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The Effects of Body Posture on Vigilance Performance

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THE EFFECTS OF BODY POSTURE ON VIGILIANCE PERFORMANCE

by

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ABSTRACT

THE EFFECTS OF BODY POSTURE ON VIGILANCE PERFORMANCE

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Old Dominion University, 2022
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Drivers of vehicles that use a driving automation system were tasked with supervising the vehicle to ensure it was functioning properly. This task required drivers to stay vigilant of the roadway while being ready to intervene in the case of an unexpected hazard that the driving automation system may not have detected. This study investigated whether reclining a drivers' seatback to more comfortable postures would affect their vigilance performance over time. Vigilance performance was measured by correct detections, false alarms, response sensitivity, response bias, and response time to hazardous events. Forty-five participants were recruited and randomly assigned to a postural condition with a seatback that was upright, slightly reclined, or very reclined. Their performance and comfort were measured over the course of a 40-minute driving task that used SAE Level-2 automation. Participants were tasked with classifying whether the neighboring vehicles were hazardous or safe. Based on our performance measures, we found a vigilance decrement that was potentially caused by cognitive underload stemming from the low task demand. We also found that posture did not affect any of the performance measures and that comfort ratings were similar despite the postural manipulation. This result indicates that drivers of vehicles with a driving automation system are free to adjust their seatback from an upright to very reclined posture without concern for their vigilance performance.

This thesis is dedicated to my family. Thank you, Charlie, Victoria, and Jonathan Ammons, for your love and support.

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NOMENCLATURE

DAS	Driving Automation System
RT	Response Time

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CHAPTER 1

INTRODUCTION

Humans are continuously altering their body posture throughout the course of a day. Many times, our posture will vary depending on the task at hand. Some of the basic body postures include standing up, sitting down, and lying down. There are an extensive number of tasks that require prolonged sedentary behavior. For example, throughout schooling, students are sat at a desk and told to pay attention. Office workers are given a cubical in which they remain seated for most of their shift. Lifeguards typically are sat in a highchair and must survey the pool while on duty. Drivers/pilots are forced to sit when operating their vehicles. While performing these tasks, the individual can choose to sit upright, lean forward, recline, slouch, and so on. The present study explored the transitional period from sitting upright to lying down and sets to determine if performance is affected by some of these varying postures. In addition, as the world continues to evolve into more of an automation-based and computerized society, workers are becoming less reliant on their physical ability, and more reliant on their mental processing of displays for signs of danger, failure, and so on, which require immediate action (See, 2014). The present study specifically focused on the vigilance performance of drivers using a driving automation system (DAS) while manipulating their body postures.

In doing this research, we sought to decrease the number of crashes that are caused by inattention. According to the 2008 National Motor Vehicle Crash Causation Survey, fatigued drivers led to almost 63,000 crashes from 2005-2007 (NHTSA, 2008). When crashes were caused by driver errors, 41% of the crashes were recognition errors caused by inattention, internal distraction, external distraction, inadequate surveillance, and so on. It is of importance to develop ways to combat these driver errors. In addition, drivers have now become even more passive in their role, since the invention of DAS, which can lead to greater inattention (Cunningham & Regan, 2018; Körber et al., 2015; Saxby et al., 2013). Greenlee and colleagues (2018; 2019) found that using a DAS resulted in workload, stress, and performance decrements, which is why they want to make certain vigilance is kept a point of emphasis moving forward with DAS (Greenlee, 2018). In addition, Greenlee and colleagues (2022) found that these decrements are heightened when compared to manual driving. As a result, the present study focused specifically on how drivers using a DAS can potentially reduce the effects of vigilance decrement. This research question was key to explore because reducing vigilance decrement may mitigate the errors and detection failures associated with it, leading to better driving behavior and a safer roadway environment (Campagne et al., 2004; Greenlee et al., 2018).

1.1 Levels of Automation

Automation in vehicles can be described by its six levels, ranging from Level 0 to Level 5 (SAE, 2021). Level 0 is the lowest level of automation (LOA) and describes a vehicle with no driving automation, meanwhile, a vehicle at Level 5 is fully automated (see table 1). During the lower three LOAs, the driver is responsible for performing part or all the driving tasks and can override the automation, retaking control at any time. Whereas in the upper three LOAs, the vehicle would be able to perform the entire driving task, except drivers are required to take over control upon request at Level 3 and the system can delay the driver’s request to retake control. Therefore, an automated driving system would be able to perform the entirety of the task independently at the highest LOA. As the LOA increases, more and more tasks are being taken away from the driver and being carried out by the vehicle. This means that human input is highest at the lowest automation level while automation is highest at the highest automation level

(Onnasch et al., 2014). Currently, there are no automated driving systems for commercial use that incorporate Level 3 and Level 4 automation. Therefore, the present study used Level 2 automation to target the level of automation that is being mass produced in society. This means the vehicle would control lateral and the longitudinal motion of the vehicle, but the driver had to supervise the DAS, being ready to intervene when necessary. In addition, our goal was to examine vigilance loss when using a DAS. We target Level 2 because it incorporated automation, but the driver was still responsible for supervising the DAS (SAE, 2021). Supervision is not a requirement with Levels 3 and 4 automations.

Table 1. Levels of Automation

Level	Name	Description
0	No automation	The human driver is in full control and is responsible for carrying out the entirety of the driving task independently.
1	Driver assistance	The human driver has full control but can allocate lateral or longitudinal functions to the DAS.
2	Partial automation	The DAS can carry out both lateral and longitudinal functions. The human driver is responsible for monitoring and ensuring the DAS is functioning properly in response to environmental stimuli.
3	Conditional automation	The automated driving system can carry out the entirety of the driving task in response to environmental stimuli but still expects the driver to respond to a request promptly and accordingly.
4	High automation	The automated driving system is in full control and is responsible for carrying out the entirety of the driving task. The system will still alert the driver when in need of a response but can continue even if the driver does not provide one.
5	Full automation	The automated driving system is in full control and is responsible for carrying out the entirety of the driving task independently.

Note. Represents the levels of automation. This table is based on that depicted in SAE (2021).

1.2 Effect of Posture on Performance

An individual's body posture has been shown to have mixed effects on visual search/tracking performance. Many studies have concluded that posture has no effect on response time when participants performed visual search/tracking tasks (Edwards, 1994; Jalilian et al., 2021; Paddan et al., 2012a). However, accuracy on target detection tasks have been found to significantly decline with the inclination of the back rest (Edwards et al., 1994; Paddan et al., 2012a). For example, Edwards and colleagues had participants undergo a military surveillance task in a vehicle and had them outlook a scrubland scene. The scene had LED lights hidden behind the scrubs and participants were tasked with pressing a button when they noticed the LED lights being lit up. It was found that the accuracy of target detection dropped from 67% when individuals performed the task with a backrest angle of 90-degrees to 45% when the backrest was set to a 155-degree incline. Paddan and colleagues tasked participants with keeping a target within a target area by use of a joystick. It was found that a backrest set to 90 degrees (upright) led to less tracking error when compared to both a 135-degree and 157.5-degree inclined backrest.

Body posture has also been known to affect performance on cognitive control tasks. Indeed, humans are always multi-tasking between maintaining a stable balanced posture while also completing the cognitive tasks of life (Rosenbaum et al. 2017). A standing posture requires more attention than a seated posture due to the continuous attentional demand in muscle activity that is required to maintain balance while standing (Rosenbaum et al. 2017). Since lying down requires even less attentional demand than sitting and standing, Barra and colleagues (2015) hypothesized that attention on a cognitive task would be best in this posture, due to it being the most stable. However, the opposite was found. Barra and colleagues employed a task that required selectivity of attention, which is a measure of cognitive control. The task tested participants' reaction times to identifying the direction in which a middle arrow was pointing, with other arrows flanked on both its sides, pointing in the same or opposite directions. It was found that attention improved as the postural condition became more challenging. In other words, participants responded faster when standing than when seated and faster when seated than when supine. Rosenbaum and colleagues only explored differences in sitting and standing but replicated Barra and colleagues' findings even when the cognitive control task changed. Smith and colleagues (2019) also found that task-switching cost, a measure of cognitive control, between different selectivity of attention tasks were reduced when standing opposed to sitting. In other words, participants accuracy while task switching was better while standing than sitting. Based on these findings, it has been concluded that standing equates to an increased physiological arousal leading to an improvement in cognitive control (Rosenbaum et al., 2017; Smith et al., 2019).

1.3 Effect of Posture on Comfort

Prior research has also shown that differing body postures affect comfort (Barra et al., 2015; Drury et al., 2008; Naddeo et al., 2018; Paddan et al., 2012b). For example, individuals reported a sitting posture to be more comfortable than standing when performing x-ray screening tasks (Drury et al., 2008). Among different postures, it has been found that a supine posture is the most stable, a seated posture was intermediate, and standing tandem was the most instable (Barra et al., 2015). Paddan et al. (2012b) examined individuals' comfort while manipulating seat recline, from 90-degrees (upright) to 112.5-degrees, 135-degrees, 157.5-degrees, and 180-degrees (lying down). They found that the upright posture was the most uncomfortable of all postures and comfort increased as the backrest reclined. Thus, Paddan and colleagues concluded that reclined postures allowed individuals to relax, leading to enhanced comfort. Similarly, Naddeo, and colleagues (2018) also found body posture, among other factors, related to comfort, and they suggested devices to be designed to monitor the contributing factors for various users ranging from a student sitting in a chair to a driver of a vehicle.

Comfort has always been a factor that is considered when manufacturing vehicles. Many vehicles incorporate adjustable seat rests that allow the driver to alter their seating position to their liking. Studies have shown that as seat inclination increases from an upright position, muscle fatigue and discomfort decreases (Li et al., 2015; Stanglmeier et al., 2020). The more inclination of a backrest has also been shown to promote better sleep (Stanglmeier et al., 2020).

These consequences of the more inclination of a backrest benefit driving at certain LOAs more than the others. Indeed, many drivers indicated that they would like to spend their time sleeping/resting if placed behind a fully automated driving system (Kyriakidis et al., 2015; Stanglmeier et al., 2020). However, at Level 2 and Level 3 automation, the driver may still have to retake control over the vehicle, resulting in a posture that is sufficient for relaxing but not efficient for manually driving a vehicle. Mansfield and colleagues (2021) compared discomfort ratings between drivers when driving in manual mode vs. autonomous mode (Levels 3-4), while also manipulating backrest angle (upright vs. reclined). They found that the reclined posture had significantly greater discomfort ratings than that of the upright posture when driving in manual mode; however, similar discomfort levels were found between postures when driving autonomously.

1.4 Comfort over Time

As time passes, an individual’s comfort while seated has shown to decrease (Gao et al., 2019; Fiorillo et al., 2021; Li et al., 2020). Specifically, Li and colleagues (2020) found that the legs and upper limbs grew fatigued in long-term driving (90min) compared to short-term driving (15min). Fiorillo et al. (2021) had participants subjectively rate their comfort every 15-minutes, over the course of an hour. A 5-point scale was used which ranged from not comfortable to extremely comfortable. Comfort was found to be highest in the first 15-minutes and decay in each successive period, with comfort having its lowest rating during the last period. Gao and colleagues (2019) state that when sitting in a stationary posture, an individual's muscles will eventually contract which leads to poor oxygen flow to tissues. Therefore, Gao et al. claim when driving long distances, this will lead to muscle soreness/cramps, inevitably decreasing an individual's comfort, though this claim was not directly tested in their work. The present study adopted the same global comfort questionnaire used in Fiorillo and colleagues (2021) study.

1.5 Vigilance

Vigilance is here to stay regardless of the LOA of a vehicle. *Vigilance,* often referred to as sustained attention, consists of maintaining focus/alertness to unpredictable environmental stimuli for extended periods of time (Greenlee et al., 2018; Mackworth, 1948; McWilliams & Ward, 2021; See, 2014). Vigilance occurs typically when the task is monotonous and vigilance signals unpredictable (Körber et al., 2015; McManus, 2015; McWilliams & Ward, 2021; Robertson & Garavan, 2004). *Vigilance decrement* refers to the decline in performance that occurs over time while undergoing a vigilance task, which reduces the ability of humans to accurately detect and respond to important environmental stimuli (Greenlee et al., 2018; McManus, 2015). Vigilance decrement has commonly been denoted by a decrease in signal detection and increased response times (Greenlee et al., 2018; Greenlee et al., 2019; Greenlee et al., 2022; Helton & Russell, 2011; Rubinstein, 2020). Vigilance has been studied since the beginning of World War II, when the British were committed to improving their soldiers' ability to monitor radars for incoming strikes (Mackworth, 1948). As the world continues to evolve into more of an automation and computerized based society, vigilance is becoming even more of a necessity (See, 2014). Workers are becoming less reliant on their physical ability, and more reliant on their mental processing of displays for signs such as danger and malfunction, where immediate action is required (See, 2014).

Vigilance tasks often result in task related fatigue. Task related fatigue is a form of fatigue that stems from the task factors (duration, demand, etc.) and can be further broken up into active and passive fatigue (Hadas et al., 2017; May & Baldwin, 2009; McWilliams & Ward, 2021; Saxby et al., 2013). Active fatigue is associated with cognitive overload caused by a high task demand (Hu & Lodewijks, 2021). Meanwhile, passive fatigue is the result of cognitive underload and occurs when the demand is low, and the task is long and monotonous (Hadas et al., 2017; Hu & Lodewijks, 2021; May & Baldwin, 2009; McWilliams & Ward, 2021). Passive fatigue is particularly prevalent when the task consists of automation. Due to the presence of the automation system, individuals may begin to rely on automation resulting in less effort given to the task (May & Baldwin, 2009).

Determining whether vigilance decrement stems from cognitive underload or overload has been explored in literature (Grier et al., 2003; McWilliams & Ward, 2021; Pattyn et al., 2008; Robertson et al., 1997). Some research explains vigilance decrement as the result of individuals withdrawing from the task due to the task being monotonous and having a low workload (McWilliams & Ward, 2021; Pattyn et al., 2008; Robertson et al., 1997). Other research associates the decrement to be explained by the tasks requiring too high of a mental workload (Grier et al., 2003). Thus, individuals are not able to sustain the attentional capacity needed to successfully complete the task, over time. However, both explanations may very well be two ends of the same scale. Having an optimal level of workload to promote better performance quality is consistent with the Yerkes-Dodson law (Yerkes & Dodson, 1908), which depicts how performance drops at the two extremes of the spectrum of arousal level.

Some major theories explaining the concept of vigilance decrement include the arousal theory, self-regulation theory, effort-compensation theory, and resource theory (Hockey, 1986; Hockey, 1997; Hu & Lodewijks, 2021; McManus, 2015). According to the arousal theory, monotonous tasks lower an individual’s arousal level, which lead to a decline in vigilance performance (Mackworth, 1968). More specifically, observers with a lowered arousal get bored and mindlessly undergo the task, reducing their likelihood to detect critical signals. The arousal theory appears to align with cognitive underload because the task is eliciting so little demand on the observer that their arousal levels are too low to stay engaged with the task, making their performance drop. The self-regulation theory states that individuals alter their effort according to the task demand (Hu & Lodewijks, 2021; Hockey, 1986). Meaning, individuals are able to exert low effort to maintain their efficient performance during vigilance tasks but are subject to errors when an unexpected event arises, causing them to be unready to act accordingly (Hu & Lodewijks, 2021). The self-regulation theory appears to align with cognitive underload because the monotony and low task demand causes individuals to withdraw their effort from the task, making them vulnerable to the unpredictable stimuli in vigilance tasks. The effort-compensation theory also explains vigilance decrement in terms of an individual’s effort but due to cognitive overload.

The effort-compensation theory suggests that vigilance tasks are stressful, and individuals are not able to provide the appropriate level of effort due to the accumulation of stress from the task over time, leading to fatigue and a vigilance decrement (Hockey, 1997; McManus, 2015).

This aligns with cognitive overload because for the vigilance task to be too stressful, it means that the task demand is too high and overloading the individual. The resource theory focuses on the individual's capabilities and explains vigilance decrement to result from observers' attentional resources constantly being used, not allowing time for recovery, leading to poorer attentional performance over time (Hitchcock et al., 1999; Helton & Russell, 2011). It states that attention is a limited resource and would align with cognitive overload because the resource theory views vigilance tasks as being taxing to the observer as they must continually process and determine whether the stimulus is signal or noise (Hancock, 2017; Helton & Russell, 2011; Warm et al., 2008; Wickens, 2002). Despite the different theories explaining vigilance decrement, vigilance decrement has been a robust phenomenon found in various contexts.

The signal detection theory (SDT) is a widely used model that uses measures of response bias and accuracy to analyze decision-making performance (Green & Swets, 1966; Sorkin & Woods, 1985). SDT quantifies the observer's responses when differentiating signals from noise (Meyer et al., 2001; Sorkin & Woods, 1985; Thomson et al., 2016). "Noise" refers to the stimuli presented during a vigilance task that requires no action by the observer. "Signal" represents the stimuli that the observer is instructed to respond to. As a result, there are various human actions that can be made according to the SDT model (Meyer et al., 2001). A "hit" refers to an operator correctly responding to a signal. A "miss" happens when the operator does not act on a signal. A "false alarm" occurs when an operator believes a signal to be present when it is not. Lastly, a "correct rejection" refers to correctly detecting the stimuli to be noise.

Based on SDT measures, vigilance decrement has often been attributed to changes in an individual's sensitivity and response bias (See et al., 1997; Wickens et al., 2012). Sensitivity is a measure for the distance between the means of signal and noise distributions (See et al., 1997;

Thomson et al., 2016). Sensitivity is higher when this distance increases and it becomes easier to distinguish signal from noise. Meanwhile, sensitivity is lower if there is more overlap between the noise and the signal making it harder to distinguish the signal from the noise. Response bias reflects the tendency of how often the observer makes a response and can vary depending on the individual and the task (Thomson et al., 2016; Wickens et al., 2012). On the one hand, individuals may be more liberal in their responses, meaning they are more likely to respond to the stimuli, resulting in higher hit rates and increased false alarms. On the other hand, an individual can be more conservative and less likely to make a response, resulting in more misses but fewer false alarms.

The present study used the nonparametric measures of A' for sensitivity and β''_D for response bias. We chose to use nonparametric values because See and colleagues (1997) found that the traditional parametric β was not an adequate way to measure response bias. It was found that the nonparametric β''_D was more effective than previous measures of bias because it "maintains its effectiveness over the full range of sensitivity from chance to perfect performance (p.14)." It also produces more accurate estimates of bias regardless of whether the data is collapsed or grouped (See et al., 1997). These nonparametric measures have also been widely used in vigilance studies, based on which we derived our hypotheses (Claypoole & Szalma, 2017; DeLucia & Greenlee, 2022; Greenlee et al., 2018; 2019; 2022).

The formulas used to calculate response sensitivity and response bias are shown below.

$$\boxed{A' = \frac{1}{2} + \frac{(H - FA)(1 + H - FA)}{(4H)(1 - FA)}}$$

$$\boxed{B''_D = \frac{(1 - H)(1 - FA) - (H)(FA)}{(1 - H)(1 - FA) + (H)(FA)}}$$

Response sensitivity and bias have been shown to vary over the duration of a task (Claypoole & Szalma, 2017; Greenlee et al., 2018; Greenlee et al., 2019; Greenlee et al., 2022). However, the task nature may also play a factor in the response sensitivity and bias. For example, Claypoole and Szalma (2017) had participants undergo a traditional vigilance task in which they had to determine whether the distance between the stimuli, rectangles and dots, was equal or not. The 24-minute vigilance task was separated into four 6-minute periods. It was found that response sensitivity remained unchanged over each of the periods. In addition, response bias increased as time passed, indicating that individuals became more conservative over time. Meanwhile, Greenlee and colleagues (2018; 2019; 2022) explored response sensitivity and bias in an automated-driving vigilance task. Participants were placed on a driving simulator and had to determine if a vehicle was in their lane or not. Sensitivity was shown to decrease over the course of the 40-minute drive (Greenlee et al., 2018; 2019; 2022). It was concluded that the sensitivity decrement was a result of drivers' capabilities diminishing over time, resulting in drivers being unable to properly recognize hazards within the roadway environment. However, response bias differed between Greenlee and colleagues' original work versus their follow-up studies. In the original, response bias remained unchanged throughout the course of the drive (Greenlee et al., 2018). In the follow-up studies, measures of response bias mirrored that of Claypoole and Szalma (2017) study showing that individuals became more conservative as the drive continued (Greenlee et al., 2019; Greenlee et al., 2022).

Sensitivity, which is based on the proportion of hits and FA, is a common measure of vigilance decrement although there is research that opposes its usefulness (Thomson et al., 2016). This skepticism arises due to vigilance tasks often consisting of very low FA rates which could make the sensitivity measure misleading. Therefore, sensitivity was said to only be a valid measure of vigilance decrement when false alarms rates were “sufficiently high” (Thomson et al., 2016, p. 79). Thomson and colleagues (2016) stated that response bias was a better indicator of vigilance decrement as it showed that observers were becoming more conservative in their responses. They concluded that to combat the low FA rates found on vigilance tasks, “researchers could include conditions in their designs in which a subset of distracter items yield very high false alarm rates” (p. 81). However, the present study aimed to have our experimental design that mimics a real-life driving scenario, thus creating such unrealistic situations could potentially work against this purpose. The current literature does not support the idea of sensitivity being misleading, however, we acknowledge this different view and intend to measure response bias as well. In addition, we planned to transform our data if floor effects are found within our FA rates.

Determining how body posture affects an individuals’ correct detection and false alarm rate during a vigilance task is underexplored in research. Drury and colleagues (2008) ran a two-part experiment that assessed the vigilance performance while standing, sitting, and sitting in a highchair, with a sample of TSA baggage screeners. Participants underwent an intrusion detection task in which they viewed a mock video of security camera footage and had to determine which individuals were intruders. Following, they underwent a threat detection task where they viewed x-ray images of luggage and had to determine whether it was safe or not. Correct detections and false alarms did not differ among the postural conditions for either task. Similar findings were shown in Thody and colleagues (1993) experiment where military personnel viewed radio messages, presented in text on a computer, while under various seat reclines (7-degrees, 30-degrees, 60-degrees from upright). Participants had to determine which messages were of importance to their task and respond accordingly. There were no differences found in correct detections or false alarms between individuals identifying target messages among the various postures. Response sensitivity and bias were not presented in either Drury and colleagues (2008) or Thody and colleagues (1993) studies. However, Thody and colleagues provided the raw values of correct detections and false alarms during each POW. Based on those values we calculated both the response sensitivity and bias over the course of the experiment and found they remained relatively the same.

Vigilance is important for driving. Driving is a monotonous task that requires a continual processing of information in the environment, thus making attention a necessity (McManus, 2015). A driver must be able to sense changes in the environment, understand the meaning of the change, and respond accordingly (Wickens et al., 2013). However, attention is limited, resulting in declines in performance over time (McManus, 2015; See, 2014). If attention is not being monitored correctly, important environmental information may be misinterpreted, or even go unnoticed (McManus, 2015). Therefore, a driver with inadequate vigilance can bring danger to the safety of others on the road (Schmidt et al., 2009). Unfortunately, as time passes, drivers cannot accurately assess their vigilance decrement (McManus, 2015; Schmidt et al., 2009). Schmidt et al. showed that participants self-reported that their vigilance improved when undergoing the driving task, while the objective measures showed their vigilance performance was decreasing.

Drivers using a DAS must also remain vigilant. When testing for vigilance within an automated driving task at Level 2 automation, it was found that as the drive continued, drivers' ability to correctly detect hazards declined considerably and drivers' response times increased, both being indicators of vigilance decrement (Greenlee et al., 2018). As a result, the driver's ability to manually take control over the driving task, to prevent an accident, would suffer due to vigilance decrement. There were no significant differences found in false alarm rates of the drivers. Greenlee and colleagues (2019) did a follow-up experiment manipulating task demand to determine if vigilance decrement was caused by information overload. Task demand was measured by manipulating spatial certainty (low vs. high) and event rate (fast vs. slow) of the signals, two factors known to impact vigilance performance. Participants in the fast event rate condition were presented with stimuli (stopped vehicles at an intersection) at a faster rate than those in the slow event rate condition. The fast event rate was like the presentation interval of the 2018 study. The low spatial certainty condition presented stopped vehicles on both the right and left side of the road at random. Meanwhile, the high spatial certainty condition alternated its presentation of the vehicle from left to right, making it predictable. It was found that drivers became worse at correctly detecting the signals as the vigilance task became more demanding. In other words, faster event rates and a lower spatial certainty led to worse performance. Greenlee and colleagues concluded that their results support the theory of information overload (i.e., the resource theory) being the cause of vigilance decrement. Lastly, Greenlee and colleagues found that false alarm rates followed the same trend as accuracy and decreased over time. In Greenlee and colleagues' (2022) study, they continued their research into vigilance decrement when using a DAS and compared the results to those obtained when driving with no automation (Level 0). A vigilance decrement was found when driving manually, however, the use of a DAS led to a greater decline in drivers vigilance performance compared to that of manual driving. Greenlee and colleagues (2018; 2019; 2022) used the same task in all their studies and divided their 40-minute experiment into four, 10-minute, Periods of Watch (POW). This setting allowed data to be collected and compared among POWs throughout the study to measure vigilance decrement as time passed. The current study used this same strategy to measure vigilance decrement.

Greenlee and colleagues (2019) did not replicate their 2018 or 2022 work which found that false alarms remained the same over time. However, they explained the current decrease in false alarms as being a result of their practice drive. The practice had an increased signal probability to promote familiarity with the task. However, the increased signal probability may have caused participants to become more biased in providing responses at the start of the experiment, which then decreased as they realized that signals were not being displayed at the same frequency. This conclusion seems logical, however, previous research has also found that individuals' false alarm rate decreases over time, even when there was no change in signal rate between the practice and experimental conditions on a vigilance task (Claypoole & Szalma, 2017; Dember et al., 1992; Szalma & Hanckock, 2006)

The effects of drivers' body posture on their vigilance performance while operating a DAS has been under-researched. Over the past century, the focus of driving research has mainly been placed on the driver and their responsibilities, with little focus on the passengers in the vehicle (Mansfield et al., 2021). Typical manual driving responsibilities include using gas/brake pedals, steering, continually watching the road ahead, while also being vigilant of mirrors and other display systems. However, with the implementation of DAS, drivers will possess roles very similar to that of a passenger. As a result, the seated posture of the driver may change as they seek to improve comfort or engage in other tasks such as working or sleeping (Mansfield et al., 2021). However, at Level 2 automation, the driver may have to retake control over the vehicle without having time to change their seatback to a posture more conducive for manual driving (Mansfield et al., 2021; SAE, 2021). The present study sought to investigate the effects of various driving postures on a driver's comfort and vigilance performance when using a DAS.

1.6 The Effects of Age

Younger drivers are known to display different driving habits than older drivers. Campagne and colleagues (2004) wanted to determine if fatigue affected driving performance and if age played a factor. They looked at young drivers (age: 20-30), middle-aged drivers (age: 40-50), and older drivers (age: 60-70). Over the course of the drive, vigilance loss was found among all drivers along with an increase in lane violations. Young and middle-aged drivers showed similar losses in vigilance over the drive while the older drivers displayed the worst decline in vigilance loss of all ages. In addition, lane violations were found in all individuals, but the cause may stem from different factors for different age groups. The lane violations of young and middle-aged drivers were found to be positively correlated with the faster speeds in which they drove while this was not the case for older drivers. This riskier nature found in younger drivers was also reported by Zicat and colleagues (2018) where they found increased lane deviations in younger individuals, making them high risk for crashing. Similar age effects were also found in a traditional vigilance experiment where the size of the square being presented on the screen determined if it was signal or noise (Parasuraman & Giambra, 1991). This study was divided into numerous 10-minute blocks. During the first 10-minutes, younger individuals, middle-aged individuals, and older individuals all displayed similar hit rates when deciding whether the square was a signal or noise. However, older adults began to perform worse than the younger adults in the second period. In the third period, middle-aged adults followed the same trend as the older adults and began to perform worse than younger adults as well. It was concluded that older individual’s attentional capacity diminishes much faster than that of a younger individual.

The acceptance of automation in driving between younger and older individuals also differs. It has been reported that older drivers (aged 55+) are less likely to see the value in using a DAS as compared to younger individuals (aged 16-24) (Missel, 2014). Haghzare and colleagues (2021) found that older individuals tend to have lower acceptance of autonomous vehicles than the younger group. It appears that many studies that investigated a DAS consist of younger individuals as well, having sample sizes with mean ages below 25 years old (Atchley & Chan, 2011; Greenlee et al., 2018; Greenlee et al., 2019; Körber et al., 2015). As a result, we targeted a similar sample and collected participants varying in age from 18-25 years old.

1.7 Current Study

In the field of Human Factors and Ergonomics, the goal is to improve the comfort and performance of operators while using technology (Grujic et al., 2010; Nickerson, 2011). Research on whether posture affects comfort while using a DAS has been sparse with the one exception of Mansfield and colleagues (2021) work. However, the effect of posture on vigilance performance had not yet been considered for drivers using a DAS. The purpose of the current study was to determine whether posture affects vigilance performance and comfort during an automated driving task.

Our experiment followed that of a go/no-go task which has been subject to SDT previously (Saunders et al., 2008; Young et al., 2018). The current study had participants undergo an automated driving task with Level 2 automation on a driving simulator. Numerous buildings were depicted along the right side of the roadway and individuals were tasked with getting home safely after a workday. Participants were informed to be cautious of unexpected hazards that the AV may not detect, requiring them to brake to avoid crashing. These vehicles were considered “dangerous” and were signals. Vehicles that were safely parked alongside the road were considered “safe” and were noise. Participants were asked to supervise the DAS and be ready to brake if the vehicle did not detect a dangerous vehicle. A crash would occur if the driver missed a signal. Correct detections were defined as a braking response when the dangerous vehicle entered the roadway or provided no response during normal conditions. False alarms occurred when participants braked for a “safe” vehicle (Greenlee et al., 2018). The independent variables were the driver’s body posture and POW. Body posture was manipulated by altering the recline of the seat (upright, slightly reclined, very reclined). The study took place over the course of 40-minutes; thus, the experiment was evenly separated into four 10-minute periods of watch. The dependent variables were percentage correct detections, percentage false alarms, response time, and comfort. Signal detection rate and response time were both common measures of vigilance decrement.

1.8 Hypotheses

Based on the prior studies discussed in the Introduction, we generated the following hypotheses. Note, Hypotheses 1, 2, 3, and 4 were on performance measures; Hypothesis 5 was on comfort. No hypotheses were made about the interaction effects between POW and body posture on any of the dependent variables since the combination of the two factors on our specific DVs had not yet been explored by prior literature. Therefore, the interaction effects, if any, were to serve as exploratory findings.

1.8.1 Hypothesis 1.1

As the drive continues, percentage of correct detections would decrease for all drivers. This hypothesis was based on Greenlee and colleagues (2018) study which found that correct detections declined by over 30% over the course of a 40-minute drive.

1.8.1 Hypothesis 1.2

As the drive continues, percentage of false alarms would decrease for all drivers. This hypothesis was based on research which found that false alarms decreased as time passed (Claypoole & Szalma, 2017; Dember et al., 1992).

1.8.1 Hypothesis 1.3

Participants' sensitivity would decrease over the course of the experiment. This hypothesis is a result of drivers becoming less capable of distinguishing hazardous stimuli within a roadway environment as time passes (Greenlee et al., 2018; Greenlee et al., 2019). We chose to base our hypothesis on Greenlee and colleagues (2018; 2019) studies because their work more closely mirrors our experimental design and explored DAS using a driving simulator. Meanwhile, Claypoole & Szalma (2017) was that of a traditional vigilance study where participants were presented with shapes and had to determine if the distance between them varied.

1.8.1 Hypothesis 1.4

Participants' response bias would increase over the course of the experiment. This hypothesis is based on individuals becoming more conservative as time passes (Greenlee et al., 2019). Greenlee and colleagues (2018) also found an upward trend in response bias even though it was not a significant effect. In Hypothesis 1.3, we chose to not incorporate the findings from Claypoole & Szalma (2017) study, but it is interesting to note they also found that response bias increased over time, even on a traditional vigilance task.

1.8.2 Hypothesis 2

As, the drive continues, response times to signals would increase. This hypothesis stems from prior research which found that individuals became slower when responding to a signal as time passed (Greenlee et al., 2018; Greenlee et al., 2019; Helton & Russell, 2011).

1.8.3 Hypothesis 3.1

Percentage of correct detections would remain the same as the seatback angle becomes more reclined. This hypothesis is based on studies Thody and colleagues (1993) work which showed that military personnel's ability to accurately determine targets from non-targets was unaffected by the angle at which the seat was reclined. Drury and colleagues (2008) also found no change in correct detections when among body postures was manipulated.

1.8.3 Hypothesis 3.2

Percentage of false alarms would also not change as the seatback angle becomes more reclined. This hypothesis stems from prior research finding individuals did not identify non-targets as targets any differently based on the postural condition they were placed in (Drury et al., 2008; Thody et al., 1993).

1.8.3 Hypothesis 3.3

Sensitivity would remain unchanged as the seatback angle becomes more reclined. This hypothesis stems from calculating sensitivity based off the correct detections and false alarm rates in each postural condition as presented in Thody and colleagues (1993) study.

1.8.3 Hypothesis 3.4

Response bias would remain unchanged as the seatback angle becomes more reclined. Similar to sensitivity, response bias was computed from the correct detections and false alarms for each postural condition (Thody et al., 1993).

1.8.4 Hypothesis 4

Response times would be longer as the seatback angle becomes more reclined. This hypothesis is based on Barra and colleagues' (2015) finding that individuals took longer to respond while lying down versus sitting upright.

1.8.5 Hypothesis 5.1

Participants' comfort would increase as the seatback recline increases. This hypothesis stems from Paddan et al. (2012b) which showed individuals became more comfortable as their seatback reclined past the 90-degree upright position.

1.8.5 Hypothesis 5.2

Participants' comfort would decrease over the course of the experiment. This hypothesis is backed by Fiorillo and colleagues (2021) research which had individuals subjectively rate their comfort every 15 minutes, over the course of an hour. It was found that comfort was highest during the first testing, decreasing in each following testing.

CHAPTER 2

METHOD

2.1 Participants

We used G*Power (Faul et al., 2007) to run a power analysis with a medium effect size and a power level of 95%, which resulted in a need for 45 participants. Using convenience sampling, participants were recruited via Old Dominion University (ODU)'s Sona system (odupsychology.sona-systems.com). To participate, individuals had to self-report that they were 18 - 25 years of age, possess a driver's license, and have normal or corrected to normal vision and hearing. Caffeine, gum chewing, and nicotine have been shown to positively affect vigilance performance, while alcohol has been shown to impair vigilance performance (See, 2014). Therefore, the present study asked for a 12-hour abstinence from all stimulant and depressant substances before testing and gum chewing during the experiment was prohibited (Caldwell et al., 2003; Greenlee et al., 2018; Schmidt et al., 2009). We also required that participants got at least 7-hours of sleep the night before the study. It had been found that anything less can lead to "impaired performance, increased errors, and greater risk of accidents" (Watson et al., 2015, p. 843). Participants were prohibited from using personal technology devices during testing (Greenlee et al., 2018). In addition, participants were informed that they could opt out of the study at any time. For their participation, each participant received course credit in a psychology course of their choosing.

2.2 Experimental Design

The independent variables were the driver's body posture and POW. This study used a 3 (Posture: upright, slightly reclined, very reclined) x 4 (POW: 0–10-minute block, 10-20 minute block, 20-30 minute block, 30-40 minute block) mixed factorial design. Drivers' body posture was a between-subject design to remove carryover effects that could have occurred between the three conditions. Participants were randomly assigned to a postural condition. POW was a within-subject design and represented how vigilance performance was affected as time passed. The 40-minute experiment was evenly divided into four 10-minute periods. The dependent variables were correct detections, false alarms, response sensitivity, response bias, response time, and comfort. The driving task was the same for all participants regardless of their postural condition. In addition, participants were not informed of the exact length of the drive to minimize the potential for time-related motivational strategies' (Greenlee et al., 2018).

2.3 Apparatus

The experiment took place in a controlled laboratory setting that eliminated extraneous distractions. The study was run using STISIM Drive driving simulator (Build 3.20.03) and presented on a 27" Dell Monitor (1920 x 1080, 32-bit, 60 Hz). The hardware consisted of a Logitech G920, which consisted of a steering wheel that was mounted to the same desk the monitor sat on, and pedals that were placed on the ground directly under the steering wheel. A Staples Emerge Vartan Bonded Leather Gaming Chair (Model #58542) was used which allowed for adjustable arm rest height, seat back angle, and height from ground. The chair also included a neck rest. The wheels of the chair were removed to prevent participants from rolling around during testing (see Figure 1). Once participants were seated, an immovable support was placed behind the chair, pressing against the backrest, to promote stability and prevent drivers from swiveling.

Figure 1

Postural Conditions

Note. Depicted are the seatback angles of the chair when upright (90 degrees), slightly reclined (115 degrees), or very reclined (135 degrees).

2.4 Materials

The driving scene depicted a straight, urban roadway with two ongoing lanes and cars parallel parked along the curb to the driver's right side. The vehicle drove at a constant speed of 35 miles per hour (35 ft/s) and had Level 2 automation. In other words, the vehicle could perform the driving task with the expectation for the driver to intervene when necessary (Kaber, 2018; SAE, 2021). Participants were tasked with driving home through an urban area from work. There were numerous buildings displayed on both sides of the road. Participants were informed to be cautious of unexpected hazards that the DAS may not detect, requiring them to act. Hazards occurred when parallel parked vehicles abruptly pulled into the roadway. Vehicles that pulled out from the right side of the road in the driver's lane required them to brake to avoid a collision. These vehicles were considered "dangerous" and were signals (see Figure 2). Participants were instructed to brake to avoid crashing. "Safe" vehicles were parked alongside the right-curb and are noise (see Figure 2). A crash would occur if the driver hit another vehicle. During a crash, a graphic was displayed on the screen, the steering wheel vibrated, and a crash sound was played (see Figure 3). These effects were to stimulate real life crash feedback. Following the crash, the vehicle automatically readjusted to a safe lane position and the vehicle's speed was reset to 35mph as the experiment continued. Dangerous vehicles that were successfully detected continued merging into the left lane beside the driver and traveled at a speed slower than the driver's vehicle to prevent interference with future dangerous vehicles pulling into the roadway.

Figure 2

Driving Scenes Depicting A "Dangerous" Scene and A "Safe" Scene

Dangerous

Safe

Note. Depicted on the left is a "dangerous" scene where a hazardous vehicle was pulling into the roadway. On the right is a "safe" scene where all vehicles are parallel parked on the side of the road.

Figure 3

Car Crash

Note. Depicted is what was displayed to participants upon crashing into a “hazardous” vehicle”.

There was a 5-minute practice drive with signal probability set to 5%. This resulted in participants encountering 142 “safe” and 8 “dangerous” vehicles displayed at random (Greenlee et al., 2018). The practice-drive allowed participants to familiarize themselves with which vehicles were dangerous. If the participant crashed into a dangerous vehicle, the crash effects were played alerting them of their error. In addition, the experimenter was standing-by to inform the participant that they must apply their brakes in a timely fashion to avoid crashing for the purpose of practice. The experimenter also answered any concerns the participant had during the practice drive relating to what is considered a dangerous vehicle. Half-way through the practice drive, the experimenter vocally asked participants to give a subjective rating on how they perceived their comfort to be varying from 1 (not comfortable) to 5 (extremely comfortable). The experimental drive lasted 40-minutes, and signal probability remained at 5% (the same as in Greenlee et al., 2018). The 40-minutes were divided into four continuous 10-minute POWs. Each

10-minute POW consisted of 285 “safe” and 15 “dangerous” vehicles presented at random. The experimenter asked participants to rate their perceived comfort, varying from 1 (not comfortable) to 5 (extremely comfortable), at the end of each POW. For both the practice and experimental drives, parked vehicles were presented every two seconds resulting in a vehicle being seen every 75ft. This allowed for an event rate of 30 events per minute (Greenlee et al., 2018).

2.5 Measures

All participants signed-up for a time slot to undergo the experiment. A demographics sheet was used to inquire about participants’ demographic information, handedness, and visual/hearing ability (see Appendix B). Qualtrics (qualtrics.com) was used to administer all other measures. Participants completed the Motion Sickness Susceptibility Questionnaire Short-form (MSSQ-Short) which examined how often they felt sick or nauseated throughout the course of their life when traveling by various vehicle types, ex. cars, buses, trains, aircraft (Golding, 1998; see Appendix C). This measure’s validity is r = 0.51 and has a Cornbach’s alpha of 0.87 (Golding, 1998). A single-question global comfort survey was used which measured participants’ overall comfort on a 5-point scale (Fiorillo et al., 2021). The answer choices were adapted to a 5-point Likert scale, ranging from strongly disagree to strongly agree (see Appendix D). The Short Stress State Questionnaire (SSSQ) was used to provide a baseline for evaluating task-induced stress (Helton & Naswall, 2015; see Appendix E). The SSSQ is broken down into engagement (Cornbach’s alpha = 0.81), distress (Cornbach’s alpha = 0.87), and worry (Cornbach’s alpha = 0.84). In addition, all three factors indicated adequate internal consistency (Helton, 2004).

The NASA TLX was used to assess their mental workload (Hart, 2006; Appendix F). The NASA TLX consists of various subscales which assess mental demand, physical demand, temporal demand, performance, effort, and frustration. Descriptions of each subscale used in the current study are derived from Hart and Staveland (1988). Mental demand was the amount of mental activity needed to complete the driving task. Physical demand was the amount of physical activity exerted by the participant to fulfill the driving task. Temporal demand stemmed from how rushed the participant felt due to the pace of the driving task. Performance indicated how well the participant felt they performed on the driving task. Effort indicated how much effort the participant felt that had to exert to complete the driving task. Lastly, frustration was determined based on how "insecure, discouraged, irritated, stressed, and annoyed" the participant felt while undergoing the driving task (Hart & Staveland, 1988, p. 171). The NASA TLX's validity is r = 0.57 and has a Cornbach's alpha of 0.75 (Longo, 2018).

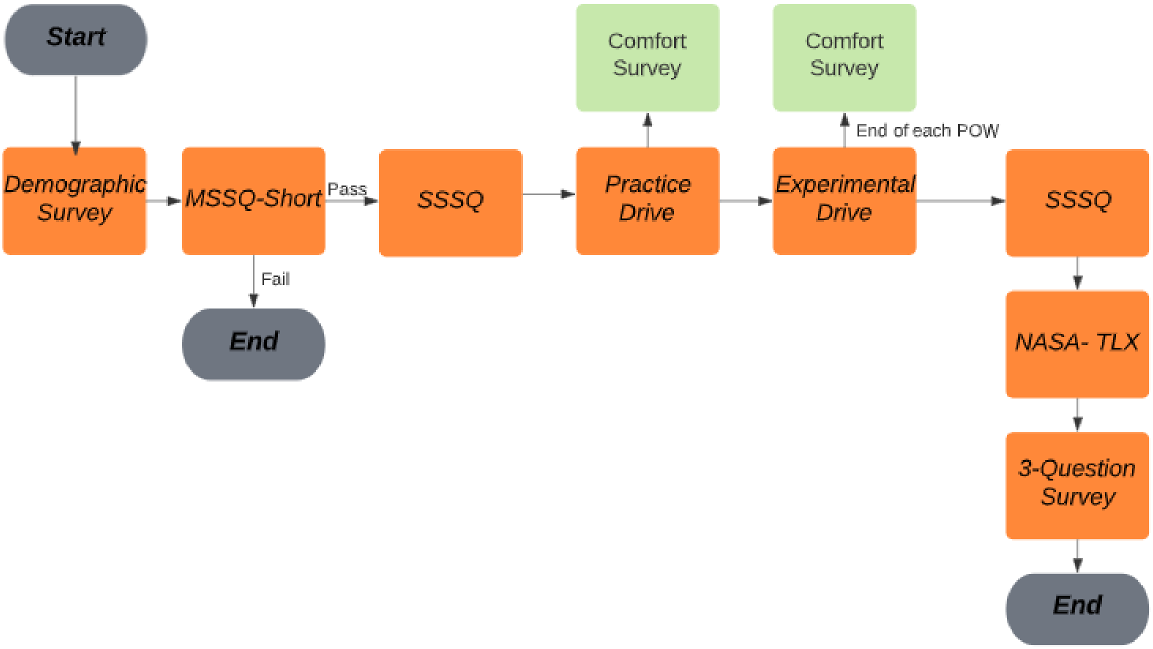
We inquired about the suitability of the drivers' posture for the task, along with questions regarding their driving history. Task suitability was measured by having participants rate their level of agreement to the statement, "The current posture is suitable for the current driving task." This was measured on a 5-point Likert scale, 1 indicating strongly disagree and 5 indicating strongly agree (see Appendix G). This question was adapted from Stanglmeier and colleagues (2020) survey which probed individuals to rate their level of agreement to the statement "The current posture is suitable for sleeping." The next two questions asked participants approximately how many years they have been driving and how many miles they drive in a typical year. Participants were able to fill in the blank to provide their answer. Lastly, we asked participants to fill in the blank with approximately how many hours of sleep they got the night before the experiment. The time of day each participant underwent the experiment was also logged by the experimenter.

2.6 Procedure

All participants signed up for a 1-hour time slot via Sona. Upon arrival, participants filled out a demographics sheet and completed the MSSQ-Short (see Figure 4). Participants that received a raw score greater than 19 on the MSSQ-Short were dismissed. Those who passed would continue to complete the Short Stress State Questionnaire (SSSQ). Following, participants were randomly placed in a stationary seat that is upright (90degrees), slightly reclined (115degrees), or very reclined (135degrees), in which they remained for the duration of the study. Next, participants underwent a 5-minute practice drive which allowed them to become familiar with the driving simulator and ask any questions they may have had. Participants were informed to press the brakes promptly and fully when they saw a hazard, even if a smoother braking option was available (see also Levy et al., 2006). Having participants slam on brakes reflects the urgency of the braking situation and ensured all participants followed the same braking technique. Participants did not have control of steering to keep consistency in the route traveled throughout the experiment. In addition, this prevented participants from potentially adopting the method of traveling in the lane furthest away from where the vehicles were pulling out. Correct detections were defined as braking when the dangerous vehicle enters the roadway or providing no response during normal conditions. False alarms occurred when participants braked for a “safe” vehicle (Greenlee et al., 2018). In addition, it was required that participants always kept their hands on the steering wheel and their foot on the brake pedal. This setting not only simulated realistic driving conditions, where a driver must keep their hands on the steering wheel, but also ensured the fastest response times possible. This also aligned with the requirements of Level 2 automation (SAE, 2021). In addition, participants were informed that they would be probed about their comfort throughout the drive and would give a subjective rating to the experimenter varying from 1 (strongly disagree) to 5 (strongly agree). Participants had to continue taking the practice drive until they correctly detect 80% of the dangerous vehicles. Drivers who maintained 100% accuracy throughout the practice drive before the last dangerous vehicle was informed to crash on the last dangerous vehicle to allow them to see what a crash looked like before continuing to the experiment. Following a correct detection rate of 80% on the practice drive, participants continued to the experimental section which consisted of a 40-minute drive with a verbal comfort survey following each POW. After each POW, the simulator would pause and the participant would be prompted on the screen to rate their level of comfort varying from the following options: strongly disagree, disagree, neither agree nor disagree, agree, strongly agree. Participants would answer vocally, and the experimenter would record their responses. Upon responding, the experimenter would resume the drive for them. Following the experimental drive, participants would be directed to Qualtrics where they would answer the post-experimental survey. The SSSQ would be reissued to determine if their task induced stress had changed over the course of the experiment. Following, they would answer the NASA TLX and a 3-question survey used to inquire about the suitability of the task and their driving history. Lastly, they were dismissed and given class credit.

Figure 4

Procedure



Note. Depicted are the procedural events that every participant would undergo from start to end.

CHAPTER 3

RESULTS

3.1 Participants

We recruited 56 participants. All participants were ODU students with an active driver’s license. One participant was excluded from data analysis because they constantly applied the brakes throughout the drive, not allowing the automation to control the vehicles speed. Seven participants were excluded for having high tendency of getting motion sickness based on their scores on the MSSQ. Three participants were excluded for being over our max age of 25-years old. This resulted in a sample size of 45 participants required by the power analysis (Male: 8, Female: 37, Age: *M* = 18.91, *SD* = 0.87; 6 left-handed and 39 right-handed). There were 20 African/African Americans, 16 Caucasians, 1 Asian, 1 Native Hawaiian/Pacific Islander, 0 American Indian/Alaska Natives, and 5 individuals of more than one race. Table 2 provides the time of day at which participants underwent the study, a breakdown of how many individuals were in each postural condition, and some demographic information.

Table 2. Description of Groups Based on Postural Condition

Condition	*N*	Time of Day	Gender	Age: *M* (SD)
Upright	15	3 Morning 8 Afternoon 4 Evening	10 Females 5 Males	19.00 (0.65)
Slightly Reclined	14	5 Morning 4 Afternoon 5 Evening	14 Females 0 Males	18.57 (0.51)
Very Reclined	16	6 Morning 8 Afternoon 2 Evening	13 Females 3 Males	19.13 (1.20)

Note. Displayed are the number of participants in each postural condition along with time of day and demographic factors. Morning represents participants who started the study before 12pm. Afternoon represents participants who started the study after 12pm. Evening represents participants who started the study after 5pm.

All participants were asked to get adequate sleep the night before the study. Nine participants reported they received less than 7-hours of sleep the night before testing. Originally, we planned to exclude these individuals due to lack of sleep possibly leading to impairments and changes in performance (Watson et al., 2015). However, an ANOVA revealed there were no differences in any of the performance variables when comparing the data of individuals who received at least 7-hours of sleep from those who did not. Therefore, we did not exclude participants based on their hours of sleep to maintain the power needed to draw statistical significance in our sample.

3.2 Performance Data

Participants' performance was measured by the percentage of correct detections, percentage of false alarms, sensitivity, response bias, and response time. The Levene's test determined if there was homogeneity of variance among the data. Each performance measure was analyzed separately using a two-factor ANOVA, with Posture (upright, slightly reclined, very reclined) as the between-subjects factor and POW (1st block, 2nd block, 3rd block, 4th block) as the within-subjects factor. Bonforroni post-hoc pairwise comparisons were used to determine differences among the different levels of Posture and POW, respectively. We used three separate equivalence tests, specifically the two one-sided tests (TOST) procedure, to compare all combinations of body posture.

When assessing sensitivity and bias, we transformed 100% correct detections (ceiling effect) to approximately 96.67%, and 0% false alarms (floor effect) to approximately 0.18%. These correction values on the floor and ceiling effects were done to “avoid confounding sensitivity and bias analyses” (Greenlee et al., 2019, p. 480). Greenlee and colleagues’ calculations are based on Macmillan and Creelman (2004) suggestion that floor effects should be transformed to 100%/(2N) and ceiling effects be calculated by 100%-100/(2N). N is the number of neutral or critical trials used to calculate the percentage.

3.2.1 Response Time

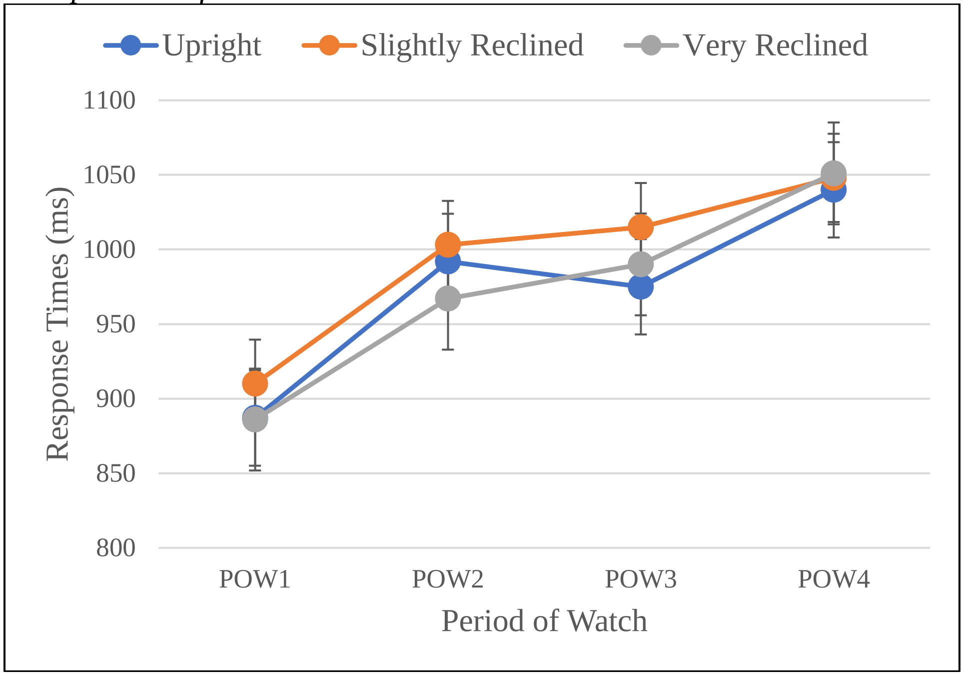
When assessing response time (RT) the sphericity assumption was violated: $\chi^2(5) = 12.44$, $p = .029$. A Greenhouse-Geisser correction was used.

POW had a significant main effect on RT (see Figure 5), $F(2.48, 126) = 32.76$, $p < .001$, $\eta_p^2 = .44$. RT increased over the course of the drive, supporting Hypothesis 2 which states RT to signals would increase. Pairwise comparisons showed that RT in POW1 were significantly longer when compared to every other POW (ps < .001). In addition, POW 4 was significantly slower than POW 3 ($p = .006$). There were no other significant comparisons between POW (ps > .05). There was no interaction effect between POW and Posture on RT, $F(4.96, 126) = 0.63$, $p = .677$, $\eta_p^2 = .03$. Posture had no main effect on RT, $F(2, 42) = 0.33$, $p = .720$, $\eta_p^2 = .02$.

As a result, Hypothesis 4 which stated that RT would increase as the seat becomes more reclined, was not supported.

Figure 5

Response Times per POW for Each Condition



Note. Displayed are the average response times per POW for each postural condition. POW1 represents 0-10min. POW2 represents 10-20min. POW3 represents 20-30min. POW4 represents 30-40min. Error bars represent standard errors of the mean.

3.2.2 Correct Detections

When assessing Correct Detections, the sphericity assumption was supported: $\chi^2(5) = 10.90$, $p = .054$.

Tables 3 and 4 provide the means for each POW and postural condition. There was no significant main effect of POW on correct detections, $F(3, 126) = 0.70$, $p = .553$, $\eta_p^2 = .02$. As a result, Hypothesis 1.1, which stated correct detections would decrease over time, was not supported. In addition, POW and Posture had no interaction effects on correct detections, *F*(6,

126) = 1.12, p = .353, η_p^2 = .05. In addition, there was no significant effect of posture on correct detections, $F(2, 42)$ = 1.43, p = .251, η_p^2 = .06.

Table 3. Means and Standard Deviations for Correct Detections per POW

Time		*M*	*SD*
POW1	Raw	99.11%	2.29%
	Transformed	95.71%	2.75%
POW2	Raw	98.51%	3.44%
	Transformed	95.72%	2.75%
POW3	Raw	98.66%	3.36%
	Transformed	95.45%	3.24%
POW4	Raw	98.25%	3.86%
	Transformed	95.44%	3.24%

Note. Displayed are the means and standard deviations for the percentage of correct detections per POW. POW1 represents 0-10min. POW2 represents 10-20min. POW3 represents 20-30min. POW4 represents 30-40min.

Table 4. Means and Standard Deviations for Correct Detection by Postural Condition

Condition	Type	*M*	*SD*
Upright	Raw	97.88%	0.54%
	Transformed	95.19%	2.68%
Slightly Reclined	Raw	98.93%	0.56%
	Transformed	96.07%	1.09%
Very Reclined	Raw	99.06%	0.52%
	Transformed	95.80%	1.76%

Note. Displayed are the means and standard deviations for the percentage of correct detections for each postural condition.

Equivalence tests were again conducted to determine whether the percentage of correct detections amongst drivers would remain equal despite a postural manipulation. The TOST procedure yielded a nonsignificant result when testing for equivalence between the upright and slightly reclined conditions, *t*(27) = 1.14, *p* = .131. Equivalence was also not found when comparing the slightly reclined and very reclined conditions, *t*(28) = 0.23, *p* = .396. Following the same trend, there was no significance when testing for equivalence between the upright and very reclined conditions, *t*(29) = 1.42, *p* = .083. Despite the nonsignificant main effect of posture in the ANOVA, Hypothesis 3.1, which stated that the percentage of correct detections would not change between postural conditions, was not supported. More research is needed to determine exactly how posture affects correct detection rate in an automated driving task.

3.2.3 False Alarms

When assessing false alarms, the sphericity assumption was violated: $\chi^2(5) = 12.02$, $p = .035$. Therefore, we used a Greenhouse-Geisser correction in the analysis.

Means for each POW and postural condition are in Tables 5 and 6. POW did not have a significant main effect on false alarms, $F(3, 126) = 1.24$, $p = .299$, $\eta_p^2 = .03$. As a result, Hypothesis 1.2, which stated false alarms would decrease over the course of the drive, was not supported. In addition, POW and Posture had no interaction effects on false alarms, $F(6, 126) = 1.41$, $p = .217$, $\eta_p^2 = .06$. The main effect of posture was not significant, $F(2, 42) = 0.34$, $p = .714$, $\eta_p^2 = .02$.

Table 5. Means and Standard Deviations for False Alarms per POW

Time		*M*	*SD*
POW1	Transformed	0.13%	0.08%
	Raw	0.00%	0.00%
POW2	Transformed	0.17%	0.05%
	Raw	0.00%	0.00%
POW3	Transformed	0.17%	0.03%
	Raw	0.00%	0.00%
POW4	Transformed	0.15%	0.06%
	Raw	0.00%	0.00%

Note. Displayed are the means and standard deviations for the percentage of false alarms per POW. POW1 represents 0-10min. POW2 represents 10-20min. POW3 represents 20-30min. POW4 represents 30-40min.

Table 6. Means and Standard Deviations for False Alarms by Postural Condition

Condition	Type	*M*	*SD*
Upright	Raw	0.00%	0.00%
	Transformed	0.15%	0.04%
Slightly Reclined	Raw	0.00%	0.00%
	Transformed	0.16%	0.03%
Very Reclined	Raw	0.00%	0.00%
	Transformed	0.16%	0.02%

Note. Displayed are the means and standard deviations for the percentage of false alarms for each postural condition.

The TOST procedure again was used to analyze Hypothesis 3.2 which states that false alarms would not significantly differ between postural conditions. The analysis yielded a nonsignificant result when testing for equivalence between the upright and slightly reclined conditions, $t(27) = 0.66$, $p = .256$. In addition, equivalence was not found when comparing the slightly reclined and very reclined conditions, $t(28) = 0.27$, $p = .396$. Lastly, there was no equivalence among the data of the upright and very reclined conditions, $t(29) = 0.56$, $p = .290$. Therefore, Hypothesis 3.2 was rejected due to the failure to demonstrate equivalence among the postural conditions, despite the non-significant main effect of posture on false alarms. As a result, more research must be conducted to pinpoint how posture affects false alarm rate in an automated driving task.

3.2.4 Response Sensitivity

The sphericity assumption was violated: $\chi^2(5) = 15.10$, $p = .010$. Therefore, we used a Greenhouse-Geisser correction in the analysis.

We provide means for each POW and postural condition (see Table 7 and Figure 6). There was a main effect of POW on sensitivity, $F(2.43, 126) = 2.97$, $p = .046$, $\eta_p^2 = .07$. However, it appeared that drivers initially became more sensitive to stimuli in the first three POWs, and sensitivity began to decline in POW 4 (see Figure 5). Thus, Hypothesis 1.3, which states drivers' sensitivity would decrease over time, was only partially supported. However, no single POW was significantly different from another according to Post Hoc comparisons. POW and Posture had no significant interaction effect on sensitivity, $F(4.86, 126) = 1.55$, $p = .184$, $\eta_p^2 = .07$. There was no main effect of Posture on sensitivity, $F(2, 42) = 0.81$, $p = .451$, $\eta_p^2 = .04$.

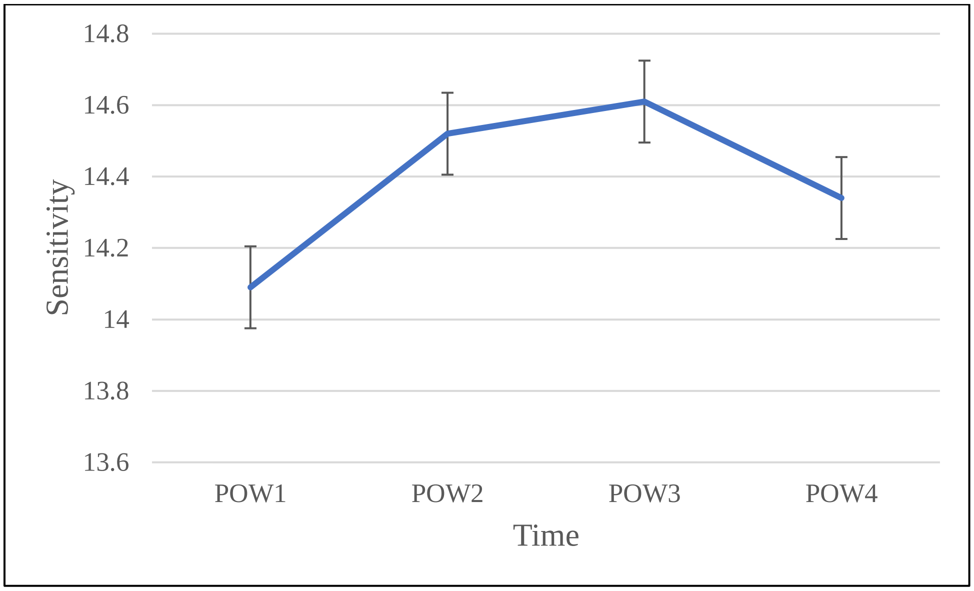
Table 7. Means and Standard Deviations for Response Sensitivity by Postural Condition

Condition	*M*	*SD*
Upright	14.26	0.13
Slightly Reclined	14.48	0.13
Very Reclined	14.44	0.12

Note. Displayed are the means and standard deviations for the sensitivity for each postural condition.

Figure 6

Response Sensitivity per POW



Note. Displayed is the average response sensitivity per POW. POW1 represents 0-10 min. POW2 represents 10-20 min. POW3 represents 20-30 min. POW4 represents 30-40 min. Error bars represent standard error of the mean.

Equivalence was not found between the upright and slightly reclined conditions, $t(27) = 1.02$, $p = .158$. Nor was it found between the slightly reclined and very reclined conditions, $t(28) = 0.30$, $p = .382$. It was also not found between the upright and very reclined conditions, $t(29) = 0.88$, $p = .193$. As a result, despite the nonsignificant main effect of posture in the above ANOVA, Hypothesis 3.3 was not supported because of the lack of equivalence among the postural conditions.

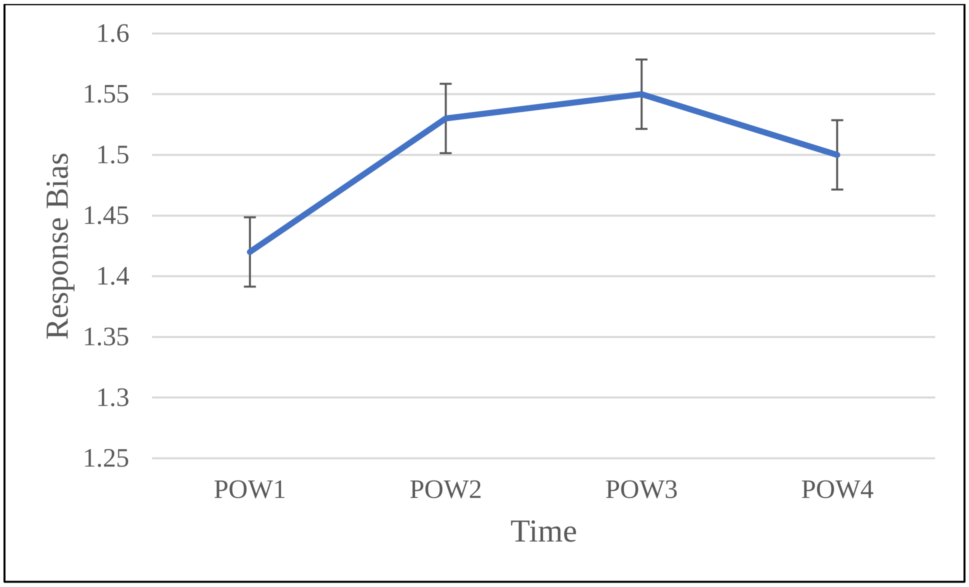
3.2.5 Response Bias

The sphericity assumption was not supported for response bias: $\chi^2(5) = 19.36$, $p = .002$. As a result, we used a Greenhouse-Geisser correction in the analysis.

Hypothesis 1.4 which states drivers' response bias would decrease over the drive was partially supported. Bias was shown to increase significantly over time, $F(2.31, 126) = 4.26$, $p = .013$, $\eta_p^2 = .09$. Pairwise comparisons showed that the significance found stemmed from drivers having a higher response bias in POW 3 than that found in POW 1 ($p = .022$). No other conditions were significantly different from another. Following POW 3, response bias began to decrease in POW 4. Means for each POW and postural condition are shown in Figure 7 and Table 8. There were no interaction effects between POW and postural condition on Bias, $F(4.62, 126) = 1.67$, $p = .155$, $\eta_p^2 = .07$. In addition, Posture was shown to have no significant effects on response bias, $F(2, 42) = 0.23$, $p = .795$, $\eta_p^2 = .01$.

Figure 7

Response Bias per POW



Note. Displayed is the average response bias per POW. POW1 represents 0-10 min. POW2 represents 10-20 min. POW3 represents 20-30 min. POW4 represents 30-40 min. Error bars represent standard error of the mean.

Table 8. Means and Standard Deviations for Response Bias by Postural Condition

Condition	*M*	*SD*
Upright	1.49	0.02
Slightly Reclined	1.51	0.03
Very Reclined	1.50	0.02

Note. Displayed are the means and standard deviations for the response bias for each postural condition.

However, the TOST procedure showed none of the conditions were equivalent to the others. The upright was not equal to the slightly reclined condition, $t(27) = 0.62$, $p = .272$. The slightly reclined was not equivalent to the very reclined condition, $t(28) = 0.38$, $p = .354$. Lastly, the upright and very reclined conditions also were not equivalent, $t(29) = 0.38$, $p = .355$. As a result, Hypothesis 3.4 which states that bias would remain unchanged between postures was not supported.

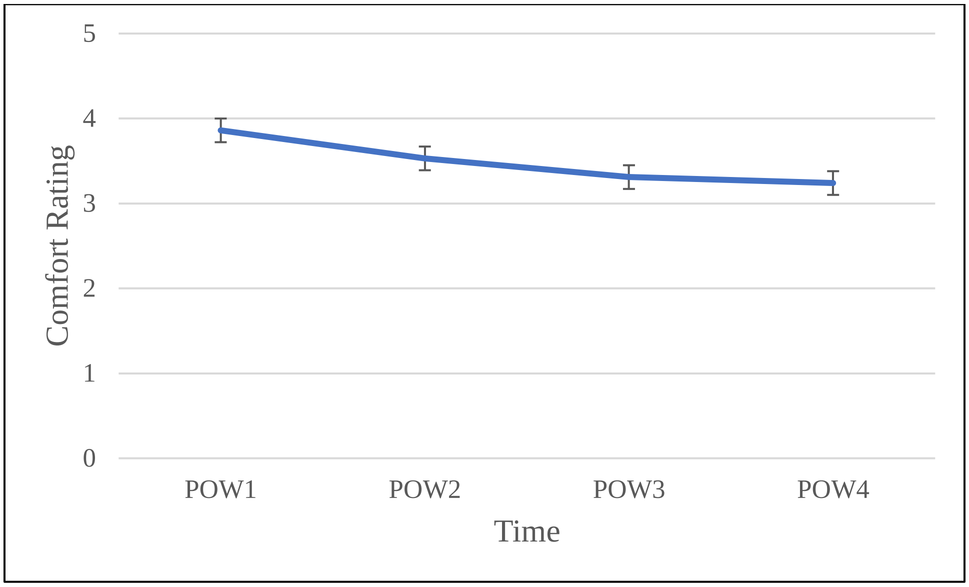
3.3 Comfort Data

We used a Greenhouse-Geisser correction in the analysis due to the sphericity assumption being violated: $\chi^2(5) = 28.45$, $p < .001$.

There were no interaction effects between POW and Posture on Comfort, $F(4.36, 126) = 1.99$, $p = .096$, $\eta_p^2 = .09$. However, Comfort was significantly affected by POW (see Figure 8), $F(2.18, 126) = 11.85$, $p < .001$, $\eta_p^2 = .22$. Comfort ratings were significantly higher in POW 1 when compared to POW 3 ($p = 0.002$) and POW 4 ($p < .001$). There was no significance when comparing all other POWs (ps > .05). Hypothesis 5.2 was supported because comfort generally decreased over the course of the experiment.

Figure 8

Comfort Ratings



Note. Displayed are the average comfort ratings per POW. POW1 represents 0-10min. POW2 represents 10-20min. POW3 represents 20-30min. POW4 represents 30-40min. Error bars represent standard error of the mean.

Postural condition did not significantly affect comfort, $F(2, 42) = 0.37$, $p = .695$, $\eta_p^2 = .02$. Therefore, Hypothesis 5.1 was not supported due to comfort not increasing as the seatback recline increased. Means for each posture are listed in Table 9.

Table 9. Means and Standard Deviations for Comfort Data by Postural Condition

Condition	Mean	SD
Upright	3.30	0.29
Slightly Reclined	3.66	0.30
Very Reclined	3.50	0.28

Note. Displayed are the means and standard deviations for the comfort data for each postural condition.

3.4 Task Suitability

We measured task suitability to determine which postures were most suitable for the automated driving task. Task suitability was measured on a 5-point Likert Scale, with the higher numbers indicating more suitability. The Levene's test indicated heterogeneity of variance for task suitability across all postural conditions, $F(2, 42) = 0.14$, $p = .868$. An ANOVA revealed task suitability did not differ across postural conditions, $F(2, 42) = 0.80$, $p = .454$, $\eta_p^2 = .04$. Table 10 displays the mean task suitability rating based on the driver's posture.

Table 10. Means and Standard Deviations for Task Suitability by Postural Condition

Condition	Mean	SD
Upright	2.67	1.29
Slightly Reclined	3.07	1.14
Very Reclined	2.50	1.32

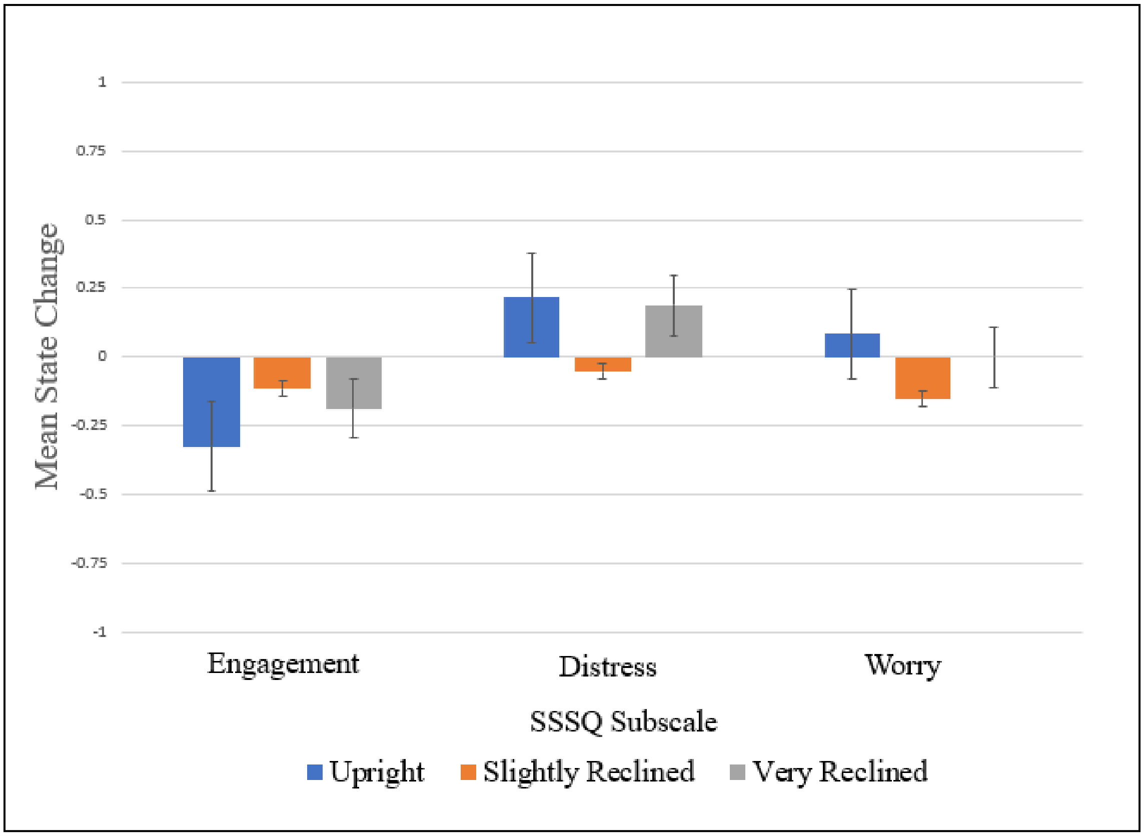
Note. Displayed are the means and standard deviations for the task suitability of each postural condition.

3.5 SSSQ

We compared the data from the pre-task and the post-task SSSQ measures to determine if there were any differences between each postural condition. Change scores were computed by subtracting the pre-task rating from the post-task rating for each of the three subscales of the SSSQ: Engagement, Worry, and Distress (see Figure 9).

Figure 9

Change Scores for SSSQ Subscales



Note. Depicted are the change scores for each postural condition for the three SSSQ Subscales. Error bars represent standard error of the mean.

3.5.1 Engagement

The Levene’s test indicated heterogeneity of variance for engagement across all postural conditions, $F(2, 42) = 0.25$, $p = .783$. An ANOVA revealed engagement was unaffected by postural condition, $F(2, 42) = 0.56$, $p = .577$, $\eta_p^2 = .03$.

3.5.2 Distress

The Levene’s test showed heterogeneity of variance for engagement across all postural conditions, $F(2, 42) = 0.66$, $p = .523$. An ANOVA revealed distress was unaffected by postural condition, $F(2, 42) = 1.75$, $p = .186$, $\eta_p^2 = .08$.

3.5.3 Worry

The Levene’s test displayed heterogeneity of variance for worry across all postural conditions, $F(2, 42) = 0.33$, $p = .719$. An ANOVA revealed worry was unaffected by postural condition, $F(2, 44) = 1.06$, $p = .356$, $\eta_p^2 = .05$.

3.6 NASA TLX

We compared the raw NASA TLX scores for each subscale between each postural condition. The means and standard deviations are reported in Table 11.

Table 11. Means and Standard Deviations for NASA-TLX subscales by Postural Condition

Measure	**Condition**	**Mean**	**SD**
Mental	Upright	3.73	0.48
	Slightly Reclined	3.21	0.50
	Very Reclined	3.88	0.47
Physical	Upright	2.40	0.45
	Slightly Reclined	2.36	0.46
	Very Reclined	2.50	0.43
Temporal	Upright	1.53	0.31
	Slightly Reclined	2.00	0.32
	Very Reclined	1.69	0.30
Performance	Upright	6.33	0.27
	Slightly Reclined	6.07	0.28
	Very Reclined	6.13	0.26
Effort	Upright	2.80	0.39
	Slightly Reclined	2.79	0.40
	Very Reclined	2.31	0.37
Frustration	Upright	2.93	0.52
	Slightly Reclined	2.86	0.54
	Very Reclined	2.81	0.50

Note. Displayed are the various mean and standard deviations for each postural condition based on the NASA-TLX measure.

3.6.1 Mental

The Levene's test indicated heterogeneity of variance for mental workload across all postural conditions, $F(2, 42) = 2.22$, $p = .121$. An ANOVA revealed mental workload was unaffected by postural condition, $F(2, 42) = 0.51$, $p = .603$, $\eta_p^2 = .02$.

3.6.2 Physical

The Levene's test indicated heterogeneity of variance for physical workload across all postural conditions, $F(2, 42) = 2.21$, $p = .122$. Based on an ANOVA, posture did not affect physical workload, $F(2, 42) = 0.03$, $p = .973$, $\eta_p^2 = .00$.

3.6.3 Temporal

The Levene's test showed heterogeneity of variance for temporal workload across all postural conditions, $F(2, 42) = 2.89$, $p = .067$. Temporal workload was not affected by postural condition, $F(2, 42) = 0.56$, $p = .576$, $\eta_p^2 = .03$.

3.6.4 Performance

The Levene's test displayed heterogeneity of variance for performance across all postures, $F(2, 42) = 0.55$, $p = .581$. An ANOVA determined posture did not affect performance, $F(2, 42) = 0.26$, $p = .774$, $\eta_p^2 = .01$.

3.6.5 Effort

The Levene's test showed heterogeneity of variance for effort across postures, $F(2, 42) = 0.74$, $p = .482$. Effort was unaffected by postural condition, $F(2, 42) = 0.53$, $p = .592$, $\eta_p^2 = .03$.

3.6.6 Frustration

The Levene’s test indicated heterogeneity of variance across all postural conditions, $F(2, 42) = 1.83$, $p = .174$. An ANOVA found that a drivers posture did not change their level of frustration, $F(2, 42) = 0.14$, $p = .986$, $\eta_p^2 = .00$.

CHAPTER 4

DISCUSSION

Drivers are constantly seeking vehicle manufacturers to create vehicles that promote comfort as well as enhance their performance (Grujicic et al., 2010). The present study sought to explore the vigilance performance in operators of DAS under various body postures. Performance has been found to decrease as comfort increases in other contexts (Paddan et al., 2012a; Paddan et al., 2012b). It was of importance to determine if this finding extends to the driving context, in which attentional performance may worsen as the seat back reclines and comfort potentially increases. Our design was based off the evidence that comfort increases with seatback recline, and that comfort and performance are negatively correlated. Meaning, as an individual's posture changes, so does their comfort which in turn may affect performance. As a result, we incorporated postures that had previously shown to vary in comfort ratings on a driving task (Mansfield et al., 2021; Paddan et al., 2012a; 2012b). In addition, performance had shown to differ from start to finish on driving tasks (Greenlee et al., 2018; Greenlee et al., 2019; Greenlee et al., 2022; McManus, 2015; Schmidt et al., 2009). This explains why we examined how performance was affected over the course of the drive.

The present study focused on a new and unanswered line of research. For starters, we incorporated driving autonomation systems which is a newer field that attracted attention from the research community as it continues to develop (Banks et al.,2018; Greenlee et al., 2018; Greenlee et al., 2019; Greenlee et al., 2022; Hartwich et al., 2018; Mansfield et al., 2021; Vogelpohl et al., 2019). In addition, determining whether posture affects vigilance performance is under-researched in the literature with only a few postures being explored thus far (Drury et al., 2008; Thody et al., 1993). Drury and colleagues (2008) explored standing versus sitting. Thody and colleagues (1993) manipulated the seatback recline (7-degrees, 30-degrees, 60-degrees from upright). Neither study found differences in vigilance performance amongst the various postures, so we sought to determine if this transferred to an automated driving task. Lastly, the theories used as a backing for the cause of vigilance decrement have not yet been agreed upon in research. For example, some research explains vigilance decrement according to the arousal theory (Atchley & Chan, 2011; Körber et al., 2015; Schmidt et al., 2009) while others explain its causes using the resource theory (Greenlee et al., 2019; Greenlee et al., 2022; Helton & Russell, 2011; Helton & Warm, 2008; Hitchcock et al., 1999; Parasuraman, 1979; Warm et al., 1998; Warm et al., 2008). Our results can add to the discussion.

4.1 Cognitive Underload Versus Overload

The current study uses cognitive underload to explain the vigilance decrement but still acknowledges cognitive overload as a valid explanation of vigilance decrement. We propose that the theory best explaining vigilance decrement depends on the nature of the task. For example, research that incorporates more demanding and frustrating tasks tend to explain their vigilance decrement using cognitive overload due to the difficulty of the task requiring more of the observer’s attentional resources to complete it, leading to poorer performance over time (Greenlee et al., 2019; Greenlee et al., 2022; Helton & Warm, 2008; Parasuraman, 1979; Warm et al., 1998; Warm et al., 2008). Meanwhile, vigilance research that implements easier tasks, like that of the current study, are better explained by cognitive underload due to the observer being able to undergo the task without using much mental/physical effort (Atchley & Chan, 2011; Körber et al., 2015; Schmidt et al., 2009; Thomson et al., 2015). This is consistent with drivers using DAS lower self-reported levels of engagement by the end of the drive (McWilliams &

Ward, 2021). Research in favor of cognitive overload has often overlooked and disregarded cognitive underload as a possible explanation, but our findings provide further evidence that cognitive underload should not be ignored.

Greenlee and colleagues' (2019; 2022) NASA TLX data suggested that supervising the DAS on a drive is a challenging task. In addition, their SSSQ scores revealed that the task was also stressful. This finding aligns with that of previous literature using the NASA TLX which found vigilance tasks to have a high workload, with the primary factors stemming from a high mental demand and frustration (Warm and colleagues, 1998). Warm and colleagues (2008), who favor the resource theory, stated that vigilance tasks are "exacting, capacity draining assignments that are resource demanding" (p. 434). Parasuraman (1979) found vigilance tasks require a lot of effort causing the perceiver to become less able to produce the resources needed to meet the task demand. Therefore, it was reasonable that Greenlee and colleagues (2019; 2022) used the resource theory (overload) to explain their findings, due to individuals viewing the vigilance task as taxing on their resources. However, the present study's task was shown to be rather easy and not stressful, yet we also observed a vigilance decrement as well. In our case, theories aligning with cognitive underload would be a better explanation of vigilance decrement. For example, it's possible that the self-regulation theory may explain our decrement given participants self-reported low levels of effort and lost engagement over the course of the experiment. According to the self-regulation theory individuals may have withdrawn effort from the task but were still able to maintain efficient performance due to the task's ease. However, individuals were more vulnerable when unpredictable stimuli occurred because they were not in a readied state to respond. The arousal theory is also a possible explanation of the vigilance decrement, although the current study did not provide direct evidence for this theory due to arousal typically being measured through physiological measures such as brain activity, heart rate, blood flow, and so on (Luna et al., 2020; Martínez-Pérez et al., 2022; Paus et al., 1997; Smolders et al., 2012).

Atchley & Chan (2011) provide more evidence as to why cognitive underload is a valid explanation of vigilance decrement. They explored the vigilance performance in drivers during a monotonous drive. It was found that introducing a concurrent task when vigilance was at its worst improved a driver's performance because it reduced the monotony of the primary driving task. Their finding also aligned with the cognitive underload, because if vigilance would have been caused by overload from the task, introducing a secondary task would only tax the individual more. Schmidt and colleagues (2009) compared drivers' subjective perception of their vigilance performance to their objective performance on a monotonous driving task. It was found that drivers believed they were improving on the task over time when they were getting worse. As a result, close attention needs to be paid to the vigilance decrement that occurs from cognitive underload because the perceiver can be unaware their performance is getting worse due to the ease of the task.

Our interpretation on how the theories involving cognitive underload and overload explain vigilance decrement can also justify why our experiment showed very high detection rates of signals with hardly any false alarms over the entire duration of the study, because our task was not challenging enough to make a lot of mistakes. The dangerous vehicles in the present study, which moved through the display, were so dissimilar to the safe vehicles, which remained stationary, that the dangerous vehicles stood out when they became present, making them very easy to detect. As a result, the vigilance decrement could not be observed through correct detections and false alarms. Our results on correct detections and false alarms align with Körber and colleagues (2015) who also found barely any misses or false alarms in their data. They explained this to be a cause of their task possibly being “too easy for a performance decrement to occur” (p. 2408). They also attributed it to participants arousal levels not being high enough due to the ease of the task. In addition, Körber and colleagues collected eye tracking data and self-report measures. Their eye tracker, which measured blink frequency, pupil diameter, and blink duration, found that drivers became more fatigued over time. The self-report measures revealed that drivers’ day-dreamed more as the experiment continued. This shows the drivers were losing engagement with the driving task. Our results from the SSSQ on engagement replicated this finding as our change ratings for engagement were all negative showing that individuals became more disengaged as time passed. In addition, there were no significant effects found between postural conditions. This further shows the monotony of the task and how the disengagement amongst our drivers may have contributed to them giving less effort to the task.

4.2 Performance Data

The performance measures included were correct detections, false alarms, response sensitivity, response bias, and RT. We found that correct detections and false alarms did not vary over the course of the experiment nor between postural conditions. As a result, Hypotheses 1.1 and 1.2 which stated they would decrease was not supported. This result may be due to the floor and ceiling effects that were found within our data due to the task being too easy to detect signals. Our signals were very salient and used motion to intrude into the drivers’ driving lane, making them almost impossible to miss if the driver was taking the experiment seriously. As a result, we transformed all floor and ceiling data according to Macmillan and Creelman (2004) suggestions when calculating response sensitivity and bias. There seems to be a speed-accuracy trade-off given the increase in both sensitivity and RT throughout the first 30-minutes of the experiment. In other words, when individuals took their time responding to stimuli, they were able to better distinguish signals from noise. However, the results for the last 10-minutes (POW 4) captured the vigilance decrement with prolonged RT and decreased response sensitivity. It is possible that due to the low task demand, sensitivity did not begin to decrease within our data until disengagement was at its peak.

4.2.1 Response Sensitivity and Bias over Time

We found that response sensitivity and bias followed similar trends to each other, and Hypotheses 1.3 and 1.4 were partially supported. Hypothesis 1.3 assumed sensitivity would decrease over the drive. Hypothesis 1.4 predicted response bias would increase. Our results showed that both measures increased up until about 30-minutes of driving before declining during the last 10-minutes of the drive. This means that drivers were initially improving in their ability to distinguish a dangerous vehicle from a safe vehicle. However, drivers' response sensitivity identifying dangerous vehicles from safe vehicles dropped during the last 10-minutes. Similarly, individuals appeared to become more conservative over the course of the drive. Meaning, they were less likely to respond to the vehicles parked alongside the road. Our results on response bias in the first three POWs align with that of previous literature which showed drivers became more conservative over time (Claypoole & Szalma, 2017; Greenlee et al., 2019; Greenlee et al., 2022). However, when their ability to separate signal from noise began to decline in the last 10-minutes, drivers appeared to become more liberal in their decision making. This liberal behavior may have been an attempt by drivers to ensure that signals were detected even if it meant more false alarms.

Our results on sensitivity differ from Greenlee and colleagues (2018; 2019; 2022) studies which found sensitivity to decrease during the drive. Greenlee and colleagues (2019) conducted their follow-up study with the primary purpose of determining whether changing various aspects of the task would affect vigilance. Based on their findings, it was concluded that whether vigilance decrement occurred or not on a dynamic vigilance task was dependent on the task. In other words, the task length, event rate, type of signal, signal salience, and so on, could all possibly play a role in an observer's ability to separate the signal from noise (Greenlee et al., 2019). The differences in results between our studies may be due to the driving task we chose to use. Greenlee and colleagues' (2018; 2019; 2022) signals were vehicles parked at an intersection that were slightly obtrusive to the driver's path of travel. This signal was stationary and very closely resembled the safely parked vehicles making the signals harder to distinguish. In addition, participants self-reported that the task consisted of a high workload. Meanwhile, the present study incorporated vehicles abruptly pulling into the driver's path of travel, and our signals used motion which may have drawn attention to them, making them easy to detect as they became present.

The differences in sensitivity between Greenlee and colleagues' (2018; 2019; 2022) studies compared to the present study could also be due to the different types of processing that was required. Exogenous attention uses bottom-up processing and is not controlled in a voluntary manner (Pattyn et al., 2008). Endogenous attention utilizes top-down processing and occurs when an individual intentionally allocates their attention to a specific target as instructed or because they feel it is important (Pattyn et al., 2008). Our task appeared to rely on exogenous attention as individuals may have been automatically attracted to our dangerous vehicles pulling into the roadway as they moved through the display. Meanwhile, Greenlee and colleagues' participants had to intentionally focus to discern the slight difference between their safe and dangerous vehicles. In other words, our vigilance task was a detection task while Greenlee and colleagues' (2018; 2019; 2022) studies used a discrimination task. Lastly, the signal salience was further reduced in Greenlee and colleagues (2022) experiment due to their driving task being presented in grey scale.

The decline in sensitivity found within the last 10-minutes of the present study did resemble Greenlee and colleagues (2018; 2019; 2022) work which also found a decline in sensitivity throughout their study. As previously stated, we do not associate the causes of our sensitivity deficit to be rooted in the same theory. Greenlee and colleagues concluded that their drivers were overloaded making their attentional capabilities become worse over time. Meanwhile, our causes of vigilance decrement would be explained by theories aligning with cognitive underload. For example, it is possible that the monotony and ease of our vigilance task made the participants not always give the appropriate amount of effort to the task, and they were caught off guard by the unpredictable nature of our dangerous vehicles. Other possibilities could include individuals exhibiting low arousal or even mind-wandering while undergoing the task leading to the decrease in sensitivity. Our study did not resemble that of a traditional vigilance task which found response sensitivity to remain unchanged throughout the experiment (Claypoole & Szalma, 2017). This is possibly due to the differences that arise between traditional vigilance tasks and the vigilance task created from our driving scenario. As a result, the two types of vigilance tasks may not be directly comparable regarding sensitivity.

4.2.2 Response Time over Time

Another common measure of vigilance decrement is an increase in RT. We found that drivers took longer to respond to dangerous vehicles as the drive progressed. As a result, Hypothesis 2 was supported. We associate this to be a cause of the driving task being easy, decreasing the drivers’ effort levels, making them less ready to act. Many have found vigilance decrement to be caused by the observer running out of attentional resources, which has shown to be supported in previous literature (Greenlee et al. 2019; Helton & Russell, 2011). However, based on the information presented later from our NASA TLX and SSSQ, it was shown that our sample did not feel overloaded due to the demands of the task. In conclusion, cognitive underload causes drivers to react more slowly over time and thus harder to avoid crashing into dangerous vehicles (McWilliams & Ward, 2021).

Our results resemble that found previously in vigilance research. An increase in RT have also been consistently found on traditional vigilance tasks (Claypoole & Szalma, 2017; Helton & Russell; 2011). We found that RT were fastest during the first 10-minutes of the drive and were significantly slower in every proceeding period of watch when compared back to the first 10-minutes. A similar trend was found in Greenlee and colleagues (2018) study in which drivers were significantly faster when responding to dangerous vehicles in the first 10-minutes compared to when in the 10–20-minute block and the 20–30-minute block. Körber and colleagues (2015) also had drivers undergo an automated driving task but separated it from the reaction time task. Drivers were responsible for responding to a specific auditory pitch and it was found that RT increased over the course of the drive.

4.2.3 Posture

The drivers' posture did not influence any of the performance measures nor cause interaction effects with POW. This means that postural manipulations did not affect vigilance performance in this driving context, similar to prior research conducted in other contexts (Drury et al., 2008; Thody et al., 1993). We predicted that posture would not affect correct detections, false alarms, sensitivity, and bias. Although equivalence was not found among the data and we had to reject Hypotheses 3.1, 3.2, 3.3, and 3.4 which predicted equivalence, there were also no significant effects. As a result, more research must be done to better examine why that is.

Hypothesis 4 predicted that RT would be longer as the seatback angle became more reclined. This was also not supported as posture did not affect drivers' RT. Previously, we presented the argument of how the cause of vigilance decrement may be rooted in the difficulty of the task. It can be concluded that manipulating posture does not make the task any more or less difficult. This might be due to the vigilance tasks being mental in nature, so if the observer can process the stimuli, it would not matter what posture they are placed in.

4.3 Comfort Data

Drivers reported that their comfort decreased over the course of the drive. Therefore, Hypothesis 5.2 was supported. We found that comfort was highest in the 1st POW and decreased in each successive period, having the lowest rating in the last POW. There was no significant change in comfort ratings until after 20-minutes of driving. All comfort ratings following 20-minutes were significantly different than those obtained during the first 10-minutes of the drive. Our results align with that found in previous literature (Fiorillo et al., 2021; Gao et al., 2019; Li et al., 2020; Mansfield et al., 2021). Fiorillo and colleagues (2021) had participants rate their comfort every 15-minutes for an hour. Comfort was found to be highest in the first POW and decrease thereafter. Similarly, Mansfield and colleagues (2021) found higher levels of discomfort being reported after 29-minutes of driving. The rising discomfort found over the course of the drive seems best explained by Gao and colleagues (2019) who state that the muscles in the body contract leading to poorer oxygen flow to the tissues when sitting in a stationary posture for long durations. More specifically, Li and colleagues (2020) found it was the legs and upper limbs that experienced the most discomfort in long-term driving (90-min) compared to short-term driving (15min). We did not ask participants to self-report comfort ratings per body region, but it can be assumed the same effects took place in the present study which led to the drivers’ comfort worsening due to the duration of the drive.

We found that drivers’ comfort ratings were similar between all postural conditions. This did not align with Hypothesis 5.1 which predicted that a driver’s comfort would increase if the seatback recline was increased. Our result differed from what was found in Paddan and colleagues (2012b) work possibly due to Paddan and colleagues not having participants undergo a task when assessing their comfort. In addition, their participants were able to place their arms/hands comfortably by their sides. Meanwhile, we required participants to supervise a DAS while always keeping both hands on the steering wheel.

Our results on comfort resemble that of other research exploring comfort in automation. Mansfield and colleagues (2021) had explored whether comfort ratings varied when manipulating posture (upright vs. reclined) while driving manually (Level 0) vs. automated (Levels 3-4). It was found that when driving manually, sitting reclined produced more discomfort than when sitting upright. However, similar discomfort ratings were found between the upright and reclined conditions when using automation. We did not base our hypotheses off this finding due to Level 2 automation not being explored, and we were unsure whether our findings would mirror that of manual or higher automation. However, our findings using Level 2 automation align with that found in higher automation because comfort ratings were similar between postural conditions. Using an automated driving system has been shown to bring about more passive fatigue than active fatigue (Körber et al., 2015). Therefore, it is understandable how comfort levels when driving manually could be affected by one’s posture because tasks include steering, acceleration/deceleration through physical force, constantly checking mirrors, and so on. Therefore, an inadequate posture may cause additional strain. Meanwhile, with Level-

2 automation and higher the driver would only be responsible for supervising the system at most while the automation is activated.

4.4 Subjective Report Data

The subjective report data obtained in the current study showed that supervising a DAS was not a challenging task. We had participants complete the NASA TLX and the SSSQ to assess their workload and stress levels. This allowed us to compare the data between the postural conditions and determine if undergoing the task in a specific posture affected workload and/or stress. We found that the individuals in each postural condition did not differ in their self-reported workload and stress levels on any of the subscales measured. This means that the postural manipulation did not alter how drivers perceived the task or their performance on it. Based on this finding, we can conclude that the occurrence of any performance decrements on the task would not be due to drivers feeling overloaded but instead possibly caused by inefficient effort on the task or even mind-wandering/boredom.

The NASA TLX provided great insight into how participants viewed the task. Participants indicated very high ratings (*M* = 6.17) when asked how they felt they performed. In addition, they indicated the task required very little effort to maintain their high level of performance (*M* = 2.63) and that the task brought about minimal frustration (*M* = 2.87). Our findings align with previous literature which found that cognitive underload brings about lower scores on the NASA TLX (McWilliams & Ward, 2021). The NASA TLX also explored task demand broken down into mental demand, physical demand, and temporal demand. Ratings were low across all three levels of demand, with temporal demand displaying the lowest of the three. It is interesting to note that the task did elicit a slightly higher mental demand (*M* = 3.61) than physical demand (*M* = 2.42), showing that automation does bring about a more passive nature. This aligns with previous literature which states automated driving elicits more passive fatigue than active fatigue (Körber et al., 2015). In addition, it aligns with research that incorporated a NASA TLX and found manual driving (Level 0) to elicit more physical demand on the driver when compared to using DAS (Greenlee et al., 2022). However, this finding does not align with research supporting cognitive overload that found vigilance tasks to elicit a significant workload and great deal of stress to the observer (Helton & Russell, 2011; Greenlee et al., 2019; Greenlee et al., 2022; Warm et al., 2008). Our results on the SSSQ align with research in support of cognitive underload which found that drivers self-reported less engagement with the task over time (McWilliams & Ward, 2021).

4.4.1 Task Suitability

Following the experimental drive, we had all drivers rate how suitable their posture was for the driving task. Task suitability did not differ between postures, which means that drivers can be free to recline their seatback up to 135-degrees without worrying about it affecting their perceived suitability of their drive. However, based on our results, we noticed that all ratings of task suitability were particularly low amongst all postural conditions. This may be due to participants being required to hold the steering wheel with both hands for the entire duration of the drive even though they were never required to steer due to the automation. The experimenters reported having to remind participants to keep their hands on the wheel when they would consciously or unconsciously remove them. To prevent this, we suggest the use of adjustable armrests to allow drivers of these vehicles better support when holding the steering wheel which may lessen the likelihood of the removal of their hands. The current study had armrests in a fixed position to ensure all participants underwent the same experimental conditions. It is possible that many of the fixed factors of our experiment played a role in the low suitability ratings, for example, we did not allow participants to alter their seat-back recline position to their liking, another request often asked by participants. Therefore, a lack of choice in the matter may contribute to the low ratings since drivers are typically in full control of their seatback to the exact degree. More research must be done to determine ways to boost task suitability in drivers using a DAS.

4.5 Contributions

The present study provided the missing link in research and explored both posture and comfort data within the same sample. Paddan and colleagues (2012a; 2012b) were able to separately determine which postures promote the best performance and which postures promote the best comfort. Similarly, Mansfield and colleagues (2021) partially explored this question by determining whether comfort ratings varied when manipulating posture while driving but did not report performance data on the driving task. With that said, there was a need for exploring both performance and comfort together.

Previous literature explored comfort in manual driving compared to driving with higher automation when manipulating posture (Mansfield et al., 2021). Mansfield and colleagues (2021) found that when driving manually, sitting reclined produced more discomfort than when sitting upright. However, similar discomfort ratings were found when using automation (Levels 3-4). The present study incorporated Level 2 automation which was not explored previously. We found that when manipulating posture, ratings on comfort when using Level 2 automation mirrored that of higher automation, a finding which was not yet known in literature. Overall, it appears that posture does not affect performance or task suitability when supervising a DAS. As a result, drivers can be free to choose whatever posture they deem comfortable, if it falls between sitting upright to a recline of 135-degrees, without worrying about a decline in their perceived ability to detect important environmental stimuli.

4.6 Limitations

Comfort was a very important factor to the present study. To gather data on comfort we had participants verbally state how they felt at the end of each POW. We acknowledge this method of gathering data as a limitation due to the interruption effects that may have occurred from participants taking a brief break from the driving task (Fluegel, 2020; Speier et al., 1999; Westbrook, 2010). However, with comfort being a key factor in the study, we did not want to risk waiting until after the experiment to gather comfort data. Doing so could have caused participants to recall or even guess how their level of comfort changed throughout the study. Therefore, we sought to prevent the potential errors in recall by asking for their comfort ratings in real-time following each POW. We created a buffer where a signal was not present for the first 1000ft of each POW. This setting was to eliminate any immediate crashes upon task resumption, which could had biased our data. Participants were not made aware of this buffer.

This study was conducted in a laboratory setting with many factors fixed. These fixed factors were to control for potential extraneous variables, but we acknowledge this may have led to limitations. For starters, the steering wheel was mounted to the desk and could not be adjusted by participants. In addition, we had fixed postural conditions that we placed our participants in. Lastly, we did not allow our participants to engage in other tasks while undergoing the experiment. As a result, the implementation of our design would be different in reality. For example, drivers can adjust their steering wheel height and position from their body. In addition, drivers have complete control over their chair height, recline, and longitudinal positioning.

4.7 Future Research

This study manipulated drivers' posture to determine which posture was the most suitable for an automated driving task. There were no differences in task suitability between postures and all postures displayed a relatively low suitability rating. Future research should explore how to boost these task suitability ratings amongst various postures. Posture also had no effect on vigilance performance. We previously noted how the explanations of vigilance performance may be task related and how our experiment consisted of a relatively easy task. Therefore, future research may also explore whether posture is still an insignificant factor in experiments that implement more demanding vigilance tasks.

Future research should also investigate whether the absence of a neck pillow affects performance on an automated driving task when in different postures. Using the NASA TLX, Mansfield and colleagues (2021) found that perceived workload was higher on the driving task when reclined versus sitting upright. However, in a follow-up experiment, drivers were given a neck rest and it was found that the perceived workload more closely mirrored that of the upright condition. It was concluded that a neck rest mitigated the adverse effects of the reclined backrest because of its ability to allow drivers to maintain torso and head stability in that posture, improving comfort. Although they did not measure performance on the driving tasks, this result showed that performance could possibly be affected by the neck rest. The chair used in the current study incorporated a neck pillow attached to the head rest. The neck pillow was vital because without it our participants gaze would have been focused above the display when in the very reclined position. As a result, even though a neck rest is recommended, future research should manipulate posture while measuring performance without incorporating a neck rest.

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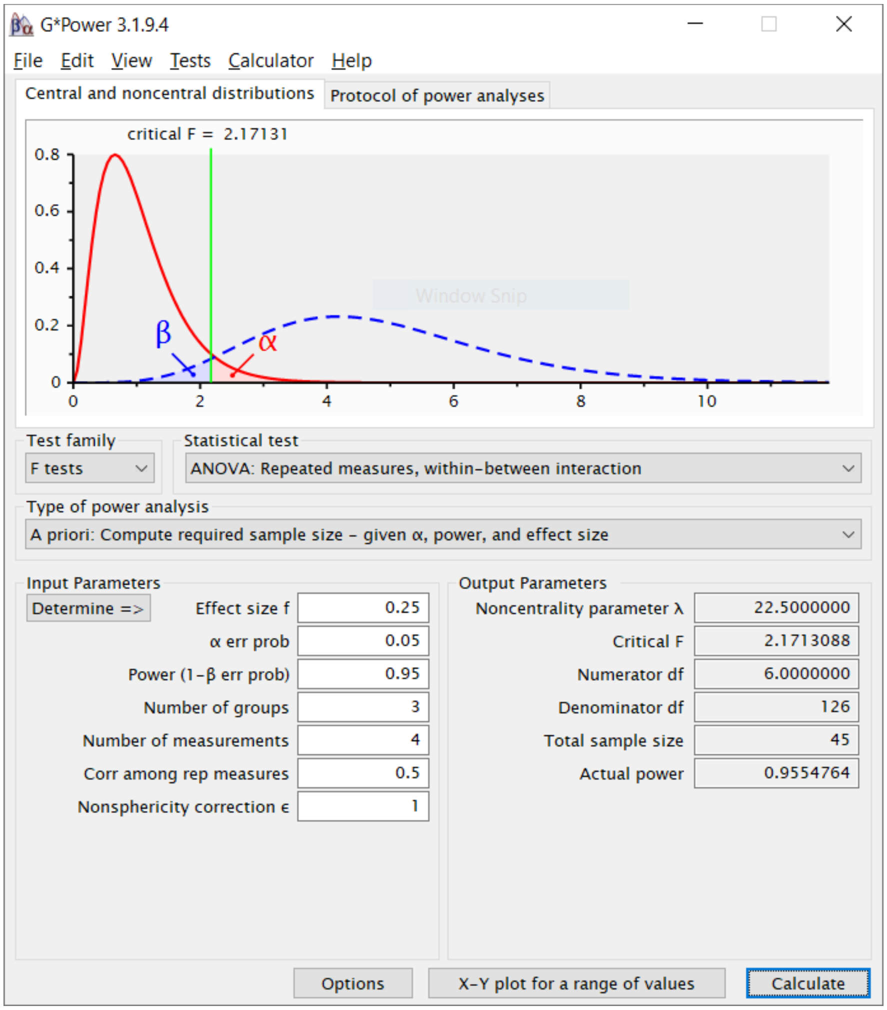
APPENDIX A

POWER ANALYSIS OF SAMPLE SIZE; POWER 0.95

Figure A

Power: 0.95



Test family: F tests

Statistical test: ANOVA: Repeated measures, within–between interaction

Type of power analysis: A priori: Compute required sample size – given α, power, and effect size

Input Parameters

Effect size f	0.25
α err prob	0.05
Power (1–β err prob)	0.95
Number of groups	3
Number of measurements	4
Corr among rep measures	0.5
Nonsphericity correction ε	1

Output Parameters

Noncentrality parameter λ	22.5000000
Critical F	2.1713088
Numerator df	6.0000000
Denominator df	126
Total sample size	45
Actual power	0.9554764

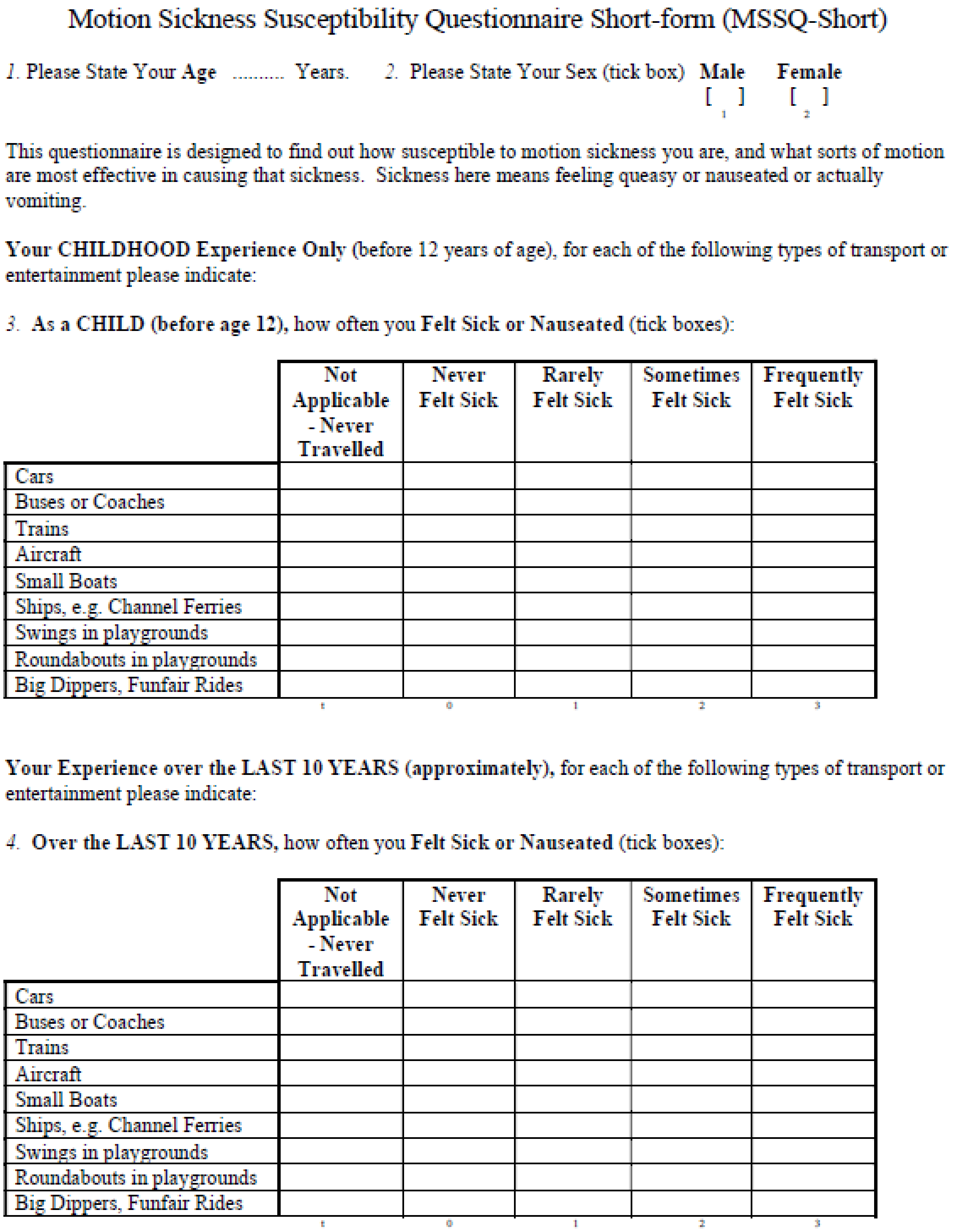
APPENDIX B

DEMOGRAPHIC INFORMATION SURVEY

					Gender		Ethnicity (please select one)							Dominant Hand	Normal or Corrected to Normal	
Date	RA	Expt	Subject No.	Age	M	F	American Indian/ Alaska Native	Asian	African/ African American	Caucasian	Native Hawaiian/ Pacific Islander	More than one race	Other/ Unknown	L/R	Vision (Y/N)	Hearing (Y/N)

APPENDIX C

MSSQ-SHORT FORM



Motion Sickness Susceptibility Questionnaire Short-form (MSSQ-Short)

1. Please State Your **Age** .... Years. *2.* Please State Your Sex (tick box) **Male** [ ] $_1$ **Female** [ ] $_2$

This questionnaire is designed to find out how susceptible to motion sickness you are, and what sorts of motion are most effective in causing that sickness. Sickness here means feeling queasy or nauseated or actually vomiting.

Your CHILDHOOD Experience Only (before 12 years of age), for each of the following types of transport or entertainment please indicate:

3. **As a CHILD (before age 12),** how often you **Felt Sick or Nauseated** (tick boxes):

	Not Applicable - Never Travelled	**Never Felt Sick**	**Rarely Felt Sick**	**Sometimes Felt Sick**	**Frequently Felt Sick**
Cars					
Buses or Coaches					
Trains					
Aircraft					
Small Boats					
Ships, e.g. Channel Ferries					
Swings in playgrounds					
Roundabouts in playgrounds					
Big Dippers, Funfair Rides					
	t	0	1	2	3

Your Experience over the LAST 10 YEARS (approximately), for each of the following types of transport or entertainment please indicate:

4. **Over the LAST 10 YEARS,** how often you **Felt Sick or Nauseated** (tick boxes):

	Not Applicable - Never Travelled	**Never Felt Sick**	**Rarely Felt Sick**	**Sometimes Felt Sick**	**Frequently Felt Sick**
Cars					
Buses or Coaches					
Trains					
Aircraft					
Small Boats					
Ships, e.g. Channel Ferries					
Swings in playgrounds					
Roundabouts in playgrounds					
Big Dippers, Funfair Rides					
	t	0	1	2	3

APPENDIX D

COMFORT SURVEY

1 = Strongly Disagree   2 = Disagree   3 = Neither agree nor disagree   4 = Agree   5 = Strongly Agree

Participants were asked to rate how they feel to the statement: “Overall, I am comfortable sitting in this chair”

APPENDIX E

SHORT STRESS STATE QUESTIONNAIRE

1 = Not at all 2 = A little bit 3 = Somewhat 4 = Very much 5 = Extremely

I feel dissatisfied.

I feel alert.

I feel depressed.

I feel sad.

I feel active.

I feel impatient.

I feel annoyed.

I feel angry.

I feel irritated.

I feel grouchy.

I am committed to attaining my performance goals.

I want to succeed on the task.

I am motivated to do the task.

I am trying to figure myself out.

I am reflecting about myself.

I am daydreaming about myself.

I feel confident about my abilities.

I feel self-conscious.

I am worried about what other people think of me.

I feel concerned about the impression I am making.

I expect to perform proficiently on this task.

Generally, I feel in control of things.

I thought about how others have done on this task.

I thought about how I would feel if I were told how I performed.

APPENDIX F

NASA TASK LOAD INDEX

	1	2	3	4	5	6	7	
Very Low	○	○	○	○	○	○	○	Very High

Mental Demand: How mentally demanding was the task?

Physical Demand: How physically demanding was the task?

Simple Demand: How hurried or rushed was the pace of the task?

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

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

Frustration: How insecure, discouraged, irritated, stressed and annoyed were you?

APPENDIX G

TASK SUITABILITY SURVEY

“My body posture was suitable for the driving task.”

1: Strongly disagree

2: Disagree

3: Neither agree nor disagree

4: Agree

5: Strongly agree

VITA

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EDUCATION

2020 - Present	M.S., Psychology (Concentration: Human Factors) - Old Dominion University (ODU)
2016 - 2020	B.S., Psychology (3.72 Overall GPA, 3.88 Psychology GPA, Magna Cum Laude) - ODU
2012 - 2016	Tabb High School (3.76 GPA, Summa Cum Laude)

SELECT PUBLICATIONS, CONFERENCE PROCEEDINGS, AND PRESENTATIONS

- Ammons, J. G., Parker, C., Chen, J. (2021). Time pressure and user ratings on consumers' choice and eye fixations. *International Journal of Human-Computer Interaction, 38* (11), 993-1003*.*
- Ammons, J., Parker, C., & Chen, J. (2021). Effects of Time Pressure and User Ratings for Online Shopping. Talk presented at the Human Factors and Ergonomics Society 65th International Annual Meeting. Baltimore, MD.
- Pacailler, M., Yahoodik, S., Sato, T., Ammons, J., & Still, J. (2022). Human-centered artificial intelligence: Beyond a two-dimensional framework. *To appear in HCII 2022 - Late Breaking Work – Papers.*

AWARDS

-ODU Graduate School's Fifth Annual Thesis Competition: 1st Place Winner (Prize $1000)

- Title: The Effect of Body Posture on Attention during Automated Driving

-Departmental Honors in Psychology (ODU)

- Senior Honors Thesis: Time Pressure and User Ratings on Consumers' Choices and Eye Fixations
  - Selected for Alan Chaiken Undergraduate Honors Thesis Award of the Year

-Dean's List ODU (F16, F17, S18, F18, S19, F19)

-Graduated from the Perry Honors College (ODU)