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Driver Workload Response to In-Vehicle Device Operations

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NOTES

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A central concern of Intelligent Transportation Systems (ITS) is the effect of in-vehicle devices (e.g., cell phones, navigation systems, radios, etc.) on driver performance and safety. As diverse and innovative technologies are designed and implemented for in-vehicle use, questions regarding the presence

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and use of these devices assume progressively greater importance. Further concerns for advanced driver training require us to develop and validate reliable and effective procedures for assessing such effects. This work examines a number of candidate procedures, in particular the evaluation of change in cognitive workload as a strategy by which such goals might be achieved.

driver distraction telematics workload cellular phones

1. INTRODUCTION

The issue of safety of use of in-vehicle devices is presently under strong societal scrutiny. Some countries (e.g., Germany, UK, Israel, South Africa) have enacted laws restricting the use of certain devices (e.g., handheld cell phones) in automobiles altogether. In the USA, a number of individual states are scrutinizing the problem with a view towards legislative changes. As there exists high face-validity that these devices affect driving performance, empirical research in these areas is of utmost importance. A key issue in studying the influence of in-vehicle devices is how the effects themselves can be assessed. Indeed, it is a particular conundrum in specifying what level of performance response is “safe” (Hancock & Ranney, 1999; Hancock & Scallen, 1999; Tijerina, 1999). Measuring cognitive workload holds great promise as an assessment procedure because it covers a variety of techniques that possess both diagnostic accuracy and high face validity. Measuring primary task performance (e.g., steering control, lane violations, etc.), secondary task performance (e.g., embedded tasks such as signaling, added tasks such as time perception), taking physiological measures (e.g., heart rate variability), and subjective workload information (e.g., subjective workload assessment test [SWAT], NASA task load index [NASA TLX]) have all been shown to be valid indicators of cognitive workload and thus are useful for determining response in driving. The present study evaluates the effects of the presence and use of in-vehicle devices on driver performance through a survey of empirical studies that have employed cognitive workload as the primary assessment metric. One use of these measures for driving has been for dynamic assessment of driver state as an input to adaptive driver systems (see Hancock & Verwey, 1997). The overarching goal of our current program is to develop an assessment procedure by which to evaluate current and proposed in-vehicle technologies (see also Edwards, 2001). To accomplish the present workload component of our program, we have developed a matrix that evaluates the capabilities and characteristics of the driver, the environment, the task, and the candidate in-vehicle technology. Details of this matrix including its development and refinement are presented next.

2. MATRIX DEVELOPMENT

To frame the initial matrix we used two primary axes. The first axis represented all extant measures of cognitive workload that were derived from an extensive literature review and from information contained in previous texts, which have summarized the state-of-the-art at different junctures in time (see Hancock & Meshkati, 1988; Meshkati, Hancock, Rahimi, & Dawes, 1995; Moray, 1979). On the second axis of this extended matrix, we established conditions that affect driving performance consisting of the major categories of driver characteristics, vehicle characteristics, roadway characteristics and interactions between these contingencies. (This overall matrix can be found on our Transportation Group Website: http://pegasus.cc.ucf.edu/~trg/matrix.htm). Into this extensive descriptive field we then incorporated the quantitative findings from existing studies. Our content criterion was that the candidate study had to have reported experimental data concerning the influence of the presence of an in-vehicle device on measures of cognitive workload. These empirical studies were identified through exhaustive search and through the commissioning of a number of professional search services. Obviously, these experimental studies constituted a small set of the possible constellation of effects identified in the supra-ordinate matrix and this identification process allowed us to pinpoint areas of needed research as well as those effects that had already been investigated. Here, we report a summary of the appropriate experimental research findings that have been reported to date.

As it is rare to find more than one study that has reported on the effects of a specific form of workload assessment on a common measure of driving performance in the presence of an in-vehicle device, each cell is essentially composed of a single experiment. In order to represent these findings, we have simplified both axes so that the cognitive workload axis is divided into its appropriate assessment method. The driving axis is divided according to study specific described environment circumstances. On the vertical axis, we have indicated the level of cognitive workload change due to the presence of the in-vehicle device. Such change is categorized as either low, medium, or high additional workload.

For example, the cell in Figure 1 corresponding to “steering through gaps” on the vertical axis and “on road” on the horizontal axis represents the data reported by Brown, Tickner, and Simmons (1969), who found low effects of workload change during an on-road driving task while concurrently performing a telephony task. Further, the cell corresponding to “brake reaction time” on the vertical axis and “dialing cell phone” on the horizontal axis represents the data reported by Lamble, Kauranen, Laakso, and Summala (1999). Lamble et al. (1999) aimed to investigate drivers’ ability to detect a car decelerating ahead while doing mobile phone-related tasks. The tasks involved phone-related tasks: dialing numbers on a keypad (visual divided attention) and a non-visual task (an addition task) used to simulate the non-visual cognitive load associated with phone conversations. Drivers’ detection ability was impaired by about 0.5 s in terms of brake reaction time and almost 1 s in terms of time-to-collision, when they were doing the non-visual task whilst driving. This impairment was similar when the drivers were dividing their attention between the road ahead and dialing numbers on a keypad. These authors concluded that neither a hands-free option nor a voice controlled interface removes the safety problems associated with the use of mobile phones in a car.

The cell in Figure 1 corresponding to “task time” on the vertical axis and “age” on the horizontal axis represents the data reported by McKnight and McKnight (1993) who investigated the effects of different cell phone tasks on individual’s driving performance. All distractions led to significant increases in both the number and situations in which drivers failed to respond and in the time it took to respond when response was evident. Complex phone conversations created the greatest distraction, simple conversations the least. Placing a phone call was no more deleterious than a simple conversation in causing situations to go unnoticed, but delayed responses to about the same degree as complex calls. The increase in likelihood that some highway situation will go unnoticed while dialing or conversing on a cellular phone was for the older group (50–80) twice that of their younger counterparts (26–49) and considerably less than the youngest group (17–25). Because we found no studies reporting a decrease in cognitive workload increment, we show only cognitive workload increase on the vertical axis. This matrix of summarized current studies is illustrated in Figure 1.

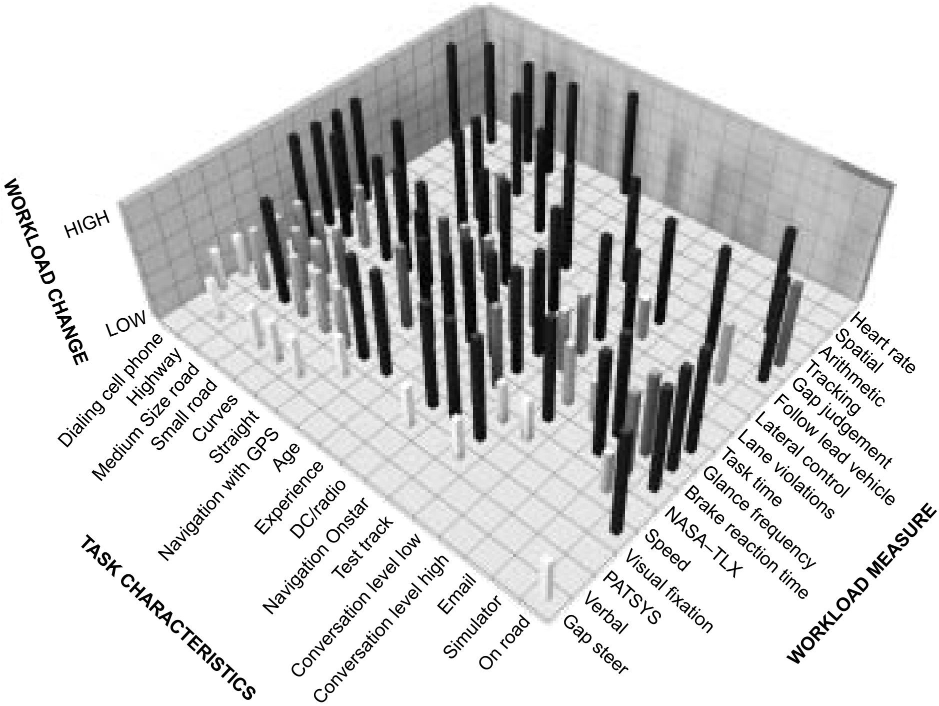

Figure 1. Workload change matrix showing the degree of cognitive workload increase due to the presence of an additional in-vehicle device. The base axes describe first, the specific workload measure and second, the driver characteristics and driving environment in which the test was conducted.

What is immediately clear is that most of the combinations result in a high level of cognitive workload increase. This is not unexpected given that driving, under most of the experimental circumstances specified, is already a considerably taxing task. Those task combinations that result in either medium or low cognitive workload increase are generally those we expect to show little dual-task decrement. Wickens attentional resource model again provides a useful heuristic for organizing these data. Despite questions as to its applicability as a theory of attention, the Wickens “boxes” indicate a simple and effective way to divide input task demand and output effector response in order to minimize structural interference (e.g., trying to do two things at the same time with one hand) as well as central, functional limitations upon divided attention (Wickens, 1987). It is our current plan to continue to use this model of dual-task competition as guide with which to assess the impact of future in-vehicle devices as they are implemented.

There are a number of general facets of the present matrix that are worthy of further comment. First, it is very sparse, such that existing experimental studies are far outweighed by the vacant cells of the master matrix (http://pegasus.cc.ucf.edu/~trg/matrix.htm). Clearly, there is an important need for both further empirical data as well as solid theoretical advances in respect of this issue. Also, it should be noted that given the state of the present literature, we have made no detailed differentiation between the in-vehicle devices themselves. Although this is a most necessary step, if it were performed at the present stage there would be virtually no unifying factors at all. We are very aware that there are probably many proprietary studies on prototype devices that have been conducted but not reported in the open literature. If it is possible to characterize the results of such efforts, without fracturing proprietary agreements we would strongly encourage such publication in order to enrich and elaborate the existing database of studies. However, as technological developments will nearly always overwhelm post hoc assessment (see Hancock & Diaz, 2002), there is an especial need for further development of dual-task theory and Wickens conception certainly provides an initial basis for such a development.

3. DISCUSSION

Many in the driving research community are engaged in a common search for methods and techniques with which to assess the impact of emerging in-vehicle devices. One fundamental barrier faced by all such researchers is that we still do not have a good basic model of normative driving (see Hancock & Scallen, 1999) and without this baseline it is more than problematic to assess performance change. What is required is some form of “figure of merit” that combines the baseline elements of momentary vehicle control with those more strategic decisions, for example, route selection, to provide a fundamental and agreed base measure against which to compare all candidate technologies. Whereas there are on-going attempts to establish this measure in driving, we can benefit significantly from technology transfer from the realm of aviation, which has to synthesize the pilot’s need to aviate, navigate, and communicate in very much the same manner (Edwards, 2001). Having agreed upon a baseline, we then have to societally define what we believe is “safe.” Safety is always a relative term. Even though it appears to be amenable to definition as a ratio measure, there are always intrinsic trade-offs involved and so the next step is for the traffic research community to identify a common in-vehicle task against which to compare the specific effects of newer (Intelligent Transportation Systems) technologies. This is a consensus necessity and is not a task amenable to simple experimental resolution. Having set such a task, we can then create comparative scales that can specify the baseline task as more or less demanding than the candidate "target" task. The assessment of "safety" is then a public health issue, again contingent upon consensus, informed by such comparative studies. It is towards this goal that the steps given in the present work are directed.

In this work we have presented one step along the development toward a full assessment program to evaluate proposed in-vehicle technologies and their effect on driver performance and safety. The issue of the safety of use of in-vehicle devices is clearly a concern for law enforcement, legislators, driver groups, the automotive industry, and of course the device manufacturers themselves. To develop our present cognitive workload assessment procedure, we evaluated the capabilities and characteristics of the driver, the environment, the task, and the candidate technology in a taxonomic matrix. These characteristics were determined and a comprehensive literature search revealed which areas have been studied, as well as identifying those that are deficient in empirical evaluation. The matrix displays the characteristics each researcher investigated and shows what measures the researcher used for workload assessment. The application of this taxonomic matrix can be useful in identifying the current state of research in the area, the methodologies that have been fruitful, and what areas are most in need of researchers' attention. With this accomplished, a definitive assessment procedure for the evaluation of in-vehicle devices might be determined.

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