Jun 29th, 12:00 AM

Road Environment and Driver Fatigue

Tal Oron-Gilad
University of Central Florida, Orlando

Richard A Hancock
University of Central Florida, Orlando

Oron-Gilad, Tal and Hancock, Richard A. Road Environment and Driver Fatigue. In: Proceedings of the Third International Driving Symposium on Human Factors in Driver Assessment, Training and Vehicle Design, June 27-30, 2005, Rockport, Maine. Iowa City, IA: Public Policy Center, University of Iowa, 2005: 318-324. https://doi.org/10.17077/drivingassessment.1179

ROAD ENVIRONMENT AND DRIVER FATIGUE

Tal Oron-Gilad, Peter A. Hancock
MIT[2] Laboratory
Department of Psychology & Institute for Simulation and Training
University of Central Florida
Orlando, Florida, USA
E-mail: torongil@mail.ucf.edu

Summary: We distinguish between fatigue caused by the demands of the driving task itself (see Hancock & Desmond, 2001) from the standard traditional approach that links fatigue predominately to the lack of sleep. Fatigue can be caused by two sources: (1) the driver's initial state before starting the drive, or (2) the characteristics of the drive and the road environment; both sources can have a cumulative effect. It is not clear what principles are involved in making one road environment more prone to inducing driver fatigue than another. For the purpose of the current presentation we provide empirical data on road environment and driver fatigue summarized from a series of three experiments that the first author has conducted at Ben-Gurion University (see Oron-Gilad, 2003; Oron-Gilad, et al., 2001). Those are examined in relation to the Hancock and Warm (1989) model of adaptability. The most significant and consistent findings of the three experiment is in the way that fatigue is reflected in driving performance across different road environments. These findings suggest that drivers are flexible in the way they handle fatigue over the course of time. They can adopt different strategies to compensate for their performance decrement, by focusing efforts on critical elements of each different type of roadway. Understanding of this dependency of fatigue symptoms on road conditions is of especial relevance to designers of technological fatigue countermeasures as well as those of future roadway systems.

INTRODUCTION

While the term driver fatigue is used frequently, it is a very general term and is used in many different ways. The one statement most agreed upon is that a fatigued driver is not a safe driver; however, the situations or the reasons for this impaired state may vary. We distinguish fatigue caused by the demands of the driving task itself (see Hancock & Desmond, 2001) from the more standard traditional approach that links fatigue to the driver's state and predominately to the lack of sleep (see Mackie & Wylie, 1992). Thus, fatigue can be caused by two sources: (1) the driver's initial state before starting the drive, or (2) the characteristics of the drive and the road environment. Both sources can have a cumulative effect. Regardless of the cause of fatigue, it is an unwanted state. However, different causes of fatigue may require different means of intervention. Specifically, fatigue caused by lack of sleep can be corrected by sleep, a strategy that may not improve the passive fatigue caused by a monotonous road. Furthermore, it is not clear what makes one road environment more prone to driver fatigue than others.

Resource theories and adaptive models of stress and sustained performance provide contrasting explanations for the effects of the driving-task demands. Resource theories (e.g., Wickens, 1984) are frequently applied to performance of multiple component tasks such as driving. Those propose that an individual can be characterized by a limited supply of capacity of data both for attention and processing. A decrement in performance efficiency can be found when there is an insufficient quantity of resources unable to match the demands for resources made by the task or tasks to be performed. The actual performance is determined by the individual's strategy for allocating resources across the various tasks. For example, in order for an overloaded driver to maintain effective vehicle control, there may be a reduction in the efficiency of processing information from the traffic environment. Existing research provides a number of demonstrations of performance overload where task demands are increased by imposing additional task components, consistent with the prediction of resource theory (e.g., Brown, Tickner & Simmonds, 1969; Harms, 1986; 1991). On the basis of the same rationale, Hancock, Wulf, Thom and Fassnacht (1990) have shown that vehicle turn sequences are associated with greater attentional demands than straight driving. Multiple resource theories also propose that qualitatively different tasks may utilize independent reservoirs of capacity, such that dual task interference is reduced when tasks are dissimilar. Since driving is primarily a visual-motor task, the indication may be that in-vehicle countermeasures should utilize different input and output modalities. Empirical studies do not always support the resource theory (for example, Matthews, Sparks & Bygrave, 1996).

Dynamic models of stress and sustained performance (Hancock & Warm 1989; see Figure 1) are based on the notion of adaptation to task demands. The Hancock and Warm model suggests that it may be difficult to adapt to conditions of both under-load and over-load. According to this model, the individual is often able to compensate for dynamic variations in workload and

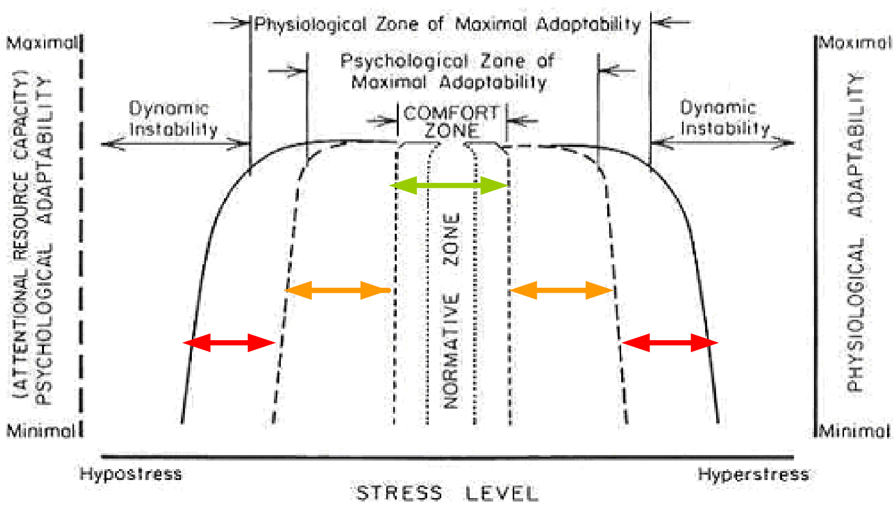

Figure 1. The extended-U model of stress and performance initially proposed by Hancock and Warm (1989)

environmental factors that moderate levels of stress. The potential hazard of fatigue is that matching effort to task demands may be impaired because fatigue reduces the range or efficiency of strategies available for regulation of effort. Adaptation to task demands is particularly relevant in driving since the task includes rapid variations in workload, as shown in Figure 2. Generally, under normal conditions, as shown in Figure 2(a), the contextual demands of the drive are lower than the driver's optimal attentional capacity. However, one of the great problems of powered travel is that normal circumstances can rapidly change into conditions requiring emergency response. As shown in Figure 2(b) drivers respond to emergencies by focusing all of their attention onto the situation; the so called “narrowing of attention” effect (see Hancock & Weaver, 2005).

Paradoxically, when the task was relatively difficult (curved road), fatigued drivers were more often able to cope with increased demands; when it was easy (straight road) performance tended to deteriorate, implying that fatigued drivers are failing to adjust their effort effectively (Desmond & Matthews, 1997). Hence, complacency problems may increase as a result of fatigue in consistency with the Kahneman’s (1973) model that the resource availability is variable. More recent analyses (Hancock & Warm 1989; Hockey 1993; 1997) have supported Kahneman's conclusions, indicating other costs of performance deterioration, such as attentional errors and reduction in subsidiary aspects of task performance. The compensatory control model described in detail in Hockey (1993; 1997) suggests that the system is typically biased toward maintaining high-priority goals under stress at the expense of neglecting the other goals.

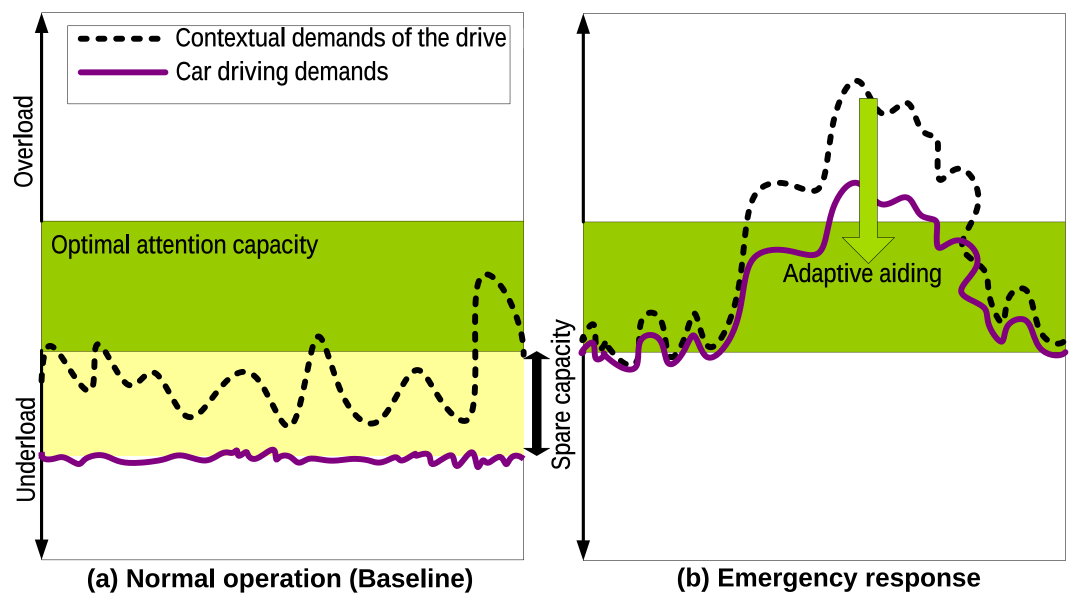

Figure 2. Attention capacity and driving demands for drivers

For the purpose of the current presentation, we provide empirical data on road environment and driver fatigue summarized from a series of three experiments that the first author conducted at Ben-Gurion University (see Oron-Gilad, 2003; Oron-Gilad, et al., 2001). Those are combined with theoretical implications developed by both authors in relation to the empirical data and to the Hancock and Warm (1989) model of adaptability. Difficulties in defining robust criteria for driver fatigue have been related mostly to the large individual differences among drivers (Brookhuis & de Waard, 2000). In a previous study (Oron-Gilad, et al., 2001), we suggested that difficulties in defining robust criteria for driver fatigue can also be traced to the use of different coping strategies in various road conditions. In Ronen, et al. (2002), we showed that the low demand (straight) road and the high demand (curved) road vary in the way they affect mental workload, which we measured by heart rate variability (HRV). In a prolonged drive we assume that the changing road situation will have an impact on driving performance measures as well.

We suggested that drivers adopt different fatigue-coping strategies relative to the demands and conditions of the task, hence, drivers may be aware of a general decrement in their performance due to fatigue, and the way they handle the decrement is related to the demands of the road.

METHODS

Three experiments examined the effect of road characteristics on fatigue and fatigue-coping strategies in simulated driving. For all three experiments, driving performance measures, reaction time measures, physiological (ECG and EEG) measures, and subjective measures were collected. A total of 27 drivers (10 professional military truck drivers and 17 students from Ben-Gurion University) participated in the experiments. Perceived fatigue related to the driving task was assessed by the Swedish Occupational Fatigue Inventory-20 (SOFI) (Aahsberg, 1998). The first experiment used three different road environments, each simulating a different road in the southern part of Israel; a winding road driven either uphill or downhill, a two-lane straight rural road, and a straight four-lane divided highway. The other two experiments used only the winding and the rural road environments. The experiments varied in the way the different roads were presented. In the first and second experiments, different road sections were combined into a single driving scenario, while in the third experiment, drivers drove either one of the two possible roads (winding or rural).

RESULTS

The analysis of results consistently showed significant differences in driving performance among the various road environments and changes over the course of time. Driving performance was measured by four parameters that were recorded by the simulator: the root mean square (RMS) of the lane position, RMS of the steering wheel rate, the average longitudinal speed and the RMS of the longitudinal speed. For the driving performance measures, the most striking results that were consistent across all three studies were that (1) there was a fatigue-related performance decrement, and (2) that decrement was manifested differently for each type of road. In each type of road, drivers chose to “loosen up” in what they perceived as the most tolerant element. On the two-lane winding road the change in performance appeared in the longitudinal speed, with speed being significantly higher as the driving progressed. On the two-lane undivided straight road, the deterioration in performance was significant for the quality of the lane positioning and the corresponding steering wheel control. There were no significant differences in speed. Figure 3 depicts the differences in steering wheel control in the third study. Even though these findings were consistent across all three studies, there were differences among the studies in the degree of change measured throughout the drive. Also, greater individual differences were identified among the professional military truck drivers than among student participants. As a group, the latter tended to drive more poorly from the initial period of the drive.

The subjective rating of fatigue, using the SOFI, indicated that after the completion of the drive, drivers felt a change in their sleepiness, in their motivation to continue driving, and in their level of energy, as well as an overall increase in feelings of fatigue.

The heart rate variability measure (derived from the ECG) provided additional evidence of the sustained performance effect of driving; time on task had a pronounced effect on drivers and fatigue onset varied across experiments but appeared after approximately 50 minutes. Figure 4 shows this phenomenon as it was captured in the third experiment, where participants drove either one of the roadways.

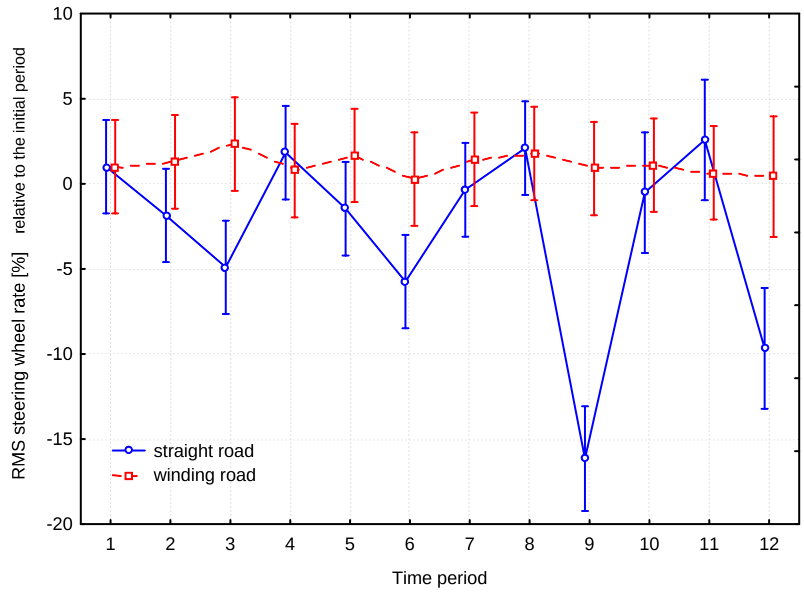

Figure 3. RMS steering wheel rate for the winding road and for the straight road relative to the initial period of the drive for driver in experiment 3 (the 60 minutes drive was broken into 12 time periods)

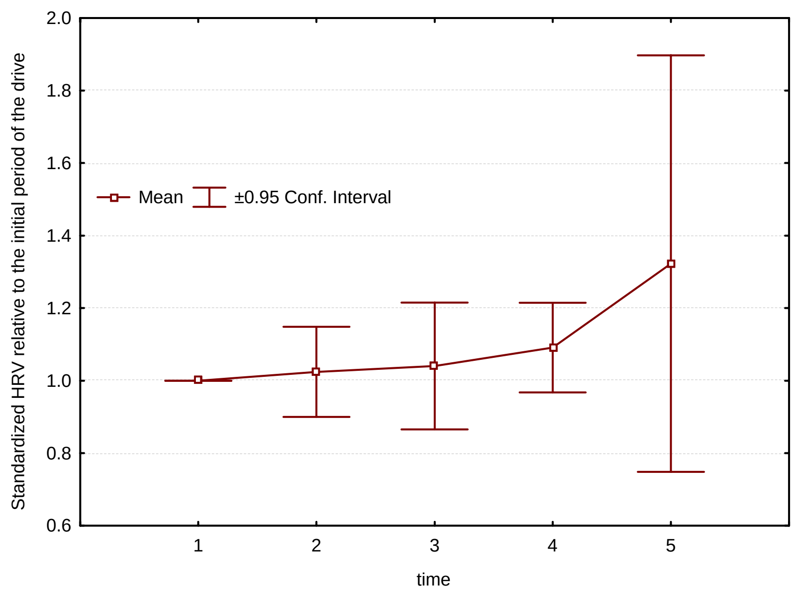

Figure 4. Standardized HRV relative to the initial period of the drive for all drivers in Experiment 3 (the 60 minutes drive was broken into 5 time periods)

DISCUSSION

The most significant and consistent findings of the three experiment is in the way that fatigue is reflected in driving performance across different road environments. Our results suggest that drivers are flexible in the way they handle fatigue over the course of time. They can adopt different strategies to compensate for their performance decrement, by focusing efforts on critical elements of the road. Understanding this dependency of fatigue symptoms on road conditions is of high relevance to designers of technological fatigue countermeasures. When driving performance decrement varies as the road conditions (or road demands) vary, one has to be very cautious in implementing countermeasures that are based on a single or on a limited number of performance measures. Theoretical models are therefore required to address this pattern and advance our understanding of driver behavior in relation to the road environment characteristics.

ACKNOWLEDGMENTS

This work was facilitated by the DoD Multidisciplinary University Research Initiative (MURI) program administered by the Army Research Office under grant DAAD19-01-1-0621, Peter A. Hancock, Principal Investigator. The views expressed in this work are those of the authors and do not necessarily reflect official Army policy. The data was collected when the first author was a Ph.D. student at Ben-Gurion University of the Negev, Beer-Sheva, Israel; David Shinar was the dissertation advisor and the study was supported in part by a grant from the GM foundation.

REFERENCES

Aahsberg, E. (1998). Perceived fatigue related to work. *Internal report, University of Stockholm, Department of Psychology, Sweden*. ISBN 91-7153-830-5.

Brookhuis, K.A., & de Waard, D. (2001). Assessment of Driver's Workload: Performance and Subjective and Physiological Indexes. In: Hancock P.A. and Desmond P.A. (Eds.), *Stress, Workload, and Fatigue* (pp. 321-333). London: LEA Publishers.

Brown, I.D., Tickner, A.H., & Simmonds, D.C.V. (1969). Interferences between concurrent tasks of driving and telephoning, *Journal of Applied Psychology*, *53*: 419-424.

Desmond, P.A., & Matthews, G. (1997). Implications of task induced fatigue effects for in-vehicle countermeasures to driver fatigue. *Accidents Analysis and Prevention*, *29*(4): 513-523.

Hancock, P.A. & Warm, J.S. (1989). A dynamic model of stress and sustained attention. *Human Factors*, *31*: 519-537.

Hancock, P.A., & Desmond, P.A. (Eds.). (2001). *Stress, workload and fatigue.* Mahwah, NJ: Lawrence Erlbaum.

Hancock, P.A., Wulf B., Thom, D., & Fassnacht, P. (1990). Driving workload during different driving maneuvers. *Accidents Analysis and Prevention*, *22*: 281-290.

Hancock, P.A. & Weaver (2005). Temporal distortions under extreme stress. *Theoretical Issues in Ergonomic Science*, *6*(2): 193-211.

Harms, L. (1986). Drivers' attentional response to environmental variations: A dual-task real traffic study. In: A. G. Gale, M. H. Freeman, C. M. Haslegrave, P. Smith and S. Taylor (Eds.), *Vision in Vehicles* I (pp. 131-138). Amsterdam: North Holland.

Harms, L. (1991). Variations in drivers' cognitive load. Effects of driving through village areas and rural junctions. *Ergonomics*, *34*: 151-160.

Hockey, G.R.J. (1993). Cognitive-energetic mechanisms in the management of work demands and occupational health. In: A. D. Baddeley and L. Weiskrantz (Eds.), *Attention, selection, awareness and control: a tribute to Donald Broadbent* (pp. 328-345). Oxford: Oxford University Press.

Hockey, G.R.J. (1997). Compensatory control in the regulation of human performance under stress and high workload. *Biological Psychology, 45*: 73-39.

Kahneman, D. (1973). *Attention and effort*. Engle wood cliffs, NJ: Prentice Hall.

Mackie, R.R., & Wylie, C.D. (1992). Driver fatigue: Accidents, Assessments, and countermeasures. *Report no. 92-00169, Human Factors Research laboratory, Essex corporation*.

Matthews, G., Sparks, T. J., & Bygrave, H. M. (1996). Stress, attentional overload and simulated driving performance. *Human Performance*, *9*(1): 77-101.

Oron-Gilad, T. (2003). *Alertness maintaining tasks while driving*. Ph.D. Thesis, Ben-Gurion University of the Negev, Beer-Sheva, Israel.

Oron-Gilad, T., Ronen, A., Shinar, D., & Cassuto, Y. (2001). Fatigue of professional Truck Drivers in Simulated Driving: A preliminary Study, Traffic Safety on Three Continents, International Conference in Moscow, Russia, 19-21 Sept.

Ronen, A., Oron-Gilad, T., Shinar, D., & Cassuto, Y. (2002). Assessment of driver's mental effort while driving roads of different complexity. In: de Waard D., Brookhuis K. A., Weikert C. M. and Toffetti A. (Eds.), *Human Factors in Transportation, Communication, Health, and the Workplace*. Maastricht, NL: Shaker Publishing.

Wickens, C.D. (1984). *Engineering psychology and human performance*. New York: Harper.