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Eye Tracking as a Control Interface for Tele-Operation During a Visual Search Task

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**EYE TRACKING AS A CONTROL INTERFACE FOR TELE-OPERATION DURING A
VISUAL SEARCH TASK**

by

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B.A. December 2014, Virginia Wesleyan College

A Thesis Submitted to the Faculty of
Old Dominion University in Partial Fulfillment of the
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ABSTRACT

EYE TRACKING AS A CONTROL INTERFACE FOR TELE-OPERATION DURING A VISUAL SEARCH TASK

Jeffrey Neal Levy
Old Dominion University, 2017
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This study examined the utility of eye-tracking as a control method during tele-operation in a simulated task environment. Operators used a simulator to tele-operate a search robot using three different control methods: fully manual, hybrid, and eye-only. Using Endsely's (1995a) three level SA model and a natural interface (e.g., eye-tracking) as a more user-centered approach to tele-operation, the study measured objective, electroencephalogram, and subjective (NASA-TLX) measures to reflect both workload and situation awareness during tele-operation. The results showed a significant reduction in mental workload, as reflected by EEG measures. However a significant effect was found where the operators' perceived mental workload scores, as reflected by the TLX, significantly increased while using the natural interface. The difference in perceived mental workload was also mirrored by a *post hoc* analysis where frustration scores, also reflected by the TLX, supported the initial findings of the differences in perceived mental workload scores between the three conditions. The results of this study can be explained by both incomplete mental models of motor movements and differences in affordances offered by the different control conditions. Additional considerations for system designers and future research are also discussed.

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This thesis is dedicated to Family and ODU/VWC faculty mentors.

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CHAPTER 1

INTRODUCTION

In the past few decades the popularity of complex technology has burgeoned in society (LaViola Jr., 2014; Miller & Parasuraman, 2003). Engineering psychologists have investigated potential costs (e.g., long reaction time, high task demand, and high intrusiveness) and limitations (e.g., subjective measures, low diagnosticity, high automation bias) of utilizing the many types of technology (Durso et al., 2010; Miller & Parasuraman, 2003; Muir, 1987; Parasuraman et al., 2000; Sheridan & Verplank, 1978; Sorkin & Woods, 1985; Wickens et al., 2013). There has been much research focused on understanding automation use as well as their effects on task operators (Endsley, 1995; Prewett et al., 2010; Wickens, 2002). Although complex system use presents many important considerations, two of the most critical operator constructs are workload and situation awareness, both potentially detrimental to operators' performances if not properly managed (Brooking et al., 1996; Endsley, 1995a; Jones & Endsley, 1996; Prewett et al., 2010; Wickens, 2002).

In an effort to reduce the risk of personnel injuries, teleoperation of unmanned vehicles has been increasing in popularity in many respected communities (Miller & Parasuraman, 2003; Mouloua et al., 2001). With the increase in use of unmanned vehicles researchers must investigate not only variations of SA and workload, but physical dislocation of operators. The popularity of teleoperation emphasizes the importance of interface design (e.g. visual displays and inputs and outputs), where the dynamic relationship between system and operator hinges upon the display of data as well as its interpretation (Van Erp, 1999). As discussed by Parasuraman and colleagues (2000), the decision to use automated systems may have both benefits and costs. Benefits may include a reduction in attentional resource demand, whereas

costs may include the reduction of the operator's situation awareness (Kaber et al., 1999; Parasuraman et al., 2000).

As engineering psychologists acknowledge the need for operators to be efficient and effective, there are many changes to be considered if system designers want to achieve these goals (Boucsein, 2000). This study uses Boucsein's (2000) definition to define efficiency and effectiveness. Effectiveness is defined as "the quality of performance" and efficiency to describe "the relationship between the quality of performance and the effort invested in the completion of the task" (Boucsein, 2000). One consideration would include re-evaluating the design of existing systems to reduce task demands and prevent operators from having to learn about new technology and techniques. System designers make decisions on the basis of expected inputs, system commands, outputs, and system feedback. Historically, system designs have followed a technology-driven approach, where functions are implemented and the operator is asked to adapt (Oviatt, 2006). At times this may be appropriate because of its simplicity. However, it often leaves out the capabilities and limitations of the task operator. One increasingly popular technological tool is eye tracking. Eye-tracking technology has not only become a critical tool in data collection but also allows researchers to take a more user-centered approach to facilitate the interaction between operator and system (Poole & Ball, 2006; Smith et al., 2015).

Of prime importance to designers is the effective management of operators' mental resources so that there is sufficient memory and attention to interact with the task, the automated system, and the task environment (Oviatt, 2006; Parasuraman et al., 2000; Wickens, 2002). The proposed study reflects a collective definition of mental resources as information processing capacity that is expended during task performance (Van Merriënboer et al., 2005). Automation includes devices or systems that accomplish a function that was previously, or conceivably could

be, carried out by a human (Parasuraman & Riley, 1997; Parasuraman et al., 2000; Warm et al., 2008).

Because of the potential for automated system control to degrade cognition, the proposed investigation evaluates the non-applicableness of Multiple Resource Theory (MRT), a performance theory often used by system designers to guide the exchange of information and interactions between complex systems and operators, and leverages both a user-centered approach and Situation Awareness (SA) as a guiding framework to enable the evaluation of three different control methods for tele-operation: fully manual, hybrid, and eyes-only (Endsley, 1995a; Oviatt, 2006; Wickens, 2002). The planned manipulation of control method as an independent variable will feature the possibility of eye-tracking technology to assist operators in the tele-operation of a robotic vehicle during a visual search task. The experiment will investigate changes in physiological data, performance data, and subjective mental workload and situation awareness that may occur given the manipulation of command input modality. An important aspect of the experimental manipulation is the inclusion of a natural interface condition that features an eye tracker (Endsley 1995; Prewett et al., 2010; Smith et al., 2015; Wickens, 2002). The goal of this study was to record objective, EEG, and subjective measures to investigate the impact of using eye-tracking technology during tele-operation, and what changes cognitive may occur as a result of using a natural interface, such as an eye-tracker (Brünken et al., 2003; Parasuraman et al., 2000; Oviatt, 2006).

Taking a human-centered approach to designing a system for the tele-operation of an Unmanned Ground Vehicle (UGV) includes identifying task demands that impose any Extraneous Cognitive Load (ECL) on the operator. In this study, extraneous cognitive load is defined as any attentional resource demand imposed upon an operator as a result of the

formatting of the inputs, commands, and outputs, system feedback, of a system (Brünken et al., 2003). More specifically, previous research characterized ECL as workload imposed on an operator during the operation of a system (e.g., manipulating two joystick during tele-operation or turning a steering wheel while pressing a car's gas pedal), but does not contribute to the understanding of environment, or stimuli (Brünken et al., 2003). For example, a person tele-operating a UGV with two joysticks has two essential goals: 1) manipulate vehicular and camera control of the UGV and 2) successfully navigate through an environment to complete a task. The task demands of tele-operation determine the amount of ECL imposed onto the operator. The task demands to tele-operate a UGV may actually detract from the operator's knowledge about the task environment. Such demands draw limited attentional resources from the operator's working memory (Brünken et al., 2003; Endsley, 1995; Wickens, 2002).

Proper management of ECL would increase available attentional resources to maintain situation awareness or complete a task (Endsley, 1995; Oviatt, 2006; Wickens, 2002). Judicious management of ECL imposed upon tele-operators would require evaluating the task demands of the tele-operating system and considering alternative approaches such as natural interfaces.

CHAPTER 2

BACKGROUND OF THE STUDY

Natural Interfaces

In an effort to focus attention on critical concerns regarding tele-operation, researchers have advocated the use of natural interfaces (Mouloua et al., 2001; Stone, 1991). Natural interfaces are systems designed to interpret naturalistic behavior, or movements (e.g., hand gesture movements, voice commands, and eye movements), as input commands to operate a specific function. Such interfaces promote learnability, speed, and reduction of motor movements (Jacob, 1990; Wachs et al., 2011, Stone, 1991). It seems that many of the suggested benefits are dependent upon the natural movements emulated by the system; natural interfaces should be easier to operate because they require behavior patterns that have been previously learned (Wachs et al., 2011). The use of eye-tracking technology is a particularly relevant example (Jacob, 1993).

Dünser and colleagues (2015) compared the use of eye tracking with the use of traditional tele-operation techniques (e.g., two joysticks or mice) during a Fitts test. A test that was designed to predict the movement time between two points based on the distance to be traveled, size of the target, and features of the motor system for movement (Fitts, 1954). They noted a distinct speed advantage that eye movement has over traditional arm and hand movement, perhaps because of rapid saccade movements. However, Dünser and colleagues reported that the two eye-tracking interfaces were slower than the other manual traditional methods (e.g., mouse and touchscreen) because they required more learning by participants. Notably, using the NASA Task Load Index (TLX), the eye-tracking methods were rated as imposing significantly less perceived workload than the manual methods (Dünser et al., 2015).

In a similar study, Smith and colleagues (2015) compared the use of eye-tracking technology against keyboard use for a task that required participants to switch monitor controls in a simulated surveillance system. The authors reported that eye tracking was significantly faster than keyboard switching. However, Smith and Colleagues (2015) also reported eye-tracking as greater in perceived workload ratings.

Multiple Resource Theory

The ECL workload benefit supports using a natural interface as an input technique for tele-robotics (Oviatt, 2006; Stone, 1991). Contrary to suggestions that Multiple Resource Theory (MRT) may be used as theoretical framework to support system design changes, it is identified that the current MRT is not fit to support the system design used in this study (Dünser et al., 2015; Oviatt, 2006; Smith et al 2015). Multiple Resource Theory is a performance theory that characterizes attentional resource allocation; and has been used by some system designers to manage attentional resource demands imposed upon operators for multitasking environments (Oviatt, 2006; Wickens, 2002). MRT predicts operator performance based upon the distribution of cognitive resources among independent attentional reservoirs. The general consensus being that the more a task, system, or environment requires an operator to simultaneously use cognitive resources within the same reservoir interference is generated that generally yields poorer performance (Wickens, 2002). Ideally if MRT were applied to tele-operation, it would be used to evaluate task demands of a tele-operating system and support designs that would reduce the amount of interference between resource reservoirs. One distinct advantage of using MRT as a framework for system design is the potential to design a system that accommodates cross-modal time-sharing of attentional resources (Wickens, 2002). Time-sharing is defined as the allocation of attentional resources among the multiple resource pools as described in MRT (Wickens,

2002). Wickens (2002) emphasizes that even if a system is designed to accommodate cross-modal inputs, operators may still experience perceptual interference, see Figure 1 (Wickens, 2002).

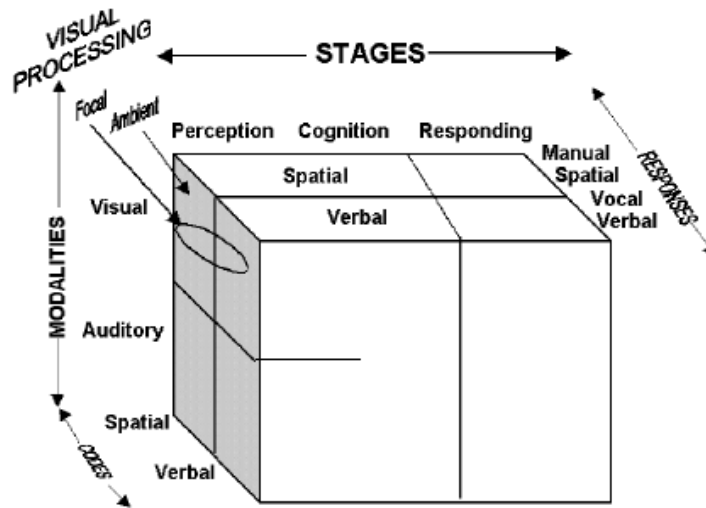


Figure 1. A 3-D model representation of multiple resources as described in Wickens (2002).

Applying MRT (2002) to the current study reveals a critical limitation in the model. As proposed by Wickens, MRT describes the visual system as a collector of perceptual information and does not address the visual system as the initiator of a manual response, as used in this study using eye-tracking (Wickens, 2002). Consequently, MRT does not predict the impact of ocular motor responses on sensory or motor cognitive resource pools (Wickens, 2002). Because of this limitation, an alternative framework must be identified. Possible candidates include theories of mental workload or frameworks to explain the development and enhancement of situation awareness, such as the model offered in Figure 2 (Brünken et al., 2003; Endsley 1988a/95a; Parasurman et al., 2000). The cognitive model proposed in Ensley (1988a), Figure 2, would be a

more appropriate model to support the system design change used in this study and as framework for designers in the future. The model follows an information processing approach towards Situation Awareness (SA) and provides guidance towards how cognitive resources are held and allocated (Endsley, 1988a). This study utilizes this model as framework.

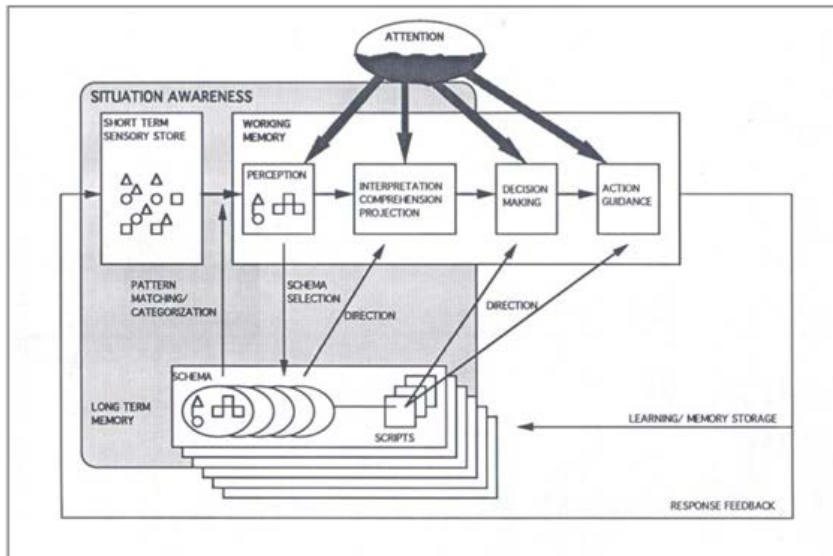


Figure 2. Mechanisms of situation awareness (Endsley, 1988a).

Eye-Tracking and Automation Use

Parasuraman and colleagues (2000) recommended that a decision to use automation must be accompanied by its likely effects on the operator, such as changes in mental workload and situation awareness. Jacob (1990) suggests that the use of eye-tracking technology is no exception to such influences. Jacob (1990) identified a potential cost of eye-tracking technology is as the “Midas Touch.” The Midas Touch is described as a result of using eye tracking to command a system inadvertently activating functions, or inputs, on an interface that were not meant to be activated (Jacob, 1990). An example of this would be an operator trying to move a

mouse cursor across an interface but inadvertently selecting undesired icons. Jacob (1990) explains that the Midas Touch may have a negative impact upon an operator's frustration and/or stress.

The Midas Touch could occur in this study in the this study. There was a possibility that the operators may be influenced by the design of control methods for tele-operation. In this study, eye-tracking was used as a method of camera control, and as an object selection method. During the use of eye-tracking for camera control the Midas Touch could have occurred if the tele-operator is trying to visually inspect a stimulus in the simulated environment and the camera moves without the intention of the operator. This occurrence of the Midas Touch during camera control may have been distracting.

The Midas Touch may have also occur during the selection method. To control for this, the eye-tracking technology was designed to measure fixation periods across the interface. When the system recognizes that the tele-operator has a fixation across a set of pre-programmed pixels the progression of a "selection circle" begins (see Figure 2). If the tele-operator does not maintain a fixed focus on the pre-programmed pixels, the progression of the circle will disappear and reset. However, if the tele-operator's intention was to simply inspect a stimulus in the simulated environment then the progression of the selection circle may begin without the intention of the tele-operator and could interfere with the intended visual inspection.



Figure 3. Visual feedback given to the tele-operator in eye-tracking conditions during target selection. The feedback signifies that the current visual fixation point is in the process of being selected. When a completed circle is presented the tele-operator responds with a nod of the head to acknowledge the selection of the intended target.

The particular design of the eye-tracking interface was designed to facilitate a continuous stream of visual information. Such a stream occurs naturally when humans move their eyes and heads to focus on visual targets. Unlike traditional methods of tele-operation, the operator may refocus attention smoothly and seamlessly to build awareness. No joysticks or manual controls are necessary for shifting the viewpoint, and no associated loss of information should occur.

Ultimately, the smoothness of an eye-controlled camera should constitute a more user-centered design than the traditional tele-operation design (Oviatt, 2006). The design used not only allowed the operator to search the environment freely without the interruption of joystick manipulation for camera panning, but it also allowed information to pass directly across the fovea to be immediately evaluated for acquisition.

Subjective Mental Workload

One of the goals of this study was to reduce the amount of perceived mental workload of the operator. Mental workload is defined as the total amount of information processing demanded by a task (Eggemeier, 1988; Warm et al., 2008). Oviatt (2006) and Parasurman and

colleagues (2000) point out that a system's design may be able to accommodate the information processing demands of a task by designing the system interaction to accommodate the operator rather than the traditional technology driven approach. In the study, measuring perceived workload during tele-operation was expected to provide further support for modality dependent resource demand. In an effort to measure changes in perceived mental workload the present study used the two workload measures described below.

Subjective Mental Workload Measure: NASA-Task Load index

Of the various techniques used to measure cognitive workload, the most widely accepted is the TLX (De Winter, 2014). The TLX was developed by Hart and Staveland in 1988 and measures the mental workload of a task across six dimensions: mental demand, physical demand, temporal demand, performance, effort, and frustration (Hart & Staveland, 1988; Rubio et al., 2004). The TLX reflects the idea of workload and performance being dependent upon the allocation of attention, which makes it a popular method for assessing workload in multitask environments (Hart & Staveland, 1988; Rubio et al., 2004).

In a study by Rubio et al. (2004) the TLX was compared with the Subjective Workload Assessment Technique (Reid & Nygren, 1988) and the Workload Profile (Tsang & Velazquez, 1996) to see how well each met suitability requirements to evaluate mental workload as suggested by Eggemeier and Wilson (1991). These requirements include sensitivity, diagnosticity, selectivity/validity, intrusiveness, reliability, implementation requirements, and subject acceptability. Rubio and colleagues (2004) reported that the TLX was the most useful and sensitive subjective measure used in the comparison (Rubio et al., 2004). Similarly, Dünser et al., (2015) and Smith et al., (2015) used the TLX to evaluate changes in workload during eye-tracked control. In both studies the task demands of a complex system relying heavily on motor

movements (e.g., arms, hands, and fingers) were compared against a system that relied only on the motor movements of the visual system (e.g., eye movements). In both studies, the system utilizing eye-tracking technology required less mental workload (Dünser et al., 2015; Smith et al., 2015). Importantly, the findings from both studies showed that the TLX can detect a significant reduction in workload from the use of eye-tracking technology.

Convergent validity for the use of the TLX has been demonstrated by its correlation with physiological measures (e.g., eye-blink, heart rate, and EEG). An electroencephalogram is a physiological monitoring device that monitors, and records, electrical activity in brain (e.g., multiple brainwave patterns) (Antonenko et al., 2010; Gevins & Smith, 2006; Parasuraman et al., 2000). Brookings and colleagues (1996) used the TLX concurrently with an EEG to evaluate workload in a simulated Air Traffic Control (ATC) environment. They found that the TLX was sensitive enough to detect changes in workload for each level of difficulty during the ATC task (Brookings et al., 1996) and that the TLX correlated with the level of activation in an EEG theta power band (brain wave of 4-8 Hz) . EEG theta wave activity is considered to have a positive relationship with workload, and the alpha wave activity (brain wave of 8-16 Hz) has a negative relationship with workload (Antonenko et al., 2010; Gevins & Smith, 2006; Parasuraman et al., 2000).

Much research has used the NASA-TLX to measure workload; yet, it remains a self-report method that relies on the operators' opinions (Rubio et al., 2004; Winter, 2014). As such, it should be used and interpreted with caution (Stanton et al., 2013). In this study, EEG was used in conjunction the TLX to assess workload.

Physiological Measure: EEG

Byrne and Parasuraman (1996) identified psychophysiological measures as important for assessing the influence of automation upon the intended operator (Byrne & Parasuraman, 1996). As described by Parasuraman and colleagues (2000), understanding how automation can be implemented and how its implementation can affect the operator is an essential consideration (Parasuraman et al., 2000). Studies using similar methods of measuring workload as this study have consistently reported a negative relationship between both the alpha and theta EEG bands (1-8 Hz) and subjective workload (Aricò et al., 2015; Brookings et al., 1996; Gevins & Smith, 2006). Additionally, in a seminal literature review, analyzing the use of continuous EEG use, Antonenko and colleagues (2010) suggested that the alpha band demonstrates a desynchronizing pattern as task difficulty increases and the theta band demonstrates a synchronizing pattern that increases concurrently with task difficulty (Antoneko et al., 2010).

Situation Awareness

As mentioned by Parasuraman and colleagues (2000), considering the effects of automation use is critical when designing a complex system. Technological influences on Situation Awareness (SA) is central to Endsley's research (Endsley, 1995a). Endsley (1988) defines SA as "The perception of the elements in the environment within a volume of time and space, the comprehension of their meaning, and the projection of their status in the near future." Endsley (1995a) proposed a three-level model of SA based on an information-processing approach (See Figure 3; Salmon et al., 2008).

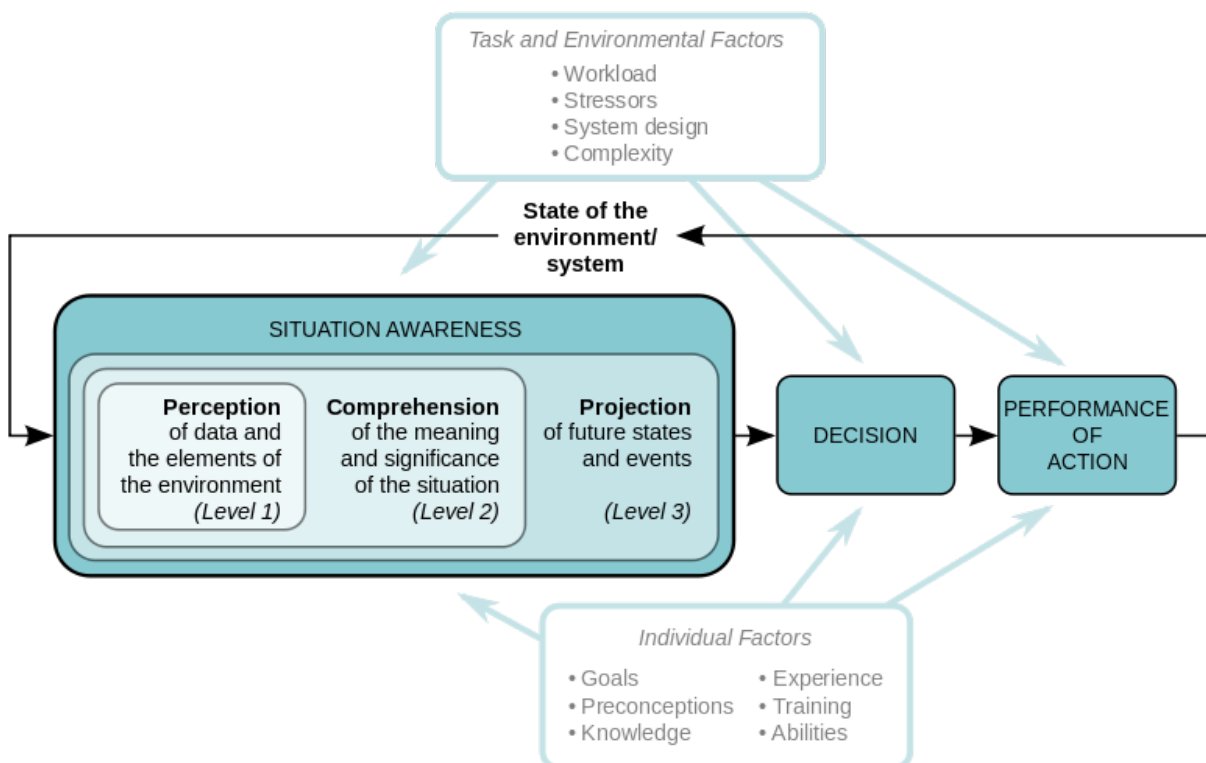


Figure 4. A three-level model of situation awareness (Endsley, 1995a).

In her (1995a) study Endsley described SA as a process that occurs after perception and that is independent from other cognitive constructs such as workload and situation assessment. She also presents the three levels of SA hierarchically (Endsley, 1995a; Salmon, 2008). Her claim of level dependence coincides with how information is collected from the environment by sensory systems, then continuously processed for recognition and meaning (see Figure 3).

In the first level of SA, an operator perceives relevant stimuli (e.g., status of gauges, auditory and visual alarms, status of a system) within the dynamic working environment. The operator identifies relevant stimuli that do or may contribute to the understanding of an environment or as information needed towards the completion of a goal (Endsley, 1995a; Salmon et al., 2008). In this study, such elements could consist of information and objects presented on the interface of the simulator (e.g., characteristics of targets and non-targets, system status, and

visual cues) as well as spatial information and the status of control interactions. Though an error in this first level of SA may be harmful for the successful completion of a task goal, additional top-down factors such as experience may help the operator avoid errors (Endsley, 1995a).

Endsley (1995a) characterizes the second level of SA as consisting of the synthesis of the elements from the first level of SA and the recognitions or assumptions, that result in the interpretation of such elements and how they relate to their mental model or goal. Though novices and experts may both be successful in identifying relevant elements in a working environment, they may differ in their synthesis of those elements (Endsley, 1995a). For example, a novice may be able to identify a selection of relevant elements, but may not have the knowledge or training to build a mental model from the information obtained (Endsley, 1995a). An error in this level of SA was also described by Jones and Endsley (1996).

In this study, examples of the second level of SA would consist of operators properly interpreting visual cues for navigation and target discrimination.

The third level of SA that was identified by Endsley (1995a) was the projection of future status. It is in this level that the understanding of Level one and Level two information is utilized to predict the future status of stimuli within a dynamic environment (Endsley, 1995a). For example, while stopped at a 4-way stop a driver may notice an oncoming car from their right. The operator may then have to decide when to proceed through the intersection. The operator may already be processing Level 1 and 2 SA and may have an incomplete projection of Level 3 SA information. As the approaching vehicle comes closer to the operator's vehicle more information can be obtained, providing accurately detailed information regarding any potential threats of collision if the operator decides to proceed.

Because tele-operation relies on the perception of information presented within an interface, SA is a critical component to consider. During tele-operation operators must rely on data obtained through interface features (e.g., camera zoom and graphical overlays) that may influence the operator's performance (Van Erp, 1999). As suggested by Endsley (1995a) and Salmon et al. (2006), additional factors such as experience and design elements may accommodate good performance even if an operator has limited SA. Likewise, factors such as workload may lead an operator to have poor performance while having good SA (Endsley, 1995a). It is important for researchers to study SA in different task domains and evaluate how system design can affect SA.

In addition to Endsley's proposed three level model of SA (1995a), researchers have proposed alternative models to describe SA (Bedny & Meister, 1999; Salmon, 2008; Smith & Hancock, 1995). Bedny and Meister (1999) proposed using *theory of activity* for modeling situation awareness (See figure 4; Salmon et al., 2008). Bedny and Meister describe SA as being part of a complex cognitive process that has three core components: a person's conceptual model, the person's image goal, and the person's subjectively relevant task and conditions (Bedny & Meister, 1999; Salmon et al., 2008). Bedny and Meister propose that SA is a component used during interaction with an environment. Interactions occur when an operator has an ideal goal to achieve, evaluates their current situation, and then evaluates possible interactions that may lead the operator to achieve that goal (Salmon et al., 2008).

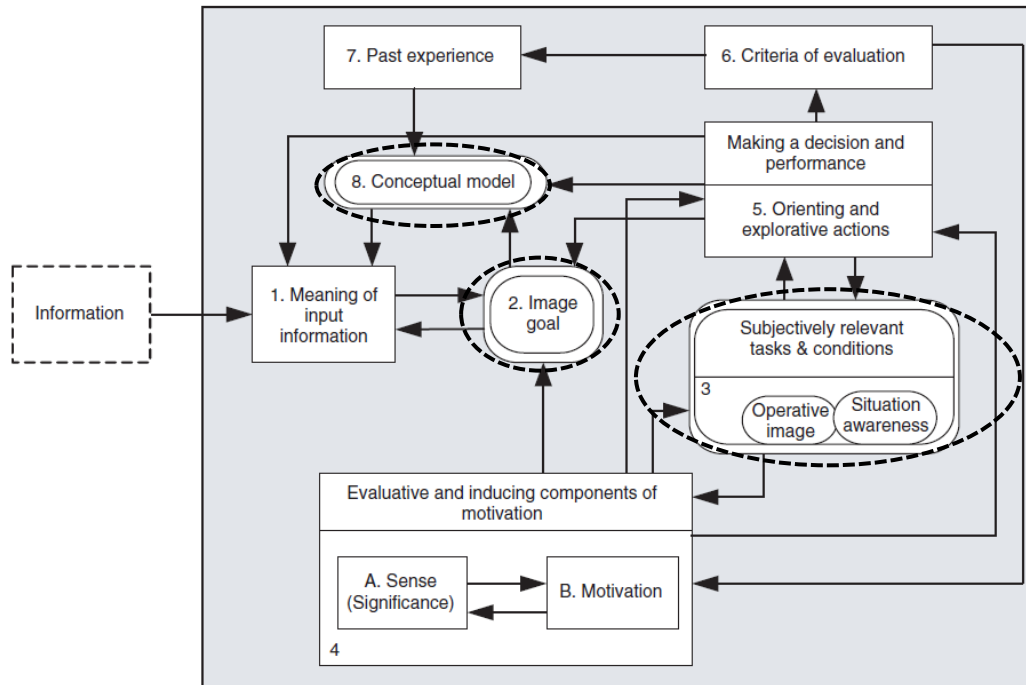


Figure 5. Using *theory of activity* to describe situation awareness with the core components: (8) Conceptual model, (2) Image goal, and (3) Subjectivity relevant tasks & conditions (Bedny and Meister, 1999).

Smith and Hancock (1995) use an ecological approach to describe SA based on the perceptual cycle (See Figure 5). SA is described by Smith and Hancock as both a product and an internal process (Salmon et al., 2008). Smith and Hancock's (1995) description of SA reflects an operator having existing goal-relevant knowledge that is continuously expanded and modified through interactions with the environment.

When comparing the models previously mentioned to describe SA a common theme of agreement is that SA is essential for successfully completing a task and should be considered in performance criteria. Moreover although both SA models: Smith and Hancock (1995) and Bedny and Meister (1999) may be relative towards the definition of SA, when applied to the current

study neither were found as fit to guide both the measurement and interpretation of SA as Endsley's (1995a/1995b) three level model. Endsley provides both clear descriptions of the parts of SA and detailed accounts, and interpretations, of measuring each level of SA (Endsley's (1995a/1995b)).

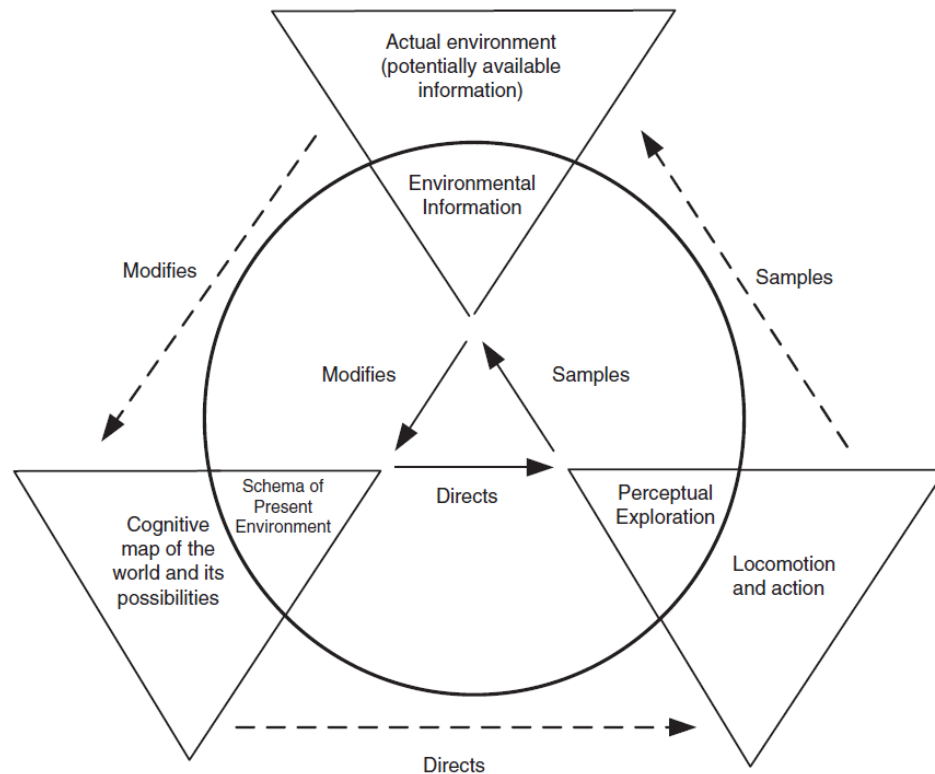


Figure 6. The perceptual cycle model of situation awareness (Smith & Hancock, 1995).

Measuring SA

Though many measurement strategies are offered by Endsley (1995b), most are either subjective and rely on operators' recall. Examples include the Situation Awareness Global Assessment Technique (SAGAT) and the Situation Awareness Rating Technique (SART) (Durso & Sethumadhavan, 2008). In this study, SA was measured using performance scores as an

indirect measure of SA. A limitation to the consideration of SA as an internal cognitive process is the limited ability to measure an abstract concept.

Though Endsley (1995b) reports that certain subjective measurements strongly correlate with performance, Andre and colleagues (1991) consider SA as an ambiguous construct. Andre and colleagues (1991) promoted using performance scores to assess SA. The use of performance based measures is also supported by Endsley (1995b), though she cautions about their interpretation. Specifically, Endsley highlights the importance of considering the particular level of SA where errors occur during the interpretation of a performance based SA measure. This was especially pertinent to this study. Though Endsley's SA model is appropriate as a framework to support the advantages of hybrid control, the benefits observed are likely limited to SA Levels 1 and 2. Also, the interpretation of performance-based measures for SA may suffer from errors of diagnosticity (e.g., the performance score may be measuring only one level of SA, or measuring one level may influence the validity of the others). However, as suggested by Salmon and colleagues (2006), using performance measures to assess SA represents a more naturalistic, non-intrusive measurement method that utilizes real-world tasks. Ultimately, though performance measures provide a global measure of SA, they are still more objective than a questionnaire (Endsley, (1995b).

Given the nature of the visual search task in this study operators with good SA will likely identify more targets than operators with poorer SA. Additionally the decision to use a performance measure to assess SA in this study was justified because of the method's non-intrusiveness and the facilitation of the physiological measures, EEG, being recorded.

Purpose

The purpose of this research was to investigate the use of eye-tracking technology as a control method for the tele-operation of an unmanned ground vehicle during a visual search task. It is important to determine whether tele-operators perform more effectively using a natural interface than a conventional interface that is mediated by a physical controller. Because of this there were three conditions in this study that were defined, administered, and monitored: manual control, hybrid control, and hands-free control. This study evaluated not only performance scores, but cognitive effects (e.g., changes in workload and situation awareness) that may, or may not, occur as a result of using a natural interface.

Previous research examining eye-tracking technology as an independent variable has included examining eye-tracking as a tool to execute a specific function (e.g., a speller, Fitt's test, task switching). However there seems to be a gap in the literature where eye-tracking is used as a continuous motor control method, such as camera panning or driving, as used in this study.

CHAPTER 3

HYPOTHESES

H¹: There will be a significant difference in perceived mental workload among the three experimental conditions, as reflected by the TLX subscale. More specifically, it is predicted that the hybrid (combination of manual tracking and eye tracking) control method will result in significantly lower perceived cognitive workload than the other two conditions.

Previous research comparing the use of eye-tracking technology against conventional manual control methods has reported lower levels of perceived cognitive workload by their participants (Dünser et al., 2015; Smith et al., 2015). These findings of reduced perceived workload are expected by using eye-tracking technology to manage the allocation of attentional resources and to reducing task demand imposed upon the operator (Oviatt, 2006).

H²: There will be a significant difference in EEG theta band averages across the three control conditions. More specifically, average EEG theta band energy readings in the hybrid condition will be significantly lower than similar readings for the other eye tracking and manual control conditions.

Theta wave activity has been consistently reported to increase as task difficulty and mental workload increase (Antoneko et al., 2010; Aricò et al., 2015; Gevins & Smith, 2003). Researchers have also reported that using eye-tracking as an input method has reduced perceived mental workload (Dünser et al., 2015; Smith et al., 2015). In the current study the reported positive relationship between theta wave activity and self-reported mental workload is expected.

H³: There will be a significant difference in EEG alpha band among the three control conditions. Specifically, it is predicted that the EEG alpha band average in the hybrid condition will be significantly higher than the alpha band average for the other two conditions.

Previous research has reported an increase in alpha wave activity as mental workload decreases (Brookings, 1996). Research has suggested that utilizing a system that is user-centered, rather than technology driven would result in a reduction in the use of attention resources (Oviatt, 2006). Such a reduction in workload should be observed by examining the EEG data (Antoneko et al., 2010; Gevins & Smith, 2003).

H⁴: Participants will identify more targets in the hybrid control condition than the other two conditions. Previous researchers have examined the use, or design, of automation and reported the potential benefits of reducing an operator's workload and increasing their SA with the common goal of increasing task performance (Endsley, 1995a; Parasuraman et al., 2000; Oviatt, 2006).

H⁵: There will be a positive correlation between perceived cognitive workload scores, reported by the TLX, and average theta wave activity.

In previous studies by Aricò et al. (2015) and Brookings et al. (1996) TLX and EEG workload measures detected similar changes in perceived workload and task difficulty. This relationship is expected to be present in the proposed study, where the rank order of the perceived cognitive workload, measured by the TLX is expected to be mirrored by the average EEG theta wave activity (Gevins & Smith, 2006).

CHAPTER 4

METHOD

Design

This study utilized a one-way, within-subjects design. The independent variable, unmanned vehicle control method, was manipulated across three conditions:

- 1) Manual. This control method required participants to utilize two joysticks concurrently: one for vehicle directional control and velocity and one to control the vertical and horizontal angle movement of the camera.
- 2) Hybrid. This control method was similar to manual except for the camera control. For camera control eye tracking was used.
- 3) Hands-Free. This control method required participants to use eye tracking for both tasks: vehicular movement and camera movement.

The order in which participants experienced each control method was counterbalanced to prevent any possible carryover effects. The decision to counterbalance, or use a crossover design, was to both control for any main effect of order and to increase the internal validity of any findings (Maxwell & Delaney, 2004). The tasks in this experiment required participants to navigate through a simulated environment and detect targets using each of the control methods during the three testing sessions. The manipulation of control method as a within-subjects factor was chosen to control for individual differences among participants, thus reducing error and increasing statistical power (Maxwell & Delaney, 2004).

To effectively evaluate the effects of using each control method during tele-operation the dependent measures in this study consisted of: 1) A subjective mental workload measure, the NASA-Task Load Index (Hart & Staveland, 1988), 2) an objective measure of mental workload,

the averages of both alpha and theta power bands during tele-teleoperation within each experimental session (Antonenko et al., 2010), and 3) an indirect performance measure of global situation awareness dependent upon the total number of targets identified by the operator during each experimental session (Endsley, 1995b).

Apparatus/Materials

Simulator Setup. Using a driving simulator, participants viewed a virtual environment on a high-resolution (1280X1024) computer monitor. The simulator included two joysticks and three eye-tracking cameras, one mounted on the top of the monitor and two at the bottom. Each camera was calibrated using Smart-eye's calibration program, accuracy reported by Smart-eye as: Rotation .5 degrees, translation < 1 mm, and a gaze vector of .5 degrees, which calculated the variances between the three cameras to increase the accuracy of the eye-trackers. A visual descriptive and detailed account of the simulator's physical properties can be found in Appendix A.

EEG Extraction Technique

The data extraction technique was a replication of the method used by Barry and colleagues (2007). A 16-channel EEG with an adjustable full cap, wet electrodes, and the 10-20 international electrode placement was utilized to collect EEG data in this study. Barry and colleagues (2007) collected data from 19 sites (Fp1, Fp2, F7, F3, Fz, F4, F8, T3, C3, Cz, C4, T4, T5, P3, Pz, P4, T6, O1, O2). For the current study, the experimenter worked with Old Dominion Universities' Biomedical department to condense the site locations to 16 sites (FPz, F7, F3, Fz, F4, F8, T7, C3, Cz, C4, T8, P3, Pz, P4, O1, O2) to maintain the reliability achieved by Barry et al. (2007). The resulting system collects more reliable data than low-cost EEG headsets (Duvinae et al., 2013). The EEG data were time-synced within each experimental session. The

signals were amplified (EEG X 20,000, EOG X 5000) with a bandpass of 0-30 Hz and sampled by a 16 bit A/D converter at a rate of 512 samples collected per second. The data window for continuous collection consisted of 2-second epochs and had power bands of each wave of interest averaged across each epoch to obtain the average load for each condition (Antonenko et al., 2010; Barry et al. 2007). To execute bandwidth filtering a Butterworth filter was utilized to modify the frequencies of interest for latter artifact removal. Data artifact removal was controlled by reviewing the recorded experimental sessions and identifying actions that would most likely cause an artifact (e.g, selection methods of nodding the head and trigger pulls). Once an action caused artifact was identified the data occurring more than 1 second prior to and after the artifact was removed. All epochs containing artifacts (e.g., eye-blinks, head and arm movements) were removed prior to analysis. The power bands to be monitored during data collection were both theta (4-7 Hz.) and alpha (8-13Hz.) (Antonenko et al., 2010; Barry et al. 2007). The data collected were averaged across each experimental session to evaluate the impact of the control methods.

NASA-Task Load Index

The TLX measures the workload of a task across six dimensions: mental demand, physical demand, temporal demand, performance, effort, and frustration (Hart & Staveland, 1988). The mental demand subscale was the primary subjective measure of interest in the current study. In a comparison study the TLX was reported as having high convergent validity with a Pearson correlation coefficient of $r = .9817$ with the SWAT, and a $r = .9863$ with the Workload Profile (Rubio et al., 2004). Rubio and colleagues (2004) also reported the TLX as having higher concurrent validity with a correlation of $r = .751$ with the performance measures used than the other workload measures used. Moreover the TLX was found to have high sensitivity, being able

to discriminate between single and dual tasks. Matthews and colleagues (2015) investigated the psychometric properties of the TLX and physiological measures using a sample size of 150 participants. They reported that the TLX had high sensitivity, diagnosticity, and internal consistency (Cronbach's Alpha of $r=.825$). In the current study a computer was used to administer the TLX. Hart and Staveland (1988) reported that the results of computer administration are sufficiently related to those from paper and pencil administration ($r=.94$) (See Appendix B).

Performance Measures

In an effort to measure the global SA of each operator during tele-operation a performance score was recorded. The performance score consisted of the total number of targets identified which using each control method (See Figure 7). The total number of targets in each session was 14, and the total number of non-targets in each scenario was about 100 (See Figures 7 & 8). In each experimental session there were designated locations for each targets and non-targets, so all participants were tested on the same scenarios for each of the three control methods. However, each control method's scenario was different with regard to target/non-target placement and navigation path (See Figures 9 & 10).

In addition to the total number of targets identified, the total time spent to complete each experimental session was recorded. Hicks and colleagues (2015) reported that the average completion time for this specific simulation was about 15 minutes per scenario. Each recorded time series began when the operator demonstrated interaction with the interface (e.g., searching the simulated environment or navigating the UGV).



Figure 7. Picture of a non-target in the simulated environment (Hicks et al., 2015).



Figure 8. Picture of a target in the simulated environment (Hicks et al., 2015).



Figure 9. Picture of required navigation path in simulated environment (Hicks et al., 2015).

Simulated Environment and Tasks

The setting for the simulated environment was an industrial area (See Figures 9 & 10). This environmental setting was chosen to present the participant with a non-hostile environment. The simulated environment allowed for the participant to interpret a believable real-world environment and to understand his or her role as a tele-operator.



Figure 10. Picture of simulated environment (Hicks et al., 2015).

There were two tasks to be performed throughout each testing session. Participants were to tele-operate the simulated UGV through each scenario using the given navigation path, a simulated oil pattern on the ground (See Figure 8). Operators were required to actively search the simulated environment, identifying and labeling each target (See Figure 7).

Procedure

Upon arrival at the testing location, participants were asked to complete the Informed Consent Form (Appendix C) and the Demographics Form (Appendix D). Participants then received experimental instructions, which were also read aloud by the researcher (Appendix E). To prevent operators from committing the Midas Touch during target selection a two-second fixation period was used, where the progression circle selection began after the fixation period had elapsed.

Following the task instructions, participants were fitted for an EEG cap. Once the researcher confirmed the participant was adequately connected to the EEG system the first

method of control was identified and the participant's practice session began. Each participant completed three brief practice sessions to learn each control method and the features in the simulated environment. During the practice sessions operators not only became familiar with the different control selection methods but also saw the simulated non-damaged industrial barrels (non-targets) and the damaged industrial barrels (targets). They were also exposed to the simulated navigation path. The order of practice sessions and test sessions continued in the same manner for all three control methods. For example, if the intended control method was fully manual then the operator practiced using the fully manual control method. After the participant verbally reported to the experimenter that he or she was comfortable with the control method the experimental session began.

Once the experimental session was completed the participant was asked to complete a computer-based version of the NASA-TLX (Appendix B). The participants were then asked to relax and stretch for five minutes. Following this short break the experimenter identified the next control method. A second practice session began, followed by the second experimental session. This process was continued until each participant completed an experimental session using each control method. During all practice sessions the simulated environment was identical (e.g., navigation pattern and target location). The only thing different during the practice sessions was the method control for tele-operation. However, each of the three experimental sessions were different in terms of method of control for tele-operation, location of non-targets and targets, and designated navigation path. For each control method there was a specific simulated environment to ensure that all participants were tested with the same control methods and in the same test environment. Upon completion of all three experimental sessions the participants were thanked,

debriefed and awarded two credits for their participation. Each session lasted approximately 2 hours.

Participants

Twenty participants were initially recruited for this experiment through Old Dominion University's SONA system. The SONA system allowed students who are enrolled in a psychology course to participate in campus experiments in exchange for course credit (see Appendix F). Data from two of the twenty participants could not be utilized due to data collection errors. The first error was a result of the reference electrode not being properly placed, which resulted in unreliable data to be collected. The second error was an equipment malfunction where data was not collected by the EEG system. Because of this only 18 participants' data ($N = 18$, age $M=24.33$) were analyzed: male ($n = 7$, age $M= 25.71$) and female ($n = 11$, age $M= 23.45$).

The participants for this study were expected to represent an equal number of male and female students between the ages of 18 and 30. The only criterion for students to participate in this study was that the student must have had normal or corrected-to-normal vision (contact lenses only because of technical limitations of the eye tracker). Students who met these requirements were eligible to participate in this study. Written informed consent was obtained from all participants prior to their participation (Appendix A). Data collection began after approval from ODU's Institutional Review Board.

CHAPTER 5

RESULTS

Prior to any statistical analyses the data were inspected to ensure that the three assumptions of ANOVA were met: independence, normality, and homogeneity. Any data found to exceed a z -score of 1.645 SD from the mean were classified as extreme values, or outliers, and were Winsorized and analyzed to define their influence (Ghosh & Vogt, 2012). To Winsorize extreme values the smallest and largest data points were replaced with the nearest data point towards the mean in an effort to meet the assumption of normality and test the intended population (Ghosh & Vogt, 2012).

Upon inspection of the data the following measures needed to be Winsorized:

- Two data points from the manual control condition, where theta-wave activity was measured.
- Two data points from the manual control condition, where alpha-wave activity was measured.
- One data point from the hybrid control condition, where alpha-wave activity was measured.
- One data point from the hybrid control condition, where theta-wave activity was measured.
- One data point from the eye-only control condition, where alpha-wave activity was measured.

During inspection of the data, one participant was found to have missing data, and one additional participant's data was determined to be unreliable due to an error made in procedures of EEG setup. Therefore, subsequent data analysis was completed by replacing the two cases in

question with the group mean of interest. It was found that the inclusion of the two cases did not influence the statistical findings and conclusion of this experiment.

Prior to analysis the data were inspected to ensure all statistical assumptions of ANOVA were met (e.g., normality, independence, and homogeneity). For this study critical alpha was set at $p < .05$ based on the an acceptable probability of committing Type I and Type II errors; which is that there will be a 95% chance that the results obtained are replicable, and a 5% chance that the results are not replicable. Descriptive statistics were calculated for the dependent measures (see Table 1).

Table 1.
Descriptive Statistics of Dependent Variables.

Source Condition	Mean (SE)	N
Target Detection Accuracy Score		
Manual	10.28 (.51)	18
Hybrid	11.06 (.392)	18
Eyes-only	9.78 (.527)	18
Avg. Alpha Wave Activity		
Manual	14.40 (1.45)	18
Hybrid	13.46 (1.05)	18
Eyes-only	13.12 (.96)	18
Avg. Theta Wave Activity		
Manual	18.15 (.99)	18
Hybrid	16.33 (.85)	18

Table 1 Continued

Eyes-only	15.95 (.93)	18
Mental Workload (TLX)		
Manual	46.83 (5.43)	18
Hybrid	64.28 (5.26)	18
Eyes-only	60.56 (5.70)	18
Effort (TLX)		
Manual	58.56 (6.40)	18
Hybrid	63.11 (4.56)	18
Eyes-only	53.78 (5.62)	18
Frustration (TLX)		
Manual	22.67 (5.13)	18
Hybrid	42.33 (7.78)	18
Eyes-Only	42.56 (6.78)	18

TLX Mental Workload subscale

To test the first hypothesis, that there would be a significant difference in TLX Mental Demand workload subscale score between the 3 control conditions, a one-way within-subjects ANOVA was conducted. The analysis did support the hypothesis as a significant difference was found $F(2,34) = 8.66, p = .001$, partial $\eta^2 = .337$. However the *post hoc* analysis revealed that the data did not support the direction of the hypothesis. A Bonferroni *post hoc* test was used for a pair-wise comparison to further investigate the differences in Mental Demand scores. As suggested by Maxwell and Delaney (2004) the Bonferroni pair-wise comparison is a statistical analysis that allows up to three pair-wise comparisons without having to use an alpha correction,

(.05/ c), without violating a family-wise alpha of .05 (Maxwell & Delaney, 2004). That analysis revealed that the Mental Demand scores for the manual control condition ($M = 43.83$, $SD = 23.06$) were significantly lower than mental workload subscale scores in the hybrid condition ($M = 64.28$, $SD = 22.30$) $p = .003$, $SE = 4.46$ with an alpha level set at .025 (see Figure 11).

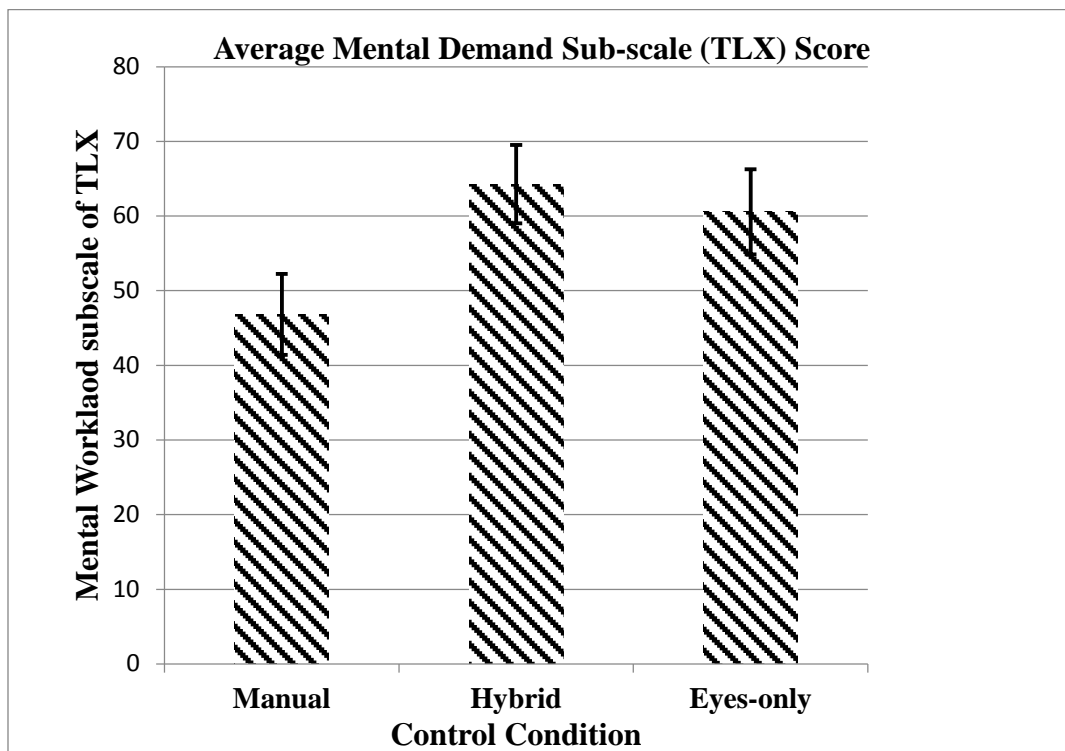


Figure 11 Reported Mental Workload Scores sub-scale of NASA-TLX

EEG Theta-Wave Activity

To test the second hypothesis, that there would be a significant difference in EEG theta-wave measures among the 3 control conditions, a one-way within-subjects ANOVA was conducted. As previously mentioned the data points collected and used in this analysis were collected at a sampling rate of 512 per second; and a Butterworth filter was used for artifact

filtering for 2 second epochs. The analysis did confirm the hypothesis as a significant difference was found $F(2,34) = 8.48, p = .001, \text{partial } \eta^2 = .333$.

A Bonferroni *post hoc* test was used for a pair-wise comparison to further investigate the differences in the average theta-wave activity. The contrast revealed that the average theta-wave activity for the hybrid control condition ($M = 16.32, SD = 3.62$) was significantly lower than that in the manual control condition ($M = 18.15, SD = 4.21$) $p = .01, SE = .512$. Also, the average theta-wave activity in the eyes-only control condition ($M = 15.95, SD = 3.95$) was significantly lower than the manual control condition, $p = .01, SE = .658$. These findings would suggest that both the hybrid and eyes-only control conditions require significantly less cognitive resources than the manual control condition (see Figure 12).

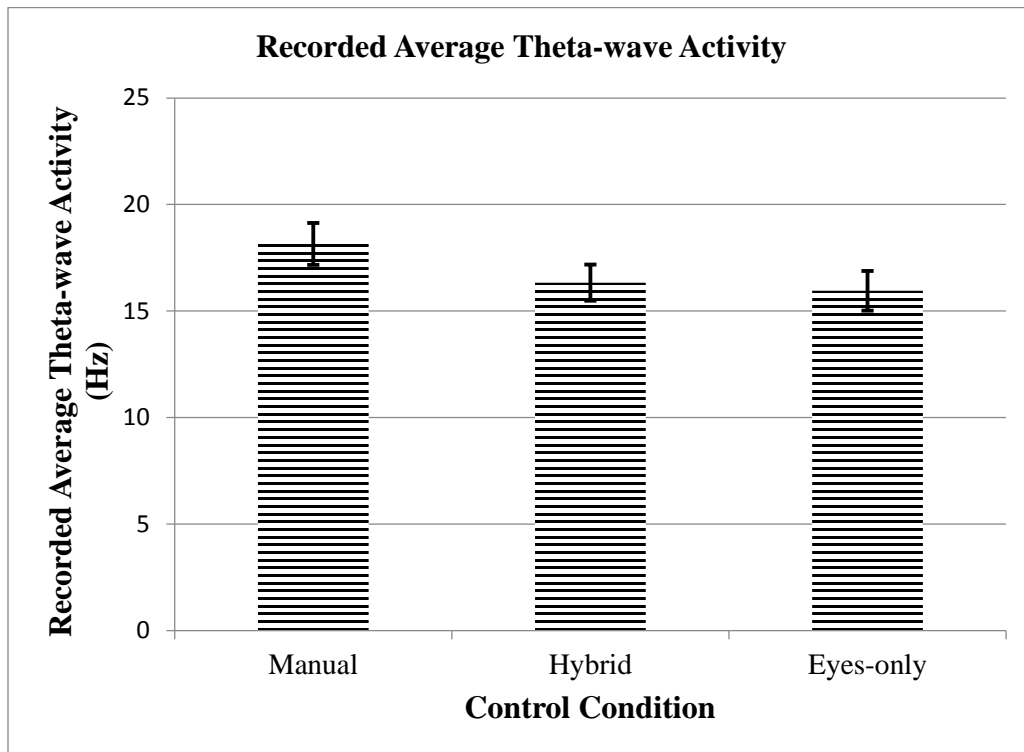


Figure 12 Recorded Average Theta-wave Activity

EEG Alpha-Wave Activity

To test the third hypothesis, that there would be a significant difference in EEG alpha-wave measures among the 3 control conditions, a one-way within-subjects ANOVA was conducted. The analysis did not support the hypothesis as no significant differences in average alpha-wave activity were found $F(2,34) = 2.27, p = .12, \text{partial } \eta^2 = .118$.

Performance Score, SA Measure

To test the fourth hypothesis, that there would be a significant difference in SA, as reflected by performance score measures, among the 3 control conditions a one-way within-subjects ANOVA was conducted. Although the analysis did not support the hypothesis, a significant difference in performance scores was found $F(2,34) = 3.94, p = .03, \text{partial } \eta^2 = .188$.

The Bonferroni *post hoc* test revealed that performance scores, number of targets identified, for the hybrid control condition ($M = 11.06, SD = 1.66$) were significantly higher than the performance scores of the eyes-only ($M = 9.78, SD = 2.24$) $p = .05, SE = .477$. However contrary to prediction the contrast also revealed that the performance scores in the hybrid control condition were not significantly different than the performance scores in the manual control condition ($M = 10.28, SD = 2.16$) $p = .33, SE = .461$.

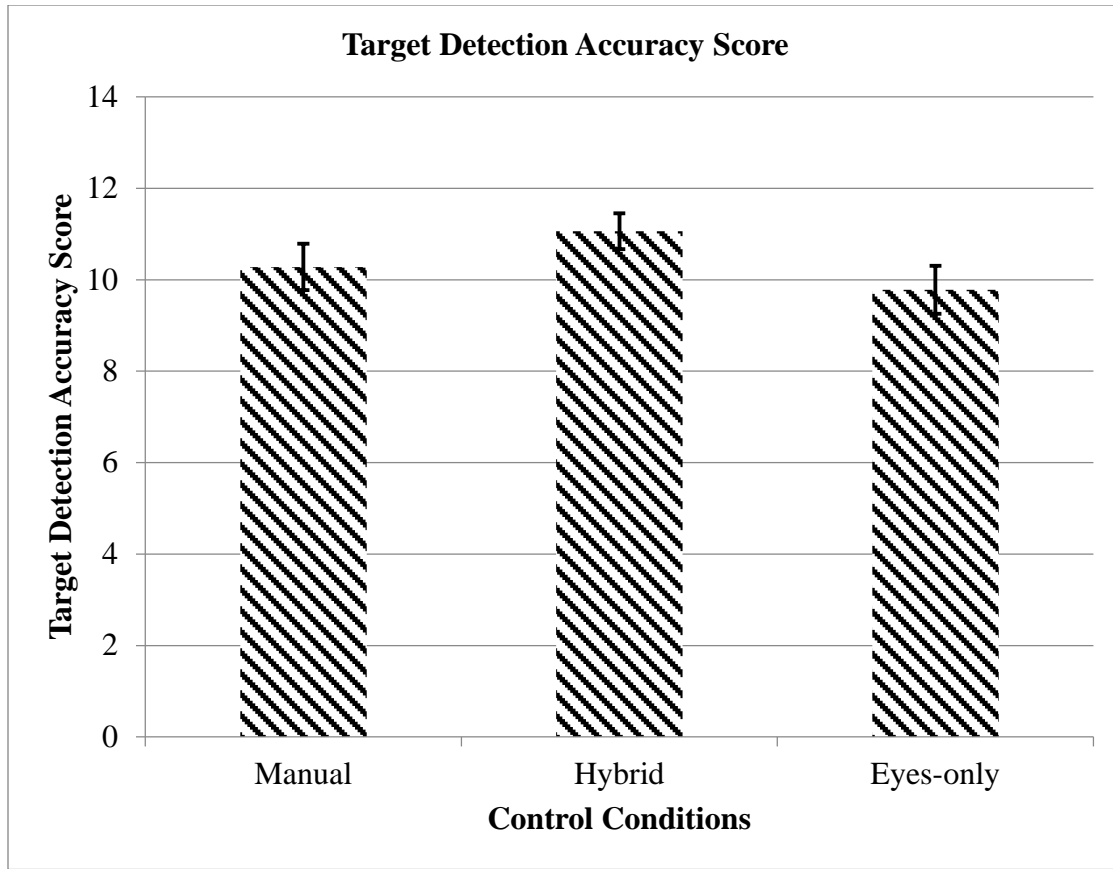


Figure 13 Target Detection Accuracy Score out of 14 targets

Correlates

To test the fifth hypothesis multiple one-tailed Pearson's r tests were conducted to analyze the relationship between reported mental workload, TLX, scores and average theta wave activity. However, the correlations did not reveal any significant relationships among variables across the three control conditions: (mental workload and average theta wave activity in manual control condition) $r = .17$, (mental workload and avg. theta wave activity in hybrid control condition) $r = -.07$, and (mental workload and avg. theta wave activity in eyes-only control condition) $r = .06$.

Additional correlational analyses were conducted to evaluate any possible relationships between the following variables: age, sex, video game experience, computer experience, and performance measures, no significant correlations were found.

Post hoc Analysis

To further interpret the collected data two additional *post hoc* analyses were conducted. A one-way within-subjects ANOVA was conducted to evaluate the scores on the Effort subscale of the TLX, among the three control method conditions. The analysis did not reveal any significant differences between Effort scores $F(2,34) = 1.17$, partial $\eta^2 = .064$.

An additional one-way, within-subjects ANOVA was conducted to evaluate the reported NASA-TLX Frustration scores among the three control conditions. The analysis revealed a significant difference in reported Frustration scores $F(2,34) = 4.51$, $p = .02$, partial $\eta^2 = .21$. A *post hoc* pair-wise comparison was conducted to further examine the one-way within-subjects ANOVA. The contrast revealed that Frustration scores were significantly lower in the manual control condition ($M = 22.67$, $SD = 21.80$) than the hybrid condition ($M = 42.33$, $SD = 33.01$) $p = .04$, $SE = 7.15$. However the pair-wise comparison did not find a significant difference between the frustration scores from the manual control condition and the eyes-only condition ($M = 42.56$, $SD = 28.79$) $p = .08$. See Figure 13.

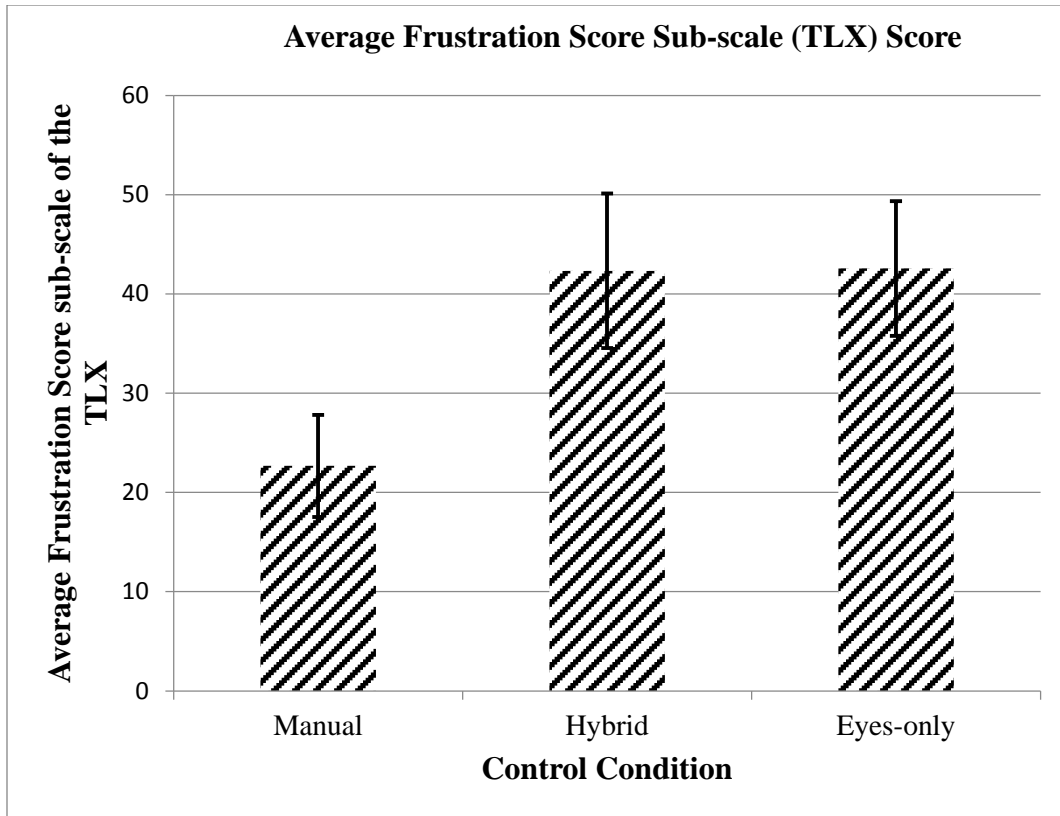


Figure 14 Reported Frustration Scores subscale of NASA-TLX

CHAPTER 6

DISCUSSION

The findings of this research highlight the need for system designers to use an appropriate cognitive model when considering interface design, control methods, and possible effects of system design. The aim of this work was to reduce the amount of Extraneous Cognitive Load (ECL) imposed upon an operator with the intent that the mental resources would be allocated towards other tasks (e.g., visual search task and navigation tasks) (Brünken et al., 2003; Endsely, 1995a). The results from this study provide evidence that the manipulation in control method did support a significant reduction in mental workload as measured by EEG measures. However, the results do not provide evidence that the residual mental resources were reallocated towards the visual search task or the navigation task. The results provide evidence that the use of eye-tracking as a control method significantly increases the perceived mental workload of the operators. This significant increase is reflected by the reported TLX mental workload sub-scale scores, where the manual control condition was reported to require significantly less mental workload than either the hybrid or eyes-only control conditions.

This study provides an example of why researchers should, when possible, consider using multiple methods to measure mental workload. This study revealed conflicting results between the two workload measures, TLX and EEG, which may not have been found without using different measurement techniques for mental workload. If the two measurement techniques were not used then there would be a significant change in interpretation of the findings from this study.

The significant reduction in mental workload, as measured by EEG, was predicted by Endsley's (1988a) Mechanisms of Situation Awareness model and Oviatt's (2006). Oviatt (2006)

suggests the use of user-centered designs to reduce ECL and Endsley (1988a) emphasizes the importance of mental models and the costs of an operator having an incomplete mental model.

In the current study operators' mental models of motor movements and scripts were likely incomplete because of the novel nature of the hybrid control interface. A reduction in motor movements offered by the hybrid control condition resulted from the use of eye-tracking technology, which was reflected by the EEG. There was also a reduction in conventional (e.g., proprioceptive, kinesthetic, tactile, and force) feedback given to the operator through motor movements. In contrast, during the manual control conditions the operator received conventional motor and sensory feedback. During the hybrid control condition most of the conventional feedback was lacking. Therefore, compared to the hybrid control condition the feedback operators received in the manual control condition more closely resembled pre-existing models already held in their Long Term Memory (LTM) that could be facilitated by an increase in activation information retrieval.

The benefit for system designers to rely on an appropriate cognitive model to predict, or consider, possible effects of design is evident from the perceived mental workload scores. Endsley (1995a) does emphasize the importance of operators developing the correct mental model through learned scripts. Endsley describes that such mental models and schemas are developed over time, with training, and repeated exposure to situations. She suggests that as operators create mental models a bias occurs, which during task execution facilitates early schema, or model, recognition (Endsley, 1995a). Interestingly Endsley (1995a) even cautions about the potential negative influence of perceived system complexity and how the extent of the operator's knowledge about the system (e.g., how the system inputs and outputs are designed) may influence their mental workload and situation awareness. Wickens (1984) supports

Endsley's claim regarding the importance of operators having the correct mental model for a given situation, or task. He describes that if an operator does not have a mental model for the given situation then one must be generated, which would pose a heavy load on the operator's working memory (Wickens, 1984). The generated heavy load would consist of the operator having to consistently maintain and modify a model regarding: the factors involved, rules for change, effects for actions, and differences between previous and current (Wickens, 1984).

The importance of using, and designing, a system that would lessen the load of an operator's working memory and supports the use, or creation, of a mental model is central to human factors, and it is believed that this is the cause of the significantly higher perceived mental workload scores between the manual control condition and the hybrid control condition in this study (Endsley, 1995a; Parasurman et. al., 2000; Still, 2009; Wickens, 1984).

It is likely that mental workload scores were higher in the hybrid and eye-only control conditions because participants held incomplete mental models (Endsley, 1995a; Still, 2009). In particular, few participants had ever experienced eye-tracking control technology. Though such control may have reduced mental workload, as reflected by EEG measures, it did not feature the multimodal feedback that most humans have come to expect from interactions with their environment (Keele, 1968). Humans constantly interact with their environment, creating, modifying, and strengthening mental models of situations and motor movements (Adams, 1987).

Ultimately, incomplete mental models of motor movements could have significantly influenced the perception of system complexity, as described by Endsley (1995a), and created an increase in cognitive workload, as supported by Endsley (1995a) and Wickens (1984). Thus this deviation of the hybrid interface from the norm of motor movement feedback clearly explains the

significant differences in perceived mental workload and the perceived frustration between the manual control condition and the hybrid control condition.

An additional explanation of the differences in perceived mental workload concerns the design of the simulator and the affordances available within the different control conditions. Gibson (1979) initially described affordances as emergent potential interactions between actors and physical object artifacts (Still & Dark, 2013). Later this description was expanded to include mental and environmental influences such as culture, logic, and semantics (Norman, 1988; Still & Dark, 2013). One clear reason for an interface designer to consider perceived affordances is to help operators recognize potentially available interactions with a system using minimal cognitive resources (Still & Dark, 2013). Still (2009) suggested that correctly implemented perceptual affordances will create activation in LTM and require less cognitive processing than a culturally learned interaction. Still (2009) proposed a decision tree, provided below as Figure 14, that designers may utilize to determine the effects of pre-existing affordances and newly created affordances. In Figure 14 two modules in the flowchart are circled with a dashed line. It is during these two modules that the focus of availability and effects of affordances provided by the different designs in control conditions are discussed.

Still (2009) explains that the “consistent design” module is vital if a designer’s goal is to exploit a perceptual affordance. He explains that not only should both the locations and interactions of affordances be continuous, but the user must recognize the consistency of design, interactions, and constraints. If the user is unable to interpret, or retain, the consistency of a system after interacting with it repeatedly, then the design should be reconsidered (Still, 2009). In the current study, the affordances available in the manual control condition (e.g., dual joysticks for navigation and search) were more naturally available than those in the hybrid

control condition. Also, if the users have had little, or no, experience with eye-tracking technology then it would be inaccurate to assume that the users would consider eye-tracking technology as a perceived affordance. Therefore, Still would support the claim that the manual control condition did have more perceptual affordances, perceivable interactions, than either the hybrid or eyes-only conditions. Therefore, users' perceived mental workload should have been lower in the manual control condition than in the other conditions Still's suggestion is strongly supported by the findings of this study. The manual control condition was found to require significantly less perceived mental workload than the other two novel control conditions.

The "effortless" component of the model in Figure 11 is in reference to the inquiry of asking if enough practice sessions have been completed for an interaction to become a perceptual affordance (e.g., an interpretable interaction that is identified through direct perception) (Still, 2009). Still suggests that, depending on the stimuli, if a sufficient amount of practice sessions have occurred and the user is not effortlessly interacting with the intended perceptual affordance then the practice sessions should cease and the design should be reconsidered (Still, 2009). With the suggestions of Still (2009) in mind, perhaps users' perceived less mental workload in the manual control condition because the manual control condition required significantly fewer practice sessions for the perceptual affordance to become effortless. This would also make sense and explain the difference in results of the perceived mental workload across the three conditions as reflected both sub-scales of the TLX perceived mental workload and frustration.

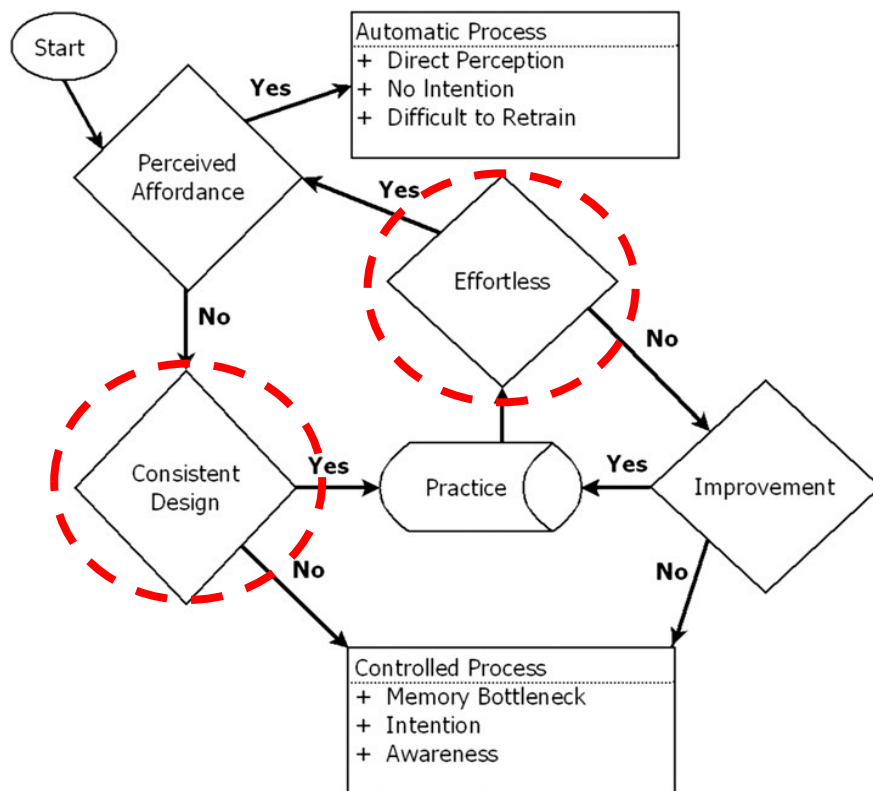


Figure 15. Evaluation of user and design interactions within the context of automatic and controlled processing (Still & Dark, 2013).

Conclusion

This study explored the use of using eye-tracking technology within two compared control methods during a visual search task. This study also provided implications about how the use of natural interfaces may not be as predictable as demonstrated in this study. This study gives designers a suggestion when considering system designs. That is unless the operators of a system are perceptually receptive towards the design they will may not interpret, or perceive, specific design features as an advantage or as requiring less mental workload. Moreover this study provided a great example of why it is imperative that, when possible, the correct dependent measures are used in an effort to explain both results and functional control. The results of this

study revealed that although the use of eye-tracking technology as a control method did significantly reduce operators' mental workload, as implicated by the EEG theta-wave data, however it did not reduce the operator's perceived mental workload, as implicated by the Mental Demand sub-scale of the NASA-TLX. Additionally, the use of a performance measure as a measure of global SA did seem to have some interpretability, but was most likely underpowered in this study.

Future studies analyzing the use of eye-tracking technology during tele-operation should investigate both the effects of using novel technologies and the time requirement needed for an operator to be able to take advantage of residual resources that may be available as a result of a change in system design (Endsley, 1995b). Moreover there should be some research to expand upon Hicks and colleagues (2015), and this study, to investigate how novel technology (e.g. eye-tracking) effects behavioral changes (e.g., time to visually scan, number of stops to scan/search for targets) and may influence mental resources (e.g. fatigue, attention, sustained attention) over time. An appropriate follow-up to this study would be an extension of the simulated environment to evaluate sustained attention, and perhaps an additional task to measure any residual resources that may be available while completing the visual search task.

An additional direction for future research should be to investigate the resilience of an intended operator who may be using a novel technology; and how that operator may be affected if they required to revert to a conventional technology. Resilience being defined by Woods (2006) as *“how well can a system handle disruptions and variations that fall outside of the base mechanisms/model for being adaptive as defined in that system.”* It is imperative that even though a system designer may have strong evidence to support the use of a novel technology, that the researchers explore and attempt to understand how the operators will respond if that

novel technology is not readily available to them, or how the novel technology may assist the operator when interacting with a permutation that is not within $\pm 1 SD$ of the mean in a normal distribution. As new technology emerges and novel methods are introduced to different operational environments it will be vital to any mission or task, to investigate: how novel technology can be used, why should novel technology should be used, and most importantly should this novel technology be used. As research communities investigate these topics, changes in equipment, systems, and procedures will be strongly supported that should benefit both the operator's well-being, and mission/task objectives.

Limitations

This experiment did incorporate some limitations regarding interpretability and validity. The general interpretation of the results is dependent upon the variables of interest and the metrics chosen. For example, the most popular subjective measure of workload has been the NASA-TLX. However, researchers have at times questioned the validity of that measure. Realizing this, other measures of workload were also employed; however, readers should consider the NASA-TLX findings with caution (De Winter, 2014). Moreover, this study only used one objective measure of workload: EEG power-bands. Though there is a history of the theta-wave energy fluctuations being related to the consumption of attentional resources (e.g., Antonenko et al, 2010; Brookings et al., 1996) those fluctuations were not found to be significantly related to the subjective measure used in this study.

In terms of validity the intent of this study was to evaluate the differences in using a novel technology compared to a conventional technology. However given that the population tested was college students who had little, or no, experience in teleoperation control, it could be argued that this study was studying early stages of learning for both control methods. Future

researchers are encouraged to conduct experiments to further investigate objective teleoperation data or to employ subjective measures administered at pre-determined intervals.

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APPENDIX A

PHYSICAL DESCRIPTION OF SIMULATOR



(Papelis, Yiannis E., Watson, Ginger S., & Hicks, Kathryn. (2015, March 31-April 2). MODSIM World 2015. Analyzing Eye-Tracking Effectiveness With and Without Cursor Feedback During On-Screen Button Presses. *Proceedings of the MODSIM World 2015 Conference*. Virginia Beach, VA.)

A picture of the driving simulator on a high-resolution (1280X1024) computer monitor. The simulator included two joysticks and three Smart-eye eye-tracking cameras, one mounted on the top of the monitor and two at the bottom. Each camera was calibrated using Smart-eye's calibration program, which calculated the variances between the three cameras to increase the accuracy of the eye-trackers.

APPENDIX B

SUBJECTIVE WORKLOAD MEASUREMENT METHOD

*This is a pen/pencil version of the NASA-TLX that will be used. In the experiment an electronic version will be used (Sharek, D. (2009). **NASA-TLX Online Tool (Version 0.06) [Internet Application]. Research Triangle, NC.**) *This Scale will be administered after each experimental session.

Rating Scale Definitions

Title	Descriptions
MENTAL DEMAND	How much mental and perceptual activity was required (e.g., thinking, deciding, calculating, remembering, looking, searching, etc.)? Was the task easy or demanding, simple or complex, exacting or forgiving?
PHYSICAL DEMAND	How much physical activity was required (e.g., pushing, pulling, turning, controlling, activating, etc.)? Was the task easy or demanding, slow or brisk, slack or strenuous, restful or laborious?
TEMPORAL DEMAND	How much time pressure did you feel due to the rate or pace at which the tasks or task elements occurred? Was the pace slow and leisurely or rapid and frantic?
PERFORMANCE	How successful do you think you were in accomplishing the goals of the task set by the experimenter (or yourself)? How satisfied were you with your performance in accomplishing these goals?
EFFORT	How hard did you have to work (mentally and physically) to accomplish your level of performance?
FRUSTRATION LEVEL	How insecure, discouraged, irritated, stressed and annoyed versus secure, gratified, content, relaxed and complacent did you feel during the task?

Place a mark at the desired point on each scale:

MENTAL DEMAND



Low

High

PHYSICAL DEMAND



Low

High

TEMPORAL DEMAND



Low

High

PERFORMANCE



Good

Poor

EFFORT



Low

High

FRUSTRATION



Low

High

APPENDIX C

INFORMED CONSENT FORM

INFORMED CONSENT DOCUMENT

The purposes of this form are to give you information that may affect your decision whether to say YES or NO to participation in this research, and to record the consent of those who say YES.

TITLE OF RESEARCH: Eye-Tracking as a Control Interface for Tele-operation During a Visual Search Task

RESEARCHERS:

James P. Bliss, Ph.D., Professor, Responsible Project Investigator, College of Sciences, Psychology Department

Jeffrey N. Levy, Graduate Student, College of Sciences, Psychology Department

Samantha Jennings, Undergraduate Student, College of Sciences, Psychology Department

DESCRIPTION OF RESEARCH STUDY:

Throughout the past two decades the use of Unmanned Ariel Vehicles (UAVs) and Unmanned Ground Vehicles (UGVs) has been increasing in an effort to conserve resources and protect valuable personnel. This increase of use in tele-operating robots has been met with research to study how tele-operators are affected by the designs of the systems they are controlling. This study evaluates various system designs in an effort to further understand how tele-operators perform using different systems and what system designs are suggested to be the most appropriate in a visual search task.

Twenty participants will be tested in this experiment. Those who agree to be tested will complete a background information form. Following this, you will be asked to perform several familiarization session with different control methods during a visual search task. After training, you will be asked to perform the tasks in several experimental sessions in a simulated environment, while EEG data is collected. Following each practice session you will be asked to tele-operate a search robot in a simulated industrial environment using three different control methods. The three control methods to be studied in this experiment consist of a fully manual, a hybrid control, and an eyes-only control method. The control method of fully manual consist of two joysticks, one for robot orientation and one for camera control. The hybrid control method consists of one joystick and eye-tracking, the joystick for robot orientation and eye-tracking for camera control. The eyes only control consists of no joysticks and will utilize eye-tracking technology only to operator both robot orientation and camera control. The task for this experiment is a visual search task where the objective is to identify all targets in the simulated environment.

Upon the completion of the experiment you will then be debriefed and dismissed.

The entire experiment should almost 2 hours.

You will receive 2 SONA credits for participating in this study.

EXCLUSIONARY CRITERIA:

To participate, you must be over the age of 18. You must have normal vision or corrected-to-normal vision. You must also have normal or corrected-to-normal hearing. Therefore, if you normally wear eyeglasses, contact lenses or hearing aids you will need to wear them to participate.

RISKS AND BENEFITS:

RISKS: If you decide to participate in this study, then you may face a risk of eyestrain similar to the eyestrain experienced during normal computer usage. The researcher tried to reduce these risks by limiting the experimental participation time to less than two hours. And, as with any research, there is some possibility that you may be subject to risks that have not yet been identified.

BENEFITS: There are no direct benefits for participation in this study. However, you may learn valuable information about how research is conducted.

COSTS AND PAYMENTS:

The researchers want your decision about participating in this study to be absolutely voluntary. The main benefit to you for participating in this study is the extra credit or course credit points that you will earn for your class. Although they are unable to give you payment for participating in this study, if you decide to participate in this study, you will receive 2 Psychology Department research credits, which may be applied to course requirements or extra credit in certain Psychology courses. Equivalent credits may be obtained in other ways. You do not have to participate in this study, or any Psychology Department study, to obtain this credit.

CONFIDENTIALITY:

Your participation is completely confidential. The researcher will remove all identifiers from the information. The results of this study may be used in reports, presentations, and publications; but the researcher will not identify you individually in such publications.

WITHDRAWAL PRIVILEGE:

It is OK for you to say NO. Even if you say YES now, you are free to say NO later, and walk away or withdraw from the study -- at any time. Your decision will neither affect your relationship with Old Dominion University, nor cause a loss of benefits to which you might otherwise be entitled. The researchers reserve the right to withdraw your participation in this study, at any time, if they observe potential problems with your continued participation.

COMPENSATION FOR ILLNESS AND INJURY:

If you agree to participate, then your consent in this document does not waive any of your legal rights. However, in the event of harm, injury, or illness arising from this study, neither Old Dominion University nor the researchers are able to give you any money, insurance coverage, free medical care, or any other compensation for such injury. In the event that you suffer injury as a result of participation in any research project, you may contact Dr. James P. Bliss at 757-683-4051, Dr. George Maihafer (IRB Chair) at 757-683-4520, or the ODU Office of Research, 757-683-3460.

VOLUNTARY CONSENT:

By signing this form, you are saying several things. You are saying that you have read this form or have had it read to you, that you are satisfied that you understand this form, the research study, and its risks and benefits. The researchers should have answered any questions you may have had about the research. If you have any questions later on, please contact the researcher at the number above.

If at any time you feel pressured to participate, or if you have any questions about your rights or this form, then you should call Dr. George Maihafer (IRB Chair) from the Old Dominion University Office of Research, 757-683-4520, or the ODU Office of Research, 757-683-3460.

By signing below, you are telling the researcher YES, that you agree to participate in this study. The researcher should give you a copy of this form for your records.

----- Participant's Name	----- Participant's Signature	----- Date
----- Investigator's Name	----- Investigator's Signature	----- Date

APPENDIX D

DEMOGRAPHIC FORM

Participant # _____ Date: _____ Time: _____

The purpose of this questionnaire is to collect background information for participants in this experiment. This information will be used strictly for this experiment and for research purposes only. Please complete or circle each item to the best of your knowledge.

1. Age _____

2. Male
 Female

3. Have you ever been diagnosed as color blind or color deficient? _____

0 = No
1 = Yes

4. Have you ever been diagnosed as having hearing loss? _____

0 = No
1 = Yes

5. If yes, do you have correction with you (i.e. hearing aid)? _____

0=No
1=Yes

6. Have you ever been diagnosed as being nearsighted (myopic)? _____

0=No
1=Yes

7. Have you ever been diagnosed as being farsighted (hyperopic)? _____

0=No
1=Yes

8. If you answered yes to either #6 or #7, do you have correction with you (i.e. glasses, contact lenses, etc.)? _____

0=No
1=Yes

9. How many hours per week do you play video/simulation games? _____

10. How many hours per week do you use a computer (work and recreation combined)? _____

APPENDIX E

INSTRUCTION SHEET

Welcome to project V-Teleoperation, please put away your cell phone and turn it on silent.

Greetings and thank you for participant in this experiment. In this experiment you will be asked to tele-operate a search robot using three different control methods. The control methods used in the experiment will be chosen at random and will consist of the following:

- 1) Full manual
- 2) Hybrid
- 3) Eyes-only

Prior to the start of the experiment the experimenter will ask you to be fitted for a full-scalp EEG cap. This cap will allow the experimenter to monitor and record your brainwaves during the experiment. A non-toxic, water-based, electrode gel may be used to ensure proper conductivity. If proper conductivity can be obtained without such gel then no gel will be used.

Once the method of control has been established there will be several practice sessions that you will be allowed to practice until you feel that you are comfortable using the control method. These practice sessions will occur prior to each session, prior to the use of a different control method.

The Scenario

In this scenario you are a safety inspector for a government agency. You have been called to Refinery-A, a chemical plant, to investigate an emergency report concerning dangerous chemicals that are leaking out of barrels. You have arrived to the site where you find that the plant has been evacuated until all the damaged barrels, targets, are identified. It is your job to use your search robot to safely search and identify all damaged barrels throughout the plant.

The Task

Your tasks while operating the search robot are to navigate and search the Simulated Environment (SE) and identify specific targets in the SE. The targets that are to be identified in this simulation are damaged industrial barrels (e.g. the barrel in figure 1 is not damaged barrel). More examples of target and non-targets barrels will be demonstrated during the practice sessions. The path that is to be navigated is displayed as a darkened chemical-stained trail, as seen below in figure 1. This path will be more clearly displayed in the practice sessions.



Figure 15. Screen shot of operator's view during tele-operation (Hicks et al., 2015).

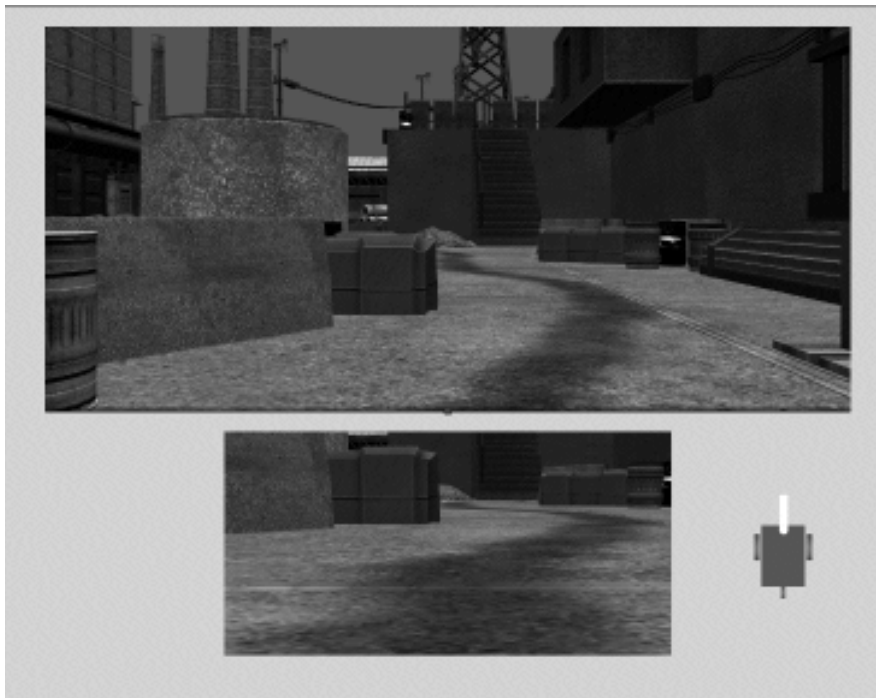


Figure 16. Screen shot of operator's viewpoint while using the eyes-only control method (Hicks et al., 2015).

Selection Methods and Displays

As previously mentioned there are three methods of control that you will be asked to test. During the Full manual and Hybrid method of control your display will be as shown in Figure 1, and for the third method of control, eyes-only, your display will be as

shown in figure 2. In both figures there is a small display of your search robot in the bottom right. This display will be in same location during the experiment and will accurately represent the orientation of your robot as well as your camera. The large rectangular portion of the robot in the bottom right of your screen represents your robot's orientation and the long narrow rectangle shape that is whitened represents your camera's orientation. This small display may be used to assist in the navigation of the simulated environment as well as assist in the scanning of the environment.

During the operation of the search robot two of the three methods will have the same method of selection, while the third will differ.

Fully Manual selection

During the Fully manual control method you will control the robot movement with one hand, and camera movement with the opposite hand. While searching the environment with your camera if you think you have found a target and would like to select the target the first step is to pull and hold the trigger on the camera joystick. Once the trigger is held the camera movement will be disabled and a reticle, a circle with crosshairs in it, will appear on the screen. You will be able to manipulate the movement of the reticle to the intended target using the camera joystick. When the reticle is on the intended target you can press the second button on the joystick, located on the top of it, and the target will be marked and logged as being identified. When you would like to continue your search simply release the trigger on the camera joystick and continue with your tasks.

You will be given several practice sessions until you feel you are comfortable using this control method.

*This paragraph will be repeated during the practice sessions prior to the use of this control method.

Hybrid and Eyes-only selection

During both Hybrid and Eyes-only control methods you will control the camera movement with your eyes. While searching the environment with your camera if you think you have found a target and would like to select the target the first step is to carefully focus on the intended target. This may be easier if you choose a specific point on the target and focus your gaze upon it. This selection method uses time of duration to indicate your intention of target selection. After a few seconds a target selection symbol will appear on the screen as shown in figure 3. This symbol will appear and begin as long as your gaze is focused on a single target. Once the selection symbol has reached a full circle you may nod your head to finalize your selection. This gesture, head nod, will allow the target to be marked and logged as being identified. If for some reason you do not want to select the target simply move your eyes away from the non-target and the selection symbol will disappear.

When you would like to continue your search simply continue using your eyes continue with your tasks.

You will be given several practice sessions until you feel you are comfortable using this control method.

*This paragraph will be repeated during the practice sessions prior to the use of this control method.



Figure 3. Display of selection method during eye-only control method.

At this point in the experiment do you have any questions regarding the task or the operations of the equipment?

If there no more questions then let us begin the experiment.

APPENDIX F

SONA RECRUITMENT ADVERTISEMENT

Eye Tracking as a Control Interface for Tele-operation During a Visual Search Task

James P. Bliss, Jeffrey N. Levy, and Samantha Jennings of the ODU Psychology Department are currently conducting an experiment.

Brief research overview: The purpose of this research is to investigate different control methods during the tele-operation of search robots.

Research overview

Twenty participants will be tested in this experiment. Those who agree to be tested will complete a background information form. Following this, you will be asked to perform several familiarization sessions with different control methods during a visual search task. After training, you will be asked to perform the tasks in several experimental sessions in a simulated environment, while EEG data are collected. Following each practice session you will be asked to tele-operate a search robot in a simulated industrial environment using three different control methods. The three control methods to be studied in this experiment consist of a fully manual, a hybrid control, and an eyes-only control method. The control method of fully manual consist of two joysticks, one for robot orientation and one for camera control. The hybrid control method consists of one joystick and eye-tracking, the joystick for robot orientation and eye-tracking for camera control. The eyes only control consists of no joysticks and will utilize eye-tracking technology only to operator both robot orientation and camera control. The task for this experiment is a visual search task where the objective is to identify all targets in the simulated environment.

When the three sessions are completed you will then be debriefed and dismissed. The entire experiment should last almost 2 hours.

You will receive 2 SONA credits for participating in this study.

VITA

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EDUCATION

Bachelor of Arts, in Psychology.

Virginia Wesleyan College, Norfolk, VA, December 2013- 2014

Masters in Science, Applied Experimental Psychology.

Old Dominion University, Norfolk, VA, June 2014-Present

Certifications:

- **Engineering Project Management**, Old Dominion University. 2016
- **Modeling and Simulation**, Old Dominion University. 2015
- **Collaborative Institutional Training Initiative (CITI)**. 2015
- **Sensitive Security Information (SSI)**, American Board for certification in Homeland Security. 2010
- **Homeland Security level I-III**, American board for Certification in Homeland Security. 2010
- **Homeland Security Level IV** (Incident Awareness, Response, and Terrorism), American Board for Certification in Homeland Security. 2010
- **Custom Border Clearance Agent-Afloat**, U.S Customs and Border Protection. 2009

Professional Experience:

Project Officer/ SME support for Telemedicine & Advanced Technology Research Center (TATRC)
August 24, 2016- Present.

U.S. Navy, July 2007- July 2011, **Honorably Discharged.**

Publications:

Levy, J. N., Tremmel, C., & Düндar, C., Karatas, K., & Sobreira, F. (Accepted, 2016).
Brain-computer-interface for entertainment and language assistance. To be presented at the Houston Human Factors and Ergonomics Society Symposium. Houston, TX.

Research Interests

- Modeling and Simulation of training environment including: Medical surgical techniques, military operations, and emergency first responder training.
- Human Computer Interaction
- User Experience Analysis
- Usability Testing and Methods