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Usability assessment of a self-propelled windrower

Behzad Bashiri

Department of Biosystems Engineering, University of Manitoba, Winnipeg, MB, R3T 5V6 Canada.

Danny D. Mann

Department of Biosystems Engineering, University of Manitoba, Winnipeg, MB, R3T 5V6 Canada.

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Department of Biosystems Engineering, University of Manitoba, Winnipeg, MB, R3T 5V6 Canada.

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ABSTRACT Prototype testing of agricultural machines has typically focused on the structural and/or functional performance of the machine, with limited attention given to its usability. There is growing recognition, however, that machine performance can be maximized when attention is paid to the interaction between the operator and machine. A thorough knowledge of this interaction is required by design engineers if usability is to be considered at the design stage. The objective of this study was to determine whether design engineers from a local agricultural machinery manufacturer possess sufficient understanding of the interaction between the operator and machine that usability can be adequately considered during the design process. The research involved interviews with design engineers followed by in-field observation of machine operators. Comparison of task analysis completed based on interview with design engineers and in-field observation of machine operators, respectively, was performed. The comparison confirmed that design engineers at the local company possess sufficient understanding of the interaction between the operator and machine. Nevertheless, field observations identified an unexpected discrepancy between operator attention to the right and left sides of the machine which warrants further investigation. It was also observed that operators seldom used the information displays during field operation, preferring information derived from environmental cues. Moderate levels of mental workload, measured by the Driving Activity Load Index, were observed which is ideal for machine operators. The level of situational awareness experienced by operators, as measured by the Situation Awareness Rating Technique, was adequate to maintain a high level of performance.

Keywords: usability, mental workload, situation awareness, agricultural machines, task analysis.

INTRODUCTION

Agricultural machine manufacturers conduct intensive prototype testing before a product is released to the market. This testing enables the engineers to gain a better understanding of the product and to identify potential changes or modifications. In most cases, their primary focus is to assess the structural and functional components of the prototype with less attention given to how the human operator interacts with the machine (i.e., the usability of the machine) (Goodwin 1987). Researchers in the field of human factors engineering have suggested that, for optimum performance, machine design should be human-centered rather than machine-centered (Endsley et al. 2003; Dey 2008). Hence, there is need to provide engineers with tools that can be used to assess the human-machine interaction during the design and prototype-testing stages.

A valid assessment should be one that can adequately evaluate the human operator based on the task performed. This is essential if the design engineer is to make effective design improvements that will enhance the usability of the machine. Endsley et al. (2003) noted that for operators to interact effectively with any machine, they sshould have an awareness of the machine's actions at all times. This awareness of one's surroundings is referred to as "situation awareness" (SA). Hence, measurement of SA allows usability to be quantified.

Several techniques have been adopted to measure SA, but the most commonly used technique is the Situational Awareness Rating Technique (SART) (Salmon et al. 2009). This technique has been largely used in aviation to assess pilot's SA (Taylor 1990; Endsley et al. 1998; Gawron 2008). It measures the user's SA based on a combination of three areas: i) demands on attentional resources, ii) supply of attentional resources, and iii) understanding of the situation. The subject answers a set of questions that is designed to cover these three areas. Values for each of the three categories are then derived by computing the average responses. The SA level is computed using the formula $SA = U - (D-S)$ where SA = situation awareness, U = understanding of the situation, D = demand on attentional resources, and S = supply of attentional resources (Taylor 1990; Endsley et al. 2003). From the computation, the individual's SA can be rated as either low, medium or high. A high level of SA means that the individual can act accordingly and timely, even when faced with very complex and challenging tasks (Endsley et al. 2003).

Another parameter that can be used to assess the usability of a machine is the mental workload (MW) associated with operating the machine. Young et al. (2002) defined MW as "*the level of attentional resources required to meet both objective and subjective performance criteria, which may be mediated by task demands, external support, and past experience*". Evaluating the level of mental workload placed on the operator and how it affects performance will help improve the design of agricultural machines. Brookhuis and de Waard (2010) noted that if an operator's mental workload is too low, it may result in fatigue and boredom. Likewise, if it is too high, it may result in errors and stress. Hence, having a moderate level of MW is important when interacting with agricultural machines.

Several techniques have been used to measure MW. The Driving Activity Load Index (DALI) is one technique. It is a subjective rating tool that has been validated in various studies related to the driving task (Pauzie 2008). It estimates the workload of drivers by evaluating three workload components of the driving task: perceptual load, mental workload, and driver's state. Mental workload can also be estimated using performance and physiological measures (Jones 2009).

Although the SA and MW can be assessed for any machine, it only makes sense to measure them in the context in which the machine will be operated. The objective of this study was to determine whether experienced design engineers from a local agricultural machinery manufacturer possess sufficient understanding of the interaction between the operator and the machine that usability can be adequately considered during the design process.

MATERIALS AND METHODS

An agricultural machinery manufacturer located in western Canada was identified for this case study. The research was carried out in two phases. In the first phase, design engineers from the agricultural machinery manufacturer were interviewed with the purpose of completing a task analysis of the task of operating a self-propelled windrower. In the second phase, field observation of windrower operators was completed with the purpose of completing a second task analysis of the task of operating a self-propelled windrower. The two task analyses were to be compared to determine the level of understanding of the interaction between the operator and the machine.

Participants

Participants were recruited from employees of the agricultural machinery manufacturer cooperating on this research project. Three participants were interviewed for the first phase and four participants were observed during field operation of the self-propelled windrower. Interviews were conducted individually with design engineers. Prior to commencement of each phase, participants were given an overview of the experiment and given a consent form to read and sign indicating their voluntary participation. The research received human ethics approval from the University of Manitoba.

Procedure

The interviews with design engineers was conducted on the premises of the cooperating agricultural machinery manufacturer to minimize inconvenience to the design engineers. The interview was comprised of both structured and indirect questions. A video camera was used to record each interview session. The three participants that were recruited had at least 10 years experience on the design of windrowers, all with this machinery manufacturer. During the interview, the design engineers were asked to describe the principles and measures adopted when designing the user interface and during the placement of controls. The aim was to gain insight into their understanding of the various factors that they consider when designing the windrower, in terms of functionality, safety, convenience, durability, quality, reliability, cost, simplicity, and intuitiveness. They were also asked to lists the tasks and task activities involved during the windrowing operation to determine if they had adequate knowledge of the various tasks to be performed.

The second phase of the study was carried out in canola fields located in both Manitoba and Saskatchewan. Field-test technicians were observed as they conducted routine testing of the self-propelled windrower. The self-propelled windrower, identified in this paper simply as Model X, had a draper header 10.7 m (35 ft) in length. A Pupil Pro eye tracking device (Kassner et al. 2014) was worn by the field-test technician during the experiment (Fig. 1) to provide data on the windrower components and environmental sectors being viewed during operation of the windrower. A Polar V800 heart rate monitor was worn by the field-test technician to enable heart rate variability to be assessed during operation of the windrower. A standard video camera was employed to record the in-field operation of the windrower. All four field-test technicians were above the age of 22. Prior to the commencement of the experiment, they were debriefed on the experimental procedure and given a consent form to read and sign, indicating their voluntary participation. Each participant was then instructed to put on the heart rate monitor sensor and eye

Figure 1. Pupil Pro eye-tracking platform.

tracking system. The investigator observed the entire operation as a ride-along. A verbal protocol was used by participants to describe their actions as well as express what he was viewing and thinking while operating the windrower. During this period, the investigator (who was also in the windrower cab with the participant) would seek explanation concerning any action or activity carried out by the participant that was not clear. Each participant was expected to complete three blocks of driving taking a maximum of 10 min break after completing a block to respond to paper-based DALI and SART subjective rating scales. Each block took 1 h to complete with the entire session lasting 3 to 4 h.

By the end of the experiment, the data gathered through verbal protocol and video footage (i.e., eye tracking system) of the entire operation were analyzed and used to compare with the task analysis developed during the first phase of the study. The data collected from the heart rate monitor and DALI questionnaire were also analyzed to determine the global MW while the SART subjective rating scale was used to evaluate the participant's SA.

RESULTS AND DISCUSSION

Task analysis generated from interview of design engineers

Based on interview of the design engineers, it was learned that engineering standards developed by ASABE and ISO are considered during the design of windrowers. Factors such as "simplicity", "intuitiveness of design", and "convenience of operation" are considered to be important and are informed by feedback from both customers and field test engineers. With respect to interface design, none of the participants reported the consideration of "importance", "frequency of use" or "sequence of use" design principles when considering the placement of the controls in the windrower. Rather, they often relied on discussion at design meetings, feedback from operators, and observation during field testing to design the control interface. One of the participants did mention the use of available standards when designing the interface components, positioning the controls, and determining the height of handles. Field testing and benchmark tests are typically used to validate the functionality of the design.

Based on the input provided during the interview, three categories of tasks associated with operation of self-propelled windrowers were identified: 1) pre-drive, 2) transportation and, 3) operation in the field (Fig. 2).

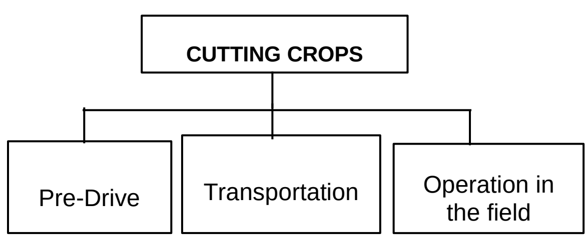

Figure 2. Higher-level tasks associated with cutting crops by windrowers.

The "pre-drive" category included those tasks and subtasks associated with the daily maintenance and routine inspection of the windrower. The "transportation" category involved those tasks and subtasks related to moving the windrower to the field. Finally, the "operation in the field" category included tasks and subtasks associated with the actual operation of the windrower in the field. In this study, "operation in the field" was the primary focus. Hence, a detailed task analysis of field operation of a windrower was developed (Table 1). From the listing of sub-tasks and task activities, a hierarchical task description of this subtasks was made. It included "tractor operation and monitoring", monitor swath roller tracking", and "header control and monitoring" (Fig. 3).

Table 1. The list of subtasks for windrower operation in the field.

Operation in the field task	Subtasks	Task activity
Navigation and routing	Way-finding	Identify Present Location Follow planned route
	Route modification	Identify need to correct or change route Select new route or direction Execute the modification
Windrower operation and monitoring	Tractor operation and monitoring	Monitor Engine operation Adjust engine RPM Monitor control system and tractor structure Adjust climate control Operate tractor speed controller Use GPS system (Routing and Navigation system) Operate lighting system Operate windshield and rear window washer/Wipers
	Monitor swath roller tracking	
	Header control and monitoring	Control header height Control header fore-aft position Control reel height Control reel fore-aft position Control draper speed Control cutter bar speed Monitor header plugging Monitor header overload Monitor draper plugging Monitor cutter bar (for broken or bent knives or guards)
Control	Speed control	Identify difference between current and desired speed Adjust throttle to control speed Verify adjustment of speed
	Position control	Identify difference between current and desired lane Adjust steering wheel to compensate Verify adjustment of lane position
Guidance and manoeuvers	Manoeuvering	Identify present speed and position Identify distance to turn point Adjust speed and position Signal turning manoeuver near turn point Execute turning manoeuver
	Hazard observation	Estimate hazard potential in the field Monitor headway route and surroundings Estimate hazard potential to vehicle Execute speed and position control Execute driving manoeuver to compensate for hazard
Reacting to emergencies	Detect emergency condition	
	Diagnose situation	
	Determine action required	
	Take appropriate action	

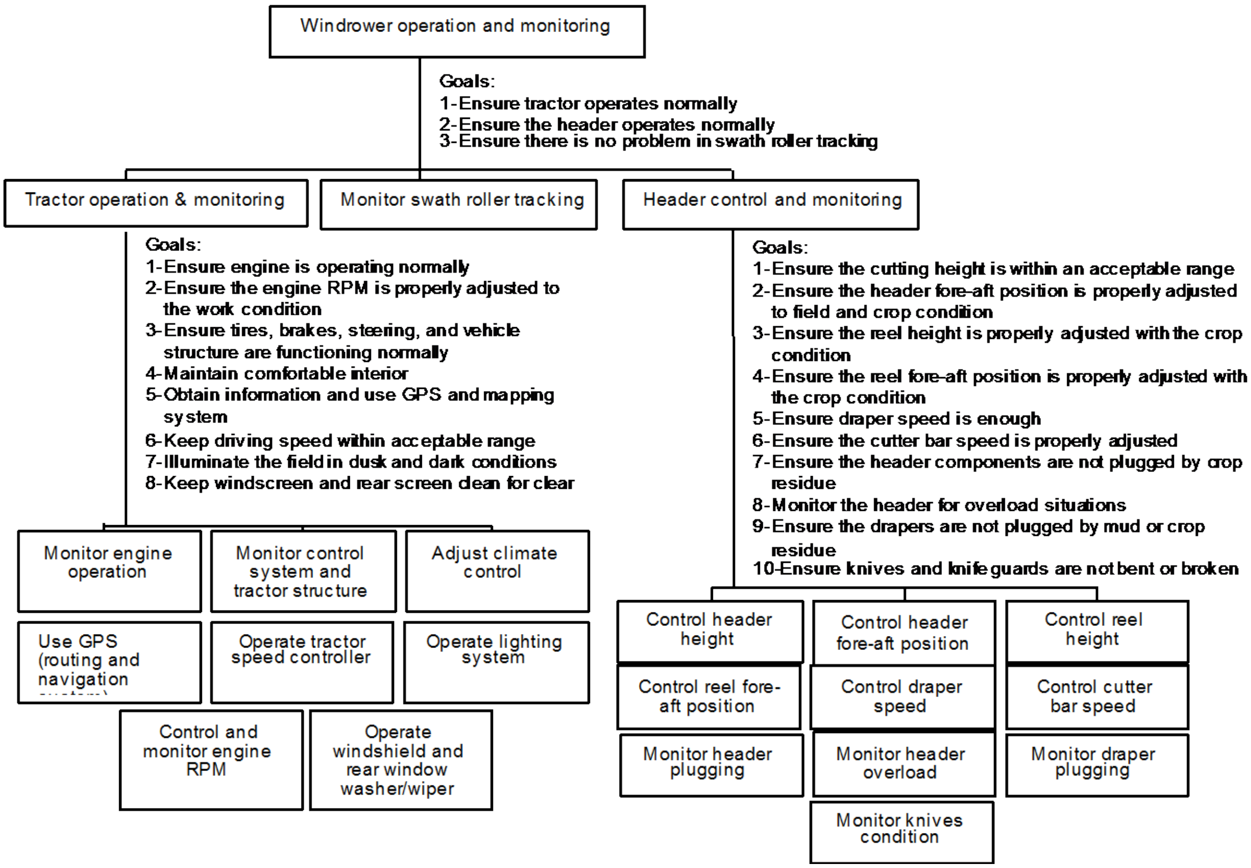

Figure 3. A hierarchy of windrower operation and monitoring tasks.

In-field observation of field-test technicians

It was observed that operators frequently had to stop the windrower to perform repairs to the machine, thereby interrupting the operation of the experiment. The stops usually occurred after the first 15 min of driving within each block. Hence, the data presented in this paper were based on only the first 15 min of driving in each block. During the in-field observation of field-test technicians, problems were experienced with the eye tracking system. Specifically, the eye tracking system was unable to maintain proper calibration due to the rapid head turns and the large angle of head motion required to monitor the entire header from left to right. Thus, it was difficult to rely on data from the eye tracking system. A hardware problem with the eye tracking system was experienced with the third participant so no gaze data were available for this individual.

From the in-field experiment, it was determined that the operator's eyes were typically focused on one of the following four areas: 1) left side of the header, 2) right side of the header, 3) ahead of the windrower, and 4) rearward to the right. All three of the field-test technicians viewed the header more than either looking ahead of the machine or rearward to the right (Fig. 4). In all driving blocks for all three participants, the number of gazes to the left side of the header was greater than the number of gazes to the right side of the header. Having a higher number of left-side views of the header in comparison its right side could be a result of the partially-obstructed view of the right side of the header caused by the placement of the GPS navigation display, windrower information display, and console (Fig. 5).

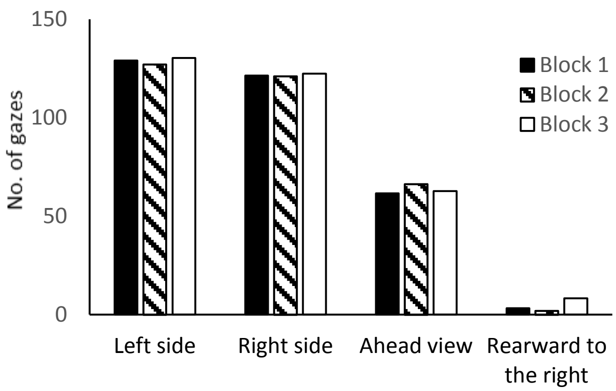

Figure 4. Gaze directions of operators during three driving blocks.

Figure 5. Operator monitoring the right side of the header; the GPS unit is obstructing the view.

Observations and self-reports revealed that operators rarely used the windrower information display during in-field operation. Instead, they focused on environmental cues such as the height of the stubble from the previous pass to maintain the header's height. Only one of the field-test technicians claimed to be using the windrower information display for this purpose.

Task analysis validation

Based on review of the data generated from the in-field observations of field-test technicians, one addition was made to the task hierarchy developed during the first phase of the study. The design engineers did not identify "monitor draper plugging", but this was a common task experienced by the field-test technicians during operation of the windrower.

Usability assessment of windrower

Mental workload observed The 0.1 Hz component of heart rate variability (HRV) showed inconsistency (Fig. 6) and no meaningful conclusions could be drawn from the results. On the other hand, the results from the DALI subjective rating scale provided more useful results. Participants involved in the in-field experiment experienced moderate global mental workload while operating the windrower (Fig. 7). They identified the "visual" and "auditory" demand as the highest and least demanding parameters, respectively (Fig. 7). This rating could be deduced from the task analysis as the majority of the tasks performed by the operator require the operators to use visual information. Thus, it is reasonable to expect high visual demand. By contrast, operators gather very limited information using the auditory channel, therefore, it is reasonable to expect low auditory demand. Overall, it can be said that the field-test technicians experienced moderate levels of global mental workload. Moderate levels of global mental workload are desirable as low levels contribute to operator underload (leading to boredom) and high levels contribute to operator overload (leading to performance decline or errors).

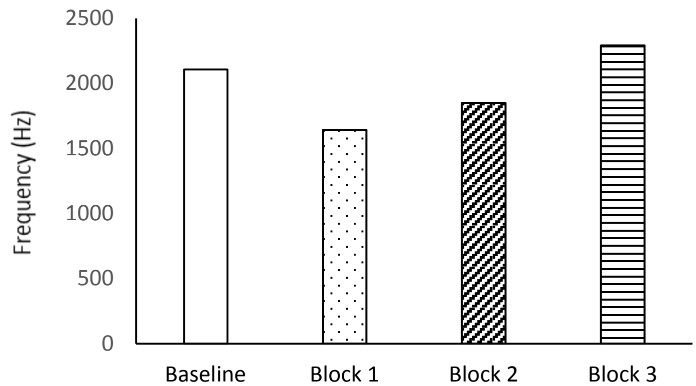

Figure 6. The 0.1 Hz component of HRV in baseline and three driving blocks (1-3).

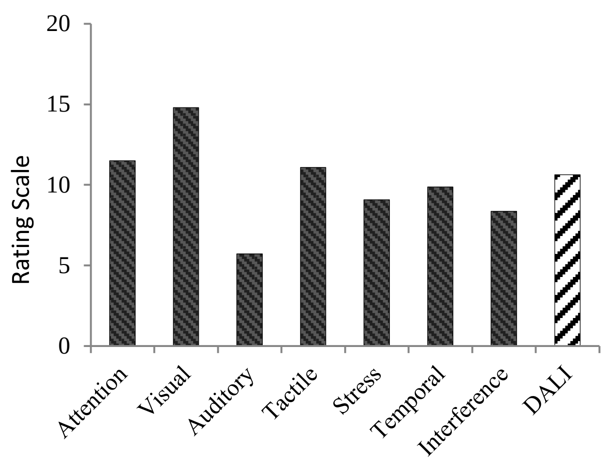

Figure 7. Mental workload parameters and global mental workload (DALI) for field-test technicians operating self-propelled windrowers.

Situation awareness observed SART was used as the subjective measure of situation awareness. Using this rating scale, 10 dimensions of situation awareness of drivers were measured. These dimensions were categorized in three distinctive groups: i) *demand on attentional resources*, ii) *supply of attentional resources* and iii) *understanding*. A value for each of these categories was derived by taking the average of responses to questions included in the appropriate categories. Lastly, the combined rate for situation awareness was inferred by subtracting the average score of *demand* from the sum of average scores of *understanding* and *supply of attentional resources*. Analysis of the SART data revealed that the field-test technicians had good understanding of the in-field operations (Fig. 8). The level of situation awareness experienced by the operators was adequate to maintain a high level of performance.

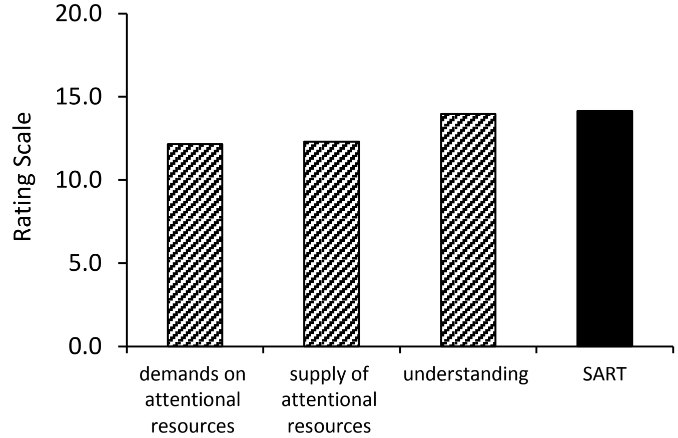

Figure 8. Situation awareness (assessed using SART) for field-test technicians operating self-propelled windrowers.

CONCLUSION

The purpose of this study was to assess the usability of a self-propelled windrower designed and manufactured by a local manufacturer and to determine whether experienced design engineers from a local agricultural machinery manufacturer possess sufficient understanding of the interaction between the operator and the machine that usability can be adequately considered during the design process. The assessment was completed using standard task analysis procedures (i.e., interviews of designers, observation of users) and accepted human performance constructs of mental workload and situation awareness.

Our research involved both windrower designers and those involved with field testing (who can be categorized as “users” of the windrower). Task analyses were conducted with both categories of personnel and the results demonstrated that both designers and test engineers have a good understanding of the tasks associated with operating the windrower. It appears that this local manufacturer has achieved a successful design environment where design engineers are heavily involved in product testing. This is an ideal situation because it enables efficient transfer of knowledge to inform the design process.

The research involved ride-alongs during canola swathing that took place in both Manitoba and Saskatchewan. With the use of eye-tracking equipment, it was observed that windrower operators did not spend equal amounts of time viewing the left and right sides of the header. There is no obvious reason why one side of the header should be favored over the other side of the header, but the results consistently showed that more time was spent viewing the left side of the header. It has been speculated that operators may have avoided the right side of the header because the view was obstructed by the GPS unit and console. Placement of all monitors should be considered carefully to avoid obstructed views of the header.

As a result of eye-tracking, it was also observed that it was rare for the operator to use the information display during windrower operation. Although this display may be needed at certain stages (i.e., initial start-up), it seems that operators rely on observation of the windrower during operating conditions. Given this observation, the monitor should be positioned with preference given to avoiding an obstructed view of the header.

A moderate global mental workload was experienced by operators while operating the windrower. Visual demand was high, but auditory demand was low. The level of situational awareness experienced by operators was adequate to maintain a high level of performance. Hence, the DALI and SART subjective scale can be used by test engineer to assess or test improvement with regard to the usability of windrower from the human factor perspective.

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REFERENCES

Brookhuis, K. A. and D. de Waard. 2010. Monitoring drivers' mental workload in driving simulators using physiological measures. *Accident Analysis and Prevention*. 42: 898–903

Dey, A. K. 2008. Mental workload associated with operating an agricultural sprayer in response to gps navigation aids. PhD dissertation. Winnipeg, Manitoba. Department of Biosystems Engineering. University of Mnaitoba.

Endsley, M. R., S. L. Selcon, T. D. Hardiman and D. G. Croft. 1998, A comparative evaluation of SAGAT and SART for evaluations of situation awareness. In Proceedings of the Human Factors and Ergonomics Society Annual Meeting (pp. 82-86). Santa Monica, CA: Human Factors and Ergonomics Society.

Endsley, M. R., B. Bolte and D. G. Jones. 2003. Designing for situation awareness: an approach to user-centered design. London; NY: Taylor Francis.

Gawron, V.J., 2008. Human performance, workload, and situational awareness measures handbook. *CRC Press*.

Goodwin, N. C. 1987. Functionality and usability. *Communications of the ACM*, *30*(3): 229-233.

Jones, R. 2009. Physical ergonomic and mental workload factors of mobile learning affecting performance of adult distance learners: student perspective. Unplished Ph.D. thesis. Orlando, Florida. Department of Industrial Engineering and Management Systems. University of Central Florida.

Kassner, M., Patera, W., Bulling, A. 2014. Pupil: An open source platform for pervasive eye tracking and mobile gaze-based interaction. *UBICOMP '14 ADJUNCT*, Seattle, WA, USA. September 13 - 17.

Pauzié, A. 2008. A method to assess the driver mental workload: The driving activity load index (DALI). *Intelligent Transport Systems, IET*, 2(4): 315-322.

Salmon, P.M., Stanton, N.A., Walker, G.H., Jenkins, D., Ladva, D., Rafferty, L., Young, M. 2009. Measuring situation awareness in complex systems: Comparison of measures study. *International Journal of Industrial Ergonomics*, 39(3): 490-500.

Taylor, R. M. 1990. Situation Awareness Rating Technique (SART): the development of a tool for aircrew systems design. Paper 3 in: Situational Awareness in Aerospace Operations, AGARD-CP-478. Neuilly-sur-Seine, France: NATO-AGARD. pp. 3/1-3/17.

Young, M. S. and N. A. Stanton. 2002. It is All Relative: Defining Mental Workload in The Light of Annett's Paper. *Ergonomics.* 45(14): 1018-1020.