 1997). Empirical investigations of the impact of such devices have found that they present a consistently high load on the driver and in turn raise the likelihood of accidents due to driver distraction (McKnight & McKnight, 1993; Jerome, Ganey, Mouloua, & Hancock, 2002; Liu & Lee, 2006; Hancock, Mouloua, & Senders, 2007).

These devices may seem innocuous alone, but seem to interact with the demands posed by the driving task to produce a source of risk (Hornberry, Anderson, Regan, Triggs, & Brown, 2006). Hornberry and colleagues demonstrated this by manipulating distraction in a simulated driving task. They had participants use either an in-vehicle entertainment system or hands-free phone while varying the roadway complexity (measured in terms of visual clutter). They found that regardless of roadway complexity (the driving environment), driver performance was degraded by the use of both distracters. This leads to questions regarding how drivers handle such sources of stress while driving.

Fuller (2005) argued that in contrast to earlier theories of driving safety which proposed that individual drivers are striving to maintain a constant level of anxiety (Taylor, 1964) or likelihood of collision (Wilde, 1982), drivers attempt to maintain a set level of task difficulty. Fuller's conceptualization of task difficulty homeostasis proposes that task difficulty is a relationship between task demand and driver capabilities, and that this balance is most prominently manifested in terms of speed choice. Under normal everyday driving conditions driver capabilities exceed the task demand, resulting in safe control of the vehicle. In situations where task demand exceeds capabilities, safe control is lost and the result is either collision, compensation by other drivers, or what Fuller terms a lucky escape, which may be better understood as a near-miss high collision likelihood scenario (see Figure 3). However, testing of such a model would prove difficult in the large numbers of variables required to be under control at any point in time, leaving this a helpful lens for understanding driving safety rather than an explanatory tool.

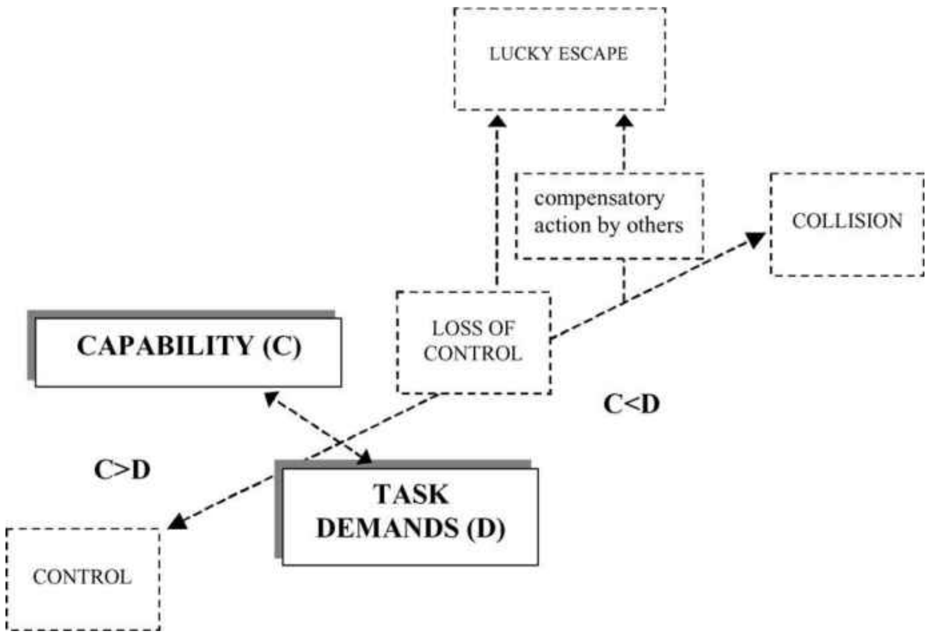

Figure 3. Outcomes of the dynamic interface between task demand and capability (Fuller, 2005).

Heads Up Displays

One aspect of modern vehicles which may lead to an increase in driver distraction are Heads Up Displays, or HUDs, which are successfully deployed in a number of applications. These have included military and civilian displays. Much of the military and civilian oriented research into HUD applications have focused on flight for obvious reasons: pilots are often presented with a multitude of information which must be processed in an extremely time sensitive manner. This aviation research has demonstrated that pilots tend to cognitively tunnel attention on HUDs,providing a figure:ground relationship between the display and the flight environment (Jarmasz, Herdman, & Johnnsdottir, 2005). Beyond this clear relationship between display and background, certain implementations of HUDs may lead to more increased and more accurate performance on tasks dependant on HUD-presented information, such as landing approaches in flight (Goteman, Smith, & Dekker, 2007).

Although drivers' subjective reports often describe HUDs as ineffective, measurable differences in performance may be obtained when comparing HUDs to either traditional gauges or Heads Down Displays (Sojourner & Antin, 1990). In-vehicle displays such as HUDs may be used to facilitate compliance with regulatory devices such as traffic control devices, particularly in high demand situations such as intersections (Caird, Chisholm, & Lockhart, 2008). These performance benefits also extend to the use of automotive HUDs as demand mitigating devices when measured in terms of driver performance; with drivers using HUDs demonstrating less steering wheel actuation, less lane deviation, and faster reaction time to roadway objects (Liu, 2003).

Many commercial and consumer vehicle manufacturers are integrating HUDs into production vehicles although the benefits, and associated demands, produced by such automotive HUDs are not fully understood. However, the average driver is becoming increasingly aware of this display application in vehicles. It is likely that the number of HUD equipped vehicles on the road will continue to rise in the coming years, making the HUD even more salient in the mind of the driver.

Driver Control

A commonly used description of aviation hierarch of control tasks is "Aviate, Navigate, Communicate," (Schvaneveldt, Beringer, Lamonica, Tucker, & Nance, 2000) which indicates the importance of the three major factors in aircraft control. Aviate indicates the most basic level of control of the plane such as safely maintaining the current course heading and speed. Navigation is the process of comparing current and intended positions in order to effect a change in course. Communicate is the connection and sharing of information between airplanes or between pilot and tower.

The Aviate-Navigate-Communicate taxonomy is powerful because it so clearly delineates between both the types of tasks performed in cockpit and the importance of each (Schvaneveldt, Beringer, Lamonica, Tucker, & Nance, 2000). As a taxonomy, each factor is clearly placed in importance and may be sacrificed in order to provide for increasing demands from higher taxa. For example, a failure in a primary plane system (aviate) or a course correction (navigate) would almost always take priority over communication between pilot and tower. As demand as a product of the task at a more basic level increases, higher levels will be forsaken to ensure accurate performance of the more basic level.

A metaphor for this process may be seen in human cognitive capacities. Under rapidly increasing task demand, the human's abilities to perform higher critical cognitive tasks may become a limiting factor (resource limited) as opposed to scenarios where a lack of capacity in the task itself poses the limiting factor (data limited). This process was captured in Michon's (1985) model of driver control. This model has three levels, the Strategic Level which allows for processes such as route selection and requires controlled processing, the Maneuvering Level which contains processes such as gap acceptance and requires controlled processing, and the Control Level which encompasses the basic control of the car such as steering and operates as an automatic process. Under rapidly increasing levels of task demand the higher levels of Michon's model (the Strategic and Maneuvering levels) are the first to suffer degraded performance. This may also be viewed as an explanation for the detrimental effects of task interactions such as using a mobile phone while driving: the conversation is occupying task resources which the Maneuver Level requires, leading to an increased possibility of error.

Mental Workload

With the question of task demand and workload, the question of measurement naturally arises. O'Donnell and Eggemeier (1986) provided a convenient taxonomy of mental workload measurement methods. These were broadly grouped as subjective techniques relying on the individual's own self-report, measurement of performance on a primary or secondary task, and measurement of the individual's level of physiological arousal. Primary task measures fall generally under the measurement of speed of completion and accuracy of completion on the current task. By the addition of a second task (dual-task assessment), the spare capacity of individual resources may be measured (Navon & Gopher, 1979).

Driver Mental Workload

Young and Stanton (2007) compared single- and dual-task assessment methods of spare attentional capacity using a driving simulator. The pragmatic limitations in the dual-task assessment method are important, as the secondary task should not draw from a separate pool of resources (Wickens, 2002) and simultaneously must not interfere with the primary process of safely controlling the vehicle (Recartes & Nunes, 2003). To determine whether or not the measurement was mediating the outcome, they administered the NASA Task Load Index (NASA TLX; Hart & Staveland, 1988) to participants as they drove a driving simulator and performed either a verbal (verbal response to a probe question) or spatial (rotated figures) secondary task. Their findings indicated that although very little detriment to driver performance was caused by the secondary task, the measures of subjective mental workload produced by the dual-task method were inflated. However, the inflation caused by the secondary task was consistent across subscales of the TLX.

Subjective measures of workload have proven popular over the years due to the ease of administration. However, in the case of multidimensional scales, the individual facets often may become undifferentiated (Muckler & Seven, 1992). Of the multidimensional self report measures, the NASA Task Load Index (NASA TLX; Hart & Staveland, 1988) and Subjective Workload Assessment Technique (SWAT; Reid & Nygren, 1988) are the most commonly used. However, the unidimensional scales, such as the Rating Scale Mental Effort (RSME; Zijlstra, 1993) have in some cases proven to be more sensitive to variations in individual workload than the multidimensional scales. This was demonstrated in the domain of driving by DeWaard (1996).

Hysteresis

Hysteresis, a term borrowed from the material and physical sciences, has been applied to the study of humans for many years (see Barendregt, Van Bergen, & Van Nooten, 1965). Both the behavioral and physical sciences utilize definitions of hysteresis which roughly equate to the subject's history affecting the present experience (Verhave & Herman, 1967). In physics, hysteresis definitions speak of current properties being affected by forces no longer active on the object. For example, a magnetically reactive material (such as recording tapes) which continues to display a response to the magnetic field, even when the field is removed, is said to demonstrate hysteresis. Other items can demonstrate hysteresis, such as springs which lose their ability to return to original form after repeated compressions. Interestingly, the term hysteresis may have derived from the older, psychological, term hysteria because of Barkhausen noises emitted by certain metals during transformation (Durin & Zapperi, 2006). The metals literally screamed as they were transformed.

In the behavioral sciences, and specifically within the domain of human performance, hysteresis is an oft-interesting yet infrequently studied topic. One of the earliest studies indicating the possible presence of a hysteresis effect is Chamberlain (1968), who examined accident rates for traffic entering versus exiting an intersection. The findings indicated that drivers' low performance (in terms of an increased number of accidents) persisted on the opposite side of the intersection (when task demand was presumably decreasing rather than increasing).

Monitoring tasks have traditionally been used to examine the effects of workload history on task performance. Early researchers such as Colquhoun and Baddeley (1964, 1967) noted such an effect of shifting event rates within the context of a vigilance decrement. This effect was also noted by Krulewitz, Warm, and Wohl (1975) who examined event rate shifts in monitoring tasks. They noted a decrease in signal detection performance when the event rate was shifted (low to high) versus maintained at a steady high level. This decrement in performance on such vigilance tasks has also been noted by researchers examining event rate shifts between monitoring sessions instead of only within session (Wiener, 1977).

Cumming and Croft (1973) used a shadowing memory task to examine information processing and demand levels. In their shadowing task, the presentation rate varied from a minimum of 0.25 to a maximum of 2.5 items per second. By increasing and decreasing the presentation rate of the auditory information in the shadowing task, they were able to demonstrate that performance at high demand rates (that is, instances with a faster presentation rate in the shadowing task) was higher than at lower demand rates until the presentation rate had been drastically lowered. When plotted as presentation rate against performance on the shadowing task, this produces two separate functions (see Figure 4). One function representing performance under increasing levels of demand, and one lower function which represented performance under decreasing levels of demand. This seemed to indicate that individual performance on the task was becoming asymptotic under task demand and indicates a hysteresis type effect was present. The people in the study were not recovering as expected, instead of a rebound of performance with the decrease in task demand, performance remained low.

In a visual shadowing task, Goldberg and Stewart (1980) asked participants to shadow characters presented on a monitor which corresponded with the eight characters of the home-row on a standard QWERTY keyboard. Their presentation rate varied from 0.5 to 4.0 characters per second. As with Cumming and Croft's (1973) findings, these researchers found that performance under increasing task demand was substantially higher than under decreasing task demand conditions, indicating the presence of a hysteresis type effect.

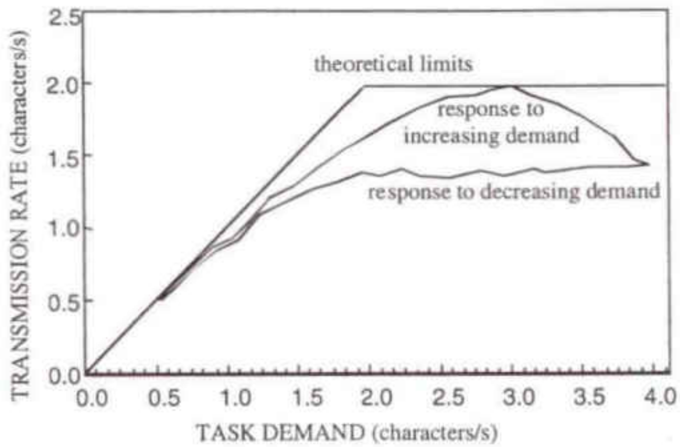

Figure 4. The variation of task performance with task demands.
This graph illustrates the non-symmetry of operator performance in response to both rising and falling levels of demand, as well as their relation to the theoretical limits expressed by information theory. From Farrell (1999), as adapted from Goldberg and Stewart (1980).

These effects concord with the findings by Matthews (1986) who, in examining the workload transitions in another visual task, concluded that people were retaining their current strategy well after task demand levels had changed. Matthews found evidence supporting the mechanism of workload transitions in hysteresis. However, Matthews failed to examine the possibilities of transitions occurring in both the positive and negative loading directions. In addition, his work failed to account for the possibility that not all workload transitions are above the operator's own criterion for detecting such a change; perhaps the operator never consciously noticed a change. In effect, if the task demand change is small enough the expectancies of the operator may be preserved. Under larger magnitude changes in task demand the mechanism through which hysteresis occurs is likely to be both operator expectancies lagging as well as the change in task demand. Thus, both hypotheses have some degree of support depending on the nature of the task demand changes.

The Yerkes-Dodson inverted-U function of stress and performance (Yerkes & Dodson, 1908) has long been used to explain transitions in human performance due to task demand characteristics. In fact, similar work within the domain of physiology developed the idea of the inverted-U function some years later. This is what Hebb (1955) described as a relationship between arousal and performance. However, the predictive power of the Yerkes-Dodson inverted-U function has been criticized (Hockey, 1983; Hancock, 1987). This criticism led to the creation of newer models of stress and human performance, such as the Extended-U model (Hancock & Warm, 1989) or the Compensatory Control Model (Hockey, 1997). Both models attempt to account for the intimate relationship between task demand and human performance, albeit in differing ways. Within these two frameworks, hysteresis effects seem to be indicative of special cases of fatigue after-effects.

One of the earliest researchers to extend the concept of hysteresis past simple control scenarios into complex task performance was Smolensky (1990). In a series of experiments, Smolensky examined whether a hysteresis effect could be demonstrated in the Air Traffic Control (ATC) domain, and if so whether the effect was due to either short term memory overload or a perseverance of expectancies regarding the task. Although a hysteresis effect was demonstrated, neither mechanistic hypothesis received clear support. Data from operational errors indicated that perseverance of expectancies was likely, however data from the controller's memory tasks indicated short term memory overload. Smolensky concluded that both memory and cueing aids would likely ameliorate any hysteresis effect present.

Hancock, Williams, Manning, and Miyake (1995) also examined the workload transition and history process in Air Traffic Control scenarios. In two experiments they examined the effect of prior workload history on current task performance and workload, and the effect of incremental changes in task demand on task performance and workload. Their findings demonstrated a strong effect for workload history in respect to current perceived workload. This indicates the presence of lag within the operator's perception of the level of task demand and interpretation of workload. Results of the examination of incremental influences over workload were inconclusive. These findings lead to the authors recommending that workload history be accounted for in the assessment of current workload.

CHAPTER THREE: EXPERIMENTAL METHODOLOGY

Hypotheses

Hypothesis 1. A history-dependant hysteresis effect will be observed in driving. The interaction will be manifested itself in the form of reports of higher perceived mental workload persisting after an epoch of high task demand has returned to its former baseline level.

Hypothesis 2. Cueing an impending higher demand phase of the driving task will eliminate the presence of the hysteresis effect predicted by Hypothesis 1.

Participants

To test these propositions, thirty-eight adults (20 females and 18 males) agreed to serve as participants in the following experiments. All participants held a valid U.S. driver's license and self-reported either normal or corrected-to-normal color vision and visual acuity. Due to problems with the simulation facility, data from two participants was unable to be recorded accurately and therefore is not included in the analysis. Additionally, four participants (one male and 3 females) were either withdrawn or self-withdrew from the experiment due to symptoms of simulator sickness (Kennedey, Lane, Berbaum, & Lilienthal, 1993). The final analysis thus included data from a balanced sample of 16 females and 16 males. This equal number of participants from both sexes were recruited in order to test for possible sex effects. Participant information is detailed in Tables 1 and 2.

Table 1. Participant demographic information.

Sex		Age	Years Licensed	Minor Accidents	Major Accidents	Speeding Tickets	Reckless Driving Tickets	Other Tickets
Female	Mean	20.38	4.31	0.63	0.50	0.38	0.06	0
	SD	2.66	2.50	0.62	0.73	0.50	0.25	0
Male	Mean	21.25	5.31	0.31	0.19	0.31	0.06	0
	SD	3.38	3.61	0.79	0.54	0.48	0.25	0
Total	Mean	20.81	4.81	0.47	0.34	0.34	0.06	0
	SD	3.02	3.09	0.72	0.65	0.48	0.25	0

Age and years licensed represented in years. All other figures represent the average for the category.

Prior to beginning any of the experimental trials, all participants completed questionnaires which assessed information including years of driving experience, average driving conditions, miles driven per year, any driving infractions (whether convicted or not) since licensure, and current state of health and well-being. These questions were collected via the Driver Stress Inventory, Driving Coping Questionnaire, Motion History Questionnaire, and Simulator Sickness Questionnaire (see Questionnaires and Self Report Measures, below, for more information; see Appendices A, B, C, and D for example questionnaires). There were no statistical differences in self-reported driver characteristics before participation as the data reported in Table 2 indicates. All participants and data collected from them was treated in full accordance with the ethical standards of the American Psychological Association (2001) and the Human Factors and Ergonomics Society Professional Standards (2006).

Table 2. Participant information by sex.

		Sum of Squares	df	Mean Square	F	Sig.
Age	Between	6.13	1	6.13	0.66	.42
	Within	276.75	30	9.23		
	Total	282.88	31			
Years Licensed	Between	8	1	8	0.83	.37
	Within	288.88	30	9.63		
	Total	296.88	31			
Driving Frequency	Between	1.53	1	1.53	2.60	.12
	Within	17.69	30	0.59		
	Total	19.22	31			
Miles Driven Per Year	Between	3.78	1	3.78	3.11	.09
	Within	36.44	30	1.21		
	Total	40.22	31			
Minor Accidents	Between	0.78	1	0.78	1.54	.22
	Within	15.19	30	0.51		
	Total	15.97	31			
Major Accidents	Between	0.78	1	0.78	1.88	.18
	Within	12.44	30	0.41		
	Total	13.22	31			
Speeding Tickets	Between	0.03	1	0.03	0.13	.72
	Within	7.19	30	0.24		
	Total	7.22	31			

Experimental Apparatus

The Driving Simulator

A fixed-base, medium fidelity, I-SIM driving simulator (GE, Version 4.0.86) was interfaced with a custom software control application written in LabVIEW (8.2, National Instruments). This simulator provides an approximately 150° field of view from three screens mounted approximately 1.0m from the driver (Figure 5).

Figure 5. The ISim driving simulator.

The simulator buck is a partial dash from a Ford Crown Victoria sedan and contains all controls present in the typical automobile such as steering, braking, throttle, gear selection, ignition, lighting, signaling, and ventilation controls (Figure 6). Adjustments are present for steering wheel position and seat position. Data generated by the simulation network was sampled at 60 Hz (i.e., 16.67 ms time slice). This data was logged for offline analyses and was subsequently parsed for vehicle and environmental information as well as time period paralleling the status of the simulated navigation system (pre-failure, immediate post failure, end of drive).

Figure 6. The ISim driving simulator dashboard and controls.

Experimental Stimuli

A simulated in-vehicle electronics route navigation/GPS system was constructed using Microsoft Powerpoint 2007. This system allows for the display of turn by turn driving directions as well as the simulation of electronic device failure and resetting procedures, all while retaining a high degree of ecological validity. The navigation system information is presented as a Heads-Up-Display (HUD) projected in the lower center portion of the center simulator image channel. This corresponds to the positioning of most current in-vehicle HUDs.

Advancement of the route guidance indicators to the next turn was performed at set points within the driving environment to ensure consistent performance between participants. Screen images of normal navigation, cueing to impending failure, and failure are displayed in Figures 7, 8, and 9, respectively.

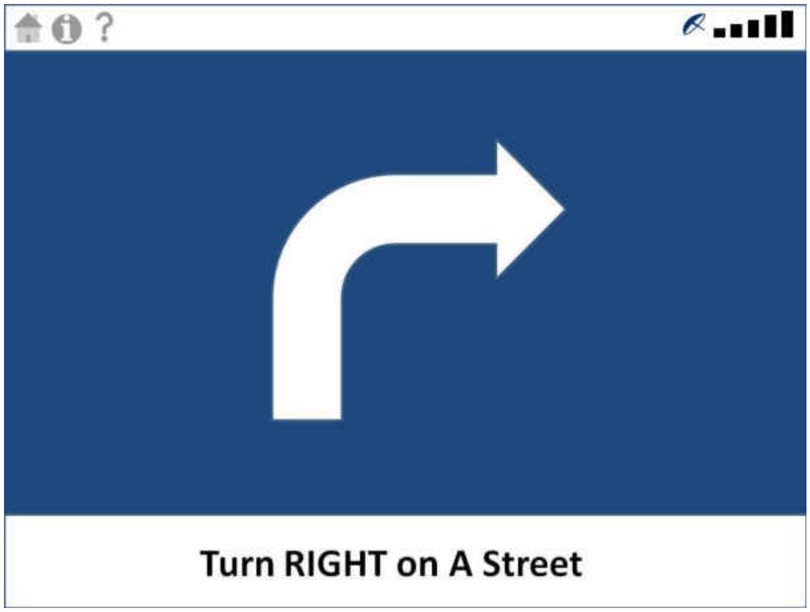

Figure 7. Nominal navigation view.

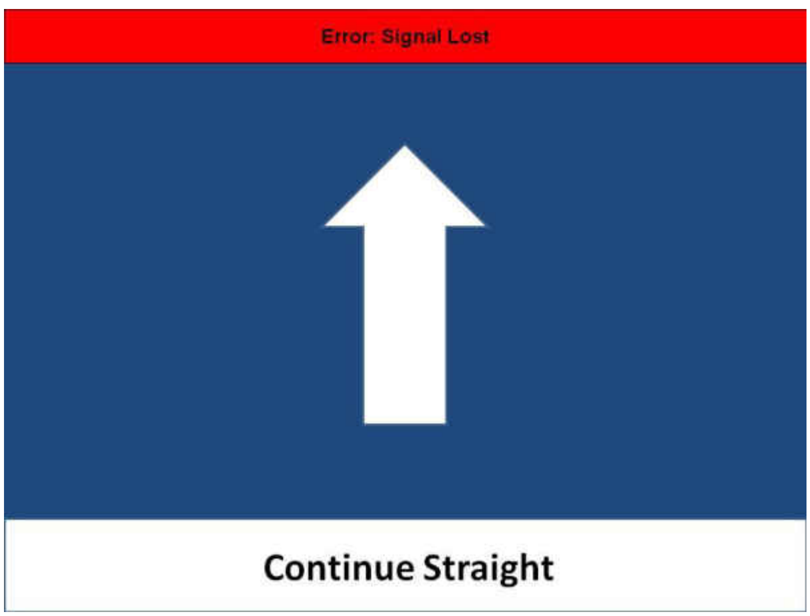

Figure 8. Cue to impending navigation system failure.

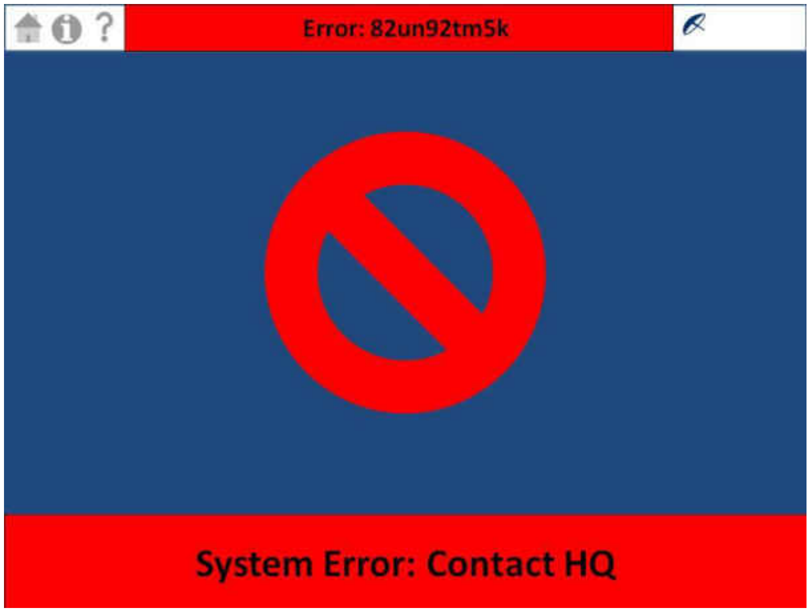

Figure 9. Navigation system failure.

Questionnaires and Self-Report Measures

The Driver Stress Inventory and Driver Coping Questionnaire (DSI and DCQ, respectively; Matthews, Desmond, Joyner, Carcary, & Gilliland, 1997) are two questionnaires which measure driver personality traits and have proven to accurately reflect driver decision making and behavior. The DSI consists of 48 questions marked on a 10 point Likert-type scale (See Appendix B), and produces five factors when scored: Aggression, Dislike of Driving, Hazard Monitoring, Thrill Seeking, and Fatigue Proneness. The Driver Coping Questionnaire consists of 35 questions marked on a 5 point Likert-type scale (See Appendix A), and produces six factors: Confrontive, Coping, Task-Focus, Emotion-Focus, Reappraisal, and Avoidance coping dimensions. A driver demographics section asking the participant to recall date of license, annual miles driven, typical driving environment, and any driving infractions precedes the two questionnaires. Both questionnaires were administered to participants prior to participation in the driving scenarios.

The Motion History Questionnaire (MHQ; Kennedy, Fowlkes, Berbaum, & Lilienthal, 1992) was used as a device to better inform participants on their risk of experiencing symptoms of simulator sickness during the experiments. The MHQ consists of a 14-item background questionnaire coupled with a preference and symptom checklist for 14 experiences with the potential of inducing motion sickness. The MHQ was administered to participants prior to participation in the driving scenarios. This data would serve to illustrate any individual differences in performance due to issues with motion sickness and past exposure to devices likely to induce motion sickness, should the need arise.

Simulators have the potential to induce physical symptoms of nausea and dizziness. The Simulator Sickness Questionnaire (SSQ; Kennedy, Lane, Berbaum, & Lilienthal, 1992) is a multifaceted scale of simulator sickness frequently used in simulator-based studies to measure the presence of such symptoms. The scale uses a 26-symptom checklist with a 4-point scale (See Appendix C) for all items to calculate scores in three factors: nausea, oculomotor, and disorientation. From these three factors, a total score may be calculated. The SSQ was administered before participation for a baseline measure and following the last trial for a post-exposure comparison if any individual participant-driver reported symptoms which were consistent with those included in the SSQ's conceptualization of simulator sickness. If needed, these scores could be used as a screening tool against any abnormal values observed in the driving tasks.

Simplified Subjective Workload Assessment Technique (S-SWAT, Luximon & Goonetilleke, 2001). The SWAT (Reid & Nygren, 1988) is a multidimensional, self report, workload scale consisting of three facets: time load, mental effort load, and psychological stress load. Each facet contains three discrete levels, resulting in a total of twenty seven possible combinations. The SWAT has traditionally been administered with a card-sorting task in order to establish an individual's baseline. However, this introduces an increased possibility of error and creates additional demand on the participant. In order to reduce the both the burden on the participant and the possibilities for introducing error into the analysis, the Simplified SWAT (S-SWAT) was used. The S-SWAT scale ranges from 0 to 100, which increases the sensitivity of the scale and reduces the burden on the participant. The S-SWAT procedure also eliminates the card sorting task. To allow for participants to become familiar with the scale and procedure for reporting their perceived mental workload using the S-SWAT, participants were asked to give S-SWAT ratings after completing paperwork and a practice drive in the simulator.

General Experimental Procedure

Prior to participation participants were given as much time as they required to read, ask questions about, and sign the statement of informed consent. Following notification and acknowledgment of informed consent, participants were asked to fill out the package of questionnaires consisting of the Driver Stress Inventory, Driver Coping Questionnaire, Motion History Questionnaire, and Simulator Sickness Questionnaire. Participant's progress throughout this time was monitored and participants were allowed to ask any questions regarding these measures.

After completing the last questionnaire, participants were given a description of the Simplified Subjective Workload Analysis Technique, including descriptions of the scales and (positive/negative) anchors for each scale. Participants were asked to give a rating of their perceived mental workload along these scales at this point in time. After recording this information, the experimenter asked the participant to be seated in the driving simulator.

The location and operation of all major controls and adjustments in the driving simulator were explained to the participant. The layout and information on the HUD navigation system was pointed out, as well as how to interpret the initial instructions this system provided. After an opportunity to ask further questions, the participant drove a brief route while following directions provided by the navigation system. The system operated 100% reliably during this time and gave no indications of failure or unexpected operations. When the participant had completed the route they were again informed of the meaning of the S-SWAT scales and given descriptions of the anchors. Participants provided a second report of their perceived mental workload at this time, providing another opportunity for them to become familiar with the scale prior to the experiment beginning. After providing their mental workload metrics participants were asked to take a brief break from the simulator consisting of a short walk. This served to reduce any symptoms of simulator sickness which manifested during their drive and allowed the experimenter to ready the simulator for the following experimental trials. On returning to the laboratory, participants began the experimental trials.

As the same participants served in both experiments, each participant completed the two experiments in a counterbalanced order to allow for the assessment of order effects. Following completion of both experiments the participant was given a post-exposure Simulator Sickness Questionnaire form and received a debriefing explaining the purpose of the experiment. Any remaining questions the participant had were answered at this time.

CHAPTER FOUR: EXPERIMENT ONE

Experimental Design

This experiment used a within-subjects repeated measures design to assess the effects of task demand on driver mental workload and driver performance. The primary task was a simulated driving task within an urban environment. The dependent measures used in this experiment were (a) workload measurement via a secondary task (accuracy in navigation) performance capacity as well as the scores on the Simplified SWAT, and also (b) primary driver performance measures including average speed, accelerator actuation, and braking actuation.

Task demand was manipulated by failures of the navigation system requiring the driver to relay the error code to the experimenter. Failures occurred once per trial and a total of four trials were recorded. No prior findings available in the literature suggested the possibility of order effects from the experimental presentation; therefore all participants experienced the same scenario sequence.

Experimental Procedure

Following the procedure described in the General Experimental Procedure, participants were given the following instructions:

> "Now we will start (continue) the experimental trials. Like your earlier drive, you are going to be driving a patrol route and following the directions of the navigation system. This system will tell you what street and direction you will need to turn before you reach the turn. Each time the screen updates with your next turn, you will hear a beep which lets you know that your next turn is now displayed.
>
> The system may have problems during your patrol. If this happens the system will display an error code at the top of the screen. When this happens continue to drive

and read the error code to me so we can reset the system. Please try not to stop or slow while reading this code, and try to read the code as quickly as possible.

The system will guide you through your entire patrol route and return you to the headquarters building. Please try to drive normally and obey all traffic signs and signals. At certain points during the drive we will be asking you to report using the three factor rating scale you've already used. Do you have any questions?"

After any questions were answered participants began the driving task. Drivers followed the instructions of the route guidance system through a series of approximately 3.5mile long routes within the urban driving environment. At prescribed points within the route the navigation system registered a failure instructing the driver to contact the dispatcher at Police HQ (the experimenter served this function).

Upon contacting the dispatcher, participants provided the error codes from the navigation system's display. This error codes consisted of a 10 digit randomly generated alphanumeric code positioned at the centered top of the display. After the driver successfully provided the error code the navigation system resumed normal operation.

Measures of mental workload via the S-SWAT were obtained in the initial stage of the drive, immediately post-navigation system failure (after the error code was relayed to the experimenter), and at the conclusion of the route. Measures of driver performance obtained from the simulator network were averaged based on time periods in concordance with the measurement of driver mental workload. Therefore, the initial stages (beginning of the drive) included data from when speed initially increased from a standstill to the time of the first S-SWAT score's recording, the second measurement period extended from this point until the second S-SWAT score was recorded, and the third period extended from this point until the end of the drive when the final S-SWAT score was recorded (see Figure 10).At the end of each trial, participants received a brief break in which they were allowed to stand up, stretch, and walk around if they desired to do so. This time period also allowed the experimenter to ready the simulator for the next trial. A total of 4 trials were recorded for each participant.

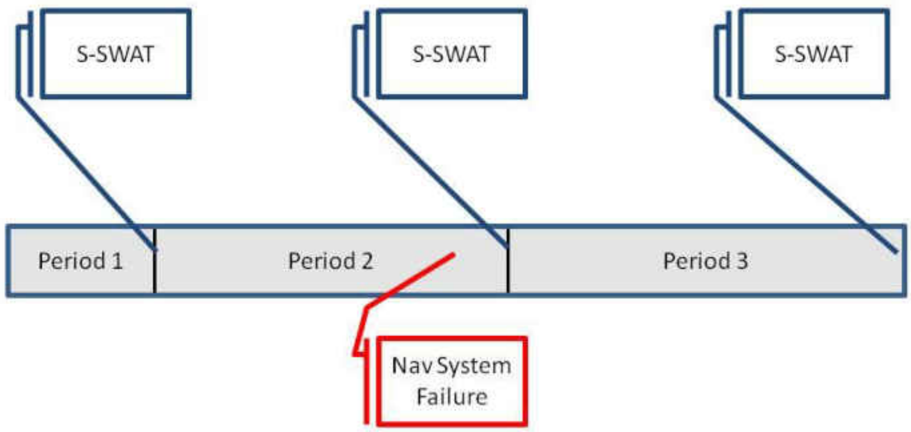

Figure 10. Depiction of the timeline for events within each trial for Experiment 1.

Results of Experiment One

General Analytic Strategy

Prior to analysis for the two experiments, all data underwent examination for accuracy of data entry, missing values, and violations of planned statistical tests' assumptions. No missing values or outliers were present in the collected mental workload data. Due to failures in the simulator data collection network, some of the driving data contained single instances of missing data points. Rather than replace these values with a mean score for the variable, they were excluded from the analysis. All analyses were conducted using SPSS for Windows, version 14.0.1, at $\alpha = .05$ unless otherwise specified. Effect sizes are given in the form of Cohen's f (Cohen, 1992), which has proven to be a reliable measure of effect size across most forms and generalizations of the ANOVA technique.

Order Effects

As the same participants served in both experiments, the possibility of order effects were examined. No main effects for order were observed in the mental workload data, $F(1, 28) = 1.66$, $p = .21$, f = .24 (see Figure 11). Likewise, no main effects were present for order in the driver performance data, $F(1,24) = 2.63$, $p = .12$, f = .33. However, presentation order was present in some significant interactions. These will be presented and discussed in the appropriate point in the results.

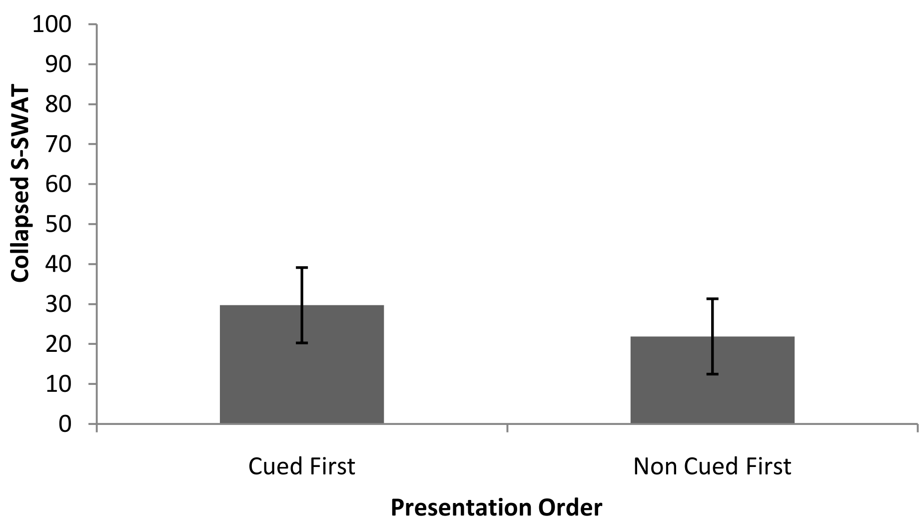

Figure 11. Collapsed S-SWAT score by presentation order. Error bars represent Standard Error.

A repeated measures multivariate analysis of variance was performed on subjective mental workload. The independent variables were sex (male versus female), trial (1 versus 2 versus 3 versus 4), and the measurement sequence within each trial (mental workload was assessed three times within each trial: at the beginning of the drive, immediately after navigation system failure, and at the end of the drive). Fisher's Least Significant Difference was used for all post-hoc tests, unless otherwise specified.

Results of Sex

A significant main effect was present for the effect of participant sex on perceived mental workload, $F(1, 28) = 5.71$, $p = .02$, f = .45. Post-hoc analysis demonstrated that, across all trials and measurement times, females ($M = 33.29$, $SD = 20.55$) reported significantly higher collapsed mental workload scores than males ($M = 19.42$, $SD = 12.15$, p = .03). Within the individual subscales of the S-SWAT, females provided higher workload measures for most facets. There was no significant sex difference between ratings of Time Demand (female $M = 30.37$, $SD = 25.35$; male $M = 22.69$, $SD = 17.19$; $p > .05$). However, Mental Effort was rated higher by females ($M = 41.16$, $SD = 26.29$) than males $M = 23.15$, $SD = 14.18$; $p = .02$), and a similar pattern was observed with Psychological Stress (female $M = 28.34$, $SD = 19.40$; male $M = 12.42$, $SD = 9.58$; $p = .01$). See Figure 12.

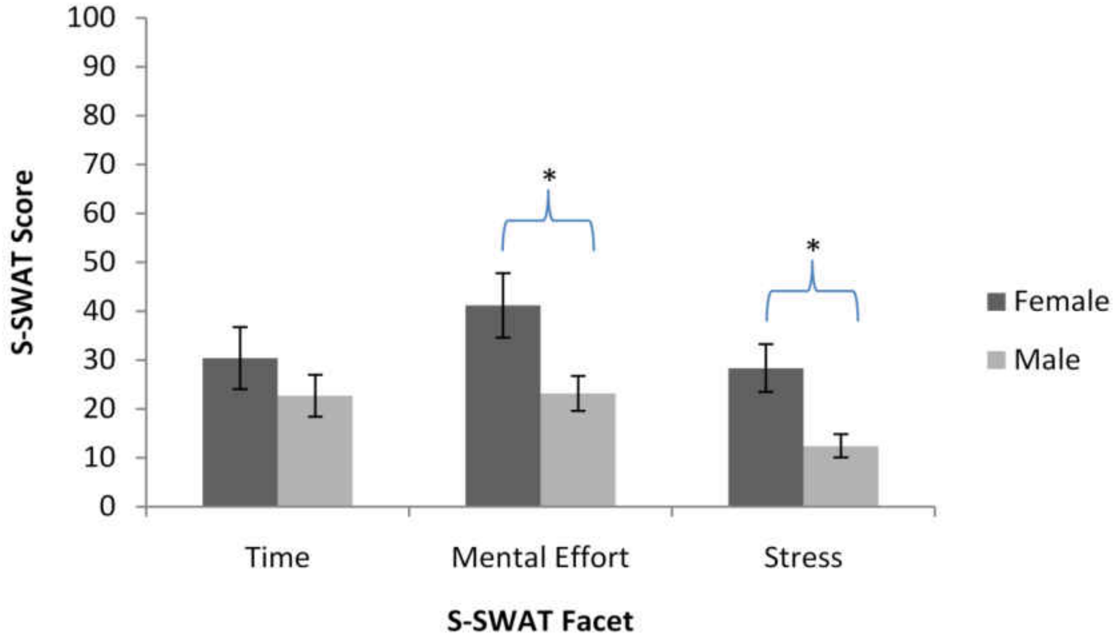

Figure 12. S-SWAT scores by sex. Asterisk indicate a statistical difference at $p = .05$. Error bars represent Standard Error.

No significant sex differences were present in the three measured aspects of driving data, $F(1, 24) = .021$, $p = .886$, f = .33. Female and male driving was approximately equal, with roughly the same speed (Figure 13), braking inputs (Figure 14), and accelerator (Figure 15) inputs across all trials.

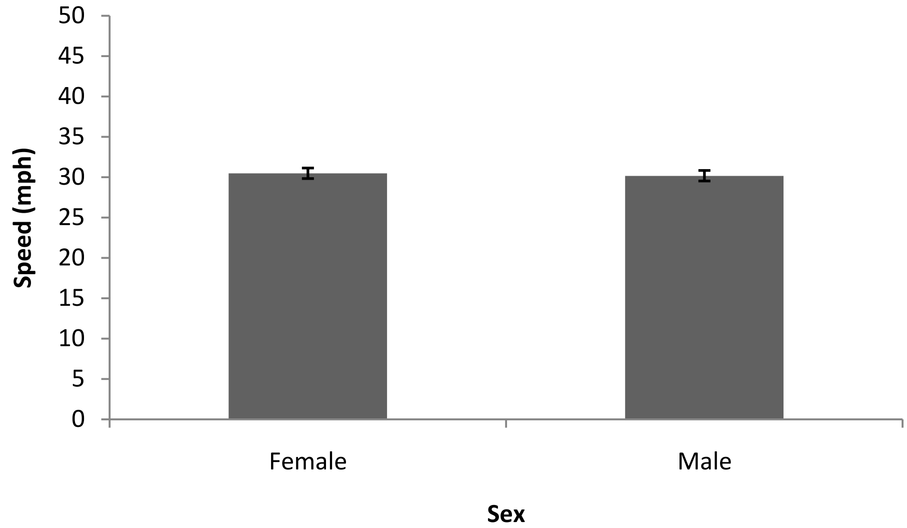

Figure 13. Speed by sex. Error bars represent Standard Error.

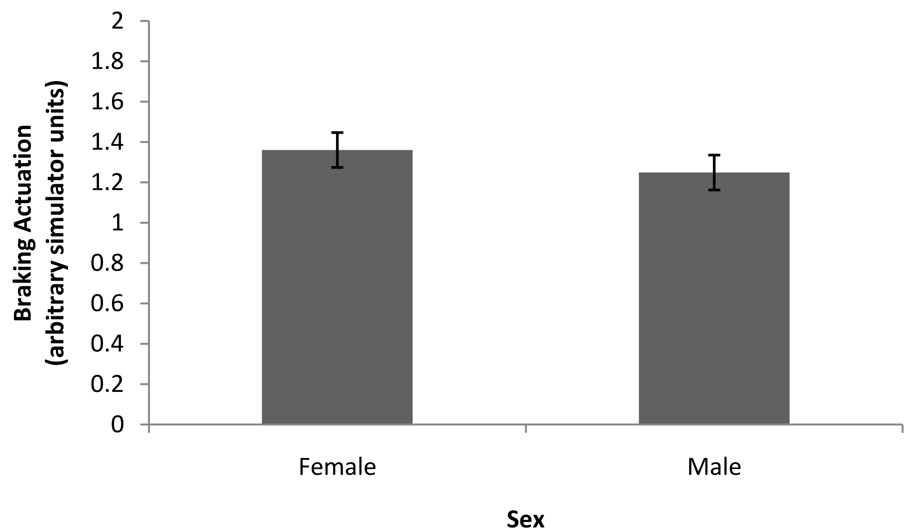

Figure 14. Braking actuation by sex. Error bars represent Standard Error.

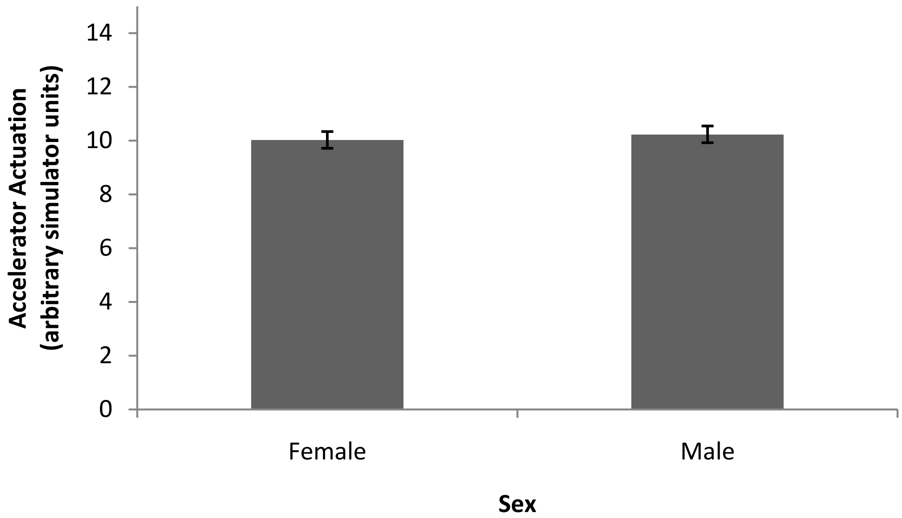

Figure 15. Accelerator actuation by sex. Error bars represent Standard Error.

Results of Repeated Trials

A significant main effect was present for mental workload across trials, $F(3, 84) = 35.64$, $p < .0005$, f = 1.13. Post-hoc analysis revealed a significant reduction in collapsed mental workload scores across sequential trials. This manifested itself as a gradual drop in score means as the experiment progressed. Trial 1 ($M = 33.26$, $SD = 20.88$) demonstrated the highest rating, which a gradual reduction was seen at trial 2 ($M = 28.42$, $SD = 17.82$), 3 ($M = 23.90$, $SD = 15.96$), and 4 ($M = 19.83$, $SD = 16.32$). This reduction across trials is illustrated in Figure 16. There was no interaction present between sex and the sequence of trials for mental workload, $F(3, 26) = 1.121$, $p = .36$, f = .36.

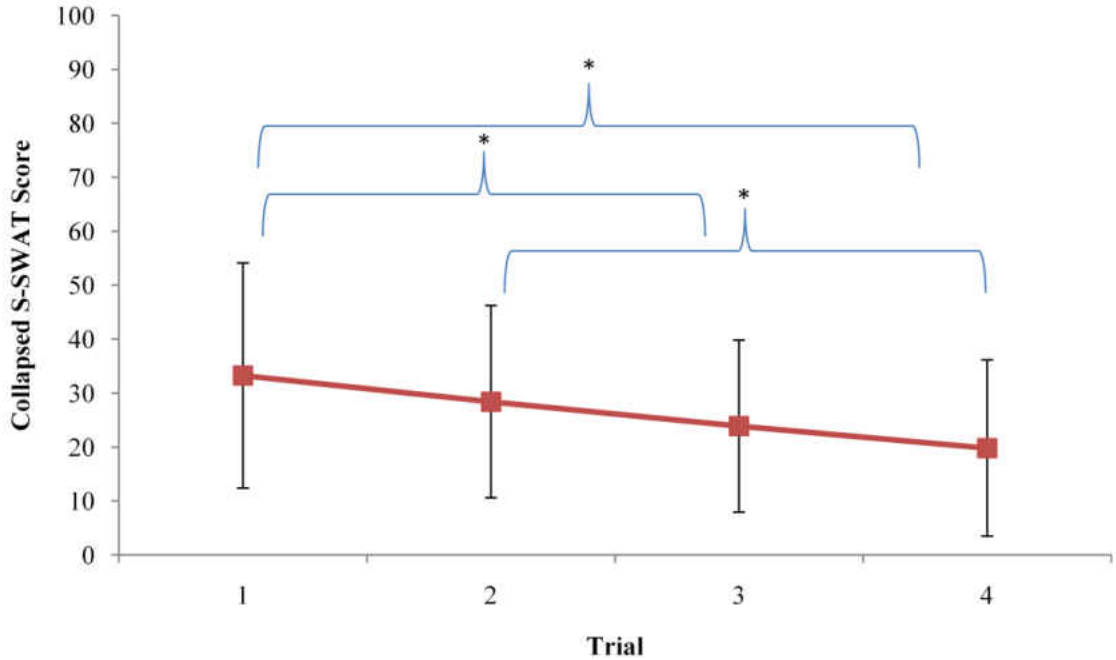

Figure 16. S-SWAT by individual trial. Note: Asterisks indicate a statistical difference of p = .05 or greater. Error bars represent Standard Deviation.

There were also significant sex differences across trials. Females consistently rated mental workload higher than males on each trial. Both females and males rated trial one as the highest, with no significant differences between females (M = 38.40, SD = 23.01) and males (M = 28.13, SD = 18.51). Trial two was rated lower for both groups, although females rated the trial significantly higher than males (females M = 36.33, SD = 21.34, males M = 20.51, SD = 13.40, p = .02). Trial three continued this (female M = 31.78, SD = 20.54, males M = 16.02, SD = 9.37, p = .01). Trial four was the lowest for both sexes, although they demonstrated significant differences in the magnitude assigned to each (female M = 26.64, SD = 20.47, male M = 13.01, SD = 10.66, p = .02). See Figure 17.

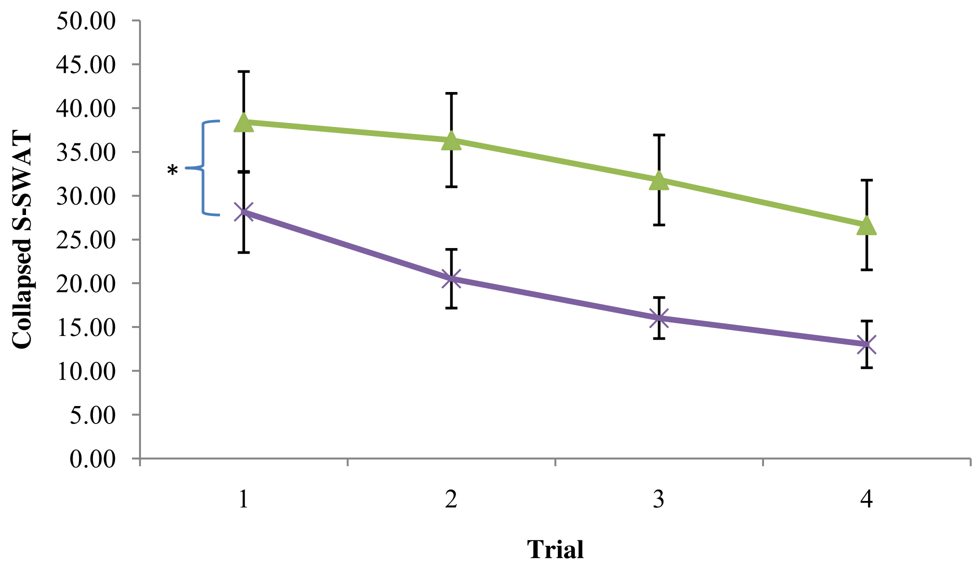

Figure 17. Sex differences in mental workload across trials. Error bars represent standard error.

The effect of trial on speed was also significant, $F(3, 81) = 1810.20$, $p < .0005$, f = 15.80. The average speed observed in trials 1 ($M = 34.09$, $SD = 2.93$), 2 ($M = 36.85$, $SD = 3.03$), 3 ($M = 22.67$, $SD = 2.92$), and 4 ($M = 20.96$, $SD = 2.69$) all differed significantly from one another at $p <$ .02 or greater (see Figure 18). Likewise, the effect of trial on braking was significant, $F(3, 81) = 11.47$, $p < .0005$, f = 1.17. Braking differed significantly between most trials, with trials 1 ($M = 1.54$, $SD = 0.48$) and 2 ($M = 1.74$, $SD = 0.52$) demonstrating the highest amount of braking actuation required. Trial 3 ($M = 1.30$, $SD = 0.39$) and 4 ($M = 1.33$, $SD = 0.40$) required less braking. The differences between all trials except for 1 and 2, and trials 3 and 4 were significant at $p = .05$ or less (see Figure 19). There was not a significant effect for trial on accelerator actuation, $F(3, 81) = 2.14$, $p = .12$, f = .51.

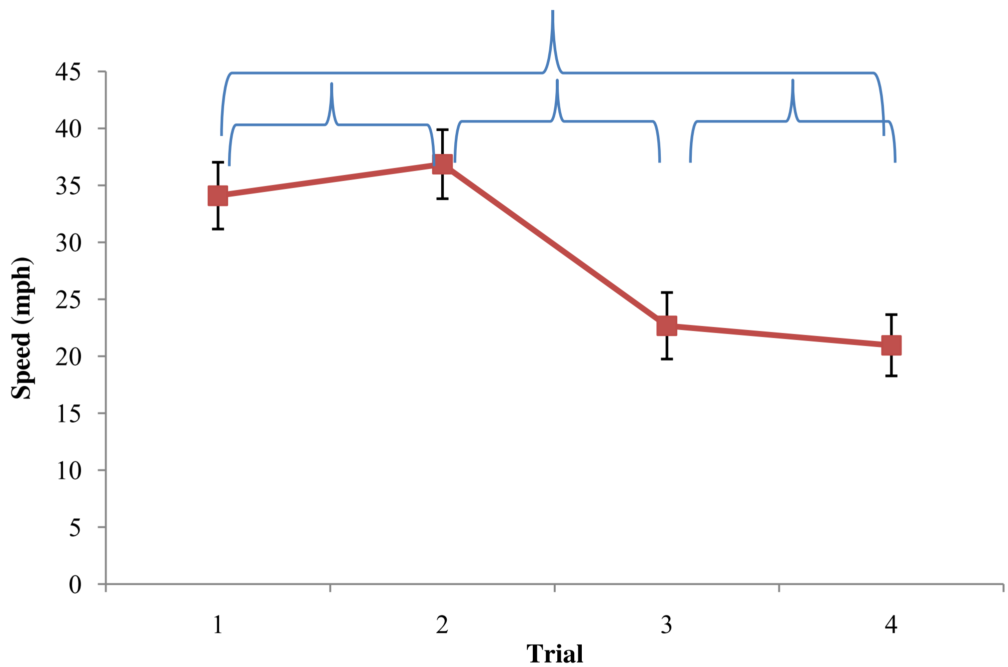

Figure 18. Speed by trial. Error bars represent standard deviations.

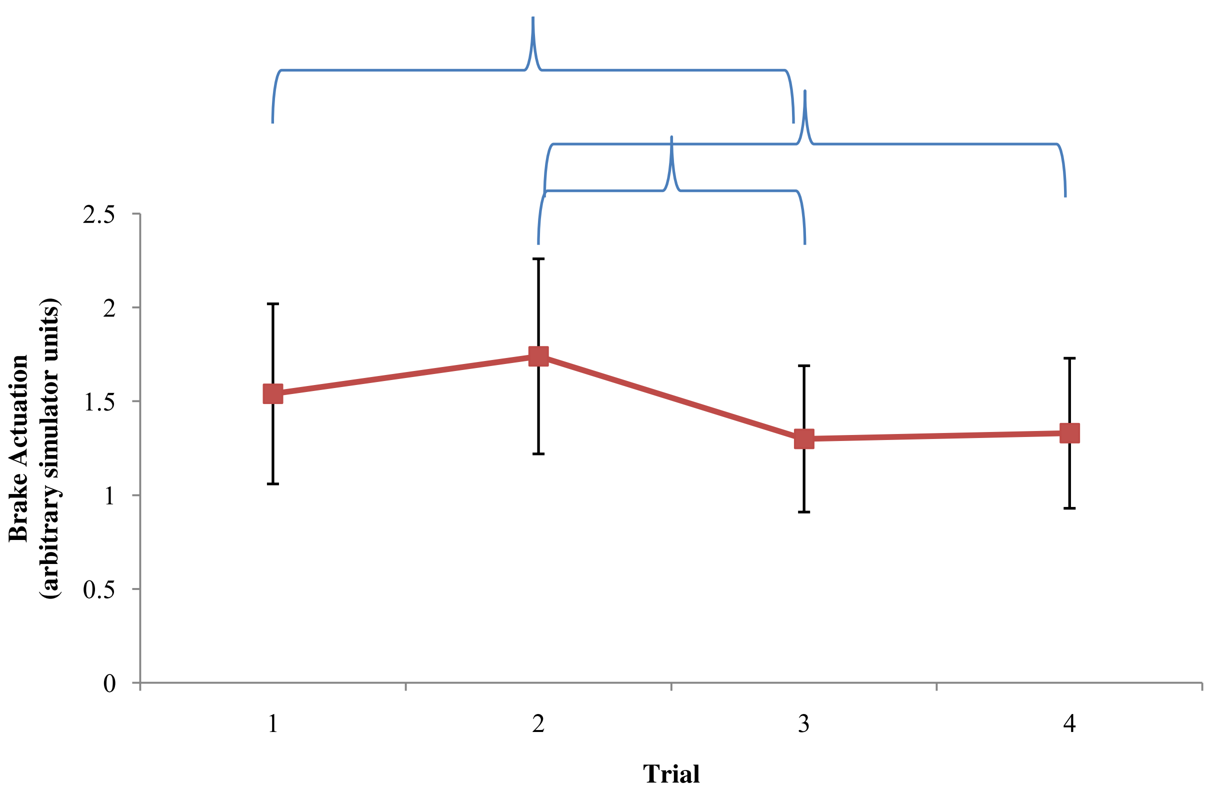

Figure 19. Braking by trial. Error bars represent standard deviation.

Results of Measurement Time

A significant main effect was present for measurement time within the trials on the subjective mental workload scores, $F(2, 56) = 45.28$, $p < .0005$, f = 1.27. Post-hoc analysis demonstrated a significant difference between all measurement periods 1 (measured at the beginning of the drive, $M = 21.12$, $SD = 11.41$), 2 (measured immediately post navigation system failure, $M = 30.53$, $SD = 13.20$), and 3 (measured at the end of the drive, $M = 27.41$, $SD = 12.07$). Except for the difference between periods 2 and 3 ($p = .33$), all differences were significant, as illustrated in Figure 20.

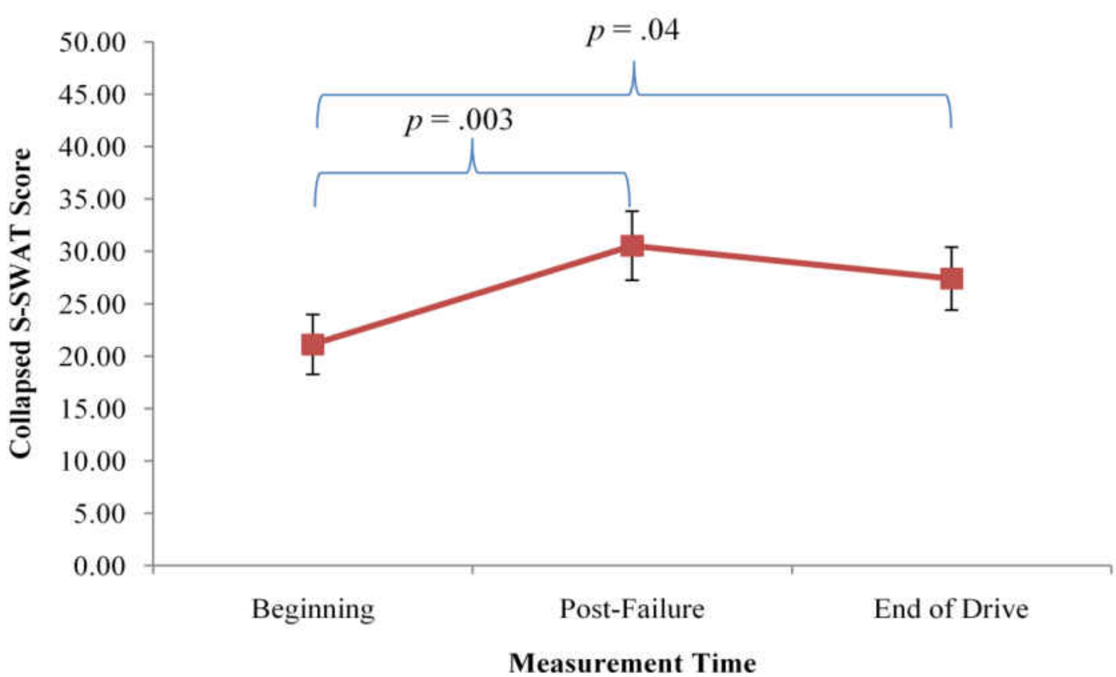

Figure 20. S-SWAT by measurement time. Error bars represent Standard Error.

The results of the individual facets of the S-SWAT were examined and demonstrated a significant main effect, $F(2, 56) = 9.38$, $p < .0005$, f = .58. Overall, the individual facets of the S-SWAT did not display differences from time demand ($M = 26.53$, $SD = 21.66$) and mental effort

(M = 32.15, SD = 21.13). However, the difference between mental effort and stress (M = 20.38, SD = 15.30) was significant (p = .01). See Figure 21.

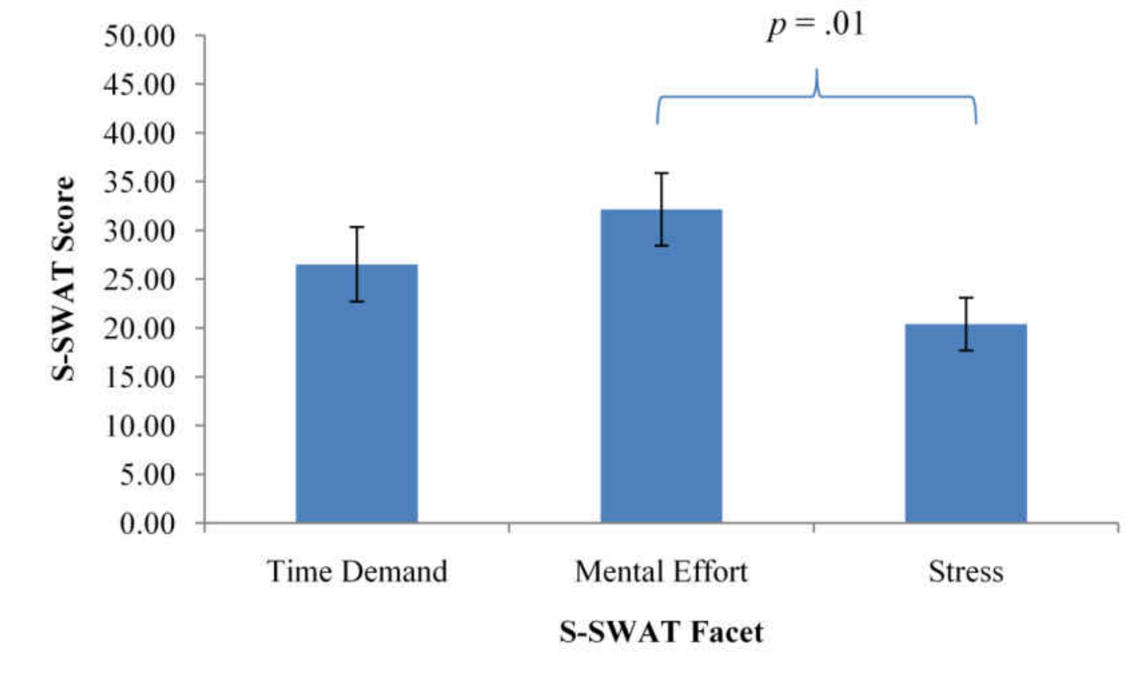

Figure 21. Individual facets of the S-SWAT. Error bars represent Standard Error.

When driver performance data was analyzed using measurement times within the individual trials, a significant main effect was present for speed, $F(2, 54) = 9262.24$, $p < .0005$, f = 5.5. The speed as measured before the failure of the navigation system (M = 18.65, SD = 1.63) was significantly lower than the measurement immediately post failure (M = 33.52, SD = 3.85, $p < .0005$) and at the end of the drive (M = 33.75, SD = 3.02, $p < .0005$). The difference between the measures of speed immediately post-failure and at the end of the drive were not statistically different (p = .57). Braking effects also proved significant when analyzed across measurement times, $F(2, 54) = 130.47$, $p < .0005$, f = 3.05. Significantly more braking was required after the navigation system failure (M = 2.64, SD = 0.70) than either at the beginning of the drive (M = 0.68, SD = 0.20) or immediately post-failure (M = 1.12, SD = 0.38). All differences between measurement times for brake actuation were significant at $p < .0005$. A similar trend was not observed with accelerator actuation, $F(2, 54) = 24.00$, $p = .052$, f = 0.33. Drivers mean accelerator actuation was approximately equal for the time before ($M = 10.45$, $SD = 2.55$) and immediately post-failure ($M = 10.30$, $SD = 1.19$). Less accelerator actuation was observed from the time immediately post-failure to the end of the drive ($M = 9.62$, $SD = 1.26$). The only statistically significant differences between measurements of accelerator actuation occurred between the time immediately post-failure and the end of the drive ($p = .03$). See Table 3 and Figures 22, 23, and 24.

Table 3. Driver performance within trials.

	Measurement Time	Mean	SD
Speed	Beginning	18.65	1.63
	Post-Failure	33.52	3.85
	End of Drive	33.75	3.02
Braking	Beginning	0.68	0.20
	Post-Failure	1.12	0.38
	End of Drive	2.64	0.70
Acceleration	Beginning	10.45	2.55
	Post-Failure	10.30	1.19
	End of Drive	9.62	1.26

Note: Speed in mph, braking and acceleration actuation given in arbitrary simulator units.

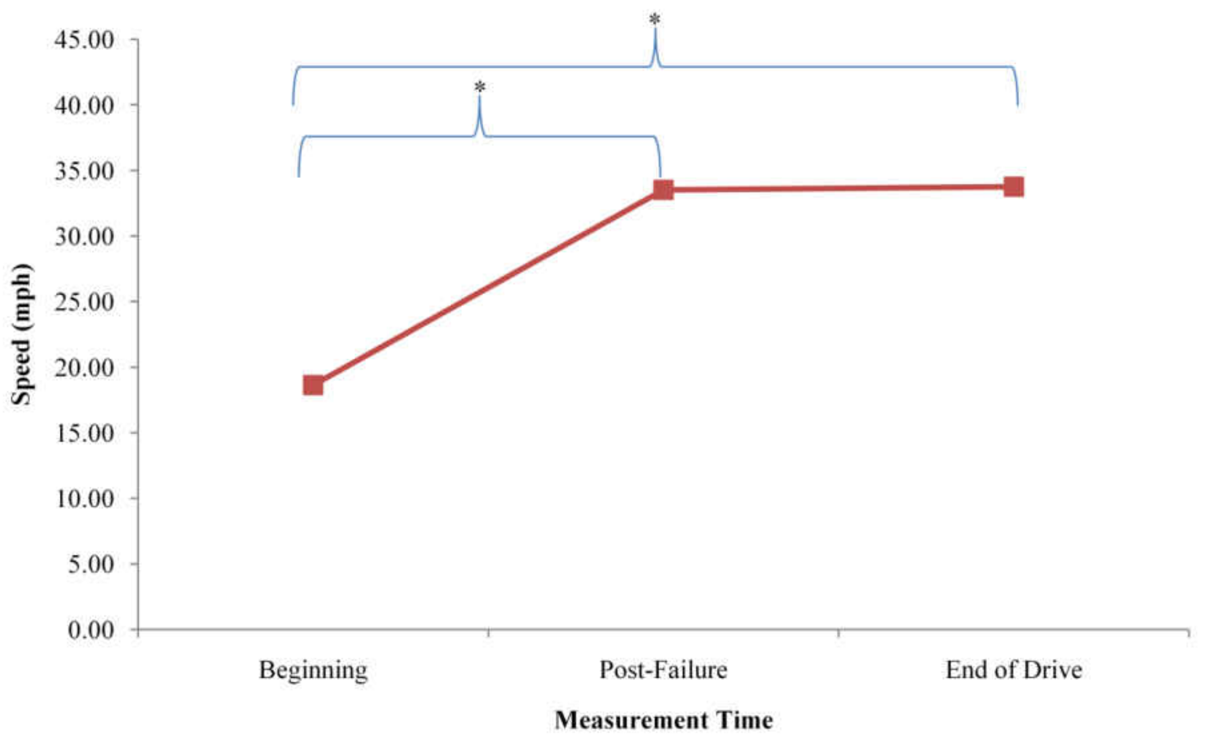

Figure 22. Speed by measurement time. Error bars represent Standard Error. Asterisks indicate a difference at p = .05 or greater.

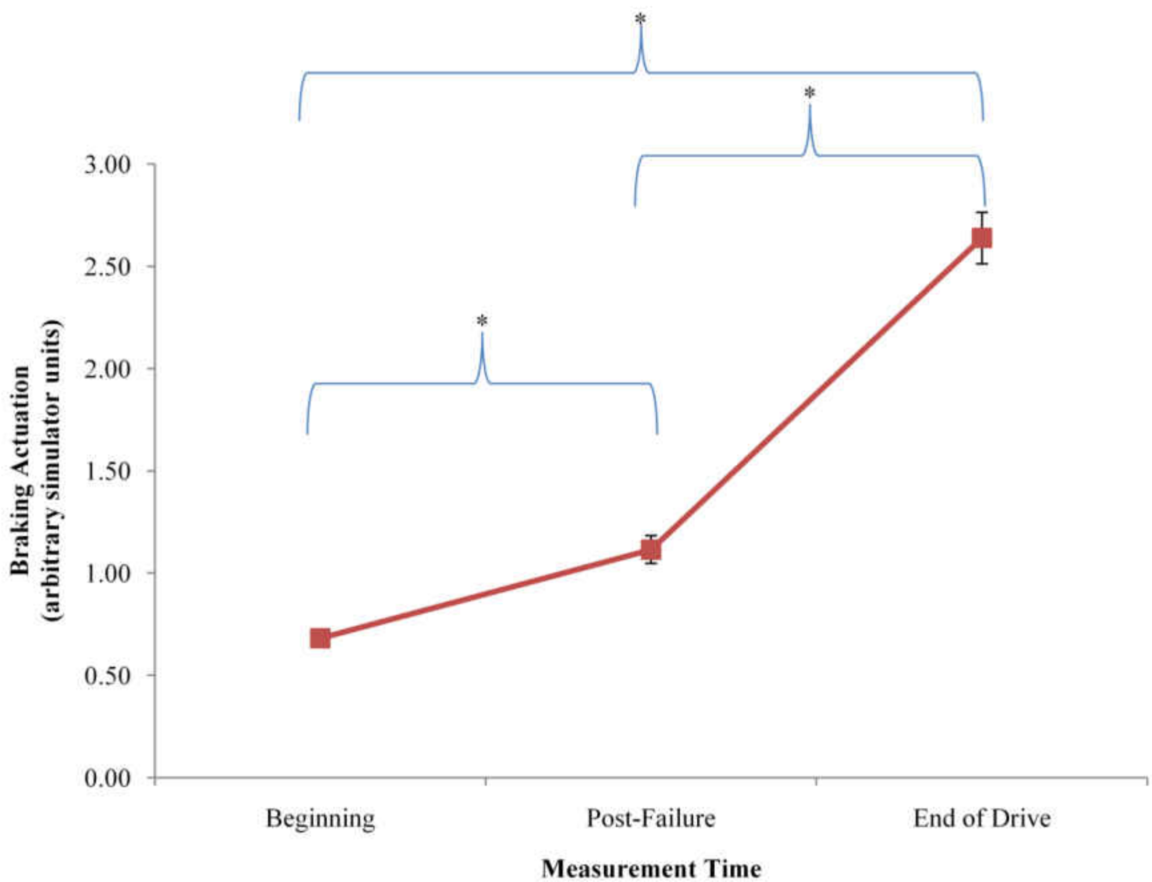

Figure 23. Braking actuation by measurement time. Error bars represent Standard Error. Asterisks indicate a difference at p = .05 or greater.

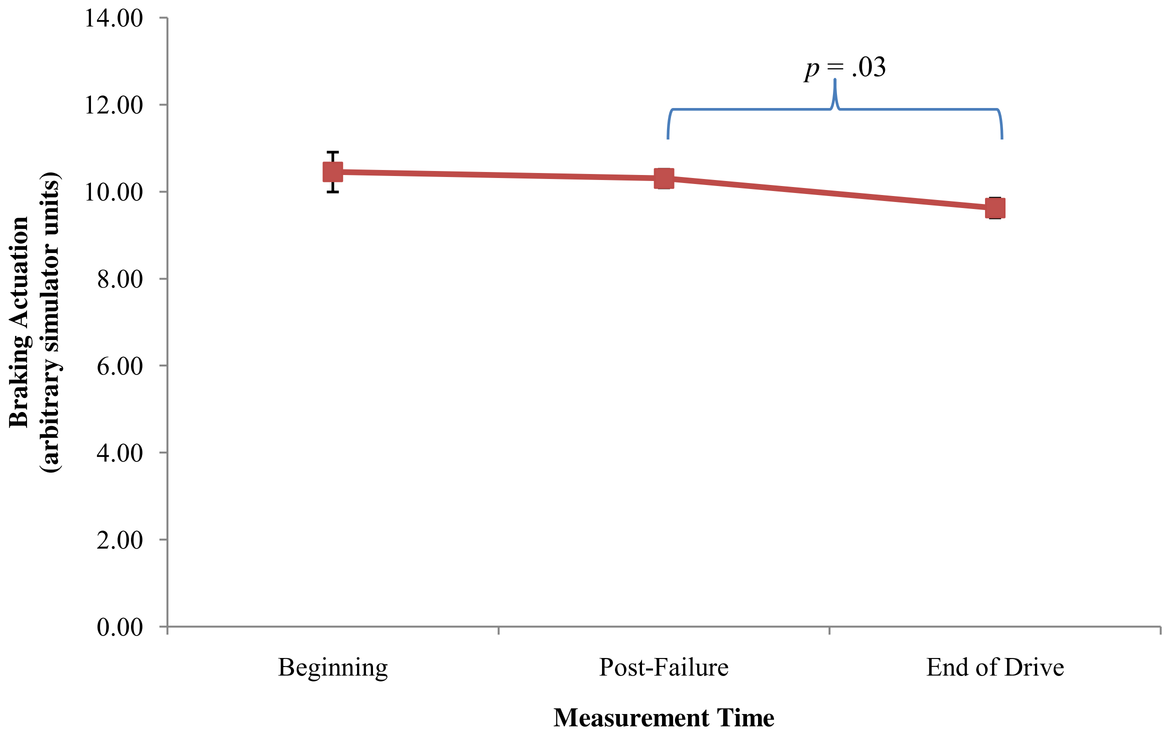

Figure 24. Accelerator actuation by measurement time. Error bars represent Standard Error.

Table 4. S-SWAT scores by trial, measurement time, scale facet, and sex.

Trial	Measurement Time	Scale Facet	Sex	Mean	SD
1	Pre-Failure	Time	Female	30.88	30.63
			Male	29.69	27.38
		Mental Effort	Female	42.56	30.95
			Male	31.31	26.41
		Stress	Female	29.81	18.99
			Male	14.69	17.27
	Immediate Post-Failure	Time	Female	35.38	31.79
			Male	38.69	28.30
		Mental Effort	Female	54.50	31.29
			Male	40.69	25.03
		Stress	Female	34.56	22.50
			Male	26.25	22.55
	End of Drive	Time	Female	34.81	25.03
			Male	29.25	21.23
		Mental Effort	Female	46.69	28.53
			Male	27.88	17.29
		Stress	Female	36.44	22.68
			Male	14.69	11.61
2	Pre-Failure	Time	Female	30.06	26.13
			Male	22.25	19.42
		Mental Effort	Female	44.38	28.86
			Male	23.00	16.46
		Stress	Female	30.38	21.31
			Male	10.00	8.94
	Immediate Post-Failure	Time	Female	36.94	28.78
			Male	29.69	20.63
		Mental Effort	Female	46.69	30.23
			Male	30.25	19.37
		Stress	Female	32.56	22.26
			Male	15.13	12.39
	End of Drive	Time	Female	29.50	26.94
			Male	23.38	18.99
		Mental Effort	Female	44.75	26.19
			Male	21.69	14.61
		Stress	Female	31.75	22.69
			Male	9.19	9.61

Trial	Measurement Time	Scale Facet	Sex	Mean	SD
3	Pre-Failure	Time	Female	16.25	24.93
			Male	9.38	9.77
		Mental Effort	Female	26.31	31.33
			Male	10.00	7.82
		Stress	Female	18.13	25.16
			Male	7.50	12.48
	Immediate Post-Failure	Time	Female	35.94	26.72
			Male	22.00	19.80
		Mental Effort	Female	48.19	30.38
			Male	24.13	15.06
		Stress	Female	30.06	24.48
			Male	13.69	13.12
	End of Drive	Time	Female	35.88	25.67
			Male	21.69	14.21
		Mental Effort	Female	43.50	29.94
			Male	22.69	15.88
		Stress	Female	31.75	24.73
			Male	13.13	14.82
4	Pre-Failure	Time	Female	18.13	25.29
			Male	7.25	10.12
		Mental Effort	Female	25.63	31.56
			Male	7.38	8.54
		Stress	Female	17.19	19.41
			Male	4.81	7.11
	Immediate Post-Failure	Time	Female	29.06	24.03
			Male	20.00	17.58
		Mental Effort	Female	33.75	24.39
			Male	21.75	15.29
		Stress	Female	22.69	20.95
			Male	10.13	12.37
	End of Drive	Time	Female	31.63	27.96
			Male	19.00	18.19
		Mental Effort	Female	36.94	27.89
			Male	17.00	16.28
		Stress	Female	24.75	23.63
			Male	9.81	12.02

Table 5. Driver measurement by trial, measurement time, variable, and sex.

Trial	Measurement Time	Variable	Sex	Mean	SD
1	Pre-Failure	Speed	Female	30.40	1.37
			Male	32.22	1.37
		Braking	Female	1.42	0.20
			Male	1.40	0.20
		Acceleration	Female	11.09	0.72
			Male	11.73	0.72
	Immediate Post-Failure	Speed	Female	35.37	1.64
			Male	34.36	1.64
		Braking	Female	1.28	0.22
			Male	1.03	0.22
		Acceleration	Female	10.43	0.52
			Male	9.87	0.52
	End of Drive	Speed	Female	34.47	1.31
			Male	33.80	1.31
		Braking	Female	2.03	0.28
			Male	2.19	0.28
		Acceleration	Female	9.60	0.58
			Male	9.67	0.58
2	Pre-Failure	Speed	Female	33.91	1.44
			Male	34.46	1.44
		Braking	Female	0.65	0.15
			Male	0.76	0.15
		Acceleration	Female	11.63	0.59
			Male	12.02	0.59
	Immediate Post-Failure	Speed	Female	38.27	1.57
			Male	37.55	1.57
		Braking	Female	1.54	0.22
			Male	1.38	0.22
		Acceleration	Female	10.52	0.48
			Male	10.27	0.48
	End of Drive	Speed	Female	37.76	1.51
			Male	36.48	1.51
		Braking	Female	2.19	0.33
			Male	2.17	0.33
		Acceleration	Female	8.52	0.54
			Male	8.86	0.54

Trial	Measurement Time	Variable	Sex	Mean	SD
3	Pre-Failure	Speed	Female	2.95	0.36
			Male	3.18	0.36
		Braking	Female	0.00	0.00
			Male	0.00	0.00
		Acceleration	Female	7.42	1.93
			Male	9.02	1.93
	Immediate Post-Failure	Speed	Female	31.21	2.05
			Male	31.01	2.05
		Braking	Female	0.91	0.16
			Male	0.74	0.16
		Acceleration	Female	10.36	0.63
			Male	10.05	0.63
	End of Drive	Speed	Female	36.36	1.74
			Male	34.71	1.74
		Braking	Female	2.38	0.34
			Male	1.96	0.34
		Acceleration	Female	10.34	0.62
			Male	9.93	0.62
4	Pre-Failure	Speed	Female	17.54	0.87
			Male	18.83	0.87
		Braking	Female	0.18	0.08
			Male	0.13	0.08
		Acceleration	Female	9.93	1.11
			Male	11.97	1.11
	Immediate Post-Failure	Speed	Female	34.81	1.35
			Male	33.61	1.35
		Braking	Female	1.07	0.24
			Male	0.82	0.24
		Acceleration	Female	10.54	0.58
			Male	9.75	0.58
	End of Drive	Speed	Female	32.55	1.13
			Male	31.79	1.13
		Braking	Female	2.68	0.34
			Male	2.40	0.34
		Acceleration	Female	9.88	0.57
			Male	9.60	0.57

Summary of Experiment One

Experiment one sought to examine whether or not a hysteresis effect was present in the driving task. This effect would be manifested as reports of higher mental workload after the driving and navigating task demand returned to a lower level. Evidence for the presence of this history dependent effect was observed in the reported mental workload data. The driver-participants in the first experiment reported a significantly higher level of mental workload under high demand conditions (the navigation system failure), and after the demand imposed by this failure was removed continued to report significantly higher levels of mental workload as compared to their earlier baseline measurements. This result, and the results of the three measures of driver performance, provides a strong degree of support for Hypothesis 1.

CHAPTER FIVE: EXPERIMENT TWO

Experimental Design

This experiment used a within-subjects repeated measures design to assess the effects of cueing and task demand on driver mental workload and driver performance. The primary task was the simulated driving task within an urban environment. The dependent measures used in the second experiment were (a) workload measurement via secondary task (accuracy in navigation) performance as well as the scores on the Simplified SWAT, as well as (b) primary driver performance measures including average speed, accelerator actuation, and braking actuation and followed those used in the first experiment.

Task demand was manipulated by failures of the navigation system requiring the driver to relay the error code to the experimenter. Participants were cued to the upcoming failure through notification bars which appeared on the HUD display. The cue to system failure was 100% reliable and always occurred the same amount of time before system failure. Failures occurred once per trial and a total of four trials were recorded. Measures of mental workload via the S-SWAT were obtained at the beginning of the drive, immediately post-navigation system failure (after the error code was relayed to the experimenter), and at the conclusion of the route. No prior findings available in the literature suggested the possibility of order effects from the experimental presentation; therefore all participants experienced the same scenario sequence.

Experimental Procedure

Following the procedure described in the General Experimental Procedure, participants were given the following instructions:

> "Now we will start (continue) the experimental trials. Like your earlier drive, you are going to be driving a patrol route and following the directions of the navigation

system. This system will tell you what street and direction you will need to turn before you reach the turn. Each time the screen updates with your next turn, you will hear a beep which lets you know that your next turn is now displayed.

The system may have problems during your patrol. If this happens, it will always be preceded by a red warning bar before the failure occurs. When the system encounters a problem, it will display an error code at the top of the screen. When this happens continue to drive and read the error code to me so we can reset the system. Please try not to stop or slow while reading this code, and try to read the code as quickly as possible.

The system will guide you through your entire patrol route and return you to the headquarters building. Please try to drive normally and obey all traffic signs and signals. At certain points during the drive we will be asking you to report using the three factor rating scale you've already used. Do you have any questions?"

After any questions were answered participants began the driving task. Drivers followed the instructions of the route guidance system through a series of approximately 3.5mile long routes within the urban driving environment. At prescribed points within the route the navigation system registered a failure instructing the driver to contact the dispatcher at Police HQ (the experimenter served this function).

Upon contacting the dispatcher, participants provided the error codes from the navigation system's display. This error codes consisted of a 10 digit randomly generated alphanumeric code positioned at the centered top of the display. After the driver successfully provided the error code the navigation system resumed normal operation.

Self-report measures of driver mental workload were collected at the beginning of each trial, immediately post-failure of the navigation system, and at the end of the route. This collection timing attempted to keep the mental workload reporting from serving as a cue to the navigational system failure. . Measures of driver performance obtained from the simulator network were averaged based on time periods in concordance with the measurement of driver mental workload. Therefore, the initial stages (beginning of the drive) included data from when speed initially increased from a standstill to the time of the first S-SWAT score's recording, the second measurement period extended from this point until the second S-SWAT score was recorded, and the third period extended from this point until the end of the drive when the final S-SWAT score was recorded (see Figure 25). At the end of each trial, participants received a brief break in which they were allowed to get up, stretch, and walk around if they desired to do so. This time period also allowed the experimenter to ready the simulator for the next trial. A total of 4 trials were recorded for each participant.

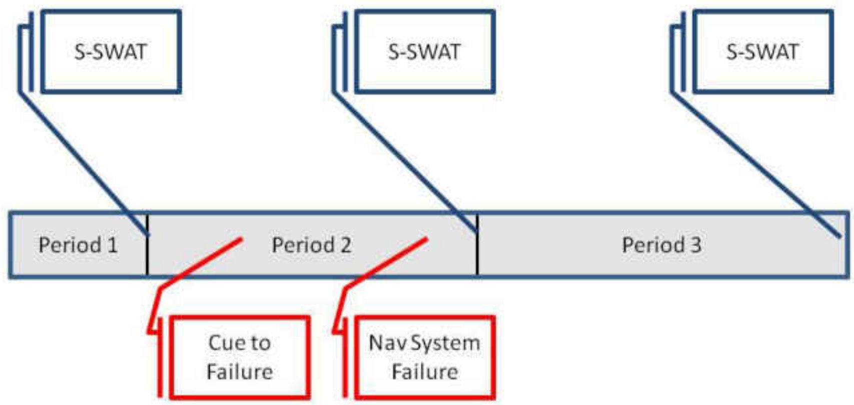

Figure 25. Depiction of the timeline for events within each trial for Experiment 2.

Results of Experiment Two

A repeated measures multivariate analysis of variance was performed on subjective mental workload. The independent variables were cueing (cued trials compared against the same participant's non-cued trials from Experiment 1) sex (male or female), trial (four trials were collected), and the measurement time within each trial (mental workload was assessed three times within each trial: at the beginning of the drive, immediately after navigation system failure, and at the end of the drive). Fisher's Least Significant Difference was used for all post-hoc tests, unless otherwise specified.

Results of Cueing

Cueing did not have a significant main effect for mental workload, $F(1, 28) = 0.65$, $p = .43$, f = .15. The collapsed S-SWAT mean for cueing across all trials did not significantly differ between cued ($M = 25.25$ $SD = 18.22$) and non-cued ($M = 26.35$, $SD = 16.88$). The individual facets of the S-SWAT did not differ significantly between cueing conditions, see Figures 26 and 27.

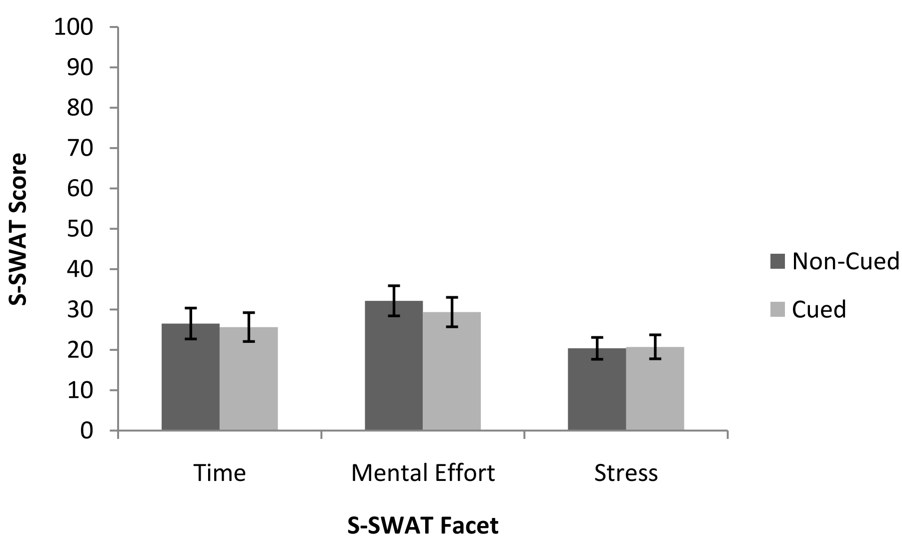

Figure 26. S-SWAT scores by cueing type. Error bars represent Standard Error.

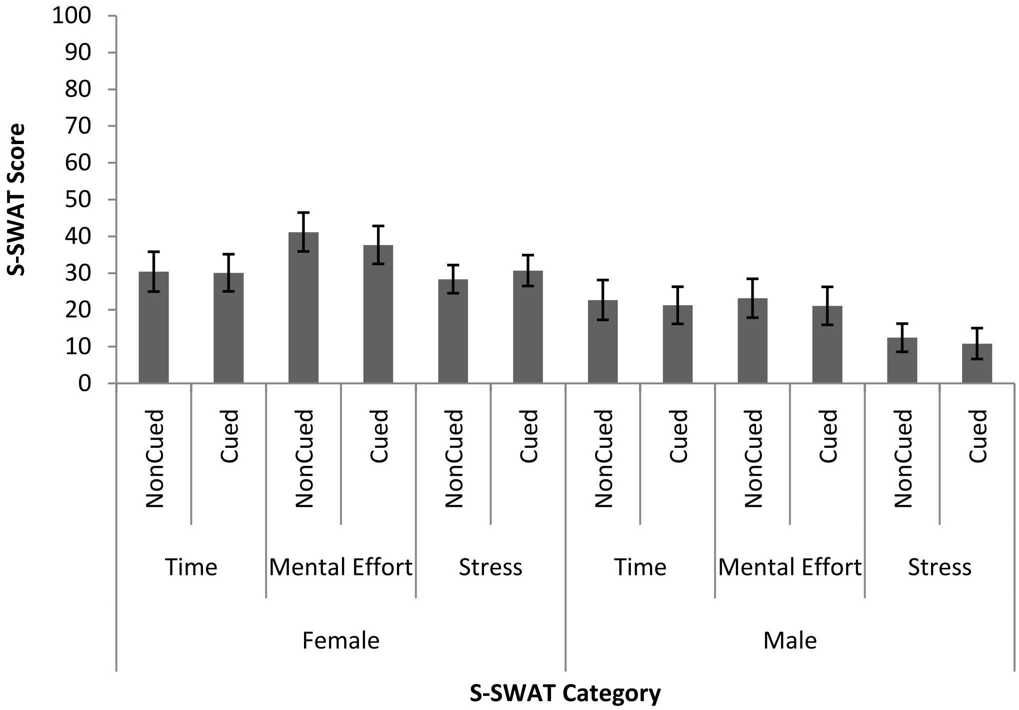

Figure 27. S-SWAT score by cueing and sex. Note that no significant differences within the sexes are present. Error bars represent Standard Error.

A significant main effect was present for cueing's effect on driver performance, $F(1, 24) = 29.03$, $p < .0005$, f = 1.10. Participants drove faster in the cued conditions ($M = 31.76$mph, $SD = 2.84$) than non-cued ($M = 28.87$mph, $SD = 2.74$, $p < .0001$). More braking actuation was required in the non-cued condition ($M = 1.49$, $SD = .10$) than the cued-condition ($M = 1.12$, $SD = .08$, $p < .0001$). Small, non-significant, differences were present in accelerator actuation between non-cued ($M = 10.15$, $SD = .34$) and cued ($M = 10.11$, $SD = .31$, $p = .73$) conditions.

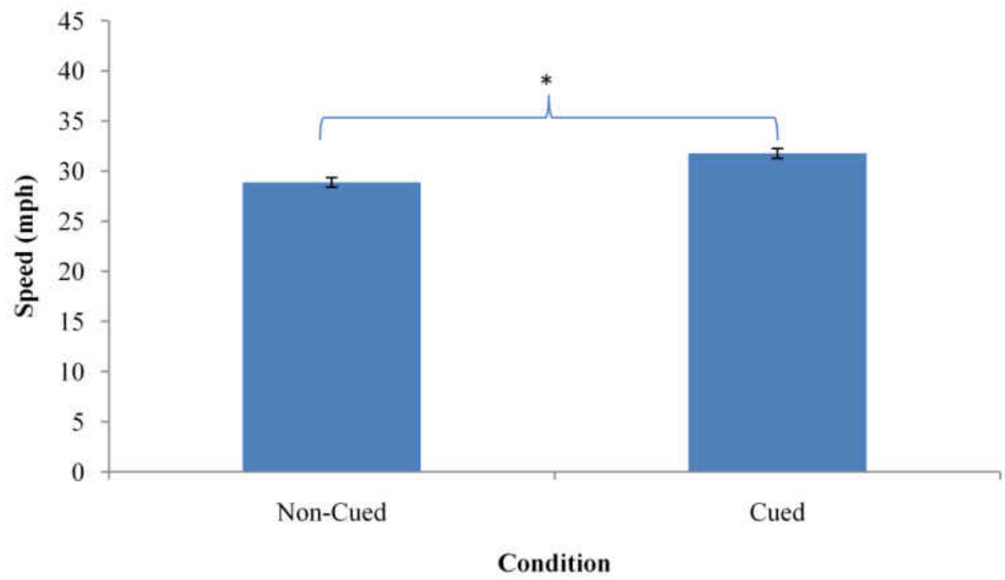

Figure 28. Speed by cueing type. * p < .0001. Error bars represent Standard Error.

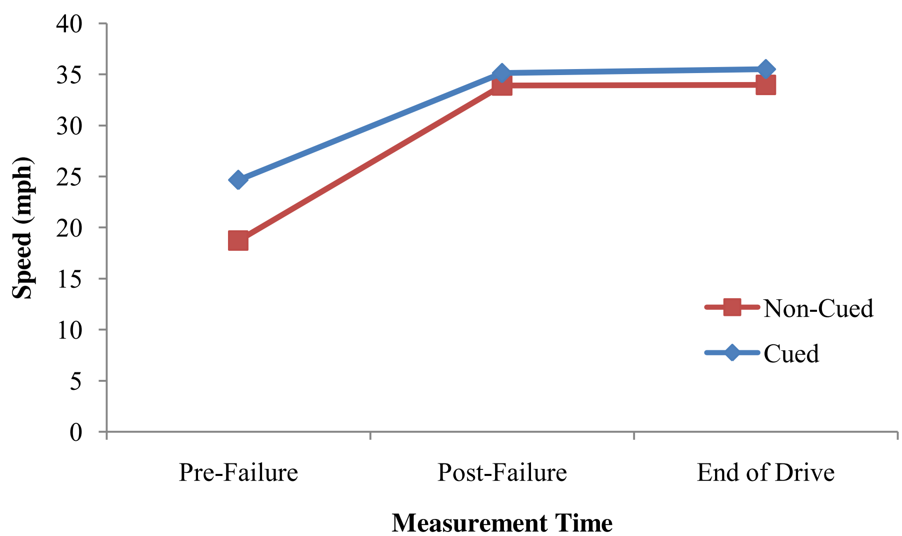

Figure 29. Speed by measurement time and cueing type.

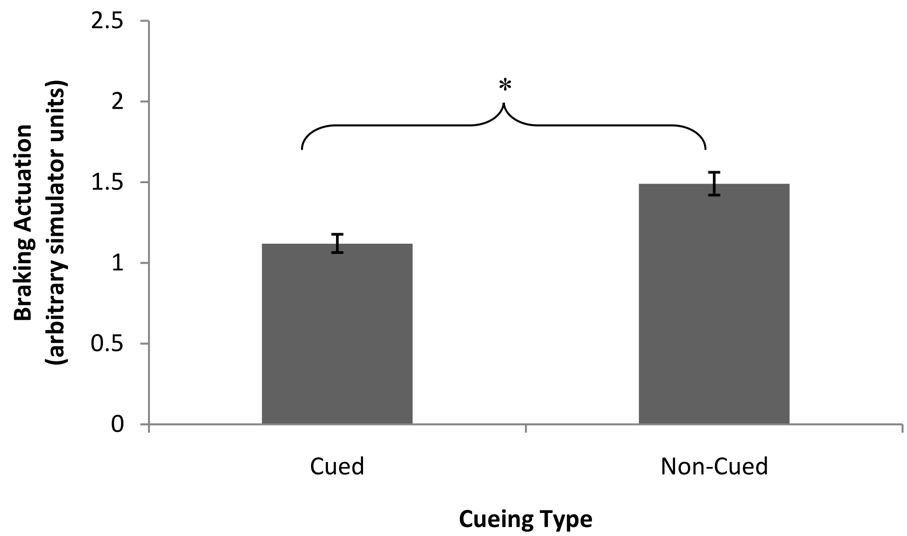

Figure 30. Braking actuation by cueing type. * p < .0001. Error bars represent Standard Error.

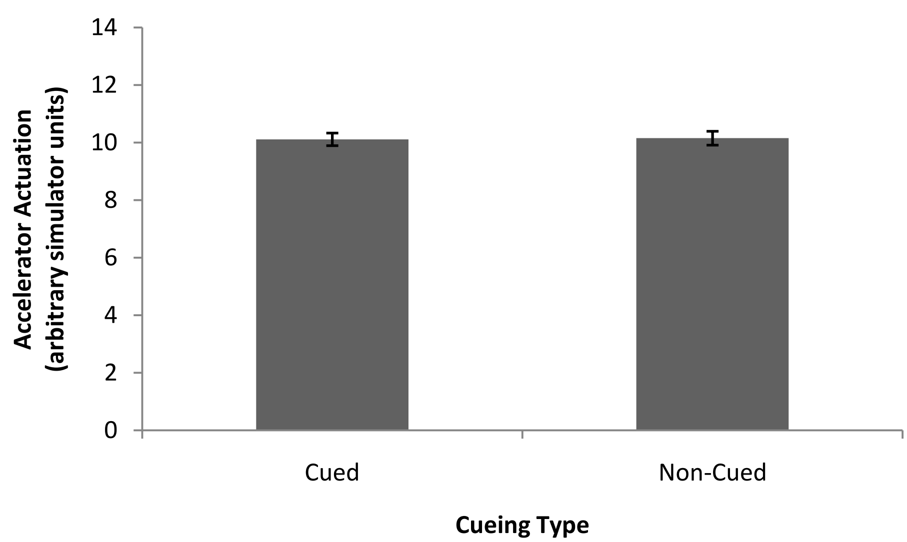

Figure 31. Accelerator actuation by cueing type. Error bars represent Standard Error.

Interaction between Cueing and Presentation Order

An interaction between order of presentation and cueing was present, $F(1, 28) = 19.64$, $p < .0001$, f = .84. Regardless of presentation order, all participants reported approximately equal levels of perceived mental workload under non-cued conditions (Experiment 1 first $M = 25.48$, $SD = 20.27$, Experiment 2 first $M = 27.23$, $SD = 27.00$, $p = .77$). Participants receiving the non-cued Experiment 1 first then reported lower levels of perceived mental workload when experiencing cueing ($M = 18.32$, $SD = 16.76$) to impending higher task demand scenarios. Participants who experienced Experiment 2 first (and thus were familiar with cueing) did not display a sharp drop when switching to the non-cued Experiment 1 ($M = 32.18$, $SD = 32.37$, $p = .04$). This interaction manifests as shown in Figure 32.

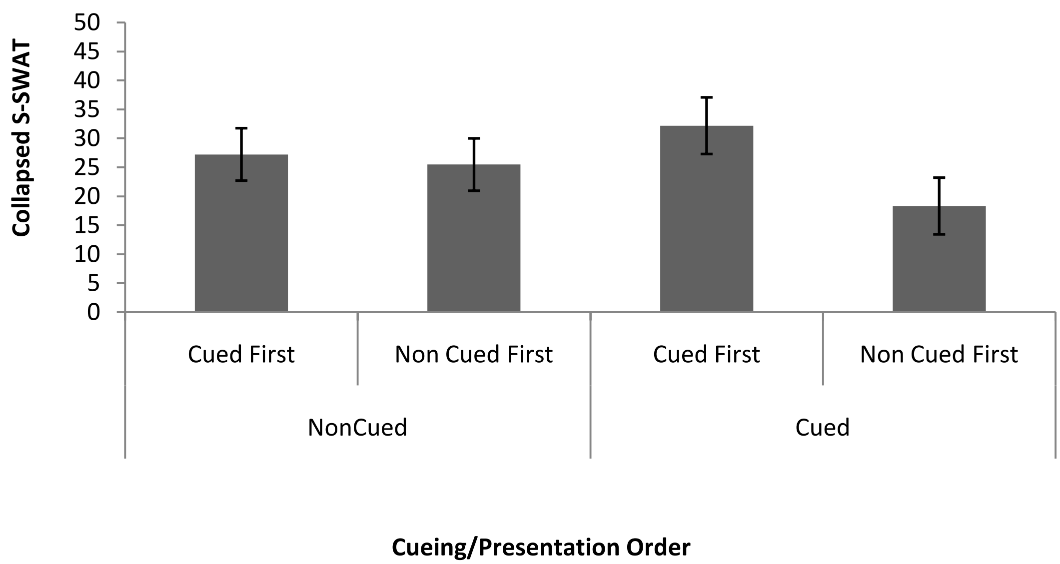

Figure 32. Interaction between S-SWAT and presentation order. Error bars represent Standard Error.

The further interaction between Presentation Order, Cueing, and the individual facets of the S-SWAT was not significant, *F*(2, 56) = .47, *p* = .63, f = .13. Means and standard deviations for the individual facets of the S-SWAT by Presentation Order and Cueing Status are given in Table 6.

Table 6. S-SWAT score by presentation order and cueing status.

Presentation Order	Cue	Facet	Mean	SD
Non Cued First	Non-Cued	Time	24.99	24.16
		Mental Effort	32.09	25.30
		Stress	19.35	18.52
	Cued	Time	19.11	18.29
		Mental Effort	22.60	19.54
		Stress	13.26	18.10
Cued First	Non-Cued	Time	28.07	35.96
		Mental Effort	32.21	33.84
		Stress	21.41	24.36
	Cued	Time	32.17	36.05
		Mental Effort	36.13	36.34
		Stress	28.25	28.32

An interaction between the measures of driver performance and presentation order was present as well. For speed, *F*(1, 24) = 11.305, *p* = .003, f = .69, this interaction appeared as a trend with no significant speed differences between cued performance, regardless of whether the participant experienced cued driving first (*M* = 32.00mph, *SD* = 3.72) or second (*M* = 31.52mph, *SD* = 4.30). However, speed for driving under non-cued conditions was dependent on whether they experienced cueing (*M* = 30.28mph, *SD* = 4.56) or non-cued driving (*M* = 27.47mph, *SD* = 3.06) first (see Figure 33). This interaction also was present in accelerator actuation, *F*(1, 24) = 10.021, *p* = .004, f = .65. Drivers experiencing the non-cued Experiment 1 first demonstrated less use of the throttle whether under cued (M = 9.99, SD = 1.90) or non-cued (M = 9.60, SD = 1.83) conditions. Those experiencing the cued Experiment 2 first used the accelerator more under both cued (M = 10.22, SD = 1.62) and non-cued (M = 10.69, SD = 2.00) conditions. No similar trend in this interaction was present in braking, $F(1, 24) = 2.595$, $p = .120$, f = .33.

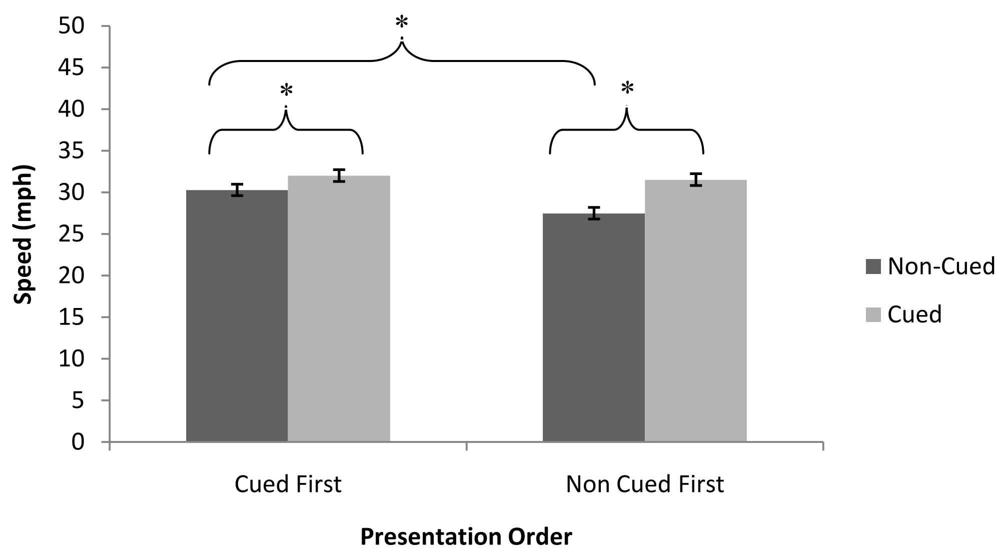

Figure 33. Speed by presentation order. Asterisks indicate a difference at p = .05.

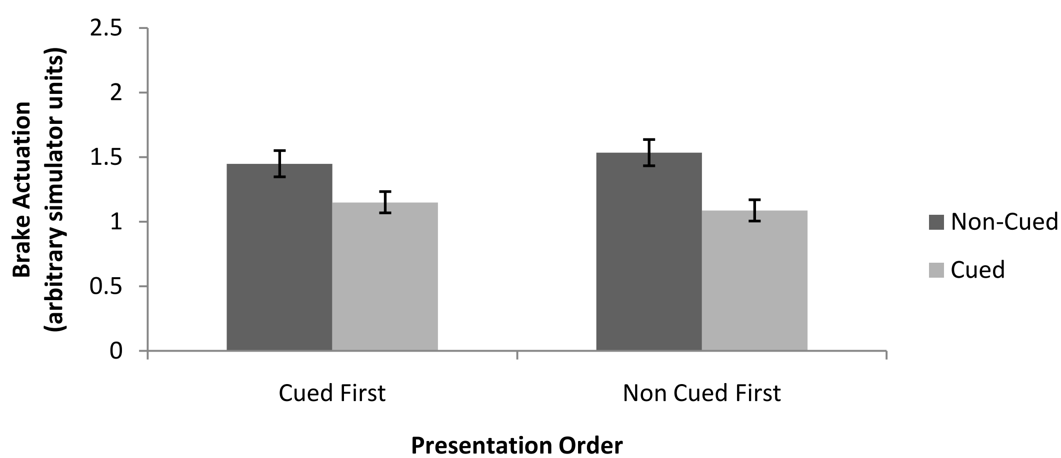

Figure 34. Brake actuation by presentation order.

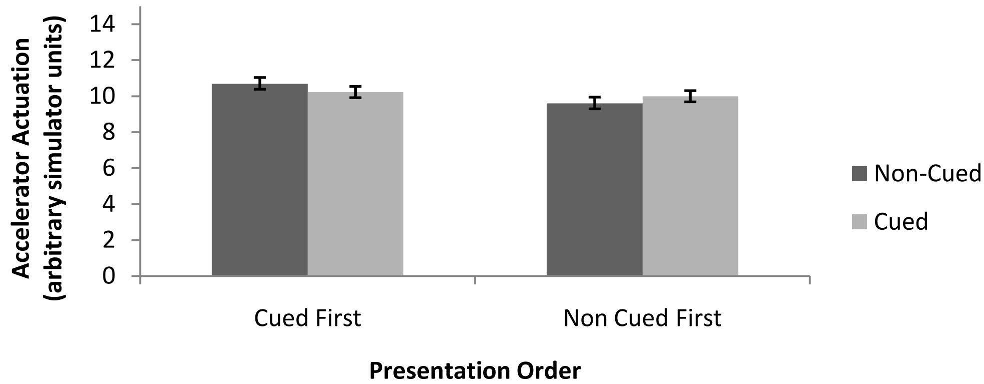

Figure 35. Accelerator actuation by presentation order.

Table 7. Driver measures by presentation order and cueing status

Presentation Order	Cueing	Variable	Mean	SD
Cued First	Non-Cued	Speed	30.28	4.56
		Braking	1.45	0.47
		Acceleration	10.69	2.00
	Cued	Speed	32.00	3.72
		Braking	1.15	0.25
		Acceleration	10.22	1.62
Non Cued First	Non-Cued	Speed	27.47	3.06
		Braking	1.53	0.66
		Acceleration	9.60	1.83
	Cued	Speed	31.52	4.30
		Braking	1.09	0.61
		Acceleration	9.99	1.90

Note: Speed is given in mph, braking and acceleration figures are actuation measures and arbitrary to the simulator.

Summary of Experiment Two

Partial support for the second hypothesis was obtained. This was evident in the objective data recorded from drivers. Although no clear trends emerged from the mental workload data, a direct increase in the amounts of and variability in objective measures of driver behavior provides partial supports Hypothesis 2.

CHAPTER SIX: GENERAL DISCUSSION

The results from the first experiment provide a degree of support for the hypothesis that hysteresis effects occur in driving. Of the possibilities present in transitions of mental workload (illustrated in Figure 36), the obtained data portrays a scenario between a moderate and strong hysteresis effect. Although there was a significant drop in perceived mental workload between the interval immediately following the in-vehicle navigation system failure and at the end of the trial, this latter difference was still significantly higher than that observed at the beginning of the trial. Although this effect was observed in every trial, the magnitude of the individual effect did decrease to some degree over the course of the four sequential trials. This could be viewed as participants either habituating to the nature and demands of the task, or that a learning effect occurring.

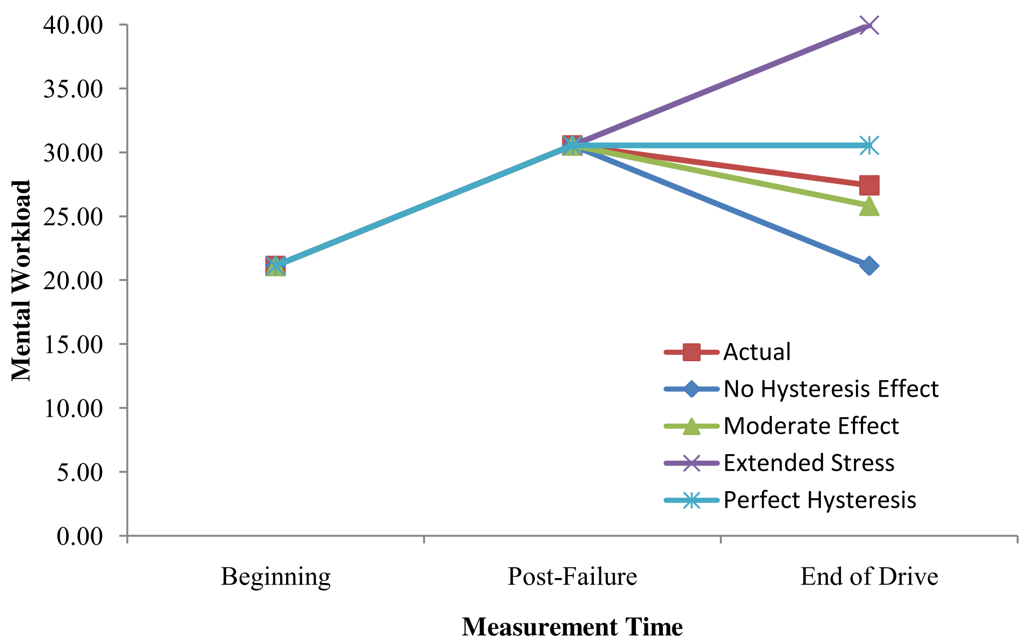

Figure 36. Variations of mental workload across time.

The sex differences present in the mental workload data indicate that females experience a higher degree of perceived mental workload in relation to the task than their male counterparts. Females reported significantly higher scores on every facet of the S-SWAT. However, this may be due to implicit gender differences (such as those observed by Hancock, 1989), or through some other factor such as boredom in the task (Hancock & Warm, 1989; Hancock, Vercruyssen, & Rodenburg, 1992). However, it is also a possibility that females were either more forthcoming in reporting their actual levels of psychological stress, time demand, and mental effort, or that males were performing some form of self-censoring (Williams, Satterwhite, & Best, 1999).

Interestingly, no significant differences between the sexes were present in the objective measures of driving (*i.e.*, speed, brake and accelerator actuation). Although it could be argued that males drive differently than females (Storie, 1977, Mannering, 1993), this difference is likely due to factors such as an increased likelihood of males driving at times and conditions involving a higher degree of risk (Deffenbacher, 2008), or in more aggressively in general (Hennessy, Wiesenthal, Wickens, & Lustman, 2004). As described by Evans (1991), there is a known difference between the sexes in terms of accident involvement. However, this relationship is not straightforward, as questions about what the exact cause of these differences are remain (Hancock & Manser, 1997). However, in the present study, no significant differences were present between the sexes in the objective driving metrics, an observation which parallels the findings of earlier work performed by Hancock, Kane, Scallen, & Albinson (2002).

The general decrease in mean mental workload across trials is not entirely unexpected. Although there was a rapid decrease in global scores from trial one (M = 32.54, SD = 7.12) to trial three (M = 22.10, SD = 5.70), the change between trial three and four (M = 21.53, SD = 5.72) was not significant. This general form of transition is indicative of a learning effect, or habituation to the task. As the participants completed each trial they became more familiar with the routine which was required of them, more familiar with the driving simulator and navigation system, and more familiar with reporting data for the S-SWAT. These results seemingly demonstrate an effect such as learning or habituation to the task rather than a floor effect, per se, partially due to the regular temporal characteristics of the trials (see Scerbo, Warm, & Fisk, 1987). It is likely that any hypothetical subsequent trials would thus show very little variation from trials three and four.

The changes present within the mental workload data within the trials are supportive of the hypothesis that a hysteresis effect is present within the driving task. The sharp increase in perceived mental workload observed from the first measurement period to the second, followed by only a slight (non-significant) decrease from the second measurement period to the end of the drive, supports hysteresis as described by Farrell (1999). The form of this inverted-U shaped mental workload function is not entirely unlike those observed by previous researchers examining hysteresis effects (Chamberlain, 1968; Cumming & Croft, 1973; Golberg & Stewart, 1980) and workload transitions in more elaborate tasks such as ATC scenarios (Smolensky, 1990; Hancock, Williams, Manning, & Miyake, 1995).

The variations in the individual facets of the S-SWAT indicated that perceived levels of time demand and mental effort were statistically equivalent within the trials. These two facets of the scale were both observed to be higher than the reported levels of stress within trials, however only the difference between mental effort and stress was significant. This does not seem to indicate any sharp differentiation between the S-SWAT and SWAT's conceptualization of workload for this particular driving task. Although the individual subscales of the multidimensional S-SWAT was of particular interest in this study, it appears that any subsequent investigations could likely use a unidimensional scale of workload which should prove more sensitive to finer variations within the task (Hendy, Hamilton, & Landry, 1993; De Waard, 1996).

Driver measures also demonstrated a hysteretic effect within trials. Although speed increased significantly from pre-failure to the second measurement period (immediately post-failure), this difference is explained by the nature and demands of the driving task. Lower speeds were required in the beginning of the drive than in the middle due to the initial turns out of the parking lot from which the drivers began their journey. This makes speed a problematic measure for hysteresis here, although it still provides a good overall measure of compliance with the instructions of the driving task as participants were instructed to drive normally and at the posted speed. The fact that participants did not show an even speed across trials indicates they were compliant with the task instructions. Brake actuation, as a measure of longitudinal control, provides a more comprehensive view of this effect (Stanton, Young, Walker, Turner, & Randle, 2001; Verwey, 2001). The mean level of brake actuation increased after the navigation system failure and remained high throughout the drive. This hysteretic effect is also demonstrated by the increases in the variance observed in braking. Brake actuation standard deviation increased from the point of failure and remained high through the end of the drive.

In the second experiment the hypothesis was examined that cueing to an impending period of higher task demand could reduce the magnitude of hysteretic effects. In order to most efficiently and effectively accomplish this, and due to pragmatic concerns, a combination of within subjects designs was chosen. The order of presentation between these two experiments was counterbalanced, allowing for the assessment of order effects. Although the omnibus ANOVAs for order effects in the mental workload and driving data was not significant, a significant order of experiment by cueing interaction was present within the driving data and the obtained measures of driver performance. Thus the starting point for drivers' experience with cueing in this study was a major determinant of how cueing impacted their performance and subjective ratings of the workload involved with the task.

No significant differences were present in mental workload data in response to cued versus non-cued conditions. No significant variations in the individual scales of the S-SWAT were observed in cued versus non-cued conditions. Only slight and non-significant reductions in time demand and mental effort were observed due to cueing. This is not entirely unexpected, as cueing has a rather complex relationship to task performance (Hawkins, Hillard, Luck, Mouloua, Downing, & Woodward, 1990; Luck, Hillyard, Mouloua, & Hawkins, 1996). In fact, this relationship between cueing and performance seems to suggest that the process operates on a perceptual levels instead of a memory/cognitive level (Luck, Hillyard, Mouloua, Woldorff, Clark, & Hawkins, 1994). However, the lack of support for the cueing-hysteresis hypothesis does provide additional support for Smolensky's (1990) idea of a Short Term Memory overload as the hysteretic mechanism.

Of the two theorized mechanisms of the hysteresis effect (continuity of expectations and Short Term Memory overload), the presence of a cueing factor in hysteresis would provide clearer evidence for the expectancies mechanism. Drivers able to follow a cue would be able to shift their operating strategies in response to shifts in task demand, remaining in an optimal strategy and eliminating hysteretic effects. This effect was not observed in the present study; the expectancies hypothesis is thus not supported by the present results. One possible source of evidence supporting this mechanism is explanation for this phenomena is that an effect of insensitivity to subsequent task performance was observed after the driver switched from the primary task of vehicle operations to the secondary task of operating the navigational system. Perhaps the drivers in the present study were simply unable to perform the resource allocation shift required to maintain task performance (Navon & Gopher, 1979) and the shift in perceived mental workload is in reaction to this.

The differences in driver measures due to cueing is illustrative. Drivers in this study traveled significantly faster in cued versus non-cued conditions. It is likely that drivers were able to travel faster due to the reduction in uncertainty associated with cueing to possible failures in their navigation device. This idea gains further support when the braking actuation results are examined in detail. Drivers in the non-cued conditions required significantly higher brake actuation magnitude than when they were driving under cued conditions. Furthermore, the brake actuation variance observed in non-cued conditions was significantly greater than that under cued driving. In these driving scenarios, cueing was able to reduce the demands on the drivers and allow them to control their automobile in a more constant and consistent manner.

The interaction between administration order and cueing present in this data presents an interesting scenario. Under non-cued conditions, drivers reported statistically equivalent mental workload regardless of whether they began the two experiments with cued or non-cued driving. However, under cued driving those who had experienced non-cued driving first benefitted more from the cueing. The benefit (in terms of reduced mental workload) that drivers obtained from cueing was strongest if it was introduced after they had experienced driving without the cue.

This interaction held for the measures of driver performance as well. The measures of speed obtained demonstrated that drivers traveled at equal speed under cued conditions, regardless of which experiment they began driving in. However, driving under non-cued conditions produced higher speeds for those who had experienced cueing first. The measures of accelerator actuation indicated that drivers who experienced cueing first provided more throttle inputs to the vehicle in both cued and non-cued conditions. Drivers who had experienced the non-cued driving first applied the throttle less. Thus benefits from cueing were obtained in terms of more consistent performance, even after the cueing ceased.

Although there was no significant effect for cueing on perceived mental workload, the measured aspects of driver performance were significant. Additionally, the data within the interaction between the order which the participants experienced cueing and mental workload and driver performance indicates that cueing may provide some benefit to drivers. Perhaps this observed effect is a operating as a process of expectancy (Vroom, 1964). Drivers expectations of events following the cue, and the associated change in self-reported measures of workload associated with these, would act as the primary explanatory factor of performance after each driver received the cue's information. Although the hypothesis that cueing will eliminate (or at least lessen the magnitude of) the hysteresis effect in driving was not supported, the results provides evidence that cueing may have some relationship to workload history effects.

This may be viewed as partial support for the hypothesis that hysteresis operates through a process of overloading short term memory. The overall reduction in both objective and subjective measures observed in the first experiment support this, and the lag in subjective workload scores returning to nominal (pre-failure) levels is the reaction to the overloading of the participant's available capacity (as described by Kahneman, 1973). Likewise, the increase in magnitude of braking actuations is an objective manifestation of this process of demand exceeding capacity. Although others (Smolensky, 1990) did not find clear support for the idea that hysteresis is a process of exceeding the capacity of an individual's short term memory (see

Goldberg & Stewart, 1980), the findings of the present experiment do lend some support to the hypothesis.

One clear parallel to the idea of hysteresis as a process of short term memory overload, and one that perhaps influenced Goldberg and Stewart's hypothesis, is Norman and Bobrow's (1975) resource allocation theory. The idea of various programs competing for finite cognitive resources allows for either data- or resource-limited processes. Most tasks shift from resource-limited at an early stage to data-limited in later stages (Norman & Bobrow, 1975; and see Kantowitz & Knight, 1976). The short term memory hypothesis of hysteresis appears to illustrate the transitional period as a task moves from resource- to data-limited, and returns to resource-limited operation. Although Norman and Bobrow illustrate the unidirectional shift in terms of the performance-resource function, the reverse direction of this function is likely hysteretic. This transition may also be viewed as a shift between a prospective and retrospective processing of time (Michon & Jackson, 1985). As the drivers in this task were transitioning from the attentionally driven prospective judgments to memory-driven retrospective processing (Block & Zakay, 1997), the conversion from one resource to another is a lagged transition.

CHAPTER SEVEN: PRACTICAL IMPLICATIONS, SUMMARY, AND CONCLUSIONS

The question of what effects technology in the vehicle has on mental workload is a common one (Michon, 1993, Verwey, 1993). This may well be anticipated since technology almost always brings along questions of the impact on the human (Hancock, 1997). One salient example that has been incorporated into modern thinking is that of the Luddites in 19th century Britain seeking to avoid employment losses from technologies (Binfield, 2004). Although the advent of more modern in-vehicle technologies such as GPS, cellular telephones, and other entertainment and information systems have raised many questions about their safe usage during driving, specific questioning regarding the effect of new technologies on driver performance are nothing new. Windshield wipers and radios faced similar questioning regarding their distraction potential with their introduction to automobiles.

What has changed, however, is the nature by which people interact with these systems. Whereas windshield wipers require infrequent input from the driver and radios are a unidirectional form of communication, a navigation system constantly demands eye fixation time from the driver. The cellular telephone not only asks for eye fixations, but also fine motor control (See Fitts, 1954) and cognitive processing. In terms of Michon's Model (1985), the strategy and maneuvering levels are receiving interference from technology. This presents a potentially dangerous situation, as is demonstrated by the increasing number of roadway accidents attributed to driver distraction (Klauer, Dingus, Neale, Sudweeks, & Ramsey, 2006).

Therefore, it becomes ever more important to understand the nature of perceived mental workload which is associated with these tasks. Any reduction in overall capacity as a result increases in driver mental workload due to technology-related factors may have serious consequences for the driver (DeWaard, 1996; Kantowitz, 1992, Wierwille & Eggemeier, 1993). If increased task demands (presented by the introduction of new in-vehicle technologies) coupled with an overall decrease in driver cognitive capacities (again, presented by the introduction of new in-vehicle technologies) negatively impacts roadway safety, then it follows logically that a better understanding workload transitions in these situations would prove beneficial. In fact, many automakers have attempted to define levels of workload associated with the use of these systems within vehicles. These systems are being examined for the immediate impact on levels of driver workload (see Angell et al., 2006). However, an understanding of the impact in terms of the immediate past history of the individual driver's mental workload has not been accounted for.

The presence of a hysteretic-type workload transition in the studies described show that the history of task demand most likely has a strong effect on driver spare capacity well after the reduction in demand. Although these studies were conducted in a simulation environment, it is reasonably most likely safe to assume that the results extrapolate to the actual roadway environment. Cueing findings indicate that workload management systems (Green, 2004) which control the timing of non-essential messages presented to the driver may serve a beneficial role in reducing hysteresis and any accompanying reduction in capacity. These results also point to the necessity of future research in this domain, including further examinations of the impact of more varied levels of task demand and scenarios.

The presence of hysteresis effects in driving also raises interesting questions in regards to resource theories (Kahneman, 1973; Navon & Gopher, 1979; Wickens, 1980). These theories (especially Wickens's Multiple Resource Theory) posit a mechanism of inputs, processing, and outputs where demand is modulated by the relationship of task to response modality. Although some research has pointed out that emotional states may also serve as a modulating factor in this relationship (Hancock, Szalma, & Oron-Gilad, 2005), hyteresis implies that context and history also serve as a controlling variable. The constraints hysteresis places on Multiple Resource Theory would likely restrict encoding and central processing, explaining the increased variability and negative impacts seen in driver performance during the present study.

A way to examine the impacts of hysteresis on safety is by viewing hysteresis in the larger framework of Gibson and Crooks's *field of safe travel* (1938). As Gibson and Crooks discussed, when the driver travels along the roadway a spatial-temporal area in which (relative) levels of safe vehicular travel is assumed is present (and see Hancock & Diaz, 2002). The driver adjusts this spatiotemporal field as he or she travels, with factors such as traffic, speed, and uncertainty serving to either expand or constrict the field. Hysteresis may provide further definition of how drivers are dynamically defining their field of safe travel. The current context of driving (through uncertainty) serves to constrain the field. However, the history of the driver's field of safe travel should also moderate the current state of the field. If a driver travels through a series of intersections and then onto a clear and wide roadway, hysteresis should continue to constrain their field of safe travel for some time. Likewise, a driver traveling from a clear and open roadway into a series of intersections may be consciously aware of the shift in environment, however a lagging shift may be present in their operation strategy. Thus, their field of safe travel would remain inappropriately large. This leads to a scenario

One salient example of where a better understanding of hysteresis effects in driving safety is the need to better understand how drivers process information from displays which are becoming increasingly prevalent in modern vehicles (commercial and otherwise). These displays are taking the form of GPS-linked navigation systems, messaging and phone system, and secondary control systems (such as the BMW iDrive system). To some extent these systems have been explored in terms of impact on the driver (Verwey, 1993). Additionally, systems such as Generic Intelligent Driver Support (GIDS; Michon, 1993) attempt to mitigate the task demand placed upon the driver by controlling the sequencing and presentation of information to drivers based on the context of the driving task. Understanding context is of great importance in presenting information to drivers in a less taxing manner. These systems must carry context forward with the understanding that the human has a memory for not only bits of information, but also for the workload associated with their use combined with the task of safely controlling the vehicle.

Therefore it is imperative that future systems include some manner of accommodating the immediate past as well as the immediate present demands from the driver. Such systems can provide cognitive load-leveling for the driver and allow for the accommodated by scaling information presentation to not only the immediate temporal demands (a driver traveling through New York City while talking on a mobile phone), but also the history of the drive (a driver traveling through New York City while talking on a mobile phone who had just made an emergency avoidance maneuver to avoid a pedestrian).

Thus my recommendations for advanced designs for modern driving cognitive load-leveling technologies are as follows:

- Account for the immediate past history when adjusting for driving context
- Reduce message transmission rate after a high demand situation
- Provide highly reliable cues to upcoming high demand situations

It appears that hysteresis effects are present in the driving task, very similar in form to those described by Cumming and Croft (1973), Goldberg and Stewart (1980), Farrell (1999), and others in tasks restricted to more direct forms of human information processing. This has interest to a wide range of topics within surface transportation, from those dealing directly with the driver as an information processor to broader questions about safety. Future research and applications seeking to better understand the impact that contextual history has on driver mental workload and performance should have an immediate and direct impact on the overall safety and efficiency of surface transportation.

APPENDIX A: DRIVER COPING QUESTIONNAIRE

DCQ

These questions are concerned with how you usually deal with driving when it is difficult, stressful or upsetting. Think of those occasions during the last year when driving was particularly stressful. Perhaps you nearly had an accident, or you were stuck in a traffic jam, or you had to drive for a long time in poor visibility and heavy traffic. Use your experiences of driving during the last year to indicate how much you usually engage in the following activities when driving is difficult, stressful or upsetting, by CIRCLING one of the numbers from 0 to 5 to the right of each question.

	Not at all					Very much
1. Relieved my feelings by taking risks or driving fast	0	1	2	3	4	5
2. Cheered myself up by thinking about things unrelated to the drive	0	1	2	3	4	5
3. Stayed detached or distanced from the situation	0	1	2	3	4	5
4. Tried to make other drivers more aware of me by driving close behind them	0	1	2	3	4	5
5. Wished that I was a more confident and forceful driver	0	1	2	3	4	5
6. Ignored my feelings about the drive	0	1	2	3	4	5
7. Made sure I avoided reckless or impulsive actions	0	1	2	3	4	5
8. Showed other drivers what I thought of them	0	1	2	3	4	5
9. Drove assertively or aggressively	0	1	2	3	4	5
10. Tried to gain something worthwhile from the drive	0	1	2	3	4	5
11. Showed other drivers I was in control of the situation	0	1	2	3	4	5
12. Made an extra effort to drive safely	0	1	2	3	4	5
13. Felt that I was becoming a more experienced driver	0	1	2	3	4	5
14. Made an effort to stay calm and relaxed	0	1	2	3	4	5
15. Swore at other drivers (aloud or silently)	0	1	2	3	4	5
16. Thought about good times I've had	0	1	2	3	4	5
17. Wished that I found driving more enjoyable	0	1	2	3	4	5
18. Made sure I kept a safe distance from the car in front	0	1	2	3	4	5
19. Went on as if nothing had happened	0	1	2	3	4	5
20. Refused to believe that anything unpleasant had happened	0	1	2	3	4	5
21. Told myself there wasn't really any problem	0	1	2	3	4	5
22. Let other drivers know they were at fault	0	1	2	3	4	5
23. Criticized myself for not driving better	0	1	2	3	4	5
24. Thought about the consequences of having an accident	0	1	2	3	4	5
25. Flashed the car lights or used the horn in anger	0	1	2	3	4	5
26. Felt I was learning how to cope with stress	0	1	2	3	4	5
27. Deliberately slowed down when I met a difficult traffic situation or bad weather	0	1	2	3	4	5
28. Made a special effort to look out for hazards	0	1	2	3	4	5
29. Blamed myself for getting too emotional or upset	0	1	2	3	4	5
30. Concentrated hard on what I had to do next	0	1	2	3	4	5
31. Worried about what I was going to do next	0	1	2	3	4	5
32. Looked on the drive as a useful experience	0	1	2	3	4	5
33. Worried about my shortcomings as a driver	0	1	2	3	4	5
34. Thought about the benefits I would get from making the journey	0	1	2	3	4	5
35. Learnt from my mistakes	0	1	2	3	4	5

APPENDIX B: DRIVER STRESS INVENTORY

DSI

Office use only

Please check one box only unless otherwise indicated (do not write in boxes at right margin).

Section A

1. Please state your age in years: ___________

2. Please state your gender: Male ☐ Female ☐

3. What is your highest educational qualification?___________________________________

4. Please state your occupation:______________________________

5. Please state the year when you obtained your full driving license: 19____

6. About how often do you drive nowadays?
Everyday ☐ 2-3 days a week ☐ About once a week ☐ Less often ☐

7. Estimate roughly how many miles you personally have driven in the past year:
Less than 5000 miles ☐ 5000-10,000 miles ☐ 10,000-15,000 miles ☐
15,000-20,000 miles ☐ Over 20,000 miles ☐

8. Do you drive to and from your place of work?
Everyday ☐ Most days ☐ Occasionally ☐ Never ☐

9. Please state which of these types of road you use frequently (check one or more boxes as appropriate):
Freeways ☐ Other main roads ☐ Urban roads ☐ Country roads ☐

10. During the last three years, how many minor road accidents have you been involved in?
(A minor accident is one in which no-one required medical treatment, AND costs of damage to vehicles and property were less than $800).

Number of minor accidents ____ (if none, write 0)

11. During the last three years, how many major road accidents have you been involved in?
(A major accident is one in which EITHER someone required medical treatment, OR costs of damage to vehicles and property were greater than $800, or both).

Number of major accidents ____ (if none, write 0)

12. During the last three years, have you ever been convicted for:

(a) Speeding — Yes ☐ No ☐

(b) Careless or dangerous driving — Yes ☐ No ☐

(c) Driving under influence of alcohol or drugs — Yes ☐ No ☐

(d) Other moving violation - please specify: ________________________ — Yes ☐ No ☐

Section B

Please answer the following questions on the basis of your usual or typical feelings about driving. Each question asks you to answer according to how strongly you agree with one or other of two alternative answers. Please read each of the two alternatives carefully before answering. To answer, mark the horizontal line at the point which expresses your answer most accurately. Be sure to answer all the questions, even if some of them don't seem to apply to you very well: guess as best you can if need be.

Example: Are you a confident driver?

The more confident you are, the closer to the 'very much' alternative you should mark your cross. If you are quite a confident driver you would mark it like this:

not at all 0 1 2 3 4 5 6 7 8 9 10 very much

1. Does it worry you to drive in bad weather?

very much 0 1 2 3 4 5 6 7 8 9 10 not at all

2. I am disturbed by thoughts of having an accident or the car breaking down

very rarely 0 1 2 3 4 5 6 7 8 9 10 very often

3. Do you lose your temper when another driver does something silly?

not at all 0 1 2 3 4 5 6 7 8 9 10 very much

4. Do you think you have enough experience and training to deal with risky situations on the road safely?

not at all 0 1 2 3 4 5 6 7 8 9 10 very much

5. I find myself worrying about my mistakes and the things I do badly when driving

very rarely 0 1 2 3 4 5 6 7 8 9 10 very often

6. I would like to risk my life as a racing driver

not at all 0 1 2 3 4 5 6 7 8 9 10 very much

7. My driving would be worse than usual in an unfamiliar rental car

not at all 0 1 2 3 4 5 6 7 8 9 10 very much

8. I sometimes like to frighten myself a little while driving

very much 0 1 2 3 4 5 6 7 8 9 10 not at all

9. I get a real thrill out of driving fast

very much 0 1 2 3 4 5 6 7 8 9 10 not at all

10. I make a point of carefully checking every side road I pass for emerging vehicles

very much 0 1 2 3 4 5 6 7 8 9 10 not at all

11. Driving brings out the worst in people

not at all 0 1 2 3 4 5 6 7 8 9 10 very much

12. Do you think it is worthwhile taking risks on the road?

very much 0 1 2 3 4 5 6 7 8 9 10 not at all

13. At times, I feel like I really dislike other drivers who cause problems for me

very much 0 1 2 3 4 5 6 7 8 9 10 not at all

14. Advice on driving from a passenger is generally:

useful 0 1 2 3 4 5 6 7 8 9 10 unnecessary

15. I like to raise my adrenaline levels while driving

not at all 0 1 2 3 4 5 6 7 8 9 10 very much

16. It's important to show other drivers that they can't take advantage of you

not at all 0 1 2 3 4 5 6 7 8 9 10 very much ☐☐

17. Do you feel confident in your ability to avoid an accident?

not at all 0 1 2 3 4 5 6 7 8 9 10 very much ☐☐

18. Do you usually make an effort to look for potential hazards when driving?

not at all 0 1 2 3 4 5 6 7 8 9 10 very much ☐☐

19. Other drivers are generally to blame for any difficulties I have on the road

not at all 0 1 2 3 4 5 6 7 8 9 10 very much ☐☐

20. I would enjoy driving a sports car on a road with no speed-limit

very much 0 1 2 3 4 5 6 7 8 9 10 not at all ☐☐

21. Do you find it difficult to control your temper when driving?

very much 0 1 2 3 4 5 6 7 8 9 10 not at all ☐☐

22. When driving on an unfamiliar road do you become more tense than usual?

very much 0 1 2 3 4 5 6 7 8 9 10 not at all ☐☐

23. I make a special effort to be alert even on roads I know well

very much 0 1 2 3 4 5 6 7 8 9 10 not at all ☐☐

24. I enjoy the sensation of accelerating rapidly

not at all 0 1 2 3 4 5 6 7 8 9 10 very much ☐☐

25. If I make a minor mistake when driving, I feel it's something I should be concerned about

very much 0 1 2 3 4 5 6 7 8 9 10 not at all ☐☐

26. I always keep an eye on parked cars in case somebody gets out of them, or there are pedestrians behind them

not at all 0 1 2 3 4 5 6 7 8 9 10 very much ☐☐

27. I feel more anxious than usual when I have a passenger in the car

not at all 0 1 2 3 4 5 6 7 8 9 10 very much ☐☐

28. I become annoyed if another car follows very close behind mine for some distance

very much 0 1 2 3 4 5 6 7 8 9 10 not at all ☐☐

29. I make an effort to see what's happening on the road a long way ahead of me

not at all 0 1 2 3 4 5 6 7 8 9 10 very much ☐☐

30. I try very hard to look out for hazards even when it's not strictly necessary

not at all 0 1 2 3 4 5 6 7 8 9 10 very much ☐☐

31. Are you usually patient during the rush hour?

very much 0 1 2 3 4 5 6 7 8 9 10 not at all ☐☐

32. When you pass another vehicle do you feel in command of the situation?

not at all 0 1 2 3 4 5 6 7 8 9 10 very much ☐☐

33. When you pass another vehicle do you feel tense or nervous?

not at all 0 1 2 3 4 5 6 7 8 9 10 very much ☐☐

34. Does it annoy you to drive behind a slow moving vehicle?

very much 0 1 2 3 4 5 6 7 8 9 10 not at all ☐☐

35. When you're in a hurry, other drivers usually get in your way

not at all 0 1 2 3 4 5 6 7 8 9 10 very much

36. When I come to negotiate a difficult stretch of road, I am on the alert

very much 0 1 2 3 4 5 6 7 8 9 10 not at all

37. Do you feel more anxious than usual when driving in heavy traffic?

not at all 0 1 2 3 4 5 6 7 8 9 10 very much

38. I enjoy cornering at high speed

not at all 0 1 2 3 4 5 6 7 8 9 10 very much

39. Are you annoyed when the traffic lights change to red when you approach them?

very much 0 1 2 3 4 5 6 7 8 9 10 not at all

40. Does driving <u>usually</u> make you feel aggressive?

very much 0 1 2 3 4 5 6 7 8 9 10 not at all

41. Think about how you feel when you have to drive for several hours, with few or no breaks from driving. How do your feelings <u>change</u> during the course of the drive?

a)	More uncomfortable physically (e.g. headache or muscle pains)	0 1 2 3 4 5 6 7 8 9 10	No change
b)	More drowsy or sleepy	0 1 2 3 4 5 6 7 8 9 10	No change
c)	Maintain speed of reaction	0 1 2 3 4 5 6 7 8 9 10	Reactions to other traffic increasingly slow
d)	Maintain attention to road-signs	0 1 2 3 4 5 6 7 8 9 10	Become increasingly inattentive to road-signs
e)	Normal vision	0 1 2 3 4 5 6 7 8 9 10	Your vision becomes less clear
f)	Increasingly difficult to judge your speed	0 1 2 3 4 5 6 7 8 9 10	Normal judgement of speed
g)	Interest in driving does not change	0 1 2 3 4 5 6 7 8 9 10	Increasingly bored and fed-up
h)	Passing becomes increasingly risky and dangerous	0 1 2 3 4 5 6 7 8 9 10	No change

Office use only a) b) c) d) e) f) g) h)

APPENDIX C: SIMULATOR SICKNESS QUESTIONNAIRE

Simulator Sickness Questionnaire (SSQ)

Developed by Robert S. Kennedy & colleagues under various projects. For additional information contact:
Robert S. Kennedy, RSK Assessments, Inc., 1040 Woodcock Road, Suite 227, Orlando, FL 32803 (407) 894-5090

Subject Number: _______ Date: __________

PRE-EXPOSURE BACKGROUND INFORMATION

1. How long has it been since your last exposure in a simulator? ______ days
   How long has it been since your last flight in an aircraft? _______ days
   How long has it been since your last voyage at sea? _______ days
   How long has it been since your last exposure in a virtual environment? _______ days
2. What other experience have you had recently in a device with unusual motion?
3. How old are you? __________ years
4. What is your gender? (circle one) MALE FEMALE

PRE-EXPOSURE PHYSIOLOGICAL STATUS INFORMATION

3. Are you in your usual state of fitness? (Circle one) YES NO
   If not, please indicate the reason:

4. Have you been ill in the past week? (Circle one) YES NO
   If "Yes", please indicate:
   a) The nature of the illness (flu, cold, etc.):
   b) Severity of the illness: Very _______________ Very
      Mild Severe
   c) Length of illness: _______________ Hours / Days
   d) Major symptoms:
   e) Are you fully recovered? YES NO
5. How much alcohol have you consumed during the past 24 hours?
   ____ 12 oz. cans/bottles of beer ____ ounces wine ____ ounces hard liquor
6. Please indicate all medication you have used in the past 24 hours. If none, check the first line:
   a) NONE
   b) Sedatives or tranquilizers
   c) Aspirin, Tylenol, other analgesics
   d) Anti-histamines
   e) Decongestants
   f) Other (specify):
7. a) How many hours of sleep did you get last night? _____ hours
   b) Was this amount sufficient? (Circle one) YES NO
8. Please list any other comments regarding your present physical state which might affect your performance on our test battery.

Baseline (Pre) Exposure Symptom Checklist

Instructions: Please fill this out BEFORE you go into the virtual environment. Circle how much each symptom below is affecting you right now.

#	Symptom	Severity			
1.	General discomfort	None	Slight	Moderate	Severe
2.	Fatigue	None	Slight	Moderate	Severe
3.	Boredom	None	Slight	Moderate	Severe
4.	Drowsiness	None	Slight	Moderate	Severe
5.	Headache	None	Slight	Moderate	Severe
6.	Eye strain	None	Slight	Moderate	Severe
7.	Difficulty focusing	None	Slight	Moderate	Severe
8a.	Salivation increased	None	Slight	Moderate	Severe
8b.	Salivation decreased	None	Slight	Moderate	Severe
9.	Sweating	None	Slight	Moderate	Severe
10.	Nausea	None	Slight	Moderate	Severe
11.	Difficulty concentrating	None	Slight	Moderate	Severe
12.	Mental depression	None	Slight	Moderate	Severe
13.	"Fullness of the head"	None	Slight	Moderate	Severe
14.	Blurred Vision	None	Slight	Moderate	Severe
15a.	Dizziness with eyes open	None	Slight	Moderate	Severe
15b.	Dizziness with eyes closed	None	Slight	Moderate	Severe
16.	*Vertigo	None	Slight	Moderate	Severe
17.	**Visual flashbacks	None	Slight	Moderate	Severe
18.	Faintness	None	Slight	Moderate	Severe
19.	Aware of breathing	None	Slight	Moderate	Severe
20.	***Stomach awareness	None	Slight	Moderate	Severe
21.	Loss of appetite	None	Slight	Moderate	Severe
22.	Increased appetite	None	Slight	Moderate	Severe
23.	Desire to move bowels	None	Slight	Moderate	Severe
24.	Confusion	None	Slight	Moderate	Severe
25.	Burping	None	Slight	Moderate	Severe
26.	Vomiting	None	Slight	Moderate	Severe
27.	Other				

* Vertigo is experienced as loss of orientation with respect to vertical upright.
** Visual illusion of movement or false sensations of movement, when not in the simulator, car, or aircraft.
*** Stomach awareness is usually used to indicate a feeling of discomfort which is just short of nausea.

STOP HERE! The test director will tell you when to continue.

POST 00 Minutes Exposure Symptom Checklist

Instructions: Circle how much each symptom below is affecting you right now.

#	Symptom	Severity			
1.	General discomfort	None	Slight	Moderate	Severe
2.	Fatigue	None	Slight	Moderate	Severe
3.	Boredom	None	Slight	Moderate	Severe
4.	Drowsiness	None	Slight	Moderate	Severe
5.	Headache	None	Slight	Moderate	Severe
6.	Eye strain	None	Slight	Moderate	Severe
7.	Difficulty focusing	None	Slight	Moderate	Severe
8a.	Salivation increased	None	Slight	Moderate	Severe
8b.	Salivation decreased	None	Slight	Moderate	Severe
9.	Sweating	None	Slight	Moderate	Severe
10.	Nausea	None	Slight	Moderate	Severe
11.	Difficulty concentrating	None	Slight	Moderate	Severe
12.	Mental depression	None	Slight	Moderate	Severe
13.	"Fullness of the head"	None	Slight	Moderate	Severe
14.	Blurred Vision	None	Slight	Moderate	Severe
15a.	Dizziness with eyes open	None	Slight	Moderate	Severe
15b.	Dizziness with eyes closed	None	Slight	Moderate	Severe
16.	*Vertigo	None	Slight	Moderate	Severe
17.	**Visual flashbacks	None	Slight	Moderate	Severe
18.	Faintness	None	Slight	Moderate	Severe
19.	Aware of breathing	None	Slight	Moderate	Severe
20.	***Stomach awareness	None	Slight	Moderate	Severe
21.	Loss of appetite	None	Slight	Moderate	Severe
22.	Increased appetite	None	Slight	Moderate	Severe
23.	Desire to move bowels	None	Slight	Moderate	Severe
24.	Confusion	None	Slight	Moderate	Severe
25.	Burping	None	Slight	Moderate	Severe
26.	Vomiting	None	Slight	Moderate	Severe
27.	Other				

* Vertigo is experienced as loss of orientation with respect to vertical upright.
** Visual illusion of movement or false sensations of movement, when not in the simulator, car or aircraft.
*** Stomach awareness is usually used to indicate a feeling of discomfort which is just short of nausea.

POST-EXPOSURE INFORMATION

1. While in the virtual environment, did you get the feeling of motion (i.e., did you experience a compelling sensation of self motion as though you were actually moving)? *(Circle one)*

   YES NO SOMEWHAT

2. On a scale of 1 (POOR) to 10 (EXCELLENT) rate your performance in the virtual environment:

3. a. Did any unusual events occur during your exposure? *(Circle one)* YES NO
   b. If YES, please describe

APPENDIX D: IRB APPROVAL

University of Central Florida

University of Central Florida Institutional Review Board
Office of Research & Commercialization
12201 Research Parkway, Suite 501
Orlando, Florida 32826-3246
Telephone: 407-823-2901, 407-882-2901 or 407-882-2276
www.research.ucf.edu/compliance/irb.html

Notice of Expedited Initial Review and Approval

From : **UCF Institutional Review Board**
FWA00000351, Exp. 5/07/10, IRB00001138

To : **Justin F Morgan**

Date : **July 24, 2007**

IRB Number: **SBE-07-05101**

Study Title: **Driver responses to ambiguous scenarios**

Dear Researcher:

Your research protocol noted above was approved by **expedited** review by the UCF IRB Chair on 7/24/2007. **The expiration date is 7/23/2008.** Your study was determined to be minimal risk for human subjects and expeditable per federal regulations, 45 CFR 46.110. The category for which this study qualifies as expeditable research is as follows:

7. Research on individual or group characteristics or behavior (including, but not limited to, research on perception, cognition, motivation, identity, language, communication, cultural beliefs or practices, and social behavior) or research employing survey, interview, oral history, focus group, program evaluation, human factors evaluation, or quality assurance methodologies.

The IRB has approved a **consent procedure which requires participants to sign consent forms.** Use of the approved, stamped consent document(s) is required. Only approved investigators (or other approved key study personnel) may solicit consent for research participation. Subjects or their representatives must receive a copy of the consent form(s).

All data, which may include signed consent form documents, must be retained in a locked file cabinet for a minimum of three years (six if HIPAA applies) past the completion of this research. Any links to the identification of participants should be maintained on a password-protected computer if electronic information is used. Additional requirements may be imposed by your funding agency, your department, or other entities. Access to data is limited to authorized individuals listed as key study personnel.

To continue this research beyond the expiration date, a Continuing Review Form must be submitted 2 – 4 weeks prior to the expiration date. Advise the IRB if you receive a subpoena for the release of this information, or if a breach of confidentiality occurs. Also report any unanticipated problems or serious adverse events (within 5 working days). Do not make changes to the protocol methodology or consent form before obtaining IRB approval. Changes can be submitted for IRB review using the Addendum/Modification Request Form. An Addendum/Modification Request Form **cannot** be used to extend the approval period of a study. All forms may be completed and submitted online at http://iris.research.ucf.edu .

Failure to provide a continuing review report could lead to study suspension, a loss of funding and/or publication possibilities, or reporting of noncompliance to sponsors or funding agencies. The IRB maintains the authority under 45 CFR 46.110(e) to observe or have a third party observe the consent process and the research.

On behalf of Tracy Dietz, Ph.D., UCF IRB Chair, this letter is signed by:

Signature applied by Janice Turchin on 07/24/2007 11:33:05 AM EDT

Janice M. Turchin

IRB Coordinator

APPENDIX E: DSI-DRIVER HISTORY CORRELATIONS

Intercorrelations between DSI Scores and Driver History

	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.
1. Driving Frequency	--	-.41*	-.01	.14	.10	.02	.42*	-.25	.29	.19
2. Miles Driven Per Year		--	.01	.03	.34	.25	-.21	.04	-.32	.35
3. Minor Accidents			--	.13	.17	.37*	.27	-.18	.18	.08
4. Major Accidents				--	.43*	.13	.27	.05	-.04	-.14
5. Speeding Tickets					--	.18	.08	-.22	-.14	.27
6. Aggression						--	.61**	-.31	.40*	.31
7. Dislike of Driving							--	-.34	.77**	-.07
8. Hazard Monitoring								--	-.34	-.08
9. Fatigue Proneness									--	-.04
10. Thrill Seeking										--

* $p < .05$ (2-tailed), ** $p < .01$ (2-tailed)

APPENDIX F: DCQ-DRIVER HISTORY CORRELATIONS

Intercorrelations between DCQ and Driver History

	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.
1. Driving Frequency	--	-.41*	-.01	.14	.10	-.08	-.02	.25	.01	-.05
2. Miles Driven Per Year		--	.01	.03	.34	.09	-.33	-.17	.00	.31
3. Minor Accidents			--	.13	.17	.45**	-.13	.47**	.30	.14
4. Major Accidents				--	.43*	.06	.09	.25	.13	.17
5. Speeding Tickets					--	.24	-.45**	.10	-.04	.15
6. Confrontive Coping						--	-.44*	.67**	.22	.49**
7. Task Focus							--	-.11	.44*	-.24
8. Emotion Focus								--	.27	.50**
9. Reappraisal									--	.03
10. Avoidance										--

* $p < .05$ (2-tailed), ** $p < .01$ (2-tailed)

APPENDIX G: DRIVER MENTAL WORKLOAD ACROSS BASELINE TRIALS

Introduction

Some researchers have noted an increase in subjective mental workload across periods of time in vigilance type tasks. For instance, Dember, Warm, Nelson, Simons, Hancock, & Gluckman (1993) found a 3.2 unit increase in subjective rating of mental workload (using the NASA TLX) over every 10 minutes on watch. Other researchers have noted similar positive-leading trends in subscales of the NASA TLX (Szalma, Warm, Matthews, Dember, Weiler, Meier, & Eggemeier, 2004). The presence of such effects in certain tasks necesate the examination of driver's mental workload across basal tasks, especially since driving across extended periods may lead to the drop in task performance characteristic of vigilance decrements (Davies & Parasuraman, 1982).

In order to test for such an effect, 10 drivers from the University of Central Florida's undergraduate student population served as participants in this study. The 5 males had an average age of 19.0 years (*SD* = 0.7) and had held their driver's license 3.8 years on average (*SD* = 0.84). The 5 females in the study had an average age of 20.2 years (*SD* = 1.3) and had held their driver's license 4.2 years on average (*SD* = 1.1). The experimental apparatus described in Experiments 1 and 2 was used, with the modification that no failure or cue to possible failure was given via the heads-up display (HUD). Participants completed a series of four trials corresponding to those used in Experiment 2. Subjective measures of mental workload (using the S-SWAT) were recorded at the same points within the drive as used in Experiment 2.

Results

A repeated measures Analysis of Variance (ANOVA) was performed on the collected scores. The effect of trial (4), measurement time (3), and scale facet (3) on participants' subjective mental workload was assessed. A significant change in driver's mental workload was observed across trials, $F(3,24) = 3.92$, $p = .02$. This effect was present as a significant decrease in S-SWAT scores across the individual trials (see Table X). No significant effects were present within trials.

Table 8. Repeated Measures ANOVA.

Source	df (Hypothesis)	df (Error)	F	P
Sex	1	8	6.57	< .0005
Workload Across Trials	3	24	3.92	.021
Workload Within Trials	2	16	.916	.420
S-SWAT Subscales	2	16	3.90	.042

Note: N = 10.

Table 9. Cell means and standard deviations for base trials.

Sex	Measure	Mean	SD
Female	Across Trials		
	1	20.42	11.54
	2	14.51	4.11
	3	14.09	5.97
	4	7.11	7.65
	Within Trials		
	1	16.23	12.27
	2	17.62	7.76
	3	8.25	7.83
Male	Across Trials		
	1	28.33	21.36
	2	25.11	17.27
	3	29.73	14.59
	4	25.07	14.07
	Within Trials		
	1	22.30	19.99
	2	29.55	14.59
	3	29.33	22.32

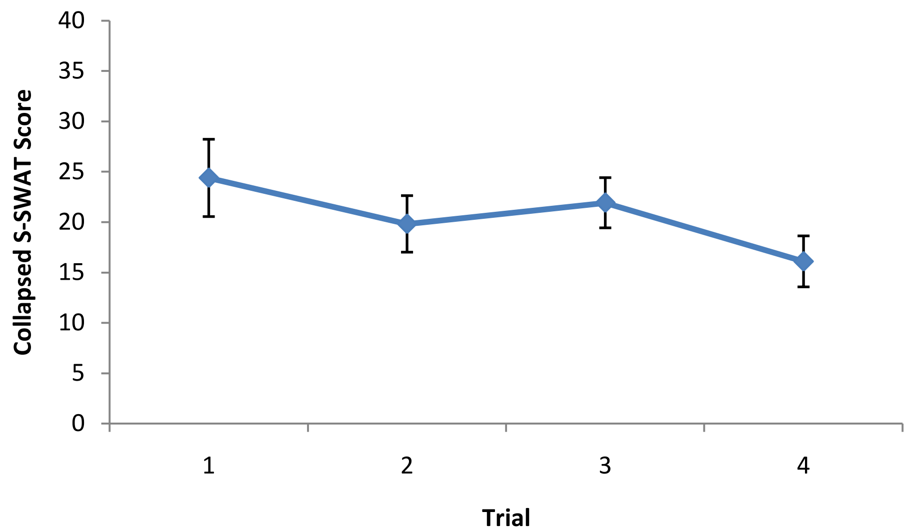

Figure 37. The individual facets of the S-SWAT displayed a similar trend across trials. Error bars represent Standard Error.

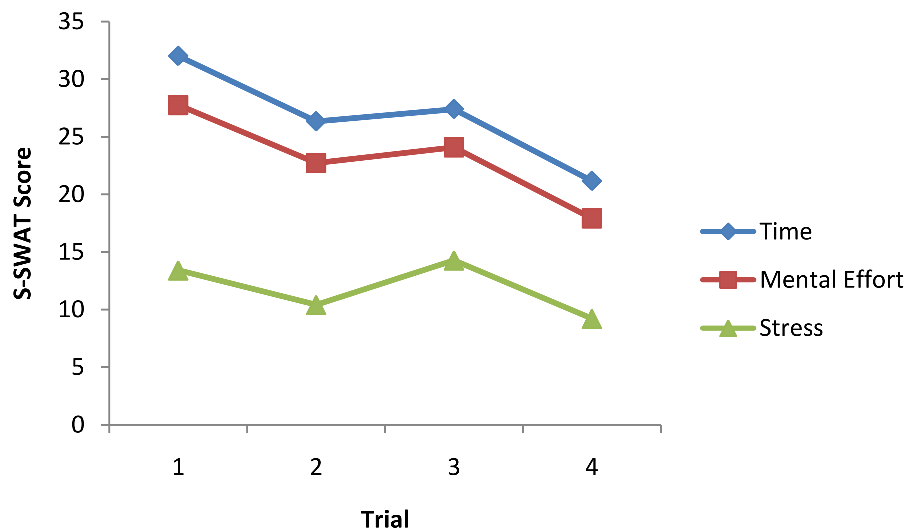

Figure 38. S-SWAT scores across trials.

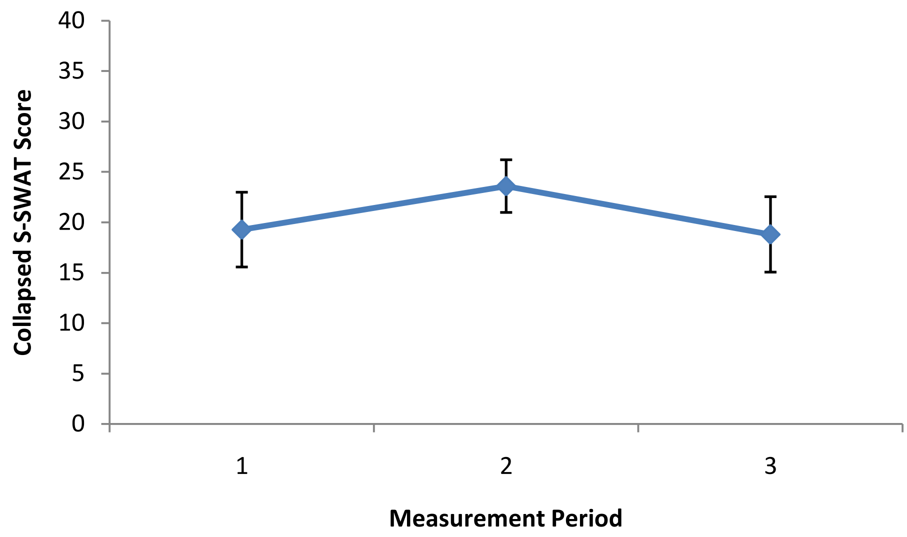

Figure 39. S-SWAT scores within the trials. Error bars represent Standard Error.

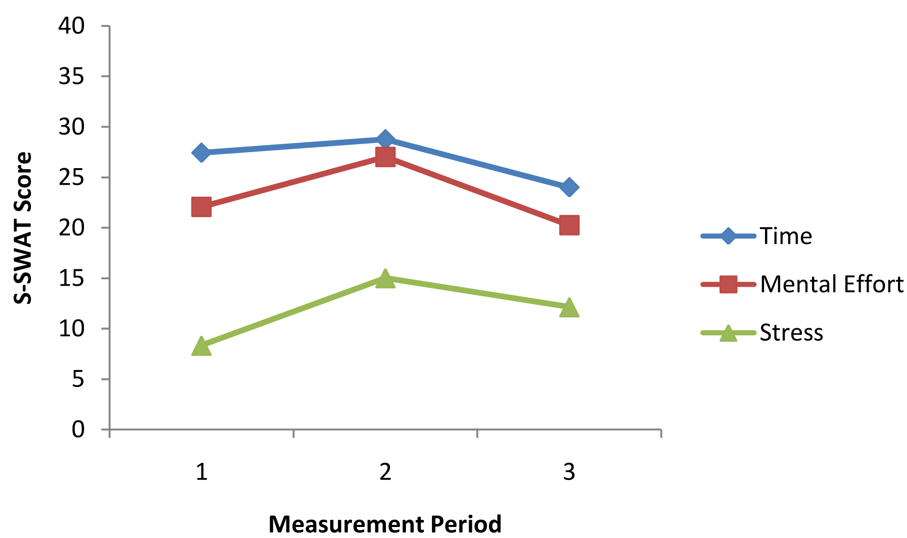

Figure 40. S-SWAT facets within the trials.

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