MENTAL WORKLOAD AND TASK PERFORMANCE FOR INDIRECT VISION DRIVING WITH FIXED FLAT PANEL DISPLAYS

Christopher C. Smyth
U.S. Army Research Laboratory
Human Research & Engineering Directorate
Aberdeen Proving Ground, MD
E-mail: csmyth@arl.army.mil

Summary: Of interest to designers of future combat vehicles is the effect of indirect vision upon vehicle driving, and in particular the effect of the camera lens field of view (FOV). In a field study, driving performance was measured for natural and indirect vision with eight participants negotiating a road course in a military vehicle. The indirect vision system was driven with fixed panoramic flat panel, liquid crystal displays in the cab and a forward viewing monocular camera array mounted on the front roof of the vehicle and tilted slightly downward. The results are that the participants successfully drove the vehicle with indirect vision for the different FOVs of the cameras: near unity, wide, and extended. However, they drove the course faster with natural vision than they did with the indirect vision systems. Further, the course speed significantly decreased with increased camera FOV. Workload ratings show a significant increase in perceived workload with increased FOV. Most participants reported a discomfort associated with motion sickness while they were in the moving vehicle with the displays. Finally, cluster analysis of the mental workload measures supports a skills-rules-knowledge model of information processing for the driving task.

INTRODUCTION

To satisfy the Army requirements for reduced gross weight, lower silhouette, and increased crew protection, designers of future armored combat vehicles will place the crew stations deep within the hull of the vehicle. The conventional optics, consisting of periscopic vision blocks and optical sights, will be replaced by electronic displays at each crew station and external vehicle-mounted sensors. These vision systems will most likely show computerized digital images that are captured from camera arrays on the vehicle. The crew member will see a selected portion of the computerized display buffer that depends upon his or her role and viewing direction. The display design may use a set of panel-mounted displays, either cathode ray tube or flat panel liquid crystal displays (LCD), which are fixed in a panoramic arrangement about the crew member's station.

One area of interest is the effect of the choice of camera field of view (FOV) upon crew performance for panoramic panel displays. The choice of camera FOV may depend upon the task being performed. This would be the case for a driver operating a tank with a visual display and camera array in place of direct vision from an open hatch or through vision blocks. To increase his perception of potential road hazards, the driver may prefer a unity perspective view for driving along a known route. On the other hand, the driver may prefer a compressed image at

road turns for route selection because of the wider scene. Of course, the increase in camera FOV without a commensurate increase in display FOV will cause a compression of the camera scene as seen at the displays and a loss of detail. Because of the need to determine design parameters for future vehicles, the Army Tank Automotive Research & Development Engineering Center asked the Human Research and Engineering Directorate of the U.S. Army Research Laboratory to conduct an experiment on the effects of camera FOV upon driving performance.

EXPERIMENTAL METHODOLOGY AND RESULTS

The experimental apparatus and questionnaires of the methodology and the results are reported here.

Apparatus. For the indirect vision driving, three fixed, flat panel, LCD were mounted side by side in the front of the cab of a high mobility multipurpose, wheeled vehicle. The displays received video returns from a forward viewing monocular camera array that was mounted on the front roof of the vehicle and tilted slightly downward. The displays provided a panoramic 110° view of the camera returns. Three different sets of camera lens were used to provide a near unity (150°), wide (205°), and extended (257°) camera FOV. Unity FOV matches direct viewing in scene resolution. The driver's seating position was enclosed during the indirect vision portion of the study to keep sunlight from washing out the displays and to prevent direct viewing of the external scene.

Questionnaires. Questionnaires used in this study were (1) attention allocation loading factors, (2) the NASA Task Loading Index (TLX) workload battery, (3) Kennedy's subjective estimation of motion sickness, and (4) Selcon and Taylor's Situation Awareness Rating Technique (SART).

Results

The results of the statistical analyses of the course times, errors (barrel strikes), and the ratings from the questionnaires are reported. Considering the large number of analyses performed, the overall family-wise alpha level of .05 is partitioned among the statistical tests with the Holm simultaneous testing procedure (Neter, Kutner, Nachtsheim, & Wasserman, 1996) to control the Type I error.

Driving Performance. The overall driving performance was analyzed with a doubly multivariate analysis of variance (DM MANOVA) applied to the measures of the course times and barrel strikes. The dependent time measure is the natural logarithmic transformation of the time to drive the study course. The error measures are the arcsine transformation of the barrel strikes. The MANOVA is an overall statistical test. For this reason, the measures are each analyzed by a separate univariate, repeated measures (RM) ANOVA with accompanying post hoc contrast of comparisons between treatment means.

1. Overall performance. The task performance as measured by course times and barrel strikes is significantly different for the viewing treatments. The multivariate omnibus DM MANOVA test of within-subjects effects is significant ($p < .002$, Pillai's trace = .75, $F = 4.199$, df = 6, error df = 42).

2. Course times. The univariate RM ANOVA test of within-subjects effects is significant ($p < .000$, $F = 15.031$, df = 2.697, error df = 18.878), following the Greenhouse-Geisser correction of

the degrees of freedom for reduced sphericity. A Tukey HSD multiple pairwise comparison test of the treatment means shows direct viewing to be significantly faster than the indirect viewing treatments (near unity: $p < .006$, wide: $p < .003$, extended: $p < .001$). Further, the near unity FOV is significantly faster than the extended FOV ($p < .047$); however, the wide FOV is not statistically significantly different from the near unity or extended FOVs.

3. Lane marker strikes. The univariate RM ANOVA test of within-subjects effects shows significant differences ($p < .035$, $F = 4.414$, $df = 1.923$, error $df = 13.464$), following the Greenhouse-Geisser correction of the degrees of freedom for reduced sphericity. However, a Tukey HSD multiple pairwise comparison test of the treatment means shows no significant difference between direct viewing and the indirect viewing treatments, and the cameras' FOVs are not significantly different from each other. A study of the mean strikes shows little practical difference, which suggests that the participants attempted to maintain a low error rate.

Subjective Questionnaires. Factor analysis was used to reduce the data for each of the questionnaires to factorial components, which were then separately analyzed with a univariate RM ANOVA. Following the literature, the TLX data (Hart & Staveland, 1988) were reduced to two factorials and the data for the SART (Taylor & Selcon, 1994) and motion sickness (Kennedy, Lane, Lilienthal, Berbaum, & Hettinger, 1992) were reduced to three for each questionnaire. Similarly, the attention allocation data were reduced to two factorials. Some factorials did not satisfy the conditions for a parametric ANOVA, since the distributions were not normal or the variances homogeneous. For this reason, these components were analyzed with the non-parametric Friedman RM ANOVA by ranks for matched samples, following ranking of the rating scores.

1. Attention allocation loading factors. The allocations of the attention resources are not significantly different for the viewing treatments. However, the data show increasing trends in allocation to the visual, cognitive, and psychomotor processing channels for the indirect systems.

2. NASA Task Loading Index (TLX) workload battery. The perceived workload increases significantly with the indirect systems as compared to the direct vision ($p < 0.004$), because of the increase in the task demand ($p < 0.000$), the temporal demand ($p < 0.004$), and the mental demand ($p < 0.010$).

3. Kennedy's subjective estimation of motion sickness. Motion sickness is significantly greater for the indirect vision than the direct vision ($p < .005$). A nonparametric RM Friedman test by ranks is significant for the Nausea symptom ($p < .008$), Disorientation symptom ($p < .017$), and Oculometer symptom ($p < .015$).

4. Selcon & Taylor's Situation Awareness Rating Technique (SART). The demand on situational awareness increases significantly with the indirect systems ($p < 0.012$). This is attributable to significant increases in the instability ($p < 0.013$) and complexity ($p < 0.013$) of the driving situation.

DISCUSSION

The effects on driving speed because of the indirect vision system FOV and the accompanying changes in workload and situational awareness are discussed in this section.

Driving Speed Performance

Vehicle speed is discussed and related to the display compression ratio. The perceived speed of travel is discussed.

Display Compression Ratio. Much of the variation in the data for this experiment is explained by the compression of the camera scene. The display compression ratio is the ratio of the camera FOV to the display's 110°. Here, the compression ratios for the near unity, wide, and extended camera FOV are 1.364, 1.864, and 2.336, respectively.

Course Speed. Considering the driving task as data limiting with the driver adjusting his speed to acquire the scene-related information needed for control decisions, an equation was derived relating the average vehicle speed to the display compression ratio. The equation is in the form of a product of the vehicle speed times the compression ratio (dcr) raised to a 1/3 power, with the product equal to the direct vision average driving speed, that is,

$$\text{speed (km/hr)} = 22.31 * dcr^{-0.332}.$$

The equation predicts that the average driving speed is greatest for the direct viewing and decreases with increasing camera FOV.

Workload and Situational Awareness

Discussed are the effects of the vision systems on the driving task as determined from the perceived workload, situation awareness, and motion sickness.

Driving Task. The driver navigates the course from the locations of the barrel pairs on the display and by recalling his knowledge of the route from his mental map. This is followed by a task-specific rule-based selection of the next barrel pair and an approach path. Finally, the driver executes skill-based driving of the vehicle between the barrel pair with speed control based on the velocity flow field on the display, before repeating the process.

Perceived Workload and Display Scene Resolution. The decrease in resolution with scene compression increases the perceived workload by reducing the sensitivity of both the velocity flow field and the control. The decrease in scene resolution reduces the visibility of the terrain detail that provides the velocity flow field. The field is shortened since the flow appears to originate from a point in the scene that is closer to the front of the vehicle. The flow appears faster and to accelerate as the vehicle approaches the scene elements.

Situational Awareness and Display Scene Distortions. The scene distortions caused by the image compression increased the demand on the situational awareness needed for course localization. At increased compression ratios, an object appears more distant than it actually is, while the

approach path bends outward and the apparent speed increases as the object approaches the vehicle. The object appears to move farther laterally and faster as it is approached.
Motion Sickness and Display Image Quality. Most participants in this study reported incidences of motion sickness. The LCD method of display update could not keep pace with the changing scene during a rapid turn and while going over a berm. The display appeared momentarily out of focus because of the motion blurring of the video return with the accompanying loss of dynamic resolution. In some participants, this apparently induced a lack of convergence accommodation resulting in blur- driven asthenopia symptoms, a source of motion sickness (Ebenholtz, 1992).

Driving Task

Essential for understanding the effects of the mental workload on performance is a descriptive model for human information processing in a form that is appropriate for the driving task. Information processing may be conceived as drawing upon the cognitive resources according to the level of processing involved, that is, skill-level, rule-based, or knowledge-based behaviors (Rasmussen, 1983, 1986, 1993). Here, skill-based behavior provides the task performance, rule-based the governing schema for skill control, and knowledge-based the schema formation for the next task problem. Workload and awareness are related since attention resources are used to acquire and maintain awareness. In turn, awareness of the task situation is needed for effective decision making and implementation.

Relationships Among the Mental Workload Measures

The relationships among the mental workload measures support the driving model described here. Note that while the perceived workload is significantly different by viewing treatment, the attention allocations are not. At this level of probability as a lower boundary, a correlation matrix for the workload measures shows three significant clusters. One cluster is formed by the correlation of the visual loading with those of the cognition and motor. Another cluster is formed from the mental, physical, and temporal workload demands, the workload performance, and the complexity and variability of the situational awareness demand. Finally, the third is formed from the motion sickness symptoms and frustration.

The implication is that the components of mental workload are associated with different realms of cognitive processing. Considering the distributions, the measures cluster into a skill-based reasoning, a task demand at the rule-based and knowledge level, and a task on awareness possibly induced by motion sickness as a stressor at a supervisory level. The visual attention clusters with the cognitive and motor allocations at the skill level. Considering the relation between demand on situational awareness and perceived workload, the workload temporal demand clusters with the demand on situational awareness at the rule level. In turn, the total severity is associated with the symptoms of motion sickness at a supervisory level. The mental response to motion sickness is one of introspective evaluation.

CONCLUSION

Increasing the camera's FOV for indirect vision driving with a fixed display decreases course speed because of scene compression. However, increasing the camera's FOV may facilitate the mental operations of spatial rotation and map imagery that are needed for navigation. The course speed is successfully predicted as a function of the camera's FOV by a mathematical model. The

model considers the effects of scene compression upon the information needs of the driver in a self-paced task.

Indirect vision driving increases both mental workload and demand on situational awareness. LCDs may induce motion sickness that in turn increases subjective stress. Over time, the increase in mental workload and stress associated with indirect vision may degrade performance through fatigue.

Cluster analysis of the experimentally derived workload measures support a skills-rules-knowledge model of information processing for the driving task. Here, separate cognitive processing levels are used for different workload measures: a task-directed skill-level, a rule- and knowledge-based task monitoring level, and a supervisory based somatic awareness level.