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R. Wade Allen, Sherrilene Classen

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Driving simulator applications
in research and clinical practice

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Abstract
This special issue reports on papers presented at a simulation user group meeting held in association with the University of Florida, Gainesville. This is the sixth in a series of special issues that have reported on driving simulator applications presented at simulation users conferences [1 - 5]. The meeting attracted 32 attendees from 5 different countries. This special issue includes 8 papers covering a wide range of research topics. The papers in this volume address in-vehicle systems, simulator sickness, simulator validation, driver behaviour and investigation of rider behaviour with a novel motorcycle simulator.

1. Introduction
This is the sixth special issue devoted to driving simulation research and application concerning driver behavior and transportation system safety. The first special issue in 2004 resulted from papers given at a conference in San Diego, California, USA [1]. The theme of the first conference was “New Directions in Driving Simulation Research.”

Four more symposia have been held and reported on in the last four years:
“Multidisciplinary new approaches to old problems: an overview of driving simulation research” held in Stuttgart, Germany in September 2005 [2];
“New approaches to simulation and the older operator” held at the Massachusetts Institute of Technology in October of 2006 [3];
the sixth conference “Training the Older Driver” was held at Universite Laval in Quebec City in 2008 [5].

This current special issue contains papers presented at two of the most recent simulation user conferences. The meeting in 2009 was co-hosted in Belgium by the Faculty of Kinesiology and Rehabilitation Sciences at the Katholieke Universiteit Leuven, and the Transportation Research Institute of Universiteit Hasselt.

The 2010 meeting was organized in conjunction with the University of Florida, Gainesville and took place in St. Petersburg, Florida during October 2010. For this meeting, the diversity of the research was remarkable and speaks out for the increasing role of simulation in studying driver behaviour and vehicle and roadway design issues.
Two keynote presentations addressed general simulator applications: Loren Staplin of TransAnalytics spoke on “Safe Driving Tactics: What Role for Low Cost Simulation?” and Orit Shechtman of the University of Florida at Gainesville spoke on “A method for validating driving simulators: comparing driving errors with on road assessment.” Technical sessions were held on Traumatic Brain Injury, Driver/Vehicle Interaction, Traffic and Roadway Interaction, Simulator Sickness, Measurement, Assessment and Training, a panel discussion on Experimental Procedures and Methodology, and a poster session on a wide variety of simulator and desktop assessment applications.

2. Contributions

“Simulator methodologies for investigating fatigue and stress in the automated vehicle”

This paper examines and illustrates the utility of using a driving simulator to investigate relationships between vehicle automation and driver fatigue. It offers several key criteria that simulator methods should meet in order to establish functional fidelity, so that simulators offer valid measures of subjective fatigue states as well as objective performance changes. Guidelines are offered for traffic researchers in evaluating the effectiveness of simulator methods as well as the influence of automation use on fatigue and stress.

“Investigating design issues for the use of touchpad technology within vehicles”

This paper provides an overview of two studies investigating the human factors design issues for touchpad technology within vehicles. The first study considered control location preferences for left handed versus right handed people. The second study considered what tasks are most appropriate for use of touchpad technology.

“Simulated lane departure warning system reduces the width of lane that drivers use”

This pilot study addressed the use of rumble strips as a lane departure warning system. Encounters with the rumble strip were simulated with auditory feedback. Results showed that the rumble strip warning reduced the number of edge line crossings, the number of drivers who crossed the edge line, and reduced lane deviations. Survey results also showed that this approach is socially valid.

“Simulator sickness among returning combat veterans with mild traumatic brain injury and/or post-traumatic stress disorder”

In this retrospective simulator study, the occurrence of simulator sickness was analyzed for combat veterans compared to healthy controls. Susceptibility to simulator sickness occurred in combat veterans at two time periods and increased as driving exposure progressed. Overall, these findings suggest that combat veterans may have pre-existing conditions that make them more susceptible to simulator sickness; and that they are affected more severely compared to healthy controls. Simulator sickness is an important side effect incurred in simulator research, and this study illustrates possible additional considerations associated with head injury.

“Validation of driving simulators”

This paper provides a literature review of driving simulator validation studies, addresses the possible reasons for the controversy in the literature, suggests using health measurement terminology for simulator validity and offers ways to match the types of measurement validity terms with examples of existing diving simulator validation studies.
“Investigating motorcycle rider behaviour: developing an integrated experiment approach”

This paper presents one of the first in-depth motorcycle simulation studies to compare groups of road users who have fundamentally different skills, attitudes and behaviours. A study was designed to compare Novice, Experienced and Advanced trained riders across a range of motorcycle activities. The approach adopted allowed for comprehensive data collection and analysis with minimal disruption to participants or biases creeping into the data.

“Driver behavior and advanced driver assistance systems: an exploratory driving simulator study”

This paper explores potential driver behavior changes due to the interactions with advanced vehicle technologies emerging on the market. These technologies were designed mainly to improve roadway safety and provide comfort to drivers. Performance without the systems was compared to that obtained while the systems were in use. Results showed changes in driving behavior due to the systems and specific driver’s characteristics that are more likely to be affected by these technologies.

“Using electrooculography for glance analysis during simulated driving”

This paper considers the feasibility of using electrooculography (EOG) to monitor eye movements during simulated driving. Electrooculography may be a feasible and affordable way to measure eye movement during simulated driving, but is understudied. Results confirmed that participants spent more time glancing away from the road to the right when visual instructions were given in the lower right hand corner of the screen. Though electrooculography does not provide the same amount or quality of data as head-mounted eye trackers and multiple camera systems, it does yield sufficient data to address questions such as the ones posed in this study.

3. Summary

Simulators continue to provide a safe and perceptive means for studying, assessing and training drivers to positively affect their safe behaviors. The technological basis for driving simulation continues to improve and will allow improvement in capability and performance for the foreseeable future.

New and innovative driving simulator applications continue as evidenced by the papers in this volume. The capability of simulation to produce realistic virtual worlds is expanding, and the cost of achieving these conditions is falling, and therefore the application of driving simulation is becoming more appealing to a wide range of researchers in various disciplines and is encouraging new innovative assessment and training applications.

The papers herein give testament to these assertions, and we see this trend continuing in the near future.

References


Simulator methodologies for investigating fatigue and stress in the automated vehicle

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Abstract
Research has shown beneficial performance gains from recent advances in automated driving systems. Although these systems show promise for mitigating potentially dangerous effects of driving, namely subjective feelings of stress and fatigue, there are some safety concerns, which may be investigated using simulator methods. This paper examines and illustrates the utility of using a driving simulator to investigate relationships between vehicle automation and driver fatigue. It offers several key criteria that simulator methods should meet in order to establish functional fidelity, so that simulators offer valid measures of subjective fatigue states as well as objective performance changes.

The present paper reviews three recent simulator studies from the authors’ laboratory, which investigated the influence that required and optional automation use has on subjective ratings of stress and fatigue, as well as on driver performance. It appears that simulators can and do produce a patterned subjective stress and fatigue response, characterized especially by loss of task engagement. These states are similar to those found in real life driving, and reflect similar cognitive stress processes, including threat and challenge appraisals. Moreover, using a simulator may also capture the potentially damaging effects of fatigue on safety, as evidenced by slowed response to an emergency effect following automated driving. Automation use elicits a state of ‘passive’ fatigue, which can be associated with chronic under-stimulation. In addition, it appears that voluntary control of automation use does not mitigate against fatigue effects. Indeed, fatigue may encourage use of automation. The findings of these studies result in guidelines for traffic researchers in evaluating the effectiveness of simulator methods as well as the influence of automation use on fatigue and stress.

Keywords – Simulator methods, active fatigue, passive fatigue, automation use, driver behavior, stress

1. Introduction
It is well known that driver fatigue is likely to be dangerous during vehicle driving [1, 2]. Understanding and countering driver fatigue is thus an essential ingredient to improving traffic safety. It is well known that driver fatigue contributes to potentially fatal car crashes [3]. Although the effects of driver fatigue may be well known, two key research issues should be highlighted. First, it seems that the effects of fatigue are multifaceted and may overlap with other factors such as subjective stress (e.g., negative mood), with symptoms that may be expressed in a wide range of subjective states [4]. Different forms of driver fatigue may have differing impacts on safety [5]. Second, technology-based countermeasures for fatigue are becoming increasingly salient [6, 7].
Specifically, recent advances in automated vehicle systems may remove some of the task load placed upon the driver and therefore decrease subjective feelings of stress and fatigue. The purpose of these automated systems is to improve performance of the human operator by creating a less stressful, more workable environment, resulting in optimal workload conditions.

Examples of technologies that may be found in future road transport systems include automated highway system (AHS) and adaptive intelligent cruise control (AICC) [5]. AHS enables the majority of driving functions such as steering and braking to be automatically controlled, while AICC emits a laser or radar, which allows the vehicle to automatically slow or speed up when needed. These advances may benefit the driver by decreasing subjective ratings of workload and fatigue in the driver, although there are few empirical studies investigating the relationship between subjective states and automation. Alternatively, automation use may exacerbate driver fatigue and stress by reducing the driver’s situation awareness [8, 9] and perceived lack of control [10, 11]. In addition, it appears that the effects of driver stress and fatigue may be influenced by required or optional (self-initiated) automation use.

The aim of this article is to examine the utility of a driving simulator for examining the effects of vehicle automation on the multiple facets of the fatigue response. We will, first, define the problem of interest, by outlining the potential dangers and benefits of automation. Next, we will examine methodological requirements for using a driving simulation as a tool for addressing this research problem. In the final part of this article, we will briefly summarize key findings from our recent empirical approach, before arriving at conclusions on the simulator methodology.

2. The dangers and benefits of vehicle automation

Automated systems are typically seen as beneficial to the human operator. A key benefit is reducing the cognitive workload placed upon the driver, which may in turn reduce feelings of stress or fatigue. Although potentially helpful, it may be that automated systems only improve certain aspects of the driver’s mental state. In a simulator study, Funke et al. [12] found that automating control of speed of driving, while requiring the driver to control lateral position, alleviated subjective ratings of workload and distress, but not fatigue. The use of a multivariate assessment model for evaluation of driver response may provide a more nuanced picture of the effects of automation than a simple workload-reduction.

Although automated systems initially appear to promote safer driving, the technology may also introduce unsuspected dangers. Continued automation use may reduce situation awareness, exhibited by a slowing of reaction time to a sudden event [9, 13], the effects of which may be made worse for the already fatigued driver. Prolonged automation use may result in the driver over-relying on the system, which may be dangerous when the driver suddenly needs to switch from automated to manual control. To better understand how well drivers are able to switch from automated to manual control, Desmond et al. [14] performed an experiment that required drivers to suddenly regain control of the vehicle. Following automation failure, they found that drivers placed in the manual condition were better able to recover than those placed in the automated condition, suggesting that total automation may be hazardous. By contrast, partial automation [12] requires the driver to remain somewhat involved, which may protect against driver complacency.

Fatigue has also been linked to a more “passive” style of performance [15]. The operator may adopt a strategy for managing the system that reduces effort, by relying on a reactive strategy of responding to events as they occur, rather than making proactive attempts to maximize performance [16]. Thus, there appear to be some parallels between fatigue states and the complacent, disengaged state that may result from automation [9].
We may then ask whether automation use might exacerbate the loss of alertness that may be associated with fatigue, or whether the workload reduction derived from automation remains beneficial to the fatigue driver.

3. Investigating driver fatigue: methodological issues

Simulator methods are well suited to investigating a variety of human factors issues related to automation, because of the ease with which various forms of automation may be reproduced [17]. However, the experience of fatigue is not necessarily the same in real and simulated driving. The issue is really one of whether the simulator shows ‘functional fidelity’ [18] in producing fatigue responses that correspond to those associated with real driving [19]. Broadly, the fatigued driver should exhibit changes in subjective state and objective behavior that correspond to those seen in real driving, and which reflect the same underlying psychological mechanisms. Functional fidelity of fatigue elicited by driving simulators may be evaluated against the following criteria.

3.1. Correspondence of subjective response patterns

Fatigue is a potentially complex, multifaceted subjective state that may be experienced in a variety of ways during task performance. Very often, the demands of operating a vehicle in a tired or sleepy state also elicit stress and negative emotion, as the person strains to maintain safety [20]. A multidimensional subjective state model may be used to characterize the subjective experience of driving fatigue [17].

Matthews et al. [21] developed a psychometric model of stress states that differentiates three broad dimensions or factors that describe the subjective experiences that accompany task performance. Task engagement is defined by energy, task-directed motivation and interest, and concentration. Conversely, low task engagement corresponds to a prototypical fatigue state of tiredness, loss of motivation and distractibility. Distress is defined by negative moods and lack of confidence, whereas Worry refers to self-focus of attention, low self-esteem and intrusive thoughts that interfere with attention to the task.

Data from field studies of vehicle driving suggest that in both professional and non-professional samples, prolonged driving tends to elevate distress and lower task engagement [22]. Qualitatively similar results have been obtained in two studies of simulated driving, in which fatigue was induced by requiring the driver to perform a demanding attentional task concurrently with vehicle operation [15]. Performance of a rather monotonous simulated drive, with little traffic or roadside scenery, produced a comparable pattern of change [23]. This study also showed that subjective state change was accompanied by changes in brain metabolism, indexed by cerebral bloodflow velocity. Even over relatively short durations of 30-40 min, simulated drives can be configured to elicit patterns of state change that broadly resemble those seen in real driving, although there may be differences in the details of the state change response.

3.2. Sensitivity to fatiguing agents

Functional fidelity requires that similar external influences govern fatigue response in both simulated and real environments. A simple example is sleep loss. The use of simulators to explore the effects of sleep deprivation is supported by evidence that simulated driving can elicit characteristic changes in subjective sleepiness, performance and psychophysiological measures such as the electroencephalogram (EEG) [24]. An extension of the same general principle is to show that countermeasures effective for simulated driving also mitigate fatigue in real driving [25].
In the case of task-induced fatigue, driver response should be sensitive to factors known to generate fatigue during real driving including high workload, monotony and the duration of the drive. The sensitivity of fatigue to task factors is captured conceptually by the differentiation of two qualitatively different forms of fatigue: active and passive fatigue [5]. Active fatigue is elicited when the driver must produce frequent control responses under prolonged high workload. By contrast, passive fatigue is characterized by monotony, boredom and underload.

The distinction between active and passive fatigue may be critical for studying vehicle automation effects in the simulator. By placing the driver in a supervisory role, vehicle automation may be likely to elicit passive fatigue by reducing the driver’s active control over the driving task. Stanton and Young [9] discuss how adaptive cruise control (ACC) seems to be related to slower emergency braking in both real (test-track) and simulated driving studies. They attribute the deleterious effects of automation to underload, which Desmond and Hancock [5] see as a key influence on passive fatigue.

3.3. Elicitation of common stress processes

According to the transactional theory of stress [26], stress and emotional responses are controlled by cognitive processes, including appraisal and coping. Consistent with this cognitive theory of stress, fatigue and stress state responses in both field and laboratory settings are shaped by appraisal and coping [27, 33]. For example, subjective task engagement is maintained when the task is appraised as challenging, and when the operator uses task-focused coping but not avoidance coping. Matthews and Desmond [15] showed that a fatigue manipulation on the simulator reduced active, task-focused coping, a process they attributed to impairment in executive control of effort. Similarly, a study of bus drivers showed that fatigue relates to the driver’s use of maladaptive coping strategies [28].

Human-machine interfaces, including automated systems, are open to a variety of cognitive interpretations by the user [29]. For example, an in-vehicle system might be variously appraised as being a useful addition to the vehicle, which is fun to use, or as a pointless extra that is more of a nuisance than a benefit. Similarly, automated systems may change the driver’s coping strategies. Systems that are positively appraised may elicit task-focused coping, as the driver actively seeks to understand the operation of the system and to find strategies for using it most effectively. Conversely, a system that is more annoying than helpful may elicit emotion-focused coping as the driver seeks to deal with the negative emotions that it produces. A hypothesis of special relevance to fatigue is that automated systems may produce a state of complacency, characterized by over-reliance on automation [30], which may be associated with reduced task-focus and increased avoidance coping. Thus, it is important to evaluate the styles of appraisal and coping elicited by simulations of automated systems [17].

3.4. Reproduction of performance deficits

Fatigue is important as a safety issue primarily because it is related to changes in driver behavior and performance impairment. There are continuing concerns over the extent to which subjective fatigue may be taken as an indicator of actual performance impairment [31]. A simulated drive that made drivers feel tired, without actually changing their behavior, would lack functional fidelity. In fact, studies using driving simulators have identified a variety of behavioral indices of fatigue, including deterioration in steering of the vehicle and loss of attention to the external traffic environment [15, 17, 32].
Beyond the simple demonstration of performance deficits, the simulator should also be suitable for testing theory-driven accounts of fatigue effects. For example, Matthews and Desmond [15] found that performance deterioration in a fatigued state was more pronounced under low workload conditions than high workload conditions. Drivers in this study also showed a reduced frequency of small-magnitude steering responses, suggesting loss of task-directed effort. This finding can be accommodated within the Hancock and Warm [33] theory of effort-regulation mechanisms for performance; fatigue impairs the driver’s ability to exert an adequate amount of effort in underload conditions. It follows that vehicle automation that reduces workload below typical levels may also disrupt effort-regulation [9].

3.5. Reproduction of individual differences

Individuals differ in their sensitivity to stress and fatigue during driving. The Driver Stress Inventory (DSI: [27, 34]) differentiates five dimensions of vulnerability, including fatigue-proneness. Studies have shown that fatigue-proneness correlates with subjective fatigue response to simulated driving [35] as it does in real-life driving [22].

Other dimensions such as dislike of driving and aggression control other elements of the stress response, including anxiety and anger.

If drivers who are prone to fatigue and stress during real driving show similar vulnerabilities on the simulator, we have further evidence for functional fidelity [27]. In this paper, our primary focus is on the impact of workload manipulations on fatigue. We will not discuss individual difference issues further, except to note that, in the studies reviewed below, we found that the DSI predicted subjective state response similar to previous studies, suggesting functional fidelity.

4. Simulator studies of fatigue and vehicle automation

The present review will address evidence from recent empirical studies on two key issues: (1) whether automation use induces or exacerbates driver fatigue and stress and (2) whether these subjective responses impair driver performance and safety. The basis for using a driving simulator for studying automation effects is that it has sufficient functional fidelity to elicit changes in subjective state and in performance that correspond to those that are (or would be) seen in similar, real-driving scenarios [19]. We will summarize findings from three recent studies that investigated the impact of fully automated driving. The general hypothesis is based on Desmond and Hancock’s [5] analysis of fatigue, and Young and Stanton’s [8] account of the passivity and loss of situation awareness that may be engendered by fatigue. It is hypothesized that full vehicle automation may provoke a state of passive fatigue, characterized especially by loss of task engagement, which is accompanied by a loss of alertness and objective performance impairment.

There are several simulated driving methods that may be used to explore the inter-relationships of the demands of the driving task, subjective stress and fatigue, and performance change. The STISIM simulator [36] used in this research is readily configured to manipulate various task demand factors, including the introduction of automation, and provides the data-logging necessary to evaluate the impact of manipulations on performance. All studies reviewed here featured a Systems Technology, Inc., STISIM Model 400 simulator, equipped with a 38” NEC XM3760 monitor.

As shown in Figure 1, the simulator is equipped with a car seat, full-size steering and braking/acceleration controls, and speed-sensitive “steering feel” provided by a computer controlled torque motor.
Simulator methods were used to explore three related issues. First, we investigated how the build up of fatigue during automated drives of increasingly long durations contrasts with subjective state response in active fatigue and in normal driving. During simulated driving, active fatigue might, for example, be induced by programming a series of continuous sharp turns while driving, which requires that the driver continually apply effort and maintains task involvement. By contrast, a ‘normal’ simulated drive might require episodic effort, but also includes periods of undemanding driving.

Second, we tested whether the passive fatigue state found to result from automation was associated with objective performance impairment. In order to examine the effects of vehicle automation on subjective fatigue during simulated driving, we created an automated drive, where vehicle controls such as steering, braking and speed were fully automated for certain periods of time throughout the drive. Another strategy for inducing a state of passive fatigue is to program a monotonous, under stimulating driving environment, such as driving on a straight road with no curves or turns, very little scenery and no interaction with other traffic.

Third, we investigated the role of fatigue in the driver’s voluntary choices over whether or not to use automation. Here, we presented a moderately stimulating driving environment to participants and allowed them to choose when they desired to use automation. By pressing the turn signal, drivers could engage in automated driving for a period of five minutes before regaining manual control of the vehicle.

4.1. Study 1: Automation and subjective response patterns in passive fatigue

In order to explore the effects of active and passive fatigue manipulations, Saxby et al. [37] ran 108 drivers in one of three conditions: normal vehicle driving (control), frequent strong wind gusts (active fatigue), which elevated driver workload, and full vehicle automation (passive fatigue). During the passive fatigue condition, participants were required to monitor for automation failure. Length of drive was also manipulated to track the development of multiple aspects of fatigue over time. The three drive durations lasted 10, 30 and 50 minutes. The aim of this study was to assess the impact of active and passive fatigue manipulations on subjective ratings of fatigue across several different drive durations. The Dundee Stress State Questionnaire (DSSQ: [21]) was used to measure subjective ratings of fatigue.
This multidimensional scale yields a key dimension of task engagement, which is synonymous with feelings of high energy and motivation. In addition, distress and worry were measured, as they are components of driver stress.

Figure 2 shows mean levels of the three post-drive state factors in each experimental condition (averaged across duration). These factors are scaled as standard scores, so that, for example, task engagement in the passive fatigue condition is around 0.9 SD below the normative mean for the DSSQ [21]. Consistent with the Desmond and Hancock [5] model, active fatigue produced the highest levels of distress and worry.

By contrast, the passive manipulation led to a large-magnitude decline in task engagement, suggesting that drivers of automated vehicles may be especially vulnerable to passive fatigue, even after reverting to normal vehicle control. Examination of duration effects showed that much of this loss of engagement was apparent after only 10 min, suggesting that even short periods of automation may produce passive fatigue.

Measures of subjective workload, cognitive appraisal and coping were also taken in this study. Consistent with expectation, workload ratings were highest in the active fatigue condition. Figure 3 shows effects of the fatigue manipulation on three dimensions of appraisal. Scores were standardized, so that mean and SD for the sample were 0 and 1, respectively, for each appraisal scale. Figure 3 shows that active fatigue elicited appraisals of threat and low controllability, but also increased challenge. Passive fatigue was not threatening, but was appraised as especially lacking in challenge. Further analyses showed that the active fatigue condition produced higher levels of both task-focused and emotion-focused coping than the passive fatigue condition. Consistent with the Lazarus [26] model of stress, appraisal and coping processes may generate the differences in subjective state seen in the different conditions. For example, low challenge may be a driver of loss of engagement in the passive fatigue condition, whereas threat, low controllability and use of emotion-focused coping may all serve to elevate distress in the active fatigue condition [21].

The methodology used in this study meet several of the above-mentioned criteria for functional fidelity of the simulator. Consistent with the first criterion, the three different configurations of the simulator employed elicited different patterns of subjective response, corresponding to differing states of stress and fatigue found in real driving [22].
In addition, effects of drive duration and workload manipulations appeared to produce fatigue and stress responses, corresponding to the effects of external influences in real life driving, meeting the second criterion for functional fidelity. Finally, the correspondences seen between post-drive state and the appraisal and coping scales suggest that different simulator configurations elicit different cognitive processes critical for stress response [26], meeting the third criterion.

4.2. Study 2: Automation and loss of alertness

In a second study (N = 168), Saxby et al. [38] explored how active and passive fatigue influence alertness, by measuring driver performance in the fatigue state. Dependent variables here were reaction times to a sudden emergency event, a van unexpectedly pulling out in front of the driver, which required the driver to take control of their vehicle and suddenly brake and swerve in order to avoid hitting the van. Fatigue manipulations were the same as before (normal vehicle driving, active fatigue and passive fatigue), with only two drive lengths: 10 and 30 minutes. Results revealed that drivers in the passive fatigue condition were slower to react to the sudden event, compared to the control and active fatigue conditions. In addition, drivers in the passive fatigue condition had significantly more car crashes than drivers in the other two groups.

In both studies, it appears that full vehicle automation, shown to elicit a state of passive fatigue, was associated with loss of task engagement and elevated distress, consistent with the claim that the monotony of an automated environment exacerbates impairments in subjective alertness and motivation [6]. The results obtained in this study met the fourth criterion posed, which states that a fatigue manipulation should elicit not only a change in subjective ratings of driver fatigue, but also performance decrements during simulated driving, corresponding to loss of safety in real-life driving.

4.3. Study 3: Fatigue and voluntary use of automation

Although it appears that automation use may actually worsen feelings of subjective fatigue [37, 38], a possible limitation to the previous two studies, and most studies of automation, is that participants were randomly assigned to automated conditions, which may not reflect the true nature of automation use.
Realistically, drivers often have control over whether or not they wish to use automated systems, an aspect that was of particular interest to the next study. It may well be that drivers prefer to use automation in moderation. It has been suggested that when automation is optional, operators may exert a desire to take control [39].

Because stress and fatigue can potentially influence whether or not a driver uses automation, Neubauer et al. [40] (submitted), gave drivers the choice of whether or not to use automation. The specific aims of this study were to test whether stress and fatigue influence optional automation use and whether this voluntary choice alleviates or worsens these subjective symptoms. These authors ran a total of 190 drivers and allocated them to one of two experimental conditions: a control (non-automated) condition and an automated optional (voluntary choice) condition. Within the automated optional condition, drivers were given the choice of engaging in automation for five-minute periods throughout the drive. Normal control was restored in the last 5 minutes of the drive where, similar to Saxby et al. [38], drivers were required to actively avoid colliding with another vehicle. Again, subjective state was measured by use of the DSSQ [21], before and after the simulated drive.

Several findings substantiated the potential of automation to produce fatigue. First, in monotonous driving conditions, even those drivers who used automation showed large declines in task engagement, suggesting that strategic, self-initiated use of automation does not protect against fatigue. Second, drivers who were initially lower in task engagement prior to driving were more likely to use automation subsequently, even though it seems that automation may exacerbate fatigue. Third, use of automation was associated with increased distress. Thus, automation use may actually tend to exacerbate driver fatigue and stress. In addition to subjective state, automation use may negatively affect driver performance. Results of the Neubauer et al. [40] (submitted) study revealed that drivers subjected to automated and non-automated drives differed in their response times to an emergency event. It appears that drivers in the automated group were somewhat slower to respond, similar to Saxby et al. [38]. The findings of this study meet the same criteria for functional fidelity as in the previous two studies, i.e., that appropriately configured simulated drives elicit changes in subjective state as well as driver performance that correspond to the fatigue of real driving.

5. Conclusions

Recent advances in automated systems appear to offer potential safety solutions for the fatigued driver. AICC and AHS technologies attempt to assist the human operator by taking over some of the control functions of the drive. Such systems attempt to decrease task demands and in turn driver stress. Although these innovations show promise, there are valid concerns that such systems may result in the driver over-relying on the system and in turn decreasing their situation awareness [8]. The purpose of this paper was to offer a review of several key studies that used simulator methods to investigate the impact that automated systems have on subjective ratings of stress and fatigue. These studies showed how differing fatigue states can be identified by profiling multiple dimensions of state change. They also showed how, consistent with theory in the area [5], different types of fatigue state vary in their consequences for performance and safety.

We have also explored the methodological advantages of using a simulator of this kind. It would be difficult to attain the requisite control over the differing external factors that produce active and passive fatigue in studies of real driving. In addition, the simulator affords logging of the specific performance measures that demonstrate loss of alertness, such as a slowed response to an emergency event controlled by the experimenter [38].
The methods used could also be extended to investigate other fatiguing agents, such as sleep loss, and to evaluate the utility of countermeasures [17].

These studies also illustrate how the functional fidelity of simulators may be evaluated against explicit criteria. The simulated drives produced patterned subjective stress and fatigue responses resembling those seen in real driving [22]. These responses appeared to be controlled by external influences such as workload and drive duration, known to be important in real life. Furthermore, the fatigue manipulations produced differing patterns of appraisal and coping consistent with observed state changes, and with cognitive theories of stress and fatigue response [26, 27]. Finally, it also appears that using a driving simulator to create an automated environment can capture the damaging effects of fatigue on driver alertness and performance.

Some limitations of the simulator method should also be noted. Most obviously, there is no physical threat to the driver. Other motivations, such as pressures to complete the drive within a given time duration, may also differ. While many drivers have experience of devices such as cruise control, full automation is unfamiliar, and it is possible that experience with the technology will mitigate fatigue. We have argued that simulators produce fatigue responses that are qualitatively similar to those seen in real driving, but there may be significant quantitative differences in single response magnitudes, and in the patterning of responses across multiple dimensions. Thus, caution should be exercised in generalizing findings to real driving, although the evidence for functional fidelity provides some confidence in generalizability.

Overall, the findings of these studies suggest that automation use may produce high levels of fatigue (loss of task engagement) and distress following the drive. More specifically, the loss of task engagement associated with passive fatigue appears to be accompanied by a loss of alertness and situation awareness. Passive fatigue, a state associated with task underload, may disrupt appropriate matching of effort to task demands [8, 15], consistent with dynamic models of resource allocation [33]. Automation might be more beneficial for drivers exposed to periods of active fatigue, which requires an operator to remain actively engaged in the task. In addition, it also seems that the opportunity to use automation has little to no effect on relieving the stress response [40] (submitted). Voluntary automation use also appears to be influenced by pre-drive state, whereby lower levels of task engagement relate to greater use of automation, although use of automation relates to greater post-task distress. Elevated levels of fatigue and stress pose a risk to drivers, whereby automation use may exacerbate their already damaging effects by further reducing alertness [37, 38, 40]. The findings emphasize the need for further development of countermeasures for fatigue in the disengaged, but wakeful driver, whereby even short durations of monotonous drives elicit negative changes in stress and fatigue.

References


