Set Your Sights High:
The Effect of Heads-Up Displays on Situation Awareness and Performance for Small Unmanned Aircraft Systems

by

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The purpose of the current study was to examine the effect of two interface designs—traditional and heads-up displays (HUDs)—on situation awareness (SA), performance, and workload for sUAS operations. The study utilized an experimental repeated measures design to determine the relationship between interface design on the various dependent variables through a simulated search and rescue mission. Participants flew two simulated search and rescue missions to find missing persons utilizing traditional and HUD displays. During the missions, participants took pictures of human targets and were queried on their SA using the freeze probe SAGAT approach. Then participants rated their subjective SA using the SART and workload using the NASA-T LX. A repeated measures MANOVA revealed no significant effects of interface on SA performance or workload. Therefore, a follow-up mixed model repeated measure MANOVA was conducted with between subject factors of interface order and UAS experience level. With experience and order included as between subjects factors, the model revealed a significant effect of interface. Univariate analyses revealed a significant impact of interface design on SA measured via the SAGAT. No significant differences were
The findings from the current study support aspects of SA theory. Consistent with Endsley’s (1995a) model of SA, interface design improved SA. Targets detected, and subjective SA measures were determined to lack adequate sensitivity for differences to emerge. Exploratory analyses of workload revealed that the HUD did not result in an increased workload. The current findings align with HUD research in medical, automotive, manned aircraft, and UAS domains. The results of this study provide support for integrating HUDs into UAS operations, such as via augmented reality technology.
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<th>Abbreviation</th>
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<tbody>
<tr>
<td>ATC</td>
<td>Air Traffic Control</td>
</tr>
<tr>
<td>AR</td>
<td>Augmented Reality</td>
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<tr>
<td>BVLOS</td>
<td>Beyond Visual Line of Sight Operations</td>
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<tr>
<td>FAA</td>
<td>Federal Aviation Administration</td>
</tr>
<tr>
<td>FLIR</td>
<td>Forward-Looking InfraRed</td>
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<tr>
<td>GPS</td>
<td>Global Positioning System</td>
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<tr>
<td>HDD</td>
<td>Heads-Down Display</td>
</tr>
<tr>
<td>HMD</td>
<td>Head-Mounted Display</td>
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<tr>
<td>HUD</td>
<td>Heads-Up Display</td>
</tr>
<tr>
<td>HWD</td>
<td>Head-Worn Display</td>
</tr>
<tr>
<td>IRB</td>
<td>Institutional Review Board</td>
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<tr>
<td>MANOVA</td>
<td>Multivariate Analysis of Variance</td>
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<tr>
<td>ND</td>
<td>Navigation Display</td>
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<tr>
<td>PFD</td>
<td>Primary Flight Display</td>
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<tr>
<td>SA</td>
<td>Situation Awareness</td>
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<tr>
<td>SAGAT</td>
<td>Situation Awareness Global Assess Technique</td>
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SART: Situation Awareness Rating Technique
sUAS: small Unmanned Aircraft Systems
UAV: Unmanned Aircraft Vehicle
VR: Virtual Reality
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“No man becomes great on his own. No woman becomes great on her own. The people around them help to make them great. We all need people in our lives who raise our standards, remind us of our essential purpose, and challenge us to become the best version of ourselves.” – Xiao Yao Pai
Chapter 1

Introduction

Background and Purpose

**Background.** An unmanned aircraft system (UAS) is defined as “an aircraft and its associated elements which are operated with no pilot on board” (ICAO, 2011, p. 12). A sUAS is defined by the Federal Aviation Administration (FAA) as an unmanned aircraft under 55 pounds (FAA, 2016). According to Dalamagkidis, Valavanis, and Piegl (2009) one of the earliest UAS, by modern definitions, was developed in 1960 by the United States Air Force to survey and inspect China and Vietnam. As of January 2018, over 1 million sUAS are registered with the FAA, including 122,000 for commercial or public use (U.S. Department of Transportation, 2018). This is a result of both the growth of the industry as well as the required registration of commercial and non-commercial use UAS. The FAA projects that the UAS industry will grow to 1.6 million vehicles for commercial use and 3.5 million for recreational use by the end of 2021 (N.a, “FAA forecasts growth,” 2017). However, it should be noted that the FAA’s projections of growth were under-projected for non-recreational/commercial UAS by 80% for 2018 (FAA, 2019).

Results of a survey of the most frequent non-recreational uses of sUAS were published in the FAA Aerospace Forecast (2019). Findings revealed that the most frequent uses included research, film and entertainment, industrial, and
environmental purposes, with smaller sectors including construction, real estate, agriculture, and emergency services. Mika (2009) defined multiple use cases for UAS operations to aid in emergency services, including: search and rescue, incident imaging for reports, fire investigation, flooding inspection, and information gathering. The FAA noted that 3% (or 8,000) of these UAS missions are based around emergency and preparedness, but that they are “at the experimental stage” and expected to grow as technology improves (FAA, 2019, p. 47). UAS have been utilized by (a) firefighters, for detecting areas of heat and fire to direct helicopters for water drops in Arizona wild fires (N.a., 2019); (b) police officers, for locating missing persons through wooded areas in Florida (“Police Drones Find Missing Man”, 2019); (c) ocean rescue personnel to deploy rafts to drowning victims in Australia (“Robots to the Rescue”, 2018); (d) mountain search and rescue teams. to find and deliver messages to a lost kayaker in the mountains of New Mexico (“Search and Rescue Team uses UAS”, 2019); (e) power agencies, to inspect areas that need reconstruction to restore power after hurricanes, and define areas that are inaccessible by bucket trucks (“Drone Crews Restore Power”, 2018); and (f) hospital personnel, to deliver transplant organs (“Unmanned Aircraft Delivered Kidney”, 2019). The potential for UAS applications in emergency situations is broad and continuing to grow. As this growth continues, there is a need to consider the human factors associated with UAS operations and to ensure that UAS
applications have adequate interface design to ensure mission success, safety, and efficiency (Balog, Terwillinger, Vincenzi, & Ison, 2017).

Current FAA regulations require a visual line of sight (VLOS) for all sUAS operations (FAA, 2016). VLOS is “an operation in which the remote crew maintains direct visual contact with the aircraft to manage its flight and meet separation and collision avoidance responsibilities” (ICAO, 2011, p. 12). Beyond visual line of sight (BVLOS) operations are currently not approved in the United States until see-and-avoid technology can be confirmed as successful for integrating UAS into the national airspace (GAO, 2015). As of December 2018, only 1.2% of waivers for BVLOS operations were approved (FAA, 2019). The current regulation states:

The remote PIC (pilot in command) and person manipulating the controls must be able to see the small UA (unmanned aircraft) at all times during flight… However, the person maintaining VLOS may have brief moments in which he or she is not looking directly at or cannot see the small UA, but still retains the capability to see the UA or quickly maneuver it back to VLOS. These moments can be for the safety of the operation (e.g., looking at the controller to see battery life remaining) or for operational necessity … a remote PIC conducting a search operation around a fire scene with a small UA may briefly lose sight of the aircraft while it is temporarily behind a dense column of smoke. However, it must be emphasized that even though
the remote PIC may briefly lose sight of the small UA, he or she always has the see-and-avoid responsibilities. (FAA, 2016, p. 16)

This requirement affects the ability of sUAS operators to maintain an overall understanding of the situation as time spent viewing flight task information on the typically-handheld controller is minimized. Alternatively, the FAA states that an operator can use a visual observer (VO) to maintain a visual line of sight (FAA, 2016). However, should a problem arise, this now requires strong team dynamics to communicate and coordinate the sUAS out of a problem situation. The ideal solution would be to improve the ability of sUAS operators to maintain VLOS while simultaneously being able to view important flight task information.

Despite the industry’s rapid growth, there is currently a gap in human factors research in the UAS domain. Much of the current research is concerned with training, operator selection, and improving the mechanical design of UAS to incorporate see-and-avoid technologies or improve mechanical performance (Balog et al., 2017). However, attention to the human factors aspect of real-time UAS operations, such as operator support through automation, interface design, and attention cueing, is lacking. UAS systems face greater issues than manned aircraft when it comes to supporting operators in maintaining situation awareness (SA). SA, with respect to UAS operations, is the understanding and comprehension of the current state of the vehicle and the environment surrounding it (Endsley, Toward a theory of situation awareness in dynamic systems, 1995a). Endsley and Jones
(2004) posited that the removal of the human from the cockpit removes information that the operator would normally gather through sight, sound, and feeling. UAS operators must now interpret the same type of information through UAS sensors and interfaces. The sensors that convey this information to the operator can exhibit poor signals, delays, and are often presented on poorly designed displays that can hinder SA. Balog, Terwiliger, Vincenzi, and Ison, (2017) noted that the lack of human factors research in this field may result in dangers, losses, and safety risks.

A current challenge in the field is to “design interfaces that provide salient information capable of maintaining SA in UAS” operations, and this must be achieved before BVLOS operations can be considered (Balog et al., 2017, p. 66).

Ensuring adequate SA is vital to mission success for emergency UAS operations. According to Endsley’s (1995a) model, SA has the potential to lead to better decisions, and ultimately, better performance. Improving SA has led to better decision making in emergency situations (Quoetone, Andra, Bunting, & Jones, 2001), as well as improved strategic decision making in driving tasks (Kaber, Jin, Zahabi, & Pankok, 2016), higher target hit ratios in police training (Saus et al., 2006), and improved performance in military planning scenarios (Salmon et al., 2009). However, SA is one of many factors that influences performance. Research by Endsley (1990) revealed that in a fighter aircraft mission simulator, SA supported the offense team’s performance in infiltrating enemy territory; however, SA did not appear to assist in defensive operations. Defensive teams were unable to
leave the base, and therefore SA on enemy locations did not result in high gains for defensive teams. This illustrates that SA is only one facet of performance, a complex construct that is influenced by numerous factors.

Incorrect decisions and poor performance resulting from low levels of SA can lead to accidents and, in some cases, fatalities. Endsley (1995b) presents a taxonomy of aviation accidents that originated from errors in SA. These errors caused poor decisions, and ultimately poor performance, ranging from landing on an occupied runway to fatal accidents, such as crashing into mountains or running out of fuel. Limited ability to detect anomalies, poor mental models, vital data being out of view, and high levels of workload all led to poor SA. Poor SA, in turn, led to poor decisions and poor performance by pilots. Schulz et al. (2016) present a taxonomy of medical incidents, ranging from routine procedures to emergency procedures that were caused by errors in SA. Poor SA led to accidents including incorrect drugs being administered, prepping patients for the wrong procedure, and administration of chemicals causing adverse patient reactions. Similar to the aviation domain, poor or incomplete mental models, anomalies, and data is difficult to detect, lack of data being within the medical personnel’s scan patterns or field of view, all led to poor SA and poor decisions, which, in turn, led to incidents.

Endsley (1995a) presents a model of SA with various individual, environment, and system influencing factors that can be targeted to facilitate or improve SA (see Figure 1.1.) According to Endsley (1995a), the individual factors
impacting SA include individual memory capabilities, abilities, training, experiences, goals, and expectations. Task- or system-related factors include the system and interface design, the complexity of the system, the level of stress and workload associated with the task, as well as the level of automation. These factors provide an opportunity to influence SA; however, for many UAS applications across the industry, several of these factors cannot feasibly be targeted.

With respect to individual factors, an operator’s memory capabilities, abilities, expectations, and experiences vary from individual to individual. It may not be feasible to effect a large change in these factors for the UAS operator population, as this would require evaluating each individuals’ deficits and

*Figure 1.1. Situation awareness model by Endsley (1995a).*
developing methods to improve those deficits. With respect to task factors, the task goals and the amount of induced stress and workload on the operator are dependent on the operator’s job. Although, the UAS design may have the ability to alter workload, the task goals and amount of stress associated with the task—especially in emergency response tasks—are ever changing and cannot be controlled. Further, targeting UAS system factors such as complexity would require re-engineering the UAV itself, which at this point in the evolution of UAS may not be practical. In addition, targeting these task-related factors would require focusing on a specific use case to make tailored improvements, or creating a one-size fits all solution that is tailored to no use case. Such an approach may not have a large impact on UAS operations as a whole. Sanquist, Brisbois, and Baucum (2016) stated that, for first responders such as firefighters, police officers, and emergency medical personnel, “direct observation [of the environment and situation] is the key method of data acquisition, and that recognizing and classifying situations is based on experience and protocols” (p. 9). Therefore, the two most impactful ways to improve SA for this use case would include training improvements and aiding direct observation.

As an example, consider the case of a firefighter, influencing experience can be costly as specialty training for using UAS in emergency response can cost up to $1000 for 40 hours of training for only one operator (Center for Disaster Risk Policy, 2019). The FAA (2019) reported 3% of all 277,000 registered non-
recreational UAS systems in 2018 were for emergency operations. This equates to a total of over 8,000 personnel to be trained on emergency UAS operations, costing upwards of $80,000—assuming training is limited to one operator per UAS. For search and rescue, the North Carolina All-Hazards Technical Search and Rescue Technical Advisory Group (2015) annual training costs for search and rescue amount to $710,000 for North Carolina. These include specialized training events directed at how to perform search and rescue missions for lost persons, boat search and rescue, canine search and rescue, and collapsed building search and rescue. Due to the novelty of the UAS search and rescue use case, it is likely that a specialized UAS search and rescue training would need to be developed. However, training just five courses on canine search and rescue amounted to $20,000 alone (NC All-Hazards Technical Search & Rescue Technical Advisory Group, 2015). As such, improvements to the level of training, or training content, may not be the most cost effective and feasible focus area for improving SA of UAS operations.

Sanquist et al. (2016) focused on providing technologies to first responder teams to facilitate SA, while simultaneously preventing information overload. For emergency teams attempting to utilize UAS operations, there are unique hurdles that impede the development of high levels of SA, including that: (a) information about the UAS system can only be absorbed through the senses, displays, and sensors; (b) the operator receives 3D information through 2D channels; (c) many systems lack multimodal interfaces; (d) technical limitations such as lag or low
resolution are currently prevalent; (e) the operator must convey information from
their system to other members with different sources of information; and (f) the
approach to the mission can change at any time (Chappell & Dunlap, 2006; Endsley
& Jones, 2004; McCarley & Wickens, 2004).

An interface design that addresses these issues could facilitate improved SA
by providing the operator with all key information in a usable format. Improving
the interface could result in SA gains in a multitude of industries. According to
Endsley and Jones (2004):

The operators’ ability to develop good SA on multiple unmanned vehicles
or task aspects will be critically affected by the degree to which the user
interface helps them to develop the needed SA with minimal effort and
within the bounds of limited attentional resources (p. 228).

Currently FAA regulations allow minimal time to look down at displays to collect
flight task information needed to maintain SA. However, if VLOS can be
maintained while simultaneously allowing for information to be viewed, this would
allow for FAA compliance, while potentially increasing SA. Research on HUDs for
sUAS operations is currently limited with most research focused on BVLOS
operators or close quarters VLOS research with limited UAS functionality
(Calhoun, Ruff, Lefebvre, Draper, & Ayala, 2007; Hedayati, Walker, & Szafir,
2018) This study will evaluate the impact of bringing flight task information up into
the VLOS on operator SA and performance.
**Purpose.** The purpose of this study was to examine the effect of two interface designs—traditional and heads-up displays (HUDs)—on situation awareness (SA), performance, and workload for sUAS operations. In the context of the current study, a traditional UAS interface (also referred to as traditional UAS operations) consisted of the UAS operator viewing all UAS parameters and sensor information on a device fixed to the controller, with the view of the environment separated. A HUD UAS interface (also referred to as HUD UAS operations) consisted of the UAS operator viewing all UAS parameters and sensor information overlaid on the view of the environment.

In the context of this study, sUAS operations were defined as using a sUAS for a visual search task and was created through a simulated search and rescue mission on a desktop computer. SA was defined as “the perception of 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” (as cited in Endsley 1995a, p. 36) and was measured in the current study using the Situation Awareness Rating Technique (SART) and the Situation Awareness Global Assessment Technique (SAGAT). Perceived level of SA was defined as subjective SA and was measured using the SART. Objective SA was defined as SA and was measured objectively using the SAGAT. Performance was defined as the number of correctly detected targets in a visual search task. Performance was measured in the current study through pictures taken by the participants, which were then scored as
correctly detected targets or false alarms. Workload was defined as the level of demand on human cognitive processes relative to the human’s capacity for collecting and processing information (Moray, 1979). Workload was measured in the current study using the NASA-Task Load Index (NASA-TLX).

**Definition of Terms**

The key terms or phrases relative to the current study were operationally defined as follows:

1. *Commercial UAS operators* were defined as individuals who fly UAS for work purposes and would likely engage in visual search tasks, such as firefighters, police officers, military personnel, and inspectors.

2. *Environmental integration* or environmentally-integrated display was defined as the utilization of augmented reality (AR), HUDs, Heads-Down Displays (HDDs) with synthetic vision, or other technology to overlay information on a visual environment (simulated or real). This can include task information overlaid onto a virtually rendered environment, camera imaging, or the real world.

3. *Experienced UAS operators* were defined as UAS operators with greater than 10 hours of UAS experience.

4. *Heads-up display (HUD)* was defined as a type of an environmentally-integrated display that integrates task information over the real-world environmental information. The primary goal of a HUD is to keep the eye level
of an operator directed at the environment or task objective within the environment. HUDs can be presented on a see-through display in front of the operator or fixed to the operator via a helmet, headset, or pair of glasses.

5. *HUD UAS interface* (also referred to as HUD UAS operations) was defined as an overlaid UAS interface where UAS parameters and sensor information was located on the UAS view of the environment. A HUD UAS interface on the simulator was accomplished by presenting UAS parameters and sensor information on the top monitor on top of the UAS and environment.

6. *Novice UAS operators* were defined as UAS operators with between 1 and 10 hours of UAS experience.

7. *Performance* was defined as the level of success in completing a search and rescue mission. Performance was captured by scoring participant pictures of missing humans compared against an answer key. Pictures were then scored as correctly detected targets or false alarms.

8. *Recreational UAS operators* were defined as individuals who fly UAS for personal enjoyment instead of work purposes.

9. *Situation awareness (SA)*, or a current understanding of a situation, was formally defined by Endsley (1987) as “the perception of 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” (as cited in Endsley 1995a, p. 36). Endsley’s definition was applied to the current study
and SA was measured using the Situation Awareness Global Assessment Technique (SAGAT).

10. *Small unmanned aircraft system (sUAS)* was defined as an unmanned aircraft under 55 pounds (FAA, 2016).

11. *Subjective SA* or self-rated perceived levels of SA is one’s own perception of his or her SA. Subjective SA was measured using the Situation Awareness Rating Technique (SART).

12. *Traditional UAS interface* (also referred to as traditional UAS operations) was defined as the common UAS interface where UAS parameters and sensor information was located on a separate display by the individual’s hand controls. An individual must look up to view the UAS in the environment. A traditional UAS interface on the simulator was accomplished by presenting UAS parameters and sensor information on the bottom monitor with the UAS and environment on the top monitor.

13. *Unmanned aircraft system (UAS)* was defined as “an aircraft and its associated elements which are operated with no pilot on board” (ICAO, 2011, p. 12).

14. *Unmanned aircraft vehicle (UAV)* was defined as the aircraft component of the UAS system.

15. *Visual line of sight (VLOS)* was defined as “an operation in which the remote crew maintains direct visual contact with the aircraft to manage its flight and meet separation and collision avoidance responsibilities” (ICAO, 2011, p. 12).
16. *Visual search* was defined as the surveying of an environment to locate and identify predetermined objects of interest.

17. *Workload* (also referred to as mental workload) was defined as the level of demand on human cognitive processes relative to the human’s capacity for collecting and processing information (Moray, 1979). In the current study, mental workload was captured using the NASA-Task Load Index (NASA-TLX).

**Research Questions (RQs) and Hypotheses**

**Research questions.** The current study was guided by two primary research questions (RQ 1 and RQ 2) and one exploratory research question (RQ 3), which was posed post-hoc due to the equivocal relationship between information integration and workload.

**RQ 1.** What is the effect of HUD UAS operation on performance for a visual search task compared to traditional UAS operation?

**RQ 2.** What is the effect of HUD UAS operation on SA as well as subjective SA for a visual search task compared to traditional UAS operation?

**RQ 3.** What is the effect of HUD UAS operation on workload for a visual search task compared to traditional UAS operation?

**Research hypotheses.** The corresponding research hypotheses for the current study were as follows (the reader will note that no hypothesis was posited for RQ 3):
Hypothesis 1. HUD UAS operation will result in higher performance compared to traditional operation for a visual search task.

Hypothesis 2a. HUD UAS operation will result in higher levels of SA compared to traditional operation for a visual search task.

Hypothesis 2b. HUD UAS operation will result in higher subjective SA than traditional operation for a visual search task.

Study Design

The current study was based on a within-group research design. This design was appropriate because the available number of UAS operators that satisfied the sampling criteria was small and by implementing a within-group design allowed for the control of any individual differences such as training or experience background. In the current study, participants experienced both traditional and HUD operations, which means that a single group of participants was measured on multiple factors. Because the same group of participants was measured twice, and because I was examining the relationship between these measures in the absence of any manipulation, this may be considered a repeated measures correlation study.

Potential Significance and Generalizability

The UAS industry is expected to grow from $13.6 billion in 2015 to $82.1 billion by 2025 (GAO, 2015). It will continue to become more prevalent in various commercial, entertainment, and emergency response operations. Ensuring that the sUAS system provides critical task information to the human operator in a manner
that facilitates efficient, effective, and safe performance of their task is a pressing issue as the UAS industry continues to expand (Balog et al., 2017). From an application perspective, the results of this study provide insight regarding the impact of utilization of a HUD interface on UAS operations performance of a visual search task, including impacts to mission success, SA, and workload. Generalizing to the experienced UAS population, the impacts of incorporating HUDs or AR technology in the UAS domain can be inferred. From a theoretical perspective, this study builds on the body of research in information-rich domains that utilized HUDs and applies it to the ever growing UAS domain. The impact of the findings related to HUD research in other domains and practical implications of the study are discussed in Chapter 5.

Limitations and Delimitations

Limitations. Limitations are aspects of the study that cannot be controlled and can affect the interpretation and generalizability of the findings. Limitations for the current study include:

1. **Low environmental fidelity.** The study utilized a desktop simulator with low environmental fidelity to present highly task-relevant targets such as missing persons as real-world emergency situations were not feasible. Although the environment attempted to address task relevancy and environment fidelity for higher generalizability, it was not comparable to real-world emergency situations in terms of workload, stress, environment, and other characteristics. As a result, real-
world operations and subsequent studies utilizing higher fidelity environments may experience different results.

2. Sample demographics. The sample consisted of UAS operators from Brevard County, Florida, which may differ from personnel in other areas of the country. For example, in California, wildfire, and earthquake emergencies are typically experienced, whereas in Florida, hurricane and tropical storm emergencies are more prevalent. Demographic information about the participants will be presented in the study results to allow the reader to make his or her own interpretations regarding generalizability. As a result, future studies utilizing demographic backgrounds different from the sample in the current study, may find different results.

3. Participant technology experience. The current study mimicked a DJI UAS interface and a USB radio controller, which are the most common currently in the UAS industry. However, the participants utilized in the current study may not be familiar with the technology utilized, or even with the simulator computer interaction requirements. Participants’ experience with UAS and camera gimbals, and which UAS information parameters they utilize in their day-to-day operations of UAS, were captured and are presented to the reader to make their own interpretations and generalizations. As a result, similar studies that utilize participants with more or less experienced operators may elicit different results.
4. **Search and rescue experience.** The current study utilized a search and rescue visual search task as the simulated mission. Participants may not have experience utilizing UAS for this purpose and therefore experience may have impacted their results. Descriptive information on sample occupation and their uses of UAS, and camera operating experience, are presented to allow the reader to make their own interpretations and generalizations. As a result, studies utilizing participants with different search and rescue experience may find different results.

5. **Participant motor skills and visual acuity.** The current study utilized a simulated search and rescue task, that required maneuvering a camera gimbal using joysticks, viewing a small camera window, and discerning human shapes from distracting targets. As a result, similar studies with participants of different visual acuity and motor skills may find different results.

**Delimitations.** Delimitations include constraints on the study that I, as the researcher, impose on myself to improve the feasibility of the study, but that may impact interpretations and generalizability. Delimitations of the current study include:

1. **Type of UAS and interface.** The current study was limited to the use of commercial off-the-shelf UAS systems from DJI and the accompanying interface design. First responders using different systems may experience different impacts on SA and performance. Therefore, studies utilizing different interfaces may experience different results.
2. **Sampling approach.** The current study included participants from various backgrounds, including commercial and recreational UAS operators. This approach was utilized to increase the generalizability of the findings and to recruit the needed sample size for the study. However, the study did not utilize a homogenous group, nor cover all domains, and therefore similar studies may find different results with different populations. Sample demographics are presented to allow the reader to make his or her own interpretations and generalizations. Therefore, future studies utilizing different sampling approaches may find different results.

3. **Sample background.** This study utilized participants with varying levels of experience. Although the original intent was to collect participants with 10 hours of experience or higher, access to this population proved difficult. Pilot testing revealed those with little to no UAS experience, and those with extensive UAS experience had similar performance and results. Therefore, the sample was expanded to include individuals with lower levels of UAS experience. These individuals were required to have some prior UAS experience; however, no specific time requirement was put in place. To control for potential experience differences, experience level was then captured as a potential between subjects variable. Therefore, information on sample UAS experience is presented to allow the reader to make their own interpretations on generalizability. Similar studies utilizing participants of different backgrounds may produced different results.
4. Experience Categories. The current study categorized operators by his or her level of experience. Based on the average length of training courses, participants were categorized into novices and experienced operators at the ten-hour mark. Similar studies categorizing operators based on experience level using different criteria may find different results.

5. Performance measurement. The current study measured performance solely from the classification of correctly detected targets. This was the most feasible, objective, and representative metric of performance given the simulator constraints. To achieve this, pictures were scored as correct as long as a missing person was present within the photo. A photo with a distractor item and a missing person within the photo was still coded as a detected target. However, other metrics of performance could include target detection time or missed targets. If manual flight operation was an option to the participants, search strategy and mission completion time could have also been performance metrics. As a result, studies using other metrics for performance may find different results.

6. Self-developed queries. The current study utilized queries made specifically for the context of this mission and for this simulator. The queries were developed utilizing the method presented by Endsley (2000), in conjunction with previously published task analyses and queries, to create 27 queries. However, they may not present a comprehensive assessment of SA due to the limited number of queries and task duration. In addition, as the queries were self-developed for the
purposes of this study, they have not undergone extensive testing to ensure validity and reliability. Therefore, the queries may not have provided the most valid and robust measure of objective SA and future studies using a different set of queries may produce different results.

7. **Change to a mixed model approach.** The current study was originally intended to be analyzed as a repeated measures MANOVA. However, in analyzing the data, it was clear that experience and learning effects were taking place. Therefore, the data analysis approach shifted to a mixed model repeated measures MANOVA approach to account for these differences. Although this approach was still appropriate to answer the a priori hypotheses, similar studies that do not modify the data analysis approach to include between subjects effects may find different results.

8. **Test-retest duration.** The current study measured each of the dependent variables twice. The time between the two measurements was approximately 15–20 minutes, and as observed with order effects, may have impacted the results. Therefore, studies that do not use a repeated measures approach or utilize different durations between measurements may find different results.

9. **Simulator Design.** The simulator monitor setup was designed to keep the following characteristics consistent as information moved across monitors: (a) visual distance of information relative to the participants’ eyes, (b) size of information, and (c) portability and replicability of the simulator setup at various
locations. This helped to ensure that the findings of the study could not be attributed to the simulator nuances and could be attributed to the changed location of information. Therefore, the simulator design consisted of two 19-inch monitors mounted on top of one another with the visual center point located where the two monitors touch. Participants sat approximately 18 inches away from the two screens. However, in a live UAS setting, the operator has no field of view constraints on their environment view, which was represented on the top monitor. Participants could use the arrow keys to “look around”. However, operators in the real world can pan their head left and right and see the whole world around them and are not limited to a view directly in front of them. Additionally, the information view would likely be on a 5-7 inch handheld mobile device located near the operator’s hands. Therefore, the size of the information view in the traditional condition was much larger than real life and was located much closer to the environment view than real UAS operations. The reader should note that findings in a real-life setting may exhibit much larger differences than the subtle differences that emerged in the current study.

10. Scenario Type. The current study utilized two self-developed search and rescue mission designs to represent a visual search task. Although the mission characteristics were derived from similar simulation studies that utilized search and rescue missions, those utilizing different search and rescue missions, or other visual search tasks, may find different results.
11. Training. The current study utilized one five-minute computer-based training slide deck and two three-minute training flight routes. This training may have been insufficient and may have affected their performance. Similar studies utilizing different training strategies may not obtain the same results.

12. Automated flight. The current study utilized an automated flight path to ensure participants were exposed to the same conditions throughout the task. This ensured that correct answers to queries would be consistent for each participant and that all participants would pass over each potential target. However, in a natural search and rescue mission, operators may begin in automated flight but switch to manual flight to investigate and close-in on potential targets. In the current study, operators had to make judgment calls from a distance. Therefore, studies utilizing manual UAS flight may find different results.
Chapter 2

Literature Review

Introduction

A review of the theory and research behind the impacts of interface design on SA is the first step to effectively addressing the human factors issues associated with UAS interfaces. The following sections discuss the theoretical construct of SA, including SA outcomes and levels. The section contains a review of research that has examined how interface design has been shown to facilitate operator SA, performance, safety, and ultimately mission success. The research reviewed includes environmentally-integrated displays, and in a range of information-rich domains, including UAS operations. Finally, a summary is presented with the overall findings from the literature and the implications for the present study.

Overview of Underlying Theory

SA, or a current understanding of a situation, is formally defined by Endsley (1987) as: “the perception of 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” (as cited in Endsley, 1995a, p. 36). Endsley (1995a) describes SA as a state in which an operator (1) collects information about the environment from various sources, then (2) the information elements are compared and combined over time to develop an understanding of the situation, and (3) finally, the operator can infer, or project, what the next state of the environment may be. Each of these three
stages is dependent on and influenced by individual factors such as the experience level, memory capabilities, and goals of the operator. Task- or system-related factors such as stress, workload, or system design can also influence the ability for operators to effectively collect information to develop SA. SA influences decision making, actions, and is a cyclical process with the ever-changing state of the environment.

SA in complex tasks such as pilot operations, air traffic control (ATC), and search and rescue by first responders is of high importance. In the context of this study for a UAS search and rescue task, high levels of SA such as knowing the search strategy of the team (Level 1 SA), understanding which areas are most important to cover first (Level 2 SA), and projecting how much of the search area can be covered with the given resources (Level 3 SA) are critical for effective decision making. Based on Endsley’s (1995a) model, a UAS operator possessing the three levels of SA can ultimately exhibit better decision making and improved mission success. The following section will describe the impact of influencing factors on each stage of SA and how these factors influence SA in a UAS setting. Particularly, the impact an integrated display, such as a HUD, could have on the influencing factors of SA in a UAS setting is discussed. The model, as shown in Figure 1.1, will serve as the framework for understanding the importance of maintaining high levels of SA, and the methods for facilitating the development of high levels of SA. Then, research presenting issues in UAS related to SA is
discussed. Finally, how SA theory can be leveraged to improve UAS operations through interface design is discussed.

**Level 1 SA: Perception of the elements.** Endsley’s (1995a) first stage of SA involves the operator perceiving or noticing elements from his or her environment, including related dynamics and characteristics of that element. Before an operator can understand any given situation, the operator must collect information available over time, within the environment. Ware (2004) describes this perception process as (a) choosing to attend to elements, (b) then collecting element information such as color, movement, location, and the change in that information, and (c) using memory and focusing attention on key elements to find patterns in information. The perception of those elements is then used to create meaning—otherwise defined as Level 2 SA (Endsley, 1995a; Ware, 2004).

Individual factors that influence the perception of elements include the operator’s goal, pre-filtering of information during scans, and attention (Endsley, 1995a). Pilots can often funnel their attention on a specific task, especially when malfunctions occur, resulting in neglect of other sources of information (Merwe, Dijk, & Zon, 2012; Wickens, 2002). In the context of UAS, Barnes and Matz (1998) discovered that the most common cause for crashing the hunter UAV in a simulator was the operator’s narrowed attentional focus on targeting tasks and failure to focus on flight task information. Given that UAS operation requires a great deal of multitasking unless salient cues are present, operators may fail to give
attention to elements that lead to safe operation (Endsley & Jones, 2004). In addition, UAS operators may distribute their attention differently. For instance, UAS operators flying for film capture, and operators flying for search and rescue, have vastly different goals and will therefore likely distribute their attention differently. However, routine flight information is still vital for mission safety in both situations. Related to the context of the current study, Wickens (2002) emphasized that displays that can integrate both routine information with safety and critical, goal-relevant information can help prevent the funneling of attention. Improving the displays by incorporating vital mission information into the field of view may prevent the neglect of this information in a UAS context.

Task-related factors that influence Level 1 SA include workload, stress, and system characteristics such as automation and cue saliency (Endsley, 1995a). As workload and stress increase, the amount of resources that can be allocated to information collection is limited. Driving research has found that distracted drivers limit their outside environment scans, focus more on operation tasks, and collect more general and less detailed information (Young, Salmon, & Cornelissen, 2013). Medical research has shown integrated displays aimed at increasing SA can decrease condition detection time and absorption of information over time and may also result in reduced cognitive workload when attempting to draw meaning from multiple data sources (Zhang et al., 2002). However, it should be noted that reviews
of research evaluating this relationship have revealed mixed results between the two variables.

Vidulich (2000) reviewed 18 studies looking at the impacts of interface design on SA and mental workload and found equivocal findings. It was discovered that changes to interfaces that added information resulted in improved SA and increased mental workload. On the other hand, studies that simply reorganized/represented existing information on an interface resulted in improved SA and decreased workload. This is due to the change in the amount of information presented to the operator. As more information is presented, attention is more sparsely allocated to each piece of information, resulting in increased workload as the operator works hard to attend to all information and maintain SA. When applied to the current study, the relationship between interface integration and workload, during UAS operations with a HUD interface, could impact performance and SA, either negatively or positively. Therefore, the current study analyzed workload from an exploratory perspective to determine the impact of interface design in a sUAS setting.

In the context of this study, distributing attention across all sources of information is key for accurate Level 1 SA in UAS operations. UAS operators must divide attention between: (a) task-related information such as a video feed, (b) system-related information such as battery life, and (c) regulation and safety information such as global positioning system (GPS) location and altitude. The
research on Level 1 SA impacts presented here highlights that high stress and workload tasks require systems to support the operator in ways that decrease workload and promote attention to sources of information. For example, a UAS operator attempting to map the size of a wildfire is concerned with UAV GPS location data and altitude to approximate information about the fire. A UAS operator that is filming an accident along a highway for a news channel is concerned with the video feed data. However, both of these operators may become absorbed in the completion of the mission task and fail to perceive elements that are critical for safe UAS operation, resulting in a collision of the UAV with environment hazards or running out of battery power.

Perception of these elements is key for mission success and operation safety and serves as the foundation for more advanced forms of SA. A HUD interface design for UAS could help mitigate neglect to information sources by integrating information into one display. The reduced distance between information sources and the improved salience of information as it resides in the peripheral vision could lead to improved Level 1 SA. The strengthened Level 1 SA could potentially lead to improved Level 2 and Level 3 SA, ultimately leading to improved decision making and performance.

**Level 2 SA: Comprehension of the current situation.** The second stage of SA is described by Endsley (1995a) as comprehension of the current situation and involves the processing and organizing of the information to give meaning to the
current state. Comprehension is described by Wang and Gaforov (2010) as a process in which humans look for relationships between information sources or characteristics to find meaning. Wang and Gaforov (2010) proposed that meaning similar to Ausubel’s (1963) theory of meaningful verbal learning where derived by comparing the new information to previous information or knowledge, and determining a likely interpretation based on past experiences. Further, if new information is lacking or cannot be compared against existing knowledge, incomprehension occurs.

Level 2 SA is impacted by individual factors including memory, experience, and training, as existing knowledge feeds comprehension (Endsley, 1995a; Wang & Gaforov, 2010). Sohn and Doane (2004) discovered that novice pilots with higher working memory capacities had higher levels of SA as it allowed them to continually acquire information, which is a need for novice performers. For experts, on the other hand, higher levels of SA were associated with higher long-term memory capabilities, as experts rely more on mental models and past experiences and thus are less reliant on working memory. According to Endsley (1995a), novices, or those with incomplete mental models, may need to revisit information frequently or refer to additional sources of information to understand what is occurring. However, experts can rely on less information and still elicit high performance, as experts rely on past experiences and mental models to project to the future. Research has shown that ATC personnel can determine a traffic conflict
from only a few pieces of information, and are more effective when they extract specific pieces of information as not all information is necessary for improved performance (Mogford, 1997). In the driving domain, experienced drivers can recall more information than novices even when distracted with cell phone use, as experts can rely on less information (Kass, Cole, & Stanny, 2007).

In the context of this study, novice UAS operators may need to frequently check the controller display and the physical UAV in the environment to determine whether the UAV is flying towards or away from them. However, an expert may be able to reference only one of these sources and be able to infer the other from long term memory and mental models, to comprehend its flying direction. Although Level 2 SA relies more heavily on characteristics of the individual, the HUD interface design may facilitate Level 1 SA and improve information gathering that can lead to a stronger and more accurate Level 2 SA.

**Level 3 SA: Projection of future status.** The third stage of Endsley’s (1995a) SA model involves taking the current understanding of the present situation and being able to predict the future state. Achieving Level 3 SA can allow an operator to make an effective decision in the current state and prepare for the future state. In the military domain, experts can more effectively utilize battlefield information compared to novices (Walker et al., 2010). Having high Level 3 SA allows an operator to consider all possible decision alternatives and select an alternative that is perceived as the best outcome to achieve the goal (Endsley,
For example, in the UAS domain, a UAS operator will need to determine how much battery time is left, and the remaining tasks needed to complete the mission, to effectively decide on the remaining flight plan. Endsley (1995a) stated that operators need a very well-established Level 2 SA to reach Level 3 SA, and it is only with experience and correct mental models that this can be achieved.

Level 3 SA is influenced by an operator’s expected outcomes, training, and past experiences that have informed an operator’s mental models. Level 3 SA allows the operator to correctly project into the future. Interfaces that project future states can help facilitate a better Level 3 SA—and consequently more informed decision making, and effective and correct actions. In the driving domain, AR turning aids have been shown to improve driver decisions on safe opportunities to make left-hand turns (Tran, Bark, & Ng-Thow-Hing, 2013).

Therefore, in the context of this study, integrating information may result in improved Level 1 and Level 2 SA allowing for Level 3 SA to be developed. By utilizing a HUD interface display, operators may be able to absorb information from multiple sources more effectively without neglecting information (Level 1 SA). Subsequently, operators can more accurately derive meaning (Level 2 SA), leading to accurate predictions of the future state of the environment (Level 3 SA), which can lead to improved performance and mission success.

**Improving SA for UAS operations through interface design.** For UAS operations, improving SA can help an operator determine the best flight plan and
where to fly the UAV next. Riley and Endsley (2004) presented SA requirements for unmanned ground vehicle (UGV) search and rescue tasks. These requirements were utilized as a framework for UAS SA requirements for the current study. A replication of Riley and Endsley’s SA requirements, which have been altered from a UGV use case to a UAS use case, are presented in Table 2.1. In the context of the current study, operators utilizing HUD interface designs should be able to more accurately determine the status of the UAS for the items presented in Table 2.1, compared to utilizing a traditional interface design.

Based on Endsley’s (1995a) model of SA, in a UAS search and rescue mission, individuals with these higher levels of SA should be able to achieve more effective decisions and outcomes. Operators with high levels of SA should be able to: (a) utilize the battery life more efficiently, (b) make better flight plan decisions, (c) identify targets more quickly, (d) identify a greater number of targets, and (e) achieve better mission outcomes. However, the current issue is how to facilitate these higher levels of SA, in UAS operators, for visual search tasks.

To help develop an understanding of the problems and user needs during unmanned ground vehicle (UGV) search and rescue operations, Riley and Endsley (2004) conducted an analysis of SA issues that arise during an UGV search and rescue task. Participants remotely piloted a ground robot for a simulated search and rescue mission, looking for victims trapped inside a collapsed building. Participants were asked to describe information that was important during their mission, the
### Table 2.1

**Example SA Requirements by Level of SA for a Search and Rescue Task**

<table>
<thead>
<tr>
<th>UAV Status</th>
<th>Level 1 SA</th>
<th>Level 2 SA</th>
<th>Level 3 SA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Speed</td>
<td>Vehicle Operations</td>
<td>Projected</td>
<td></td>
</tr>
<tr>
<td>Location</td>
<td>Distance traveled</td>
<td>Location of UAV</td>
<td></td>
</tr>
<tr>
<td>Heading</td>
<td>Area covered</td>
<td>Destination</td>
<td></td>
</tr>
<tr>
<td>Operator location</td>
<td>Proximity to object</td>
<td>Actions</td>
<td></td>
</tr>
<tr>
<td>Distance from base</td>
<td>Likelihood of damage</td>
<td>Damage</td>
<td></td>
</tr>
<tr>
<td>Battery level</td>
<td>Impact of orientation</td>
<td>Collisions</td>
<td></td>
</tr>
<tr>
<td>Lights</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

| UAV Characteristics      |                             |                             |
| Size                     |                             |                             |
| Configuration            |                             |                             |
| Weight                   |                             |                             |
| Trim/propeller status    |                             |                             |

| Objects/Obstacles        |                             |                             |
| Object characteristics   |                             |                             |
| Location of object       |                             |                             |
| Distance to object       |                             |                             |

| Task/Mission Objectives  |                             |                             |
| Time in location         |                             |                             |
| Time on task             |                             |                             |
| No. of tasks completed   |                             |                             |

| Quality of Communications|                             |                             |
| UAV with controller      |                             |                             |
| Signal strength          |                             |                             |
| GPS                      |                             |                             |

| Weather Conditions       |                             |                             |
| Search Area              |                             |                             |
| Partitioning of search area |                       |
| UAVs assigned to area   |                             |                             |
| Search strategy         |                             |                             |

| Detections               |                             |                             |
| Type of sensors detecting|                             |                             |
| Number of targets identified |                       |
| Results of past searches |                             |                             |

| Cameras                  |                             |                             |
| Functional status        |                             |                             |
| Orientation status       |                             |                             |
| Zoom                     |                             |                             |

**Impact of Weather**

<table>
<thead>
<tr>
<th>Level 1 SA</th>
<th>Level 2 SA</th>
<th>Level 3 SA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Impact of Weather</td>
<td></td>
<td></td>
</tr>
<tr>
<td>On time to complete</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Visibility</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Communications</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sensors</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

| Sensor Operations          |                             |                             |
| Camera position vs heading |                             |                             |
| Potential for latency      |                             |                             |
| Sensor coverage            |                             |                             |
| Likelihood of detection    |                             |                             |
| Quality of area covered    |                             |                             |

| Tasking                    |                             |                             |
| Task status                |                             |                             |
| Impact on mission plan     |                             |                             |
| Task priority              |                             |                             |
| UAS ability for mission    |                             |                             |

**Note:** Adapted to a UAS use case from Riley and Endsley (2004).

limitations of their current interface, and the difficulties they experienced during times with and without VLOS. Some of the key issues discovered during this
analysis included that operators: (a) quickly became disoriented and lost awareness of where the robot was in the environment, once the robot left VLOS; (b) spent significant time and mental effort attempting to become oriented in the environment, and often maneuvered the robot back to a checkpoint to become reoriented; (c) split efforts between monitoring the camera feed to assess the environment to determine where to move the robot next, and monitoring the system status and parameters; (d) experienced difficulty with distance judgments and object recognition, and often had to move the robot close to objects to accurately identify and pinpoint victim body parts; and (e) observed that the interface did not effectively integrate information (e.g., gave individual actuation information instead of synthesizing the data for the operator into a metric that is easily understood) that resulted in operator errors such as the robot flipping over. The issues experienced by the participants were a result of high mental workload, high task complexity, and poor interface design. This resulted in operator errors and misjudgments.

The UGV task required a robot operator, a searcher, and a map developer to accomplish the task. These three individuals required specific information from the robot. Due to the robot’s design, a non-experienced robot operator is unable to effectively pilot the robot because of the complexity of the design and interface. Riley and Endsley (2004) posited that if an interface synthesized and integrated the information, the task could be completed by one individual and result in higher SA.
In the context of this study, given the similar nature of these tasks, similar improvements could potentially help UAS operations. By integrating information over the operator’s VLOS, UAS-guided search and rescue missions may result in a similar outcome: higher levels of SA for one-man operation.

A factor that can be feasibly influenced to improve UAS operator SA is the UAS interface. Endsley’s (1995a) theory and discussion suggest that an interface with specific characteristics can facilitate high levels of SA. The current state of the VLOS UAS interface requires split attention between real-world cues and critical flight task information. A comparison of current UAS interfaces to each of Endsley’s interface guidance points along with the impacts to SA are presented in Table 2.2. It is clear from this comparison that there is an opportunity for improvement of current UAS interfaces. If all critical task information could be incorporated into a heads-up field of view, the interface would more adequately adhere to Endsley’s guidance for SA-facilitating interfaces.

There are many different ways in which information can be integrated into displays to support more efficient attentional processes. Integrating displays can include merging multiple sources of information into one type of display, integrating information contingent on the task at hand, presenting similar types of information together, or presenting display information over environmental
Table 2.2  
_UAS Interface Compliance with Endsley's SA Interface Guidance_

<table>
<thead>
<tr>
<th>Endsley Interface Guidance&lt;sup&gt;a&lt;/sup&gt;</th>
<th>UAS Interface Compliance</th>
<th>Description</th>
<th>Impacts to SA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Salient Cues for Attention</td>
<td>No</td>
<td>The task information is currently separate from VLOS of the UAV and requires split attention. Operator will only notice if they look down.</td>
<td>Level 1 Errors – Failure to attend to information</td>
</tr>
<tr>
<td>Presents all Necessary Information</td>
<td>Partial Compliance</td>
<td>Operator must choose which source to attend to at any given time and cannot perceive all sources of information at the same time.</td>
<td>Level 1 Errors – Failure to attend to information</td>
</tr>
<tr>
<td>Prevents Information Neglect</td>
<td>No</td>
<td>Forces neglect to one source of information if the operator is attending to the other source.</td>
<td>Level 1 Errors – Failure to attend to information</td>
</tr>
<tr>
<td>Integrate Sources of Information</td>
<td>No</td>
<td>Does not integrate sources. Task information and environmental information are currently separate.</td>
<td>Level 2 Errors – Failure to correctly comprehend the situation</td>
</tr>
<tr>
<td>Allow Source Comparison</td>
<td>Partial Compliance</td>
<td>Operator can compare sources but only if the operator elects to hold the external display up into the line of sight, which is not sustainable for long duration flights.</td>
<td>Level 2 Errors – Failure to correctly comprehend the situation</td>
</tr>
</tbody>
</table>

<sup>a</sup>As summarized from Endsley (1995a).

Environmental integration in displays has been prevalent within various domains that require high levels of information in high workload operations. Generally, environmental integration is achieved through:

- Synthetic vision systems in which virtual terrain is presented behind task information. These systems are often seen in aircraft, with flight task information presented over virtually rendered terrain information, for collision avoidance.
• HDDs in which environmental data and task information are presented in a singular display separate from the real-world view. Heads-down displays such as ground control stations provide flight task information integrated with live camera imaging from a UAS on a separate display allowing for BVLOS operations.

• HUDs in which task information is provided within the real-world view. HUDs are used in cars to present driving speed in the line of sight of the road.

• Head-mounted displays (HMDs) involve a large helmet-based HUD that travels with the operator’s head movements. These systems are often bulky and used in helicopters and fighter jets to identify enemy targets all around the operator.

• Head-worn displays (HWDs) or AR headsets involve a lighter, more form-fitting, system of a glasses-based HUD that travels with the operator head movements. For example, a surgeon may wear an HWD presenting patient vital information in peripheral view while surgery is performed. Some headsets additionally provide localized task information such as arrows pointing to screws in the real world during a maintenance task.

The main purpose of environmental integration is to reduce scan patterns and integrate information into one’s field of view (Curtis et al., 2010). For the
purposes of VLOS operations, HUD systems (including HMDs, HWDs, and AR headsets) are ideal as they facilitate VLOS of the real-world. For UAS operations, environmental integration could include integrating task information over camera streams for BVLOS operations or integrating task information over the view of the UAS via AR for VLOS operations.

A secondary purpose of environmental integration technology in displays focuses on presenting new symbology or tools over real-world information (Arthur, Kramer, & Bailey, 2005; Bailey, Kramer, & Prinzel, 2007; Wickens, Alexander, Horrey, Nunes, & Hardy, 2004). Generally, displays with new symbology include information previously unavailable to the operator from other sources such as guidance symbology, target identifiers, and attitude recovery guidance that overlay the environmental information (Wood & Howells, 2017; Abbott, 2017; Melzer, 2017). Adding new symbology can affect other aspects of performance, such as workload (Vidulich, 2000). Displays with new symbology pose new considerations such as increased workload, interface design considerations, and pre-task planning. Environmental integration in sUAS VLOS operations is still in its infancy and its effectiveness has yet to be studied in this context. This evaluation must take place before new symbology is considered.

The current study examined environmentally integrating flight task information into the interface through a HUD design for sUAS operations. The goal was to allow for improved perception of the environmental elements together,
which, according to SA theory, can lead to improved SA, decision making, and performance. Insight can be gained by reviewing the literature associated with all forms of environmental integration and various information-rich environments. The following section reviews studies with the primary focus of evaluating the impact of a range of different types of environmental integration, such as HUDs, on operator SA and performance.

**Review of Past Research on Environmental Integration and HUDs**

There are several studies with results that suggest environmental integration has the potential to increase SA for UAS operations. These include research in related domains considered high workload environments, such as automotive, medical, and manned flight. The next section presents research that has shown environmental integration to be beneficial to SA and performance in these domains.

**HUDs in information-rich environments.** The following section discusses research that focuses on the integration or reorganization of status information available to the operator, into one’s field of view, or over environmental data. The section focuses on research in industries that are information-rich, elicit a high level of workload, and are prone to errors from operators, including: medical, maintenance, automotive, and manned flight. Due to the relevance of manned flight to UAS operations, statistical information is presented only for studies focused on manned flight and UAS operations.
Medical operations. Monitoring patients under anesthesia is one of the more demanding tasks during surgery in medical operations. Similar to UAS operations, both industries require attention split between real-world information and secondary displays that provide critical task and patient information. Liu et al. (2009) studied the effect of AR on anesthesiologists. Participants were asked to perform normal tasks for an anesthesiologist in both traditional operation methods, and while wearing an AR headset that provided patient information such as heart rate, blood pressure, and CO₂ levels. It was discovered that participants wearing the AR headset spent significantly more time looking at the patient than the anesthesia machine, compared to traditional operation. The time duration spent looking at the anesthesia machine was also significantly lower when they were wearing the headset. In addition, participants rated their workload as lower, found it easier to monitor patient vitals, and had higher subjective ratings of event detection when presented with patient information on the headset.

From a performance standpoint, AR in spine surgery has shown positive benefits. A review of medical studies by Yoon et al. (2018) revealed 76 cases of using HWDs to provide a HUD during surgery. Studies were reviewed for the use of AR HWDs during surgery (simulated or real). Out of 427 studies that used some form of AR or wearable devices, 74 were included that specifically used AR HWDs to guide the surgical process. The results revealed that providing a HUD on a HWD resulted in many benefits in a range of surgical domains including reduced surgery
times, reduced expense of surgery, increased situation awareness, and the potential
to prevent accidental movements during surgery when attempting to see patient
information or camera monitors in traditional setups. These benefits were observed
in an array of medical specialties including neurosurgery, dermatology, anesthesia,
and plastic surgery.

In a study conducted during live orthopedic surgery using a traditional
display versus an integrated x-ray system, Heide et al. (2017) evaluated the number
of x-ray images needed. Heide et al. developed a display system that incorporated
x-ray image information onto live imaging that allowed surgeons to see injuries,
such as fractures, overlaid on the patient’s real-world body part. Generally,
surgeons use the imaging systems to guide the surgery to determine additional work
needed, by taking images during the surgery, to determine if more bone fragments
need to be removed. It was found that the overlaid imaging system significantly
reduced the number of x-ray images needed to guide the surgery, thereby reducing
the amount of radiation to the patient without increasing task time (Heide, et al.,
2017).

In a study conducted using AR via Google Glass and traditional video
display monitors during spinal surgery, Yoon et al. (2017) evaluated the speed of
screw placement. The AR display allowed the surgeon to see the position of where
the screw would be placed up close on Google Glass. It was found that in a task
requiring placement of more than 50 screws, the surgeons, on average, were able to
complete the placement of each screw 45 seconds faster when utilizing the AR glasses. The researchers noted that the small reduction in time is practically significant as the costs to hospitals during surgery operations is substantial. Overall surgeons experienced higher anxiety when first using the AR glasses, due to the change in procedure, but ultimately found the system helpful. Surgeons also spent less time looking away from the patient, which is a behavior that can cause unintended movements and injury to the patient.

**Automotive operations.** Research associated with environmental integration in the automotive industry has evaluated both HDDs in the dashboard and HUDs in the windshield. Allowing drivers to view driving task information and environmental information could help with tasks such as navigating and maintaining safe driving speeds (Akaho et al., 2012; Doshi, Cheng, & Trivedi, 2009). In a study by Akaho et al. (2012) a traditional heads-down navigation display depicting virtual roads and path guidance was compared to two AR displays that showed path guidance lines over live video feed of the road ahead. One AR display overlaid yellow on all roads on the video feed with a green line depicting the route. The other AR display depicted only the route to navigate in yellow. Three participants each drove using the different navigation displays for over 50 minutes. It was found that the AR display depicting both side roads and the navigation route resulted in more time staring at the navigation display due to the higher information load. However, the AR display depicting just the navigation route over the
environment resulted in similar time to identify the correct intersection to turn, compared to the traditional navigation display. In addition, participants felt more confident in determining the road on which to turn when using the AR displays. Results also indicated that the AR display’s impact on comprehension depended on the current distance to the turn. The traditional display assisted drivers most when roads were occluded or far away, as the navigation information was not obstructed by buildings in the display. The AR display was shown to help drivers specifically when located at an intersection on narrow roads, and in areas with close knit side roads. These types of scenarios require distinguishing exactly where one is and determining which road to turn on when options are very close together. The findings from the Akaho et al. study demonstrated that augmented navigation overlaid with real environmental information can help the operator distinguish details in a navigation display, understand navigation instructions more clearly, and increase driver decision confidence.

Other research has focused on creating a HUD for drivers. A survey conducted by Guo, Zhao, Wang, and Jiang (2014) asked 539 drivers to rank what information would be most critical to include in a HUD during normal daily automobile operations, and to provide input on HUD design preferences. Drivers expressed the highest desire for the following information to be displayed: (a) distance between self and leading car, (b) driving speed, and (c) traffic information, and for less emphasis to be placed on status information such as tire pressure or
engine failures. In addition, drivers preferred numerical displays of speed, and simple arrows for navigation, instead of full map displays. Drivers also indicated a preference for information to be located above the steering wheel as opposed to the sides of the steering wheel (Guo et al., 2014). The findings from this survey suggest that information relative to basic driving functions is the most vital of information to drivers. Additionally, it appears critical to bring that information as close as possible to the view of the outside environment.

Doshi et al. (2009) evaluated the impact of different speeding symbology on driver distraction utilizing a HUD. Three different versions of speeding indicators were projected onto the windshield at the 2-o-clock position from the driver’s wheel. These included: (a) a warning symbol that appeared only when speeding, (b) a fraction symbol of actual speed over the speed limit, and (c) a dynamic bar symbol that displayed numerical readings of current speed with respect to max speed limit. Participants drove a car with the HUD technology on actual roads, with speed limits varying from 15 to 60 miles per hour, for 20 minutes, utilizing each speed indicator display. The car was also fitted with an eye tracking system to collect gaze data. It was found that the bar symbol required too much cognitive processing for it to be useful to the driver. The time to slow down after viewing the bar symbol took longer than the warning symbol and had the longest amount of time spent looking at the symbol, indicating more effort to understand the status of speeding. The fraction symbol successfully kept the drivers eyes up and was
successful at directing driver attention to the symbol located above, resulting in a 63% decrease in time spent looking down. The warning symbol resulted in the highest reductions in speeding of 62%. This was due to the saliency of the symbol, as it only appeared when speeding, and drivers were less likely to notice speeding with the persistent numerical display. The results showed that environmental integration in the driver’s seat can reduce time spent looking down and reduce driver errors.

Lindemann, Lee, and Rigoll (2018) incorporated automobile status, route information, and traffic rules for the area, into a HUD above the steering wheel. In a VR driving simulation study, participant performance utilizing the HUD was compared to performance while using traditional dashboard and navigational display interfaces, in various visibility conditions. During the routes, the participants were given freeze probes to measure SA. Freeze probes involve pausing the task and asking questions directed at all three levels of SA at the time of the pause, and then coding participant responses as correct or incorrect. The results showed that the HUD improved SA for drivers as the average number of correct answers to the freeze probes was significantly higher in the HUD conditions. In addition, the decrement in SA normally caused by poor weather was lessened when given the HUD compared to the traditional displays. The results from Lindemann et al. show the benefits to operator SA by providing critical task information in a HUD aligned with environmental information.
On the contrary, similar studies by Tangmanee and Teeravarunyou (2012) have shown that providing information on a HUD for driving tasks had adverse effects on driver attention. Five participants completed a 30-minute simulated driving task with various arrow guidance symbology, while eye tracking data were collected. The addition of symbology resulted in 52.9% of driver fixations being allocated to the symbology as opposed to the environmental cues such as the road. Arrows that were presented off-set from the center field of view resulted in longer durations of gaze shifts away from the road, compared to arrows that were displayed in the center field of view. In addition, inexperienced drivers looked at the navigation arrows more frequently than experienced drivers. The results from Tangmanee and Terravarunyou revealed the potential negative effects of utilizing environmental integration in displays—the drawing of attention away from critical environmental cues.

Although research conducted by Lindemann et al. (2018) indicated that adding information to the windshield may provide benefits to SA and decision making, Tangmanee and Teeravanrunyou’s (2012) findings cautioned that creating new compelling display features may lead to attention tunneling, which has been shown in other industries to cause more operator errors (Wickens, 2009). Therefore, design of HUDs for the automotive industry must balance the benefits of presenting information in line of sight, with distracting drivers with that information.
**Maintenance operations.** According to Oliveira, Araujo, and Jardine (2014), for maintenance domains, SA is needed for various aspects such as the environment, task, equipment, system, and shift, or deadline information. The researchers posited that the use of traditional manuals can result in attentional tunneling into the task manuals, lack of task understanding, lack of understanding relative to tool risks, and failure to understand how tools should be used when diagnosing issues. The use of AR technology in maintenance tasks is quickly gaining traction. Using AR tablet applications to guide performance of maintenance tasks on parts such as engines allows information to be readily available during performance and has gained positive feedback from maintainers (Aromaa, Aaltonen, Kaasinen, Elo, & Parkkinen, 2016). However, research on AR and environmental integration in the maintenance field is currently in its infancy. Limited empirical research has been published within this field. One empirical evaluation by Henderson and Feiner (2009) compared utilization of AR headsets to use of a liquid-crystal display (LCD) for a maintenance task. Participants were military personnel presented with the task of repairing an armored vehicle. The AR condition consisted of location cues and labels overlaid on the parts in the real world along with maintenance instructions. A HUD condition was included to control any impacts on performance caused by wearing a headset and consisted of instructions presented in the corner. The HUD condition offered no location cues that the AR condition offered. The LCD condition consisted of a display that was
fixated in the vehicle to the right of the mechanic. A total of six participants engaged in 18 maintenance tasks all conducted in the left seat of the vehicle. Each task required under 5 minutes to complete. It was discovered that the AR condition resulted in quicker time to locate parts and less head movements to locate parts compared to the other two conditions. However, Henderson and Feiner noted that the LCD condition had the fastest total task completion time due to the LCD providing the most unobstructed view once the part was located. Maintenance personnel also rated the AR display as satisfying and intuitive (Henderson & Feiner, 2009). AR for maintenance tasks appears promising, however, research in this field is still developing.

The research discussed presents many benefits of environmental integration. Based on findings from the medical industry, environmental integration can facilitate more time spent looking at the patient, quicker diagnosis of issues, and faster surgeries. In the automotive industry, environmental integration has been shown to facilitate better SA about the environment and reduced driving errors. In the maintenance industry, environmental integration has led to reduced task time. All of these industries provide insight into how UAS operators may improve through the addition of HUDs. However manned flight operations is the most relevant domain from which to draw findings, as the two share many characteristics such as information types, flight requirements, collision avoidance responsibilities,
and resource management. Further, manned flight has a more robust history of AR and environmental integration from which to draw conclusions.

**Manned flight operations.** SA in the manned cockpit relies heavily on understanding information from the environment and instruments within the cockpit, and how this information impacts the mission (Abbott, 2017). The following section will discuss different methods of environmental integration in the cockpit, specifically displays that have combined task or mission information with environmental information in manned flight operations. To understand the impacts of environmentally-integrated interfaces on manned flight, these types of displays will be discussed first to present the positive and negative impacts. Then, HDD and HUD concepts and the studies that have compared the two interface types will be presented. These studies illustrate the potential improvements from transforming VLOS UAS operations from HDD interfaces to HUD interfaces. Studies discussing the impacts of HUD interfaces will be discussed in greater detail than previous sections due to the relevancy to the current study.

**Adding environmental information in aviation systems.** HDD aviation systems can include synthetic vision systems that virtually recreate environmental terrain in the cockpit for environmental awareness in low visibility conditions. According to a concept of operations by NASA for commercial aviation synthetic vision systems, these displays can improve performance and SA with respect to runway incursions, terrain avoidance, and response to abnormal events (Williams et
al., 2001). From a physiological perspective, research by Uenking and Hughes (2002) has shown synthetic vision Primary Flight Displays (PFD) to reduce workload. A total of 27 pilots with varying levels of flight experience flew 35 simulated en route and approach flight scenarios. Participants flew with both traditional and various synthetic vision system concepts while physiological measures were collected. Results showed pilots experienced lower skin temperature during the approach phase with the synthetic vision systems, $F(1, 19) = -2.831, p = .01$. Pilots also experienced lower heart rate with synthetic vision systems although this difference was not significant. Uenking and Hughes posited these differences in physiological values are indicative of lower workload and higher comfort. Additionally, higher levels of situational awareness, as measured via the SART, could have led to lower cognitive workload as the display made it easier to understand the current status of the aircraft.

Research by Arthur et al. (2005) examined an environmentally-integrated Navigation Display (ND) and PFD, as well as tunnel guidance symbology. Ten pilots flew 145 test flights using traditional displays and environmentally-integrated displays that overlaid a 3D texture to depict terrain over traditional ND and PFD information. It was discovered that the traditional display setup resulted in significantly higher pilot workload $F(3, 33) = 8.47, p < .05$ and lower SA levels $F(3, 27) = 8.18, p < .05$, as well as poorer performance (not statistically significant), compared to the environmentally-integrated ND and PFD. Arthur et al.
noted that these findings could be due to the guidance symbology and not the terrain.

Other research on this topic has shown equivocal results. Wickens et al. (2004) evaluated the effects of adding terrain information on a synthetic vision system along with a tunnel guidance system. A total of 14 pilots flew simulated approaches through complex terrain in a total of eight scenarios, each with and without terrain and guidance symbology. For flight path performance, improvements resulted from the tunnel guidance system, $F(1, 13) = 96.5, p < .01$, but no significant effect was seen with terrain information.

However, for runway incursions, Bailey et al. (2007) studied the effects of an integrated display that included: (a) forward-looking infrared (FLIR) imaging, (b) synthetic vision environmental data, and (c) aircraft status information. The integrated display was presented on a HUD for pilots flying and on an auxiliary display for pilots monitoring. A total of 24 pilots with HUD experience flew a visual arrival into an airport in a simulator. In addition, symbology depicting the path to fly was rendered in the synthetic vision for some conditions. The pilot flying and pilot monitoring experienced the highest levels of SA when performing with the integrated display concept when symbology was presented (pilot flying: $F(3, 69) = 43.61, p < .001$; pilot monitoring: $F(3, 69) = 37.78, p < .001$). However, little to no difference in performance relative to runway incursions was observed across display conditions. Therefore, the gains of added symbology over
environmental information appears to be task dependent (Geiselman & Osgood, 1994).

Snow and Reising (1999) took a different approach and, in a simulation study, looked at the effects of adding different versions of environmental data to path guidance on a HUD. Four different types of terrain depiction were utilized, including: (a) a full grid format, (b) a texture format, (c) a partial grid format, and (d) no terrain information. It was found that there was no difference in flight performance across display conditions, as measured by errors off the flight path. This suggests that pilots utilized other information on the HUD to maintain performance. However, four ground collisions occurred in the no terrain and partial grid conditions implying a lack of SA in those conditions as participants had incorrect comprehension of the location of the terrain. This behavior was further supported by SA ratings, as grid and texture conditions received the highest SA ratings with significantly lower SA ratings for the partial grid and no terrain conditions $F(3, 30) = 26.43, p < .001$. These results suggest that if guidance symbology is held constant, the addition of environmental information may result in positive gains in SA. The findings from the research presented suggest that environmental information may lead to gains in SA, and that the addition of informational symbology over terrain may assist pilot performance, depending on the task. However, caution must be taken as the addition of information may cause pilot information overload.
Wickens and Alexander (2009) noted that synthetic vision systems also have downfalls as they require rendering terrain prior to flight and include only static and unchanging ground information. Therefore, there is always the possibility of an object to exist in the outside world that does not exist in the synthetic vision system. A total of seven simulated experiments conducted by Wickens and Alexander included non-rendered objects outside the windscreen, such as a blimp or a new tower in the synthetic vision system. Across the seven experiments it was revealed that 45% of pilots failed to detect the anomaly occurring outside the windscreen due to attentional tunneling caused by the synthetic vision display. These effects are further shown in Schnell, Kwon, Merchant, and Etherington’s (2004) study that incorporated terrain information and guiding symbology on the PFD. Pilots completed approach procedures in a computer-based flight simulator while the researchers collected eye tracking, workload, and SA information. Results indicated that a PFD that provided terrain and guidance symbology led to reduced flight errors, workload, and time to complete one scan pattern when compared to traditional PFD displays. Schnell et al. noted attentional tunneling on the guidance symbology may have occurred. They explained that more attention was spent on the PFD but no changes in terrain awareness occurred. Schnell et al. noted this could be explained by the extra PFD time being directed at the guidance symbology; however, no adverse effects to this behavior were observed in the experiment.
As discussed above, when Wickens et al. (2004) evaluated the impact of adding 3D terrain and tunnel guidance symbology in a simulation study, similar results were found. Participants using the environmentally integrated displays experienced performance gains. However, Wickens et al. observed adverse effects as attentional tunneling resulted in higher numbers of missed events as indicated by participants failing to notice rogue traffic out the windshield that was not depicted on the displays. These attentional downfalls are potentially caused by the addition of new symbology, which not only results in higher SA, but can also lead to higher workload (Vidulich, 2000). However, in a review of HMD benefits and impacts, Melzer (2017) posited that bringing the information into a HUD can help mitigate the downfalls of attentional tunneling experienced when integrating information in a HDD.

**HDDs versus HUDs.** HDDs in the cockpit consist of PFDs and NDs that can include synthetic vision information. HUDs in the cockpit often consists of a see-through display mounted in the center forward line of sight for the pilot. Kramer, Prinzel, Bailey, and Arthur (2003) evaluated the differences in performance and situation awareness for (a) traditional displays, (b) synthetic vision systems in the PFD, and (c) A HUD with synthetic vision terrain. A total of 84 approach and departure flights conducted in a Boeing 757 were performed by six pilots. Pilot performance was collected by measuring vertical and lateral navigation errors. Workload was measured by collecting subjective ratings and SA.
was measured using the SA-SWORD, a subjective measure used for display configurations. The results revealed that both synthetic vision PFDs and HUDs led to a significant reduction in lateral path errors, \( F(3, 61) = 102.143, p < .001 \) and workload, \( F(6, 73) = 5.594, p < .001 \) compared to traditional displays. However, the heads-down PFD resulted in higher levels of SA than the synthetic vision HUD, \( F(6, 18) = 6.968, p < .001 \). Kramer et al. noted that the singular color design of the HUD may prevent performers from distinguishing overlaid informational cues from the environmental data, an aspect that needs further design consideration. The lack of color distinction may have resulted in performers who utilized the HUDs exhibiting lower SA scores.

However, other studies with monochrome and multicolor HUDs have not seen a difference in SA levels or flight performance with the addition of color (Arthur et al., 2017). These findings suggest that the PFD as the primary flight source may provide the most SA gains compared to the HUD due to the HUDs technical limitations. Research by Arthur et al. (2005) discussed earlier within this section also evaluated environmental integration utilizing HUDs during 145 live test flights. In addition to adding 3D terrain and tunnel symbology on an ND and PFD, the addition of a HUD with FLIR and tunnel symbology was also evaluated. It was found that offering an environmentally-integrated PFD and ND or an environmentally-integrated HUD led to equal levels of workload, SA, and performance (as indicated by non-significant analyses or post hoc analyses).
However, providing an environmentally-integrated ND and PFD in conjunction with an environmentally-integrated HUD resulted in additive effects of higher levels of SA than an environmentally-integrated PFD and ND or HUD alone, $F(3, 27) = 8.188, p < .05$. Access to environmentally-integrated versions of all three displays (HUD, PFD, and ND) is the most preferred by pilots. The studies discussed within this section have shown that integrating information can be beneficial for SA when utilizing both a HDD as well as a HUD with environmental integration (Arthur et al., 2005; Bailey et al., 2007).

Offering environmentally integrated HUDs or HDDs resulted in similar benefits to SA, workload, and flight performance, with the greatest benefits being experienced when both types of displays are provided and environmentally integrated (Arthur et al., 2005). Overall, based on the research discussed, environmental integration, in general, can improve SA, reduce errors, and improve performance. However, each method comes with caveats. The heads-down environmentally-integrated ND or PFD’s biggest downfall is the tendency to result in attentional tunneling, and performers becoming inattentive to other sources. The HUD’s biggest downfall is the low resolution, constraints on location (i.e., the pilot can only gain environmental information from directly in front of the aircraft), poor legibility in high lighting, and high workload due to the amount of overlapping information and lack of color options. In research discussed previously, Arthur et al. (2005) noted these downfalls as the potential reasons why HUDs with FLIR
imaging are associated with lower SA ratings, higher workload and lower preference by pilots. The technical limitations associated with HUDs require more cognitive processing by the pilots compared to the synthetic HDDs. HUDs that utilize high resolution displays, with low levels of clutter and with critical flight information may be more beneficial. These displays could result in improvements in SA, performance, and workload without the technical drawbacks. Bringing information into the line of sight with improved functionality and head centric operation could potentially mitigate some of the risks associated with heads-down and HUD operations.

*HMDs and HWDs.* Military industries have utilized environmental integration technology in the cockpit via Head-Mounted Devices (HMDs). An HMD is the same conceptual design as a mounted HUD, but the display is mounted to the operator and allows the operator to see information regardless of where they are looking. The pilot can look out the left side of the cockpit and still obtain task information, in addition to environment information to the left of the aircraft and is no longer limited to seeing task information when looking directly in front of the aircraft. Melzer (2017) discusses the benefits of HMDs in the cockpit as they allow the pilot to simultaneously view both vital flight information and the outside world, without limiting the pilot to environmental information directly in line with a mounted HUD. One popular use of HMDs utilized by pilots in the Apache helicopter allows for the overlay of critical flight data such as heading and altitude,
while simultaneously viewing outside the windscreen. Melzer elaborated that additional benefits to HMD technology include the ability to (a) cue information, (b) allow an operator to position their head to view information aligned with the outside world, (c) send commands or select targets while looking at the outside world, (d) focus attention on the environment outside the windscreen instead of being heads down on cockpit instruments, and (e) improve SA. Other implementations of environmental integration in an HMD system may include FLIR imaging or synthetic terrain.

Melzer (2017) described several limitations of HMDs, including that they can be heavy, expensive, and depth cues can be difficult to convey. Test flights with HMD technology have revealed issues related to discomfort, visual lag with head movement, and difficulty viewing information in harsh lighting (Korn, Schmerwitz, Lorenz, & Dohler, 2009). Funabiki et al. (2009) have shown FLIR imaging on an HMD can improve SA of terrain for helicopter search and rescue missions. However, the pilots noted that the symbology was hard to read. The HMD research presented in this section and early HWD concepts as researched by Thomas (2009) have shown negative impacts based on the technical limitations. HWDs offer a form-fitting light weight alternative to the bulky versions of an HMD.

The main difference of HWDs is the glasses-style fit as opposed to helmet-style fit with improved functionality and performance compared to HMDs. Thomas
(2009) evaluated the impact of an early concept of the HWD in a flight simulator experiment compared to HDDs and HUDs. Participants flew 12 landing approaches while flight performance data was collected along with subjective SA and workload measures. It was discovered that pilots using the HWD were more accurate on course in the initial approach compared to the HDD, $t(13) = 5.5, p < .01$. Subscales of the SA measure revealed participant’s level of understanding as significantly lower ($p < .02$), and attentional demands as significantly higher ($p < .01$) in the HWD condition compared to the HUD and HDD conditions. In addition, workload was rated as significantly higher in the HWD condition ($p < .01$). Thomas noted the technical limitations as the cause for the HWDs poor ratings. Participants experienced visual jitter on the display with head movements. In addition, the HWD would experience a visual lag with quick head movements. This resulted in pilots attempting to stay as still as possible and therefore prevented normal scan patterns. The display also required extra effort to focus on the image and draw information similar to the image quality issues experienced with HMDs. Thomas concluded that the technical issues cause individuals operating the HWD to experience lower SA than when operating traditional displays.

However, more recent light-weight HWDs with improved technology showed similar benefits to HMDs with lower costs and weight, and improved safety, display resolution, latency and stabilization (Arthur et al., 2005). Arthur et al. (2014) evaluated the more form-fitting HWDs compared to more traditional
HUDs using 12 pilots conducting departure and approach procedures in a full motion simulator. Pilots were evaluated based on their flight performance as measured by landing performance and piloting errors. In addition, subjective SA was measured using the SART, and workload was measured via the NASA-TLX. The HUD and HWD were shown to result in equivalent performance, errors, workload, and subjective SA ratings as indicated by non-significant results of analyses. However, Arthur et al. noted limitations with HWDs as the one used within the study had a latency of 85 milliseconds. Latency issues can cause long delays in information updates, image issues, and information misalignment with the real world which negatively impacts pilot understanding and SA (Arthur et al., 2014; Link, Kruk, McKay, Jennings, & Craig, 2002). Latencies less than 50 milliseconds are preferred to ensure effective pilot operations (Link et al., 2002). If technological issues could be resolved, the benefits of HWD with environmental integration could be realized. Moreover, the gains achieved in manned flight could potentially be replicated in UAS operations.

For UAS operations, AR glasses would be equivalent to an HWD in the cockpit. These systems are reported to have latencies of 16 milliseconds or less in experimental studies with AR integration using the Epson Moverio and Microsoft HoloLens systems (Kim, Hong, & Kim, 2018; Lang, Kota, Weigert, & Behrendt, 2018). Therefore, with recent technology, HWDs present the opportunity for the UAS domain to leverage this technology to facilitate SA gains.
**HUDs in UAS operations.** Currently, research on sUAS operations and display design is lacking. The following section describes studies that illustrate the issues discovered ground controls stations, and HDDs compared to HUD UAS interfaces, which have been shown to be more effective. Typical UAS interfaces display task or mission information obtained from the sensors on the UAS (in the case of sUAS, this could include satellite map data, heat map data, and video feed information; Endsley & Jones, 2004). The most prevalent evaluation in the field focuses on BVLOS UAS operations that require the use of an external display system for information and control. These systems are often called ground control stations.

Neumann and Durlach (2005) evaluated a micro UAS interface piloted BVLOS with manual flight controls utilizing a ground control station. Seven graduate students who were studying human factors participated in a micro UAS training module in which they were administered a usability questionnaire. The usability analysis revealed that many participants experienced serious issues with SA. Specifically, cues providing information related to the micro UAS speed and altitude were not salient and appeared as cluttered around various other task information. In addition, these parameters often changed location or would appear intermittently. As a result, many participants could not monitor these parameters and crashed the micro UAS. Neumann and Durlach noted that interface designs that are tailored for SA are needed to make these parameters more salient.
Other ground station research has evaluated picture-in-picture or dual visual system displays. A research study conducted by Calhoun et al. (2007) evaluated the impact of a smaller window of camera feed in the center of the display surrounded by a synthetic environment. Participants were asked to perform a search-and-identify task where operators were asked to find flags in the environment amongst other non-task relevant objects. Participants received either (a) no picture-in-picture display, (b) a window of the camera feed that filled 50% of the display and the other 50% was synthetic environment, or (c) a window of the camera feed that filled 33% of the display and the other 67% was synthetic environment. Participants were tasked to find a specific flag number in the environment. Time to complete task was collected along with subjective ratings of workload and SA. The results revealed a significant difference between the no picture-in-picture condition and the two picture-in-picture conditions, $F(2, 22) = 26.78, p < .001$. The average time to find targets was 144.2 seconds for the no picture-in-picture condition, 70.3 seconds for the 50/50 ratio, and 58.1 seconds for the 33/67 ratio. Findings also revealed significantly higher levels of subjective SA, $F(2, 22) = 8.96, p < .01$, and lower workload, $F(2, 22) = 17.62, p < .01$, when comparing the no picture-in-picture displays to the two picture-in-picture displays. There was no significant difference between the two picture-in-picture ratios. The findings suggest that integrating different view types into one display could improve SA and mission efficiency compared to non-integrated displays. By incorporating the real-world environment
field of view with camera feed and GPS location into one display, potentially the same impact could result for VLOS UAS operations.

However, the ability for sUAS to be controlled via a BVLOS ground control station (i.e., an interface on a device not located in proximity to the sUAS) is still not authorized in civil and recreational settings. A ground control station or a first-person view headset (that occludes all outside view of the environment) cannot be utilized in the field without a visual observer. These systems are not allowed for a single operator with current FAA regulations, due to the VLOS requirement (FAA, 2016). Hedayati et al. (2018) evaluated the impact of adding AR capabilities in UAS flight to allow VLOS, while simultaneously providing task information in a singular field of view. The experiment utilized a Parrot Bebop UAV with a camera. To control the UAS, the baseline condition utilized a tablet that offered touch controls and also displayed the UAV live camera feed. The AR conditions utilized a Microsoft Hololens headset for camera information and an Xbox controller to control the UAV. The headset was worn in all conditions to control for any effect caused by wearing the headset.

A total of 48 college students participated in a simulated inspection and mapping task. Participants were asked to position the UAV in front of an orange square on the wall and capture as much of the orange square in the camera frame as possible without any other content. Then participants were asked to turn the UAV around and navigate to a hard-to-reach purple square. This square required better
hovering skills and finite movements to capture only the purple square in frame. Participants were given 6 minutes to complete the task and were allowed to reset the UAS if it crashed. They were then administered a post survey that measured subjective responses regarding comfort, confidence, difficulty, and usability. In the baseline condition, participants were given the traditional tablet with UAS controls and a camera stream. In the AR condition, an Xbox controller was used for controls and three different forms of AR were utilized: (a) a geometric representation of the camera field of view that projected from the UAS to the objects in the real world to demonstrate what was in view of the UAS camera, (b) a UAV-centric live camera stream that was presented above the UAV in the real world and followed the UAV, and (c) a user-centric live camera stream that was presented in the upper right hand corner of the AR glasses. Results indicated that all AR conditions experienced improved accuracy of the pictures containing only desired objects, $F(3, 44) = 25.01, p < .0001$, but the user-centric interface resulted in the highest accuracy compared to the other two AR conditions, $p < .0001$. In addition, the AR conditions resulted in faster completion times, $F(3, 44) = 3.83, p = .016$, and less crashes, $F(3, 44) = 9.24, p < .001$, with the exception that the UAS-centric condition was not significantly faster than the baseline.

Significant differences were also found with respect to the amount of time spent looking away from the UAV. Post-hoc analyses revealed that all three AR conditions had reduced time spent looking away from the vehicle, $p < .0001$. 
compared to the baseline. In the baseline condition, participants shifted their gaze away from the UAV, on average, 50 times compared to an average of 5 times for the AR conditions, $F(3, 44) = 40.28, p < .001$. Participants rated the AR displays as significantly more comfortable, $F(3, 44) = 8.12, p < .001$, easier to use, $F(3, 44) = 4.17, p = .011$, and their confidence as significantly higher with use, $F(3, 44) = 7.93, p < .001$. Usability ratings for the AR displays were also significantly higher usability, $F(3, 44) = 7.38, p < .001$. However, the user-centric AR condition was not rated as significantly easier or more resulting in more confidence during use compared to the baseline. Hedayati et al. noted that their findings may be attributed to touchscreen controls for the baseline condition which may have resulted in less control over the UAS. However, it is discussed that the AR capabilities:

Enabled users to get live video feedback without taking their eyes off the robot [UAV], whereas current designs force users to make context switches that sacrifice either situational awareness of the robot in the environment or their ability to closely monitor the robot’s camera feed at any given time.

(Hedayati et al., 2018, p. 84)

Hedayati et al. proposed that incorporating the camera feed into the field of view could improve SA. These findings may have limited generalizability to visual search tasks in emergency operations due to fact that this study was conducted in a small indoor room with the UAV only a few feet away. Long distance operation may require more information for the operator such as GPS connection status,
altitude, and speed. In the case of inspection and mapping tasks, where the UAV is operated in close proximity, the findings from Hedayati et al. (2018) may be generalizable. Caution should be taken when interpreting the results of Hedayati et al. with respect to other applications such as search and rescue as it was limited to the capture of two targets, in a small indoor environment, over a 6-minute time period.

Simulated long distance UAS operations have been studied by Ruiz, Escalera, Viguria, and Ollero (2015). The study compared three UAS interface configurations for a safety pilot. Nine participants acted as a monitoring safety pilot, which kept the UAS in VLOS while the UAV was controlled by operators at a ground control station, with the option to take over control if problems arose. The experimental task was completed in a VR room using X-Plane as a simulated UAS environment. Participants flew three scenarios using traditional verbal-only communication, a tablet interface, and an AR device, in random order. For the tablet condition, a custom interface was developed, that displayed UAS parameters and satellite map data. For the AR condition, a custom interface was developed, that displayed only UAS parameters. The AR interface was accomplished using a monocle device called the Laster Pro Mobile Device. The details and duration of the scenarios were not described by the researchers. SA was measured via SAGAT queries that were administered during two pauses per condition with 10 questions per pause. Workload was measured via the NASA-TLX. The AR condition resulted
in the lowest workload scores, although no statistically significant difference was
discovered among the three interfaces for overall workload scores. The AR device
demonstrated significantly higher SAGAT scores than the verbal communication
and tablet conditions, $F = 3.49, p = .046$. The researchers concluded that the AR
improved SA, was rated positively, and is important for maintaining SA in crew
operations. However, they also concluded that the technology would need to be
assessed in real-world scenarios with groups such as emergency services.

For search and rescue tasks, it may be necessary to include additional
information, such as altitude, relative distance, map view, and other mission-critical
information, on the heads-up view. One of the critical tasks for UAS operation is
power management. Jones (2005) defined the necessary task information to
determine if there is enough power left to complete a mission. Operators must have
access to many parameters including but not limited to: (a) wind characteristics
such as speed and direction, (b) altitude, (c) airspeed, (d) aircraft type, (e) amount
of fuel that will be used for remaining objectives, (f) importance of remaining
objectives, and (g) time needed to accomplish the objectives (as cited in Chappell &
Dunlap, 2006, p. 1932). All of this information is needed by the operator to achieve
Level 3 SA projection. For a search and rescue task, attentional resources can be
limited as the task can be highly demanding.
Adams et al. (2007) performed a task analysis of a wilderness search and rescue task using a UAS (see Figure 2.1). UAS operators in a search and rescue task are responsible for preflight tasks, flying the UAV to the search area, and scanning for the missing target. If a potential target is identified, the UAS operator has to convey the location to ground units and maneuver the UAS close to the target. Then, based on cues and information in the environment, the operator has to dynamically change the search strategy to narrow the search. For example, a UAS operator who finds a backpack of the missing person on the edge of his or her search pattern may readjust the search pattern to centralize around the backpack.

Figure 2.1. Hierarchical task breakdown of UAV-enabled search. (Source: Adams et al., 2007.)
The operator must also forecast the available resources needed to (a) land the UAS at a retrieval area to swap batteries, (b) avoid inclement weather, or (c) reestablish a better connection. Monitoring the health of the UAS is critical to all aspects of the mission, and therefore it is also critical to ensure that system status information is available and accessible at all times. According to the task analysis conducted by Adams et al. (2007), this information can include battery life, status of GPS connection, and communication channels. If the UAS were to lose connection or run out of battery power, the result could damage the UAV, as well as lead to an increase in task difficulty for the search team, as the UAV must then be retrieved. Adams et al. also proposed that the operator interface needs to convey status information in a way that can grab operator attention.

UAS missions require high levels of operator attention. Operators must rapidly and concurrently collect mission and task information; this requires displays that can facilitate rapid checking (Endsley & Jones, 2004). Utilizing environmental integration in technology that supports visual search missions, will facilitate the presentation of key information needed for mission success. This could potentially result in similar improvements to performance and time maintaining VLOS, as shown in controlled indoor UAS experiments utilizing AR technology (Hedayati et al., 2018).

The research in this section has shown SA, workload, and performance benefits observed with environmental integration with both BVLOS and VLOS
UAS operations. Limited research has been conducted specifically on VLOS operations. Research focused on UAS VLOS HUDs has not been evaluated with: (a) long duration flights, (b) in a more applicable task mission, (c) in a more applicable environment setting, (d) and with task information beyond camera information such as GPS, altitude, and map information. The impacts of a HUD may change when the UAS operator is at a greater distance, conducting a visual search task, in a demanding environment, with all task information presented to the operator. The current study in the following sections evaluated the impact of introducing a HUD into sUAS operations on operator SA and performance, for a simulated search and rescue task.

**Summary and Study Implications**

The research presented in the previous section demonstrates examples of how integrating interfaces can benefit across a wide array of information-rich environments. Based on Endsley’s (1995a) model of SA, individual factors, task factors, and environmental factors can all impact an individual’s SA, and ultimately, his or her mission success. In these demanding environments such as medical, automotive, and manned flight, in which attentional resources are spread thin, integrated displays have helped reduce detection times, improve understanding, and improve performance. The model of SA and supporting research has led to the development of the research questions and hypotheses. For Research Question 1, the research and theory suggest that an integrated display
such as a HUD should lead to improved mission performance. For Research Question 2, the research and theory suggest that an integrated display such as a HUD should lead to improved SA and subjective SA. For the exploratory Research Question 3, the research and theory suggest that combining and overlay information can have mixed results on workload. Therefore, the exploration of workload as an exploratory research question was added. Although workload was not the main focus of this study, it is important to examine this construct as an increased workload could have a negative impact on performance.

The past research in this section helped guide the design of the current study. The use of the SAGAT approach, SART questionnaire, and NASA-TLX were selected due to their prevalence in the relevant studies presented in the previous section. In addition, the characteristics and elements of the task to evaluate integrated displays served as guidance for the development of a simulated search and rescue mission. Incorporating measures and elements from previous studies allows the current study to be compared and added to the current breadth of knowledge on interface design in various domains. The elements specifically leveraged in the development of the mission and simulator are discussed and presented in Chapter 3.
Chapter 3
Methodology

Population and Sample

Population. The target population for this study was UAS operators in the United States who utilize UAS in their operations, such as police officers, ocean rescuers, mountain rescuers, fire-fighters, military personnel, tactical teams, emergency response teams, disaster relief workers, park rangers, lifeguards, and recreational users. The accessible population included UAS operators from: (a) Brevard County Fire Rescue; (b) Kennedy Space Center Facility Inspectors; (c) Brevard County Environmentally Endangered Lands Program; (d) Brevard County Ocean Rescue; (e) recreational UAS operators and those with UAS interest from Brevard County, and (f) recreational UAS operators and those with UAS interest from the Florida Institute of Technology (FIT) population stemming from the FIT drone club, UAS program, and general FIT population.

Sample. From the accessible population, convenience and snowball sampling strategies were utilized to recruit participants. To become a proficient UAS operator, leading UAS training companies such as DartDrones offer a 9-hour training course (DartDrones, 2019). This training covers regulations, instructions, flight training, settings, and features of UAS. To recruit representative operators who would be considered proficient or experienced, I initially required participants to possess at least 10 hours of flight experience operating a UAS. However, due to
lack of access and subsequent difficulty recruiting experienced UAS operators, pilot tests were conducted on individuals of varying experience. Pilot tests revealed operators with no experience, approximately 5 hours of experience, and well over 10 hours of experience all exhibited similar levels of performance and SAGAT scores in the simulator. Therefore, I began recruiting participants regardless of prior UAS experience. Training slides were provided to the participants before entering the simulator to ensure all participants understood the interface elements before conducting any search tasks.

Demographics of the sample were collected and compared against the publicly available UAS population statistics to ensure a representative sample. For the commercial UAS operator population, demographic information was pulled from the 2018 civil airmen statistics (FAA, 2018). For the commercial UAS sample, commercial operators were identified as those who utilized UAS in their day-to-day jobs or held a Part 107 certification. For the recreational operator population, demographic information was pulled from a 2018 survey of New Zealand UAS operators (Airways, 2018). For the recreational UAS sample, all participants who did not meet the commercial operator criteria fell into this category. The reader should note that at the time of this study, large surveyed demographic information on recreational UAS users in the United States was not publicly accessible. However, New Zealand surveys were similar to United Kingdom recreational numbers and limited descriptions of United States
recreational numbers (Dronesdirect, 2017; Hitlin, 2017). Descriptive statistics of demographic information are available in Table 3.1 to allow the reader to draw his or her own conclusions related to generalizability. The reader will note that the commercial UAS sample lacks any female representation and is comprised of a slightly younger demographic. The recreational UAS sample consisted of slightly more females and of a mainly younger population due to large recruitment from a college population.

A total of 45 participants completed the study. However, data associated with five participants had to be removed for various reasons. One participant received the same route twice due to a technical error. One participant experienced interruption from a colleague during the study. One participant did not follow instructions properly. One participant did not appear to understand the task. One participant experienced diffusion due to hearing the SAGAT queries prior to the task. These data points were determined to be contaminated and were not included

Table 3.1
Summary of Population and Sample Demographics

<table>
<thead>
<tr>
<th>Operator Type</th>
<th>#</th>
<th>Gender</th>
<th>Age</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Female</td>
<td>&lt; 25</td>
</tr>
<tr>
<td>Commercial Operators</td>
<td></td>
<td>Male</td>
<td>25-34</td>
</tr>
<tr>
<td>Population</td>
<td>106,321</td>
<td>5.8%</td>
<td>8.2%</td>
</tr>
<tr>
<td>Sample</td>
<td>10</td>
<td>0%</td>
<td>30%</td>
</tr>
<tr>
<td>Recreational Operators</td>
<td></td>
<td>100%</td>
<td>30%</td>
</tr>
<tr>
<td>Population</td>
<td>882</td>
<td>4%</td>
<td>12%</td>
</tr>
<tr>
<td>Sample</td>
<td>24</td>
<td>12.5%</td>
<td>70.8%</td>
</tr>
</tbody>
</table>

*Remaining percentage did not identify gender.
in the dataset. Next, six participants with no UAS experience were removed from the sample. These participants were omitted due to the following reasons: (a) they did not represent the intended target population, and (b) they could not be analyzed as a group statistically. This was due to the low number of participants (i.e., only six) with no UAS experience, compared to 15 participants with low UAS experience (i.e., 10 hours or less), and 19 participants with high UAS experience (i.e., over 10 hours). In addition, the group’s data were not normally distributed and exhibited higher standard errors.

A total of 34 participants were utilized in the dataset. The sample characteristics relative to these 34 participants are summarized in Table 3.2. The overall mean age was $M = 27.5$ years, consisting of 29 males, 3 females, and 2 who selected “I prefer not to say.” A total of 73.5% of participants were Caucasian, followed by 11.8% Hispanic, 2.9% African American, 2.9% Asian, and 8.8% other. Two of the three who marked “Other” noted themselves as “mixed,” and a third participant did not define his or her ethnicity in the open text field. Participant’s UAS experience was distributed with: 26.5% having less than 5 hours, 17.6% ranging between 5 and 10 hours, 26.5% ranging between 11 and 30 hours, 14.7% ranging between 31 and 50 hours, and 14.7% with over 50 hours of UAS experience. Finally, a majority of the sample had high levels of gaming experience, with 76.5% having at least 5 years of video game experience. Video gaming experience is included here as gamers have been shown to be proficient UAS
Table 3.2

Summary of Sample Attributes

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>#</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Age</strong></td>
<td></td>
</tr>
<tr>
<td>M</td>
<td>27.5</td>
</tr>
<tr>
<td>SD</td>
<td>10.9</td>
</tr>
<tr>
<td>Range</td>
<td>19-58</td>
</tr>
<tr>
<td><strong>Gender</strong></td>
<td></td>
</tr>
<tr>
<td>Male</td>
<td>29</td>
</tr>
<tr>
<td>Female</td>
<td>3</td>
</tr>
<tr>
<td>I prefer not to say</td>
<td>2</td>
</tr>
<tr>
<td><strong>Ethnicity</strong></td>
<td></td>
</tr>
<tr>
<td>Caucasian</td>
<td>25</td>
</tr>
<tr>
<td>African American</td>
<td>1</td>
</tr>
<tr>
<td>Hispanic</td>
<td>4</td>
</tr>
<tr>
<td>Asian</td>
<td>1</td>
</tr>
<tr>
<td>Other</td>
<td>3</td>
</tr>
<tr>
<td><strong>UAS Experience</strong></td>
<td></td>
</tr>
<tr>
<td>Less than 5 hours of experience</td>
<td>9</td>
</tr>
<tr>
<td>6-9 hours of experience</td>
<td>3</td>
</tr>
<tr>
<td>8-10 hours of experience</td>
<td>3</td>
</tr>
<tr>
<td>11-30 hours of experience</td>
<td>9</td>
</tr>
<tr>
<td>31-50 hours of experience</td>
<td>5</td>
</tr>
<tr>
<td>Over 50 hours of experience</td>
<td>5</td>
</tr>
<tr>
<td><strong>Video Game Experience</strong></td>
<td></td>
</tr>
<tr>
<td>Less than 6 months</td>
<td>2</td>
</tr>
<tr>
<td>1 year to less than 3 years</td>
<td>4</td>
</tr>
<tr>
<td>3 years to less than 5 years</td>
<td>2</td>
</tr>
<tr>
<td>5 years or more</td>
<td>26</td>
</tr>
<tr>
<td><strong>UAS uses</strong></td>
<td></td>
</tr>
<tr>
<td>Recreational</td>
<td>27</td>
</tr>
<tr>
<td>Film/Photography</td>
<td>11</td>
</tr>
<tr>
<td>Entertainment</td>
<td>8</td>
</tr>
<tr>
<td>Education</td>
<td>7</td>
</tr>
<tr>
<td>Training</td>
<td>5</td>
</tr>
<tr>
<td>Press &amp; Media</td>
<td>4</td>
</tr>
<tr>
<td>Research &amp; Development</td>
<td>4</td>
</tr>
<tr>
<td>Emergency &amp; Preparedness</td>
<td>4</td>
</tr>
<tr>
<td>Real Estate</td>
<td>3</td>
</tr>
<tr>
<td><strong>UAS Camera Gimbal Experience</strong></td>
<td></td>
</tr>
<tr>
<td>Less than 10 hours of experience</td>
<td>20</td>
</tr>
<tr>
<td>11-30 hours of experience</td>
<td>9</td>
</tr>
<tr>
<td>31-50 hours of experience</td>
<td>2</td>
</tr>
<tr>
<td>Over 50 hours of experience</td>
<td>3</td>
</tr>
</tbody>
</table>

*Note. The UAS uses question allowed for participants to select more than one.*
operators, specifically at tasks that require visual monitoring of information and identifying targets (MicKinley, McIntire, & Funke, 2011). The occupations of commercial UAS operators included: conservation biologist, engineer, firefighter, operations control, pilot, and student. The most common uses for UAS included recreational purposes, film and photography, entertainment, education, training, press and media, research and development, emergency and preparedness, and real estate. For camera gimbal experience, a total of 59% of participants had less than 10 hours of experience, 32% had between 11 and 50 hours of experience, and the remaining 9% had over 50 hours of experience.

**Power analysis.** Based on lack of research in this area, an a priori repeated measures within-factors MANOVA power analysis was performed with assumed values. A minimum sample size was calculated using an effect size of .35, a power of .80, and an alpha level of .05 for a repeated measures (2 times) within-subjects MANOVA using G*Power 3 (Faul, Erdfelder, Lang, & Buchner, 2007). The power analysis resulted in a minimum sample size of $N = 36$. The resulting sample consisted of $N = 34$ ($N = 31$ with outliers removed) with observed power calculations from the final analysis presented in Table 3.3. The analysis demonstrates power values near or greater than Cohen, Cohen, West, and Aiken’s (2003) recommended minimum power of .8, except for the interaction between interface and UAS experience.
### Table 3.3

*Power Analysis and Calculated Powers for $\alpha = .05$*

<table>
<thead>
<tr>
<th>Factors</th>
<th>ES</th>
<th>Power</th>
</tr>
</thead>
<tbody>
<tr>
<td>Interface</td>
<td>.290</td>
<td>.697</td>
</tr>
<tr>
<td>Interface*Order</td>
<td>.452</td>
<td>.995</td>
</tr>
<tr>
<td>Interface*UAS Experience</td>
<td>.196</td>
<td>.459</td>
</tr>
<tr>
<td>Interface<em>Order</em>UAS Experience</td>
<td>.416</td>
<td>.920</td>
</tr>
</tbody>
</table>

*Note. N = 31.*

### Instrumentation

**Demographics.** The following demographic information was collected to compare the sample to the population and to inform the reader of the sample characteristics: age, ethnic background, sex, education level, occupation, UAS purposes, UAS operation experience, and UAS operation frequency. UAS gimbal experience and frequency were collected as the main task for the participants is to control the UAS camera gimbal, which is not a standard feature on all UAS. In addition, video game experience and frequency were collected as research has shown video gamers to be more effective at identifying and tracking targets than pilots (MicKinley et al. 2011). UAS gimbal and video game demographics were collected and utilized to potentially explain floor effects, ceiling effects, and differences in participant performance if they occur (see Appendix A).

**Experience with UAS information parameters.** Information related to the parameters on the interface itself was collected both before and after the task. In the pre-survey, participants were asked to select interface elements that they use in their day-to-day operations. In the post-survey, participants were asked to select
interface parameters that they used in the search task they had just completed.

Descriptive statistics of participant responses are presented to the reader in Chapter 4 to guide future interface designs based on the domain (see Appendix B).

**Performance.** Participant’s performance was captured using the simulator capabilities. When a picture was taken, it was saved locally to the simulator computer. I then checked the images against an answer key after the experiment to determine how many targets and non-target objects were captured in the images (see Appendix C). The total number of targets detected was utilized as a measure of performance. Target detection can be utilized as a measure of how well the user performs the task and can be influenced by display layouts, locations, and experience (Bhise, 2013). Therefore, target detection was determined to be a valid measure to capture performance in the current study. To address reliability, a few sampled participant performance scores were calculated a second time to demonstrate intra-rater reliability. All scores matched to their original coding.

**Situation awareness.** Based on studies that have compared SA evaluation techniques, different SA measures assess different aspects of SA (Salmon et al., 2009). Therefore, two SA measures were included in this study.

**The SAGAT.** The Situation Awareness Global Assessment Technique (SAGAT) was utilized to assess real-time SA in the environment. The SAGAT approach freezes or pauses the task at hand and asks the participant to answer SA probes targeted at each level of SA. The probes are administered either verbally or
via a computer system (Endsley, 1995c). According to Salmon et al. (2009), the SAGAT is ideal to target the objective understanding and awareness of elements during the task. Endsley, Sollenberger, and Stein’s (2000) research shows the SAGAT to be a valid measure of SA as it correlates with the SART and subject matter expert ratings of SA. In addition, the SAGAT was shown to be predictive of performance and sensitive enough to show significant differences for display design changes in an experiment. The SAGAT has shown to have a high reliability with test-retest scores of .92 to .98 when targeting only knowledge of aircraft locations (Endsley & Bolstad, 1994). Nguyen, Lim, Nguyen, Gordon-Brown, and Nahavandi (2019) stated the SAGAT can be difficult to implement in real-world tasks as freezing the whole task is generally not feasible. On the other hand, it allows the researcher to remove any subjective aspects and any inaccuracies that can occur from measuring SA after the task. To accomplish the SAGAT approach in the simulated task, the simulator paused, and the screen turned black with the SA query displayed on the screen. Once the queries were completed, the task resumed. According to Endsley (1995c), it is suggested to have a first SA freeze at least 3 to 5 minutes into the task and no two SA freezes within the same 60 seconds. In addition, Endsley’s research has shown three SA freezes with 26 probes during a 15-minute task did not have an effect on task performance, even if the freezes were up to 5-minutes long. Based on this guidance, a three-freeze approach was utilized. Nine random probes were asked per pause, which added up to a total of 27 probes.
The development of SAGAT queries. To develop the SAGAT queries, Endsley’s (2000) description and guide of the SAGAT tool in *Situation awareness analysis and measurement* was used. Endsley described the SAGAT development process beginning with an extensive SA task requirements analysis that is conducted using a combination of questionnaires, observation, and expert review, and then validated across many operators. Endsley noted this process is rigorous and often takes up to a year, but once defined, it can be applied to various tasks within that domain and can serve as the basis for query development. The target task is then determined, and the relevant SA requirements directed at that task can be used for query development. Endsley emphasized that SA requirements not relevant to the stage of task (i.e., emergency-related questions during a non-emergency related scenario), can be omitted. This approach allows a broad range of queries so that participants do not begin to narrow attention on pieces of information on which they believe they will be queried.

SA requirements from Riley and Endsley’s (2004) SA task analysis for unmanned ground vehicle (UGV) search and rescue tasks were used to develop the queries for the current study (see Appendix D). As the SA requirements for UGV and UAS both involve remote piloting of a “robot” during search and rescue missions, Riley and Endsley’s requirements served as the foundation for the development of queries using SAGAT development guidance provided by Endsley (2000). The search and rescue task was analyzed in conjunction with Riley and
Endsley’s (2004) SA requirements to determine which of the SA requirements would be most relevant for this task. SA requirements were selected based on their (a) relevancy to the simulated task, (b) relevancy based on discussions with a UAS search and rescue subject matter expert, (c) relevancy to capabilities within the UAS simulator, (d) targeting of a parameter that varies throughout the search task, (e) ability to be objectively answered within the context of this study, and (f) ability to be scored consistently for each participant. For example, weather-related queries were omitted as the weather conditions stayed constant for the duration of the task.

Next, two example sets of query formats were referenced to ensure accurate question formatting when converting SA requirements into query format. One reference in Endsley’s (2000) SAGAT guidance presented SAGAT queries from Endsley and Kiris (1995) for an air traffic control task (see Appendix E). In addition, SAGAT queries from a military simulation task by Bolstad and Endsley (2003) were also referenced (see Appendix F). Only queries with “Enter …” verbiage were used as reference such as “Enter aircraft heading” and “Enter all aircraft that will violate minimum altitude requirements in the next two minutes if they stay on their current (assigned) paths” were used. Other queries phrased with “which aircraft...” and “indicate on the map...” were not used as a reference as these queries referred to multiple aircraft or required a graphical reference. Due to technological limitations of the simulator and the nature of the task with one UAS, all queries utilized a text entry response system and an “Enter …” phrasing. For
example, the following items were utilized for a query development: the SA requirement from Riley and Endsley (2004) “Projected location of robot,” and the phrasing from Ensley and Kiris (1995b) “Enter all aircraft that will violate minimum altitude requirements in the next two minutes if they stay on their current (assigned) paths.” From these elements a query of “Enter the distance (in FT) that the drone will have traveled when the battery is at 0%” was developed. This resulted in the final list of 27 queries as shown in Appendix G.

Attention to face and content validity was achieved by having a human factors expert and a UAS subject matter expert review the queries for accuracy. For reliability, internal consistency scores or Cronbach’s Alpha could not be calculated for the SAGAT as the items target SA with respect to different pieces of information. Specifically, inter-item correlations would likely be low as knowledge of battery status does not indicate knowledge of altitude or other parameters. Test-retest reliability could be calculated however, Breakwell, Fife-Schaw, and Smith (2006) caution that test-retest reliability assumes any differences between the two measurements are due to measurement error. Breakwell et al. also discusses that test-retest reliability measures are ideal for traits that are relatively unchanging but are not effective for states that experience dynamic changes over time. For example, measures of intelligence, a relatively stable trait, have been shown to have high test-retest reliability, whereas measures of memory, a dynamic cognitive process, have been shown to have low test-retest reliability (Bird, Papdopolou,
Ricciardelli, Rossor, & Cipolotti, 2003). As a result, Salmon et al. (2009) argues that individuals may not be capable or likely to generate the same awareness when assessing the reliability of SA measures. Further, reliability has been shown to be impacted by experience levels and environmental fidelity (particularly with the SAGAT), memory, and rehearsal resulting in changes unrelated to stability of the measure (Annett, 2002; Polit, 2014; Endsley, 2000). The reader should also note that the time between measures was only 15–20 minutes and was believed to be insufficient to reduce any testing or memory effects as indicated by significant interactions between interface design and order on SAGAT scores. Therefore, the reliability of the SAGAT queries could not be properly assessed in the current study. Future research should attempt to assess the reliability of the SAGAT queries developed with a homogeneous sample, with no interface differences between the two measurements, and with ample time between measurements.

**The SART.** The Situation Awareness Rating Technique (SART) was also utilized to assess SA. The SART is a subjective survey of 10 questions developed by Taylor (1990). The SART targets the supply and demand of resources as well as their understanding of the information from those resources. The SART poses questions such as “How good is the information you have gained about the situation?” and “Is the knowledge communicated very useful (high) or is it of very little use (low)?” Participants are asked to mark their response on a scale of 1 to 7. According to Salmon et al. (2009), the SART is ideal to target the subjective
opinion of the individual and their perceived understanding and awareness after the task.

Including both of these SA measures ensured a more comprehensive approach to measuring SA. In Endsley’s et al. (2000) study of SA measures, the SART understanding dimensions have been shown to correlate to SME SA ratings. In addition, the overall SART has been shown to correlate with SAGAT Level 1 queries. The SART understanding dimension was also shown to account for 12% of the variance in predicting SME performance rating. However, reliability information on the SART is lacking (Brenton, Tremblay, & Banbury, 2007). The SART was administered after each interface design condition (see Appendix H).

**Qualitative comments.** Participants were given the opportunity to respond to open-ended questions regarding their perceptions of the HUD and traditional interface design, after exposure to both conditions. These questions included “What did you like or dislike?” and “How effective was the display configuration in completing your task?” Responses to these questions are presented in Chapter 4 supplemental analyses to support and explain other results (see Appendix I).

**Workload.** To assess operator mental workload for the exploratory research question, the NASA-Task Load Index (NASA-TLX) was administered. This measure has been used in over 500 studies for 20 years as a measure of subjective workload in various tasks (Hart, NASA-task load index (NASA-TLX); 20 years later, 2006). Six dimensions of workload are measured (mental demand, physical
demand, temporal demand, performance, effort, and frustration) on a 20-point scale from low to high. For example, participants were asked “How mentally demanding was the task?” and “How successful were you in accomplishing what you were asked to do?” (Hart & Staveland, 1988). The NASA-TLX has been shown to have high test-retest reliability with a Cronbach’s alpha of .83 (Hart & Staveland, 1988) and .75 (Longo, 2018). For validity, the NASA-TLX has been shown to correlate with other workload measures and subjective ratings of mental workload, as well as being sensitive to detect changes in workload (Longo, 2018). Participants filled out the NASA-TLX after each condition (see Appendix J).

**Procedures**

**Research methodology/design.** The current study utilized an experimental within-group research design. Participants exhibited varying levels of skill and exposure to UAS flight and came from various backgrounds. Therefore, to control for individual differences, a within-subjects design was most appropriate. The study manipulated one independent variable that was interface design (Traditional or HUD). The three dependent variables measured included: SA, performance, and workload, and were captured utilizing multiple measures (see Figure 3.1). Utilizing this approach allowed the comparison of the UAS interface design on multiple outcomes. The same group was measured twice with the absence of manipulation which may be considered a repeated measure correlational study.
**Human subjects research.** An institutional review board (IRB) application was submitted to the FIT IRB as the study was human subjects research. The risks of participation in this study did not exceed the risks of normal everyday operation of a desktop computer. I acted as the sole data collector. The major advisor and myself were the only individuals who had access to data. Participant identifying information was kept separate from his or her data to ensure anonymity (see Appendix K).

**Study implementation.** Participants were recruited via email and word of mouth for participation in the study. Recruitment utilized a convenience and snowball approach. Based on the availability of individuals located outside of the FIT network, the simulator was offered to be brought to each of the facility locations. In this case, I requested to reserve a conference or meeting room to keep location characteristics as similar as possible. Before beginning the study,
participants were asked to complete an online poll to schedule a time slot or asked about their availability for scheduling via email. Then, based on the conditions, participants were asked to come to FIT’s Center for Aeronautics and Innovation (CAI) for the study, or I met the participants at their respective facility locations during the scheduled timeslot.

When participants arrived, they were given a consent form via Qualtrics, informing them of the study purpose along with the associated risks. Participants were required to electronically sign the consent form to participate in the study. Next, participants were given a pre-survey collecting demographic information, UAS experience, and experience with UAS parameters to determine how they use task information in their daily operation. After completion of the survey, participants completed a computer-based interactive training module and a short 3-minute training flight task to become familiar with the controls and goals of the task. Participants then completed the experimental task on a desktop simulator with a counterbalanced order of interface design (traditional or HUD) and route (1 or 2), resulting in four orders to account for order effects (see Table 3.4).

During the experiment, the simulator paused and displayed SAGAT prompts to the user while the simulator collected their responses externally in an Excel file. For Route 1, the pause times occurred at approximately 5 minutes, 9 minutes, and 12 minutes. For Route 2, the pause times occurred at approximately 4 minutes, 7 minutes and 10 seconds, and 11 minutes. The pause times were designed
to occur (a) at times in the route where information had not changed in the past 5 seconds, and (b) when the UAV was not performing a turn. Constructing pause

Table 3.4

<table>
<thead>
<tr>
<th>Order Number</th>
<th>First Interface Design</th>
<th>First Route</th>
<th>Second Interface Design</th>
<th>Second Route</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Traditional</td>
<td>1</td>
<td>HUD</td>
<td>2</td>
</tr>
<tr>
<td>2</td>
<td>Traditional</td>
<td>2</td>
<td>HUD</td>
<td>1</td>
</tr>
<tr>
<td>3</td>
<td>HUD</td>
<td>1</td>
<td>Traditional</td>
<td>2</td>
</tr>
<tr>
<td>4</td>
<td>HUD</td>
<td>2</td>
<td>Traditional</td>
<td>1</td>
</tr>
</tbody>
</table>

times in this manner as a feature of the route ensured: (a) an objective scoring of the variable at the time of pause and (b) enough of a difference to appear random to the participant. After performing with each interface design, participants were asked to fill out an online questionnaire with their responses to the SART and NASA-TLX. Participants then flew the training course again utilizing the second interface design, to become familiar with the new location of information before completing the second trial. After the study was completed, participants were asked to complete a questionnaire capturing their experience with UAS interface parameters relative to the task they just completed and qualitative questions about their experiences using each interface design. Then, participants were thanked for their participation, and given contact information if they had any future questions (see Table 3.5).

**Experimental task.** Two information sources guided the development of the simulated task. First, past research on the topic was utilized to create a
foundation of task characteristics such as task type, mission length, and type of UAV. Then, a prototype simulator was shown to the Brevard County Fire

Table 3.5
Simulation Task Procedure and Timeline

<table>
<thead>
<tr>
<th>Task</th>
<th>Description</th>
<th>Duration</th>
</tr>
</thead>
<tbody>
<tr>
<td>Recruitment</td>
<td>Participants were asked to participate in the study and checked for their inclusion criteria</td>
<td>--</td>
</tr>
<tr>
<td>Scheduling</td>
<td>Participants were asked to select a time slot to participate</td>
<td>--</td>
</tr>
<tr>
<td>Introductions</td>
<td>Participants were read an introductory script and asked to sign the consent form</td>
<td>5 minutes</td>
</tr>
<tr>
<td>Pre-Survey</td>
<td>Participants completed a survey on experience with UAS interface parameters in their field along with demographics</td>
<td>5 minutes</td>
</tr>
<tr>
<td>Training</td>
<td>Participants completed an interactive training module and a short training task</td>
<td>10 minutes</td>
</tr>
<tr>
<td>Experimental Task 1</td>
<td>Participants completed a ~15 min task in the first interface design in their counterbalanced order with SAGAT queries integrated into the task</td>
<td>15 minutes</td>
</tr>
<tr>
<td>Post-Task Survey 1</td>
<td>Participants completed an online survey with the SART, NASA-TLX.</td>
<td>5 minutes</td>
</tr>
<tr>
<td>Training</td>
<td>Participants completed a short training task</td>
<td>5 minutes</td>
</tr>
<tr>
<td>Experimental Task 2</td>
<td>Participants completed a ~15 min task in the second interface design in their counterbalanced order with SAGAT queries integrated into the task</td>
<td>15 minutes</td>
</tr>
<tr>
<td>Post-Task Survey 2</td>
<td>Participants completed an online survey with the SART, NASA-TL.</td>
<td>5 minutes</td>
</tr>
<tr>
<td>Post-Experiment Survey</td>
<td>Participants completed a survey about experience with UAS interface parameters in the task completed in the simulator, and qualitative comments</td>
<td>10 minutes</td>
</tr>
<tr>
<td><strong>Total Time</strong></td>
<td></td>
<td>75 minutes</td>
</tr>
</tbody>
</table>

Department Chief of Ocean Rescue and the UAS subject matter expert (SME) for the department. The input from this SME was used to fine tune the task to be more realistic for the future participants. These adjustments included target size, number
of distractors, and simulator capabilities. Similar search and rescue UAS tasks have had varying mission durations with various levels of targets and distractors. The

<table>
<thead>
<tr>
<th>Study</th>
<th>Study Type</th>
<th>Mission Lengtha</th>
<th>No. of Targets</th>
<th>No. of Distractors</th>
</tr>
</thead>
<tbody>
<tr>
<td>Eyerman, Crispino, Zamarro, &amp; Durscher (2018)</td>
<td>Live</td>
<td>60</td>
<td>1</td>
<td>-</td>
</tr>
<tr>
<td>Lin, Roscheck, Goodrich, &amp; Morse (2010)</td>
<td>Simulation</td>
<td>35</td>
<td>1</td>
<td>-</td>
</tr>
<tr>
<td>Perelman &amp; Mueller (2013)</td>
<td>Simulation</td>
<td>1.3</td>
<td>6</td>
<td>6</td>
</tr>
<tr>
<td>Rudol &amp; Doherty (2007)</td>
<td>Automated</td>
<td>10</td>
<td>11</td>
<td>3</td>
</tr>
</tbody>
</table>

Note. aTime is in minutes.

studies presented in Table 3.6, in conjunction with input from the SME, were used to set the task characteristics for this study, as discussed in this section.

The simulated task length was identical for each participant and mimicked approximately one battery cycle of the DJI Inspire 1 UAS, which has been previously used for search and rescue studies (Eyerman et al., 2018). In addition, this UAS model provides kits to support first responder missions specifically (DSLRPros, 2019). The DJI Inspire 1 has a max flight time of 18 minutes (DJI, 2019); however, to account for wind, speed, battery decay, and return to home time requirements, which can all impact battery life duration, the task time was shortened. All participants received the simulation task with the same task duration: approximately 15 minutes.

To prevent ceiling effects and ensure the ability to show differences between conditions, this study included multiple targets. In the studies referenced in
Table 3.6, the ratio varies from one target per hour to one target per minute to one target per 7-seconds. To keep the task realistic, a one target per minute ratio was utilized. Therefore, the scenarios included 15 missing person targets and 30 distractors. The number of missing persons and distractors was designed to prevent ceiling and floor effects on the performance measure. Distractors included various objects such as bicycles and backpacks that are of similar color as the targets and have been used in other studies that employed search and rescue tasks (Goodrich, Morse, Engh, Cooper, & Adams, 2009). Participants were informed that they are to only take pictures of human targets to be sent back to the team to send to rescue squads. Participants were also informed to only take a picture of each human target once.

The simulated task was completed on a custom-built desktop computer equipped with an Intel i7-7700 CPU, 32GB of RAM, an AMD Radeon RX 5700 graphics card, and a Windows 10 Home operating system (see Figure 3.2). The simulator was developed in conjunction with the Air Force Research Lab’s Gaming Research Integration for Learning Laboratory in Unreal Engine. The simulator mimics a UAV flying on an automatic flight path. The search path consisted of long parallel scan lines where the UAV surveys the area back and forth until the entire grid has been covered. The U.S. Department of Homeland Security (2006) suggests this type of search pattern when the location of the target is not well known, the area to search is large, and searching the entire area is needed. This search pattern
method has also been used in UAV research for finding human targets (Qi et al., 2015; Rudol & Doherty, 2008).

Figure 3.2. sUAS simulator setup.

making it appropriate for the current study. The traditional operation condition consisted of a separate interface view presented on two monitors mounted one on top of the other with the environment being shown on the top monitor and the interface being shown on the bottom monitor. This configuration is used to simulate the normal position of the controller interface and VLOS in live operations. The HUD operation condition consisted of an overlaid interface view presented on one monitor with the secondary monitor appearing blank. See Figure 3.3.
Participants were given instructions verbally, read by the proctor from a script, informing them of the following aspects of the task:

- 15 missing persons have been reported in the area. Their goal is to take pictures of only human targets that will be transmitted back to the search team to send ground units to the area.
- Taking pictures of non-human targets is not their objective and could delay rescue operations.
- To only take one picture of each human target.
- The UAV is set on an automatic flight path that will fly a parallel search path.
- The camera gimbal is controlled by the joysticks on the UAS controller and space bar on the keyboard to take a picture.
- They will have approximately 15 minutes to complete the task.
- The UAV has a total battery life of 18 minutes.
- They must maintain line of sight of the UAV.
- They must maintain line of sight by using the arrow keys on the keyboard to keep the UAV in their field of view on the computer monitor.
- The simulator will pause at random times and ask them questions about the state of the vehicle, parameters, and environment at the time of the pause, as well as ask them to project to the future.
To read the questions carefully as questions differ slightly.

Figure 3.3. Simulated task conditions

**Threats to internal validity.** Campbell and Stanley (1963) defined 8 various factors impacting the internal validity of a research design in their seminal research. Since then, the community has expended the number of threats to 12 that are commonly accepted within the research community. These are defined as threats to internal validity and should be controlled to ensure effects on the dependent measures are the result solely of the treatment effects. An explanation of
all 12 threats to internal validity and attempts to mitigate these threats are discussed in detail below.

**History.** History threats can include cultural or news events that occur during the course of the study that may impact the dependent variable. For example, more stringent policies on FAA regulations for UAS operations could be implemented, resulting in participants acting more diligently in the task than previous participants. To control for this effect, changes in the UAS industry were monitored, recorded, and made apparent to the reader with the findings of the study. In addition, data collection was limited to a 3-month time frame. No notable cultural or news events occurred during data collection and therefore this threat was not applicable to the current study.

**Maturation.** A maturation effect refers to changes that occur to the participant over time, such as increased age, decreased motivation, or fatigue. In the current study, each participant completed the study within a 75-minute setting with only 15 minutes between the two measurements, which was not long enough to elicit large maturation effects. As a precaution, to ensure fatigue was not exhibited in the secondary search task, the interface design was counterbalanced to wash out any fatigue effects that may have occurred. As a results, the mitigations effects and the control measures taken, the maturation threat to internal validity had no bearing on the current study.
**Testing.** A testing effect occurs when the exposure to a pretest alters the participant’s performance on an identical posttest. Including a pretest can cause participants to prepare and perform differently on the posttest simply because of exposure to the pretest instead of the treatment. In the context of UAS, a student flying two different obstacle courses may perform better on the second obstacle course due to exposure on the first obstacle course. To control for this effect, the two routes were similar but presented targets in different locations. In addition, the task operation conditions and routes were counterbalanced across participants to reduce any order effects that may occur. However, order effects were still observed and were controlled for in the final analysis in Chapter 4 (see Appendix L). Thus, the testing threat, although relevant to the current study, was addressed by the way the study was implemented and statistically controlled.

**Instrumentation.** An instrumentation effect occurs when changes between measurements occur. This can include differences in the researcher who collects data, biases that are applied to that data, or interpretations that change as scoring continues. For example, a UAS instructor scoring UAS student flight performance may grade bumps more heavily with the first student than the last student. To control for any instrumentation effects, the following actions were taken: (a) I acted as the sole scorer for all data, (b) scoring criteria for correct versus incorrect answers to SAGAT questions were predetermined for each pause to ensure unbiased scoring, (c) a script and protocol were utilized to ensure each participant
receives the same instructions, and (d) the same instruments were administered in both operation conditions.

**Statistical regression.** A statistical regression effect occurs when participants who score very low or very high will regress towards the mean on future assessments. Those who fall towards extreme values can only change in one direction. For example, if students in a new training condition have no experience in operating UAS, they will only be able to improve in performance from a pretest. This could potentially show incorrect treatment effects compared to students with greater starting ability in a standard training condition that could improve or worsen. In this study, participants served as their own control, which should account for any statistical regression effects.

**Selection.** A selection effect occurs when participants in the control group differ from participants in the treatment group. For example, participants selected for a simulation-based UAS training over traditional training may show better performance solely because of individual differences instead of treatment differences. For this study, a within-subjects design was used, and thus participants served as their own control, which eliminated any individual differences.

**Mortality.** A mortality effect occurs when participants drop out during the course of the study (attrition). Those who decide to drop out of a UAS course may have been performing poorly under the instruction style and therefore are different than those who remained in the UAS course. If this effect occurred, then instruction
treatment effects would not accurately be represented by the remaining participants. The full study was conducted within a 1.5-hour time frame and did not experience attrition. In addition, no missing data occurred. Thus, the mortality threat was not considered an applicable threat to the current study.

Selection-maturation interaction. A selection-maturation interaction effect occurs when participants in different groups mature at different rates. For example, participants selected for a new type of UAS instruction may become more proficient than those in the traditional UAS instruction simply because of individual differences and not the instruction type. This effect did not apply to this study because a within-subjects design was used, and participants served as their own control.

Experimenter effect. An experimenter effect can occur when different experimenters may administer the treatment differently. For example, UAS instructors in one treatment condition may be more enthusiastic and involved than instructors in another treatment condition resulting in an effect caused by the instructor instead of the condition. To control for this effect, I acted as the sole administrator of the study and utilized scripted instructions.

Subject effect. A subject effect occurs when the attitude and behavior of the participant changes due to the participation in the study. These can include an increase in performance from being observed (Hawthorne effect) or different performance due to their knowledge of their group assignment (John Henry effect).
In addition, participants can react differently knowing that they were placed in a group condition with a less desirable treatment or because of the novelty of the treatment (demoralization). In the case of a UAS study, participants may put forth less effort if their condition consists of flying a basic UAS, whereas participants in the other condition are flying a state-of-the-art UAS. To control for this effect, participants experienced each condition and performed a training scenario to reduce any novelty effects in the experimental scenarios.

**Diffusion.** A diffusion effect occurs when participants communicate between groups and learn about the treatment effect. This may result in different behaviors from the participants. For example, UAS students in one course may be given simulator training, whereas students in another UAS course are given live training. Therefore, students in either condition may respond differently knowing the variable being manipulated. To control for this, a within-subjects design was used. In addition, after the study participants were asked not to share the details of the study with others. One participant who experienced diffusion was removed.

**Location.** A location effect could occur if the study is conducted in many locations. For example, a UAS study conducted on a sunny day and windy day may have different results from compared to data collection on an overcast and windless day. Considering the participants came from many different domains with different availabilities, it was not possible to conduct the experiment in the same location to recruit highly experienced operators. The simulator was moved on-site to recruit
higher numbers of participants. To reduce the effects of location, the simulator was always set up within a conference or meeting style room with high lighting and closed doors.

**Treatment verification and fidelity.** Treatment verification and fidelity refer to the extent to which the actual implementation of the study followed the planned study implementation (Shaver, 1983). Ensuring that the IVs are as intended, and the study was implemented according to plan, allows for accurate generalizability, interpretations, and replication. Therefore, the IV of interface design in this study was administered according to Table 3.5. The simulator was designed to administer the IV to ensure an identical administration of the IV for every participant. In addition, the settings for each search mission were outputted from the simulator and were confirmed to be the correct IV conditions after the task.

To further address treatment verification and fidelity from Shaver (1983), I ensured the implementation of the study was as planned. IV implementation and SAGAT queries were administered via the simulator and all surveys were administered through Qualtrics to ensure consistent implementation of these aspects of the study. Participant target detection and queries were exported by the simulator in standardized Excel files for consistent scoring. In addition, a script was utilized to ensure consistent instructions and a protocol of steps was used during each participant session. Standardization of all verbiage, implementation, and
measures ensured treatment fidelity. To further ensure ecological validity, previous research and theory were referenced to confirm the independent variable in the current study was appropriate. Further, to ensure the independent and dependent variables could be replicated, detailed descriptions of each variable are presented in Table 3.7.

Data analysis

Description of independent and dependent variables. A description of the independent and dependent variables is presented in Table 3.7. The independent variable was interface design (traditional versus HUD). The dependent variables consisted of performance (target detection), SA (SAGAT and SART), and workload (NASA-TLX).

<table>
<thead>
<tr>
<th>Table 3.7</th>
<th>Summary and Description of Independent and Dependent Variables</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Variable</strong></td>
<td><strong>Description</strong></td>
</tr>
<tr>
<td>Independent Variable</td>
<td>Interface design was a dummy coded categorical variable representing condition 0 = Traditional, 1 = HUD.</td>
</tr>
<tr>
<td>Dependent Variables</td>
<td></td>
</tr>
<tr>
<td>SAGAT score</td>
<td>SAGAT score was a continuous variable and represented the number of correct SAGAT questions. Higher scores reflected higher accuracy and higher SA.</td>
</tr>
<tr>
<td>SART score</td>
<td>SART score was a continuous variable and represented the composite score of SART = U − (D − S). Where U represented the sum of Questions 8-10, D represented the sum of Questions 1-3, and S represented the sum of Questions 4-7. Higher scores reflected higher SA.</td>
</tr>
<tr>
<td>NASA-TLX score</td>
<td>NASA-TLX score was a continuous variable and represented the summed score of each question. Higher scores reflected higher workload.</td>
</tr>
<tr>
<td>Performance score</td>
<td>Performance score was a continuous variable and represented the number of correctly detected targets. Higher scores reflected higher accuracy on target detection.</td>
</tr>
</tbody>
</table>
**Descriptive statistics.** Survey data was exported from *Qualtrics.*

Descriptive information is summarized and presented descriptively in Chapter 4 with means and standard deviations or frequencies for all measures and demographics: including age, gender, ethnicity, UAS experience level, video game experience, UAS parameter ratings, SAGAT scores, workload scores, SART scores, and performance scores.

**Inferential statistics.** To test the research hypotheses and answer the exploratory research question, a repeated measure within factors MANOVA was conducted. Using SPSS, the IV of interface design was used with four dependent measures of SAGAT score, SART score, performance, and workload. The quantitative data were analyzed from a within groups perspective to examine each individual change across the two conditions. In addition, the effects of interface order and UAS experience were also analyzed. The results of these analyses are presented in both narrative and table forms in Chapter 4.
Chapter 4

Results

Introduction

This chapter presents the results of the current study. The first section presents a summary of descriptive statistics of the dependent variables for both interface designs, including: SAGAT scores, SART scores, NASA-TLX scores, and targets detected. The second section presents the results of the inferential statistics, including the preliminary analyses, the multivariate analysis of variance (MANOVA), and corresponding univariate follow up. In the preliminary analyses, the data are analyzed for invalid or missing data, outliers, and assumptions associated with a MANOVA statistical analysis. In the MANOVA, the results of the multivariate omnibus analysis and univariate analyses are presented. The third section presents the results of hypothesis testing that corresponds to the two primary research questions defined in Chapter 1. In addition, the results of the exploratory research question related to workload are also presented.

Descriptive Statistics

During the search task performed using each interface design, SAGAT query responses and performance data were collected. After performing the search and rescue scenario on each interface design, participants were given a questionnaire containing the SART and NASA-TLX. A total of 45 individuals participated in the study. However, five participants were excluded from the sample
due to contaminated data, and six participants were excluded due to lack of UAS experience. The reader is reminded of a discussion of these participants in Chapter 3. The descriptive statistics presented here are relative to the omission of these participants from the sample resulting in a sample size of $N = 34$. The means and standard deviations of each dependent variable are provided to the reader. In addition, means associated with different experience levels and order are also presented and discussed. Novice operators represent participants who exhibited 10 hours or less UAS experience. Experienced operators represent participants who exhibited over 10 hours of UAS experience.

The SAGAT was designed to capture objective SA and was calculated by summing the total correct SAGAT queries. According to Endsley (1990), queries are deemed correct if they fall within a range that is considered to be operationally close enough to the correct answer. For example, for a correct answer of 45 feet for UAS height, a range of 40–50 feet is deemed correct. The ranges of correct responses were presented to a subject matter expert and confirmed to be of operationally relevant ranges. The ranges of correctness used for scoring are presented in Appendix M. SAGAT scores could range from 0 to 26 with higher scores representing higher objective SA. As summarized in Table 4.1, objective SA was higher with the HUD interface design ($M = 15.4$, $SD = 3.1$) compared to the traditional interface design ($M = 14.5$, $SD = 2.6$). Generally, SAGAT scores were
higher in the second trial with experienced operators exhibiting slightly higher SA than novice operators.

The SART was utilized to capture subjective SA and was administered using Qualtrics on a provided laptop. The 10-item SART was measured using a 7-point scale. A total SART score was calculated using the formula presented in Table 3.7 in Chapter 3. SART scores ranged from 3 to 47, with higher scores reflecting higher subjective SA. As summarized in Table 4.2, subjective SA was higher with the HUD interface design ($M = 19.8, SD = 7.2$) compared to the traditional interface design ($M = 18.9, SD = 6.8$). In three out of four combinations of experience and order, SART scores were higher in the second trial. Further, experienced operators reported higher subjective SA than novice operators with the
Table 4.2
SART Scores by Interface, Experience, and Order

| Condition | Novice | | Experienced | | Overall |
|-----------|--------|----------------|--------------|----------------|
|           | M  | SD  | M  | SD  | M  | SD  |
| Trial 1   |     |     |     |     |     |     |
| Traditional | 12.4 | 6.6 | 21.9 | 7.23 | 17.9 | 8.3 |
| HUD       | 15.6 | 6.7 | 21.2 | 5.9 | 18.6 | 6.7 |
| Trial 2   |     |     |     |     |     |     |
| Traditional | 20.1 | 3.6 | 20.0 | 4.6 | 20.1 | 4.0 |
| HUD       | 17.0 | 7.7 | 23.5 | 6.6 | 20.7 | 7.6 |
| Overall   |     |     |     |     |     |     |
| Traditional | 16.0 | 6.6 | 21.1 | 6.1 | 18.9 | 6.8 |
| HUD       | 16.3 | 7.0 | 22.5 | 6.3 | 19.8 | 7.2 |

Note. N = 34. The Situation Awareness Rating Technique (SART) is a measure of perceived subjective situation awareness. Scores could range from 3 to 47, with higher scores representing higher subjective situation awareness.

exception that in the second trial, traditional SART scores were the same regardless of experience.

Performance was measured by grading the pictures taken by participants during the search scenarios against an answer key of images. Pictures were then marked as either correctly detected targets or false alarms. Correctly detected targets could range from 0–15. As summarized in Table 4.3, performance variability was low. HUD ($M = 11.9$, $SD = 2.1$) and traditional ($M = 11.6$, $SD = 2.2$) interface designs exhibited nearly identical means and standard deviations. Regardless of interface or order, novice operators detected, on average, 11 targets, and experienced operators detected, on average, 12 targets.

Workload was measured utilizing the NASA-TLX and was administered using Qualtrics on a provided laptop. Workload scores were calculated by
Table 4.3

*Performance Scores by Interface, Experience, and Order*

<table>
<thead>
<tr>
<th>Condition</th>
<th>Novice</th>
<th>Experienced</th>
<th>Overall</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$M$</td>
<td>$SD$</td>
<td>$M$</td>
</tr>
<tr>
<td>Trial 1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Traditional</td>
<td>10.8</td>
<td>2.1</td>
<td>12.0</td>
</tr>
<tr>
<td>HUD</td>
<td>11.0</td>
<td>1.8</td>
<td>12.5</td>
</tr>
<tr>
<td>Trial 2</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Traditional</td>
<td>11.5</td>
<td>2.7</td>
<td>12.5</td>
</tr>
<tr>
<td>HUD</td>
<td>11.5</td>
<td>2.8</td>
<td>12.4</td>
</tr>
<tr>
<td>Overall</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Traditional</td>
<td>11.1</td>
<td>2.3</td>
<td>12.1</td>
</tr>
<tr>
<td>HUD</td>
<td>11.3</td>
<td>2.3</td>
<td>12.4</td>
</tr>
</tbody>
</table>

*Note. N = 34. Performance was measured by the number of correctly detected targets. Scores could range from 0 to 15, with higher scores representing more targets detected.*

Table 4.4

*Workload Scores by Interface, Experience, and Order*

<table>
<thead>
<tr>
<th>Condition</th>
<th>Novice</th>
<th>Experienced</th>
<th>Overall</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$M$</td>
<td>$SD$</td>
<td>$M$</td>
</tr>
<tr>
<td>Trial 1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Traditional</td>
<td>65.4</td>
<td>18.1</td>
<td>56.0</td>
</tr>
<tr>
<td>HUD</td>
<td>56.6</td>
<td>19.2</td>
<td>56.6</td>
</tr>
<tr>
<td>Trial 2</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Traditional</td>
<td>52.7</td>
<td>23.1</td>
<td>60.6</td>
</tr>
<tr>
<td>HUD</td>
<td>55.4</td>
<td>23.9</td>
<td>56.5</td>
</tr>
<tr>
<td>Overall</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Traditional</td>
<td>59.5</td>
<td>20.9</td>
<td>57.9</td>
</tr>
<tr>
<td>HUD</td>
<td>55.9</td>
<td>21.1</td>
<td>56.6</td>
</tr>
</tbody>
</table>

*Note. N = 34. The NASA-TLX is a measure of mental workload. Scores could range from 6 to 120, with higher scores representing higher mental workload.*

summing the six questions for a score range of 6–120. As summarized in Table 4.4, the traditional interface ($M = 58.6, SD = 18.9$) had a higher workload rating than the HUD ($M = 56.3, SD = 19.8$). Generally, for novice operators, workload was rated lower in the second trial for each interface compared to the first trial. For
experienced operators, workload stayed relatively stable except for those who received the traditional interface in the second trial.

**Inferential Statistics**

**Overview.** The primary purpose of the current study was to evaluate the impact of interface design on various outcome measures, including situation awareness, performance, and workload. The research methodology that was best suited to address the research questions associated with the study purpose was a within-subjects repeated measures experimental design. This design was the most appropriate as it allowed the comparison of traditional and HUD interface designs on the targeted dependent variables while also controlling for individual differences such as experience level and visual acuity. The primary inferential statistical procedure for the current study was a repeated measures MANOVA with univariate follow-up analyses.

**Preliminary analysis.** Prior to the MANOVA, preliminary analyses were conducted to clean the dataset of any outliers and missing data. Then, the dataset was checked to confirm no multicollinearity. Finally, the dataset was checked against the MANOVA assumptions. The following section outlines the steps taken to build the dataset used in the MANOVA, which is discussed in the primary and supplemental analyses presented in the following sections.

**Dataset modifications.** Due to the low number of participants in each level of experience, UAS experience was recoded into a dichotomous variable
representing participants with 10 hours or less of experience (novice) and those with over 10 hours of experience (experienced). SAGAT queries were also checked to evaluate the number of participants who answered the query correctly. The query “Enter the distance (in FT) that the drone will have traveled when the battery is at 0%” had a very low correct response rate with only 2 correct responses out of the 64 administrations of the question. Due to the nature of most participant responses, it is believed that participants misinterpreted the question, assuming it was related to the distance between the operator and the UAS, not the distance the UAS would have traveled, as the question intended. Therefore, this question was omitted from the SAGAT score calculations. No other modifications were made.

**Missing data.** The dataset was checked for missing data and revealed no missing data.

**Outliers.** Outliers are data cases that exhibit very high or low scores that can represent either contaminated data or rare cases. For contaminated data, this can occur when data have been incorrectly entered or the result of an error. For rare cases this can occur if participants exhibit an abnormal case such as a participant with vastly more flight experience than others. To check the dataset for outliers, Jackknife distances were calculated. This analysis revealed three outliers. One of the outliers was related to a participant who mentioned that she had not slept before the task and was nervous about an exam afterwards. Another outlier was related to a participant who had very low SART scores and the lowest SAGAT correctness,
implying the participant had a low understanding of the task. The last outlier was related to a participant who rated their SART very low, and an alarm had gone off during his training. It was assumed these data points were contaminated data and not rare cases and therefore were removed from the dataset.

**Multicollinearity.** One assumption with multivariate analyses is that each variable has the potential for a unique contribution to the explained variance. To ensure this, variables must not be highly correlated. To assess the relationship between the variables, bivariate correlations were analyzed between the dependent variables. It was revealed that all variables exhibit correlation coefficients below .44. Correlation coefficients of \( r > .8 \) are considered problematic, and therefore it was determined multicollinearity was not an issue.

**Statistical strategy assumptions.** After completing the preliminary data analyses discussed above, additional assumptions must be met based on the statistical strategy used. For a MANOVA, the following assumptions must be met: (a) independence of the DVs, (b) linear relationships between pairs of DVs, (c) equal variances across the DVs, and (d) normal distributions across the DVs. Each of the assumptions and the compliance with each assumption is discussed in the following sections.

**Independence.** The independence assumption is concerned with the observations of each DV being independent of one another. The reader should note that none of the scores, SAGAT, SART, workload, or performance, were dependent
on one another. Based on the fact that none of the DVs scores were dependent on each other, the independence assumption was met.

*Linearity.* The linearity assumption is concerned with the form of the relationship between DVs. To test this assumption, a bivariate correlation was conducted between each pair of DVs. It was discovered that all pairs of the DVs exhibited a significant linear relationship except (a) workload and SAGAT scores, and (b) workload and performance scores, which exhibited $p$ values of $p = .07$ and $p = .08$, respectively. This was expected as Endsley’s (1995a) theory of SA discusses that workload can impact SA. Furthermore, SA can lead to improved performance. Significant relationships between the variables were expected. The reader should note these linear relationships when interpreting the results sections.

*Equal variances.* The equal variances assumption is concerned with equal variances across the residuals regardless of the independent variable values. To test this assumption, Levene’s test of equality of error variances was conducted. It was found that all DVs satisfied the equality of error variances except for the SAGAT scores for the traditional condition. However, Stevens (2001, p. 268) notes, “…the $F$ statistic is robust against heterogeneous variances when the group sizes are equal.” The group sizes were equal for each condition of the dependent measure, and therefore noncompliance with the equal variance assumption did not preclude me from continuing with the primary analysis.
Normal distributions. The normal distribution assumption is concerned with the error of the residuals being normally distributed for each of the DVs. To test this assumption, a Shapiro-Wilk test for normality was conducted. It was found that, of the four DVs, all exhibited a normal distribution except the performance measure of correctly detected targets. This was expected due to the low variability presented in the descriptive statistics section discussed previously. However, “…the sampling distribution of $F$ is only slightly affected, and therefore the critical values when sampling from normal and non-normal distributions will not differ by much” (Stevens, 2001, p. 262). The assumption of normal distributions was met for three of the four DVs, and noncompliance with the fourth did not preclude me continuing with the primary analysis.

Summary of preliminary analyses. Following the removal of three outliers during the preliminary analysis, the total sample size included $N = 31$ participants. No missing data occurred, and no variables were removed due to multicollinearity. The independence assumption was met. Equal variance and normality assumptions were violated but should not affect the primary analyses due to the robustness of the $F$ test. The linearity assumption violations between workload and SAGAT scores, and workload and performance scores should be noted by the reader when interpreting the results.

MANOVA discussion. To examine the effect of interface design on situation awareness, performance, and workload, a repeated-measures MANOVA
was utilized. Interface design was treated as the within-subjects factor with SAGAT (objective SA), SART (subjective SA), NASA-TLX (workload), and targets detected (performance) as the dependent variables. Conducting a MANOVA allowed for an omnibus test to prevent inflation of Type I and Type II errors. An initial analysis was run and revealed an insignificant MANOVA model with $F(4, 27) = 1.60, p = .20$. The results of that analysis are presented in Table 4.5. Although the overall model was not significant, the univariate breakdown is provided in the table for the benefit of the reader.

As examination of the data led to more familiarity, it is believed that the results presented above could be spurious due to other factors. Based on the comparisons of the means presented in Tables 4.1–4.4 in the descriptive statistics section, it became apparent that: (a) performance means were consistent across all conditions with both interface designs exhibiting an overall mean of approximately 12 targets detected, and (b) there were clear differences in means based on the order in which participants received the interfaces and UAS experience level. It was
determined that, in order for effects of interface design to emerge, the effects of order and UAS experience needed to be controlled. As a result, two changes to the analysis were made. First, performance was omitted to increase power as variance of performance scores between the two interfaces was minimal. Second, the type of analysis was altered to a mixed model repeated measures MANOVA with the following variables: (a) a within-subjects factor of interface design (traditional, HUD); (b) two between-subjects factors of order (traditional→HUD, HUD→traditional) and UAS experience level (novice operators representing 10 hours or less, experienced operators representing more than 10 hours); and (c) three dependent variables (SAGAT, SART, and workload). The new analysis approach is presented in Figure 4.1. The reader should note that the new approach allowed for the control of the between-subjects factors that could have an influence on the results and was still appropriate to answer the a priori hypotheses.

The research questions were then answered relative to the new analysis where order and UAS experience were included as between-subjects factors. In addition, for the benefit of the UAS operational community, univariate follow up of the interactions are also explored in the supplemental analyses section of Chapter 4. Analyzing the interactions will allow for a discussion of training order and interface that is best for novice and experienced UAS operators. The results of the overall mixed model MANOVA are presented within this section.
The adjusted analysis—the repeated measures mixed model MANOVA—revealed a significant overall MANOVA model, $F(3, 25) = 3.40, p = .03$, as shown in Table 4.6. In addition, significant interactions between interface and order were revealed, including a three-way interaction between interface, order, and UAS experience. Therefore, univariate follow-up tests were conducted on interface, interface*order, and interface*UAS experience*order. The interactions are discussed in the supplementary analyses section.

**Main effects.** The follow up univariate analysis is presented in Table 4.7. SAGAT scores were the only dependent variable significantly influenced by interface design, $F(1, 27) = 4.24, p = .049$. The reader should note the lack of a proper reliability assessment for the SAGAT and the result should be interpreted...
Table 4.6
Repeated Measures Mixed Model MANOVA Summary of Interface on:
SAGAT, SART, and Workload with UAS Experience and Order Between
Subjects Factors

<table>
<thead>
<tr>
<th>Between Subjects Effects</th>
<th>A</th>
<th>F</th>
<th>df</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>UAS Experience</td>
<td>.819</td>
<td>1.84</td>
<td>3, 25</td>
<td>.166</td>
</tr>
<tr>
<td>Order</td>
<td>.959</td>
<td>.354</td>
<td>3, 25</td>
<td>.786</td>
</tr>
<tr>
<td>UAS Experience*Order</td>
<td>.982</td>
<td>.982</td>
<td>3, 25</td>
<td>.927</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Within Subjects Effects</th>
<th>A</th>
<th>F</th>
<th>df</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>Interface</td>
<td>.710</td>
<td>3.40</td>
<td>3, 25</td>
<td>.033*</td>
</tr>
<tr>
<td>Interface*UAS Experience</td>
<td>.804</td>
<td>2.03</td>
<td>3, 25</td>
<td>.134</td>
</tr>
<tr>
<td>Interface*Order</td>
<td>.548</td>
<td>6.88</td>
<td>3, 25</td>
<td>.022*</td>
</tr>
<tr>
<td>Interface<em>UAS Experience</em>Order</td>
<td>.584</td>
<td>5.92</td>
<td>3, 25</td>
<td>.003**</td>
</tr>
</tbody>
</table>

Note. N = 31.
*p < .05. **p < .01. ***p < .001.

Table 4.7
Repeated Measures Mixed Model MANOVA Univariate Follow-up
Summary of Interface on: SAGAT, SART, and Workload with UAS
Experience and Order Between Subjects Factors

<table>
<thead>
<tr>
<th>Interface</th>
<th>F</th>
<th>df</th>
<th>p</th>
<th>η²</th>
</tr>
</thead>
<tbody>
<tr>
<td>SAGAT</td>
<td>4.236</td>
<td>1, 27</td>
<td>.049*</td>
<td>.136</td>
</tr>
<tr>
<td>SART</td>
<td>.000</td>
<td>1, 27</td>
<td>.992</td>
<td>.000</td>
</tr>
<tr>
<td>Workload</td>
<td>3.061</td>
<td>1, 27</td>
<td>.091</td>
<td>.102</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Interface*Order</th>
<th>F</th>
<th>df</th>
<th>p</th>
<th>η²</th>
</tr>
</thead>
<tbody>
<tr>
<td>SAGAT</td>
<td>9.33</td>
<td>1, 27</td>
<td>.005**</td>
<td>.257</td>
</tr>
<tr>
<td>SART</td>
<td>6.95</td>
<td>1, 27</td>
<td>.014*</td>
<td>.205</td>
</tr>
<tr>
<td>Workload</td>
<td>2.92</td>
<td>1, 27</td>
<td>.099</td>
<td>.098</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Interface<em>UAS Experience</em>Order</th>
<th>F</th>
<th>df</th>
<th>p</th>
<th>η²</th>
</tr>
</thead>
<tbody>
<tr>
<td>SAGAT</td>
<td>.583</td>
<td>1, 27</td>
<td>.452</td>
<td>.021</td>
</tr>
<tr>
<td>SART</td>
<td>5.78</td>
<td>1, 27</td>
<td>.023*</td>
<td>.176</td>
</tr>
<tr>
<td>Workload</td>
<td>10.15</td>
<td>1, 27</td>
<td>.004**</td>
<td>.273</td>
</tr>
</tbody>
</table>

Note. N = 31. The SAGAT reliability could not be properly assessed and should be interpreted with caution.
*p < .05. **p < .01. ***p < .001.
with caution. The HUD interface design condition exhibited a SAGAT score average of one more question correct compared to the traditional interface design condition (see Figure 4.2). Interface did not have a significant impact on SART scores, $F(1, 27) = 0.00$, $p = .992$, or workload scores, $F(1, 27) = 3.08$, $p = .091$. In the context of the current study, operators using the HUD interface exhibited higher SA compared to when they were using the traditional interface. The practical significance of the mean differences is discussed in Chapter 5.

**Supplemental analysis.** The following section presents the results associated with the interactions and the third exploratory research question “What is the effect of HUD UAS operation on workload for a visual search task compared to traditional UAS operation?”. Also presented is a summary of qualitative research questions and the UAS parameter frequency ratings for day-to-day operations and within the context of the current study.

![Figure 4.2. SAGAT Scores by Interface](image)
**Interactions.** The follow-up univariate analysis for the interaction between interface and order revealed two significant variables accounting for the omnibus significance of the interaction. There was a significant interaction between order and interface with respect to SAGAT scores, $F(1, 27) = 9.33, p = .005$. Again, the reader should note the lack of a proper reliability assessment for the SAGAT and the result should be interpreted with caution. In addition, there was a significant interaction between order and interface with respect to SART scores, $F(1, 27) = 6.95, p = .014$. This was expected as participants learned the task and became more familiar with the simulator and what they would be queried on. This resulted in higher objective SA and higher subjective SA in their second trial. The interactions are displayed in Figure 4.3 for SAGAT and SART. As shown, SA increased in the second trial in all instances, except for the traditional interface subjective SA SART ratings, which remained the same between the two

![SAGAT and SART Scores by Order](Figure 4.3. SAGAT Scores by Order and SART Scores by Order)
trials. In the context of the current study, the results suggest that UAS operator’s SA increased on the second trial.

The follow-up univariate analysis for the three-way interaction among interface, UAS experience, and order revealed two significant variables accounting for the omnibus significance of the interaction. There was a significant interaction among interface, order, and experience with respect to SART scores, $F(1, 27) = 5.77, p = .023$. There was also a significant interaction among interface, order, and experience with respect to workload, $F(1, 27) = 10.15, p = .004$. In the context of the current study, this suggests that there is an interplay of interface order and experience level on SART scores and workload scores. Due to the difficulty of interpreting three-way interactions, these will not be interpreted; however, to provide some clarity to the reader, Figure 4.4 presents the data in graphical form. Also, the reader should note that for SART scores, the lowest subjective SA was

![Figure 4.4. SART Scores and Workload Scores by Order and Interface](image)

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reported by novice operators who were given the HUD in their first trial. The highest subjective SA was reported by experienced operators who were given the HUD interface in their second trial. For workload, the highest workload ratings were reported by novice operators who were given the traditional interface design condition in their first trial. The lowest workload was reported by novice operators who were given the HUD interface in their second trial.

**Workload.** As discussed in the MANOVA analyses, there was no significant effect of interface on workload as measured by the NASA-TLX, $F(1, 27) = 3.06, p = .09$. This suggests that the HUD neither significantly increases nor decreases workload ratings. The implications relative to this finding are discussed in Chapter 5.

**Qualitative comments.** To capture the “why” related to the quantitative findings, participants were asked what specifically they liked or disliked about each interface design and why. Comments were categorized as either positive comments or negative comments. Then, similar terms or themes were extracted from the comments. Similar terms and themes were then condensed into the categories. As shown in Table 4.8, the most frequently noted positive comment was that participants perceived it was easier to maintain VLOS with the traditional interface. Participants reported that the full-screen view allowed for an easier view of information that was less cluttered. Participants also commented that the traditional interface “opened up my field of view to see the drone better” and the “lack of
Table 4.8
Summary of Qualitative Comment Frequencies

<table>
<thead>
<tr>
<th></th>
<th>Traditional Liked</th>
<th></th>
<th>HUD Liked</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>VLOS easier to maintain</td>
<td>6</td>
<td></td>
<td>One screen to see all information</td>
<td>15</td>
</tr>
<tr>
<td>Full screen view</td>
<td>6</td>
<td></td>
<td>Less eye movement</td>
<td>14</td>
</tr>
<tr>
<td>Distributed/uncluttered display</td>
<td>4</td>
<td></td>
<td>Easier</td>
<td>12</td>
</tr>
<tr>
<td>Camera doesn’t block VLOS</td>
<td>3</td>
<td></td>
<td>Efficient</td>
<td>4</td>
</tr>
<tr>
<td>Contrast for reading parameters</td>
<td>3</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>Traditional Disliked</th>
<th></th>
<th>HUD Disliked</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Greater scan distance</td>
<td>16</td>
<td></td>
<td>Camera blocked VLOS</td>
<td>7</td>
</tr>
<tr>
<td>High workload/more eye movement</td>
<td>10</td>
<td></td>
<td>Camera was not fully utilized</td>
<td>4</td>
</tr>
<tr>
<td>Diverted attention</td>
<td>8</td>
<td></td>
<td>Too much info / Disorienting</td>
<td>4</td>
</tr>
<tr>
<td>Threat of missed info or VLOS</td>
<td>6</td>
<td></td>
<td>Difficult to see info (low contrast)</td>
<td>3</td>
</tr>
<tr>
<td>Camera was not fully utilized</td>
<td>4</td>
<td></td>
<td>High workload/ineffective</td>
<td>3</td>
</tr>
</tbody>
</table>

additional visual clutter from the overlapping overlay/feed allowed me to separate the information being given.” Pulling the parameter information into a separate display prevented camera view information from blocking the environment view. Finally, the traditional interface presented parameters on a black background that provided ample color contrast to read the parameters quickly. In the HUD condition, if the participant was positioned over a light area of the environment, it could be more difficult to read due to low contrast. In a real-life setting this is a relevant concern when utilizing AR technology. On the other hand, participants mainly disliked the traditional interface design due to greater scan distance to acquire information. This was due to the increased workload and diverted attention between the two displays as “there was far too much distance for the eye to travel to get the information necessary, making it less likely to be seen.” Participants felt that
there was an increased risk of missing information or breaking VLOS. For example, a participant reported that “I felt like I would miss something when I would check something else.” Participants also mentioned that “when flying for real taking eyes off one screen to focus on another can be costly as all it takes is a bird you don’t see or a tree to ruin your flight or drone.” Additionally, participants disliked the size of the camera window in the lower display. The size of the camera view was kept the same in both interface designs for experimental control of the study. This would likely not be a negative standpoint in a real-life setting where camera view can be expanded to the full size of the display.

For the HUD setting, the most frequently noted positive comment was that all of the information was accessible within one single screen. This allowed all information to be viewed at once, and participants felt it was easier and more efficient. In addition, it was noted that it required less eye movement. Participants mentioned “It was much easier to maintain situational awareness” and that it promoted a “scan, which allowed me to look at things quicker to keep an eye on the search task.” On the other hand, participants mainly disliked the fact that integrating the camera view into the VLOS made the VLOS area much smaller. The camera often blocked VLOS and required more movement to keep the UAV in view. The HUD “was much more natural and easier to scan for UAS information throughout the situation…It felt a bit more involved to keep line of sight due to the limited viewing angle, but overall a much more preferable experience.” Higher
workload was also noted along with too much information as “the screens are on top of each other, which made it disorienting, this made me forget about observing visually.” Others stated the “overlapping HUD and camera feed prevented me from focusing on any one aspect of the task effectively.” Participants also mentioned that the contrast made it difficult to read parameters against the terrain. Finally, participants mentioned they felt that the camera was not fully utilized, similar to the traditional condition. These comments related to camera size in both the HUD and traditional conditions address the design of the interface itself instead of placement, which is an area for future research. For qualitative comments, a higher number of positive comments were related to the HUD interface, and a higher number of negative comments were related to the traditional interface. Overall participants rated the traditional interface at 2.5 of effectiveness on a 5-point Likert scale, which denotes the traditional interface between slightly effective to somewhat effective. The HUD interface was rated at 3.5 of effectiveness on a 5-point Likert scale, which denotes the HUD interface between somewhat effective to very effective.

**UAS parameter frequency of use.** Participants were asked to rate the frequency of use of UAS parameters presented on the interfaces to guide future interface design research. Participants were asked to rate the use of the parameters from 1 = “Not at all” to 5 = “Always.” The average ratings for both their day-to-day operations and the search and rescue task in the current study are presented in Table
4.9. In day-to-day operations, the four most frequently used parameters included battery life indicators, altitude, camera feed, and distance. These parameters allow the operator to understand the position of the UAS, how much battery life is remaining, and to see what the UAV can “see.” These elements are general to most use cases of UAS operations. For search and rescue in the current study, the four most frequently used parameters included the camera feed, altitude, battery life indicators, and GPS map data. These elements, although slightly different from general UAS operations, do align with the qualitative comments. Many of the qualitative comments centered around the camera elements. Altitude is crucial to prevent any damage to UAS when flying low to search for targets and also provides information on how small targets may appear. Battery life indicators and GPS map

<table>
<thead>
<tr>
<th>Day-to-Day Operations</th>
<th>Rating</th>
<th>Simulated Search and Rescue</th>
<th>Rating</th>
</tr>
</thead>
<tbody>
<tr>
<td>Battery Life Indicator</td>
<td>4.7</td>
<td>Camera Video Feed</td>
<td>4.8</td>
</tr>
<tr>
<td>Altitude/Height</td>
<td>4.0</td>
<td>Altitude/Height</td>
<td>4.0</td>
</tr>
<tr>
<td>Camera Video Feed</td>
<td>4.0</td>
<td>Battery Life Indicator</td>
<td>3.9</td>
</tr>
<tr>
<td>Distance</td>
<td>3.8</td>
<td>GPS Map</td>
<td>3.9</td>
</tr>
<tr>
<td>GPS Signal Strength</td>
<td>3.6</td>
<td>Horizontal Speed</td>
<td>3.7</td>
</tr>
<tr>
<td>Return to Home Indicator</td>
<td>3.6</td>
<td>GPS Track</td>
<td>3.6</td>
</tr>
<tr>
<td>Home Point Indicator</td>
<td>3.3</td>
<td>Distance</td>
<td>3.6</td>
</tr>
<tr>
<td>Horizontal Speed</td>
<td>3.2</td>
<td>Compass</td>
<td>3.5</td>
</tr>
<tr>
<td>GPS Map</td>
<td>3.1</td>
<td>GPS Satellites</td>
<td>3.2</td>
</tr>
<tr>
<td>GPS Satellites</td>
<td>3.0</td>
<td>GPS Signal Strength</td>
<td>3.1</td>
</tr>
<tr>
<td>GPS Track</td>
<td>3.0</td>
<td>Return to Home Indicator</td>
<td>3.1</td>
</tr>
<tr>
<td>Vertical Speed</td>
<td>3.0</td>
<td>Home Point Indicator</td>
<td>3.0</td>
</tr>
<tr>
<td>Compass</td>
<td>2.8</td>
<td>Vertical Speed</td>
<td>2.7</td>
</tr>
</tbody>
</table>

*Note.* Parameters were rated on a 5-point scale from 1 = “Not at all” to 5 = “Always”.

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data both provide information on how much of the area has been covered and how much can still be covered. Recommendations and implications relative to these ratings are discussed in Chapter 5.

**Results of Hypotheses Testing**

The research questions and research hypotheses for the current study were presented in Chapter 1. The research hypotheses are restated in null form within this section for testing purposes. Each hypothesis is presented along with the corresponding decision to reject or fail to reject.

**Null hypothesis 1:** There will be no significant effect of interface design on performance for a visual search task. As shown in Table 4.5, there was no significant effect of interface design on performance scores. Therefore, Hypothesis 1 was not rejected: Interface design has no significant effect on performance relative to a visual search task.

**Null hypothesis 2a:** There will be no significant effect of interface design on SA for a visual search task. As shown in Table 4.7, there was a significant main effect of interface design type on SAGAT scores. The reader should note the lack of a proper reliability assessment for the SAGAT and the result should be interpreted with caution. The HUD UAS operations resulting in a one-point higher SAGAT score compared to traditional UAS operations. Therefore, Hypothesis 2a was rejected.
Null hypothesis 2b: There will be no significant effect of interface design on perceived SA for a visual search task. As shown in Table 4.7, there was no significant effect of interface design on SART scores. Therefore, Hypothesis 2b was not rejected: Interface design has no significant effect on subjective SA relative to a visual search task.
Chapter 5

Conclusions, Implications, and Recommendations

Summary of the Study

The primary purpose of the study was to examine the effect of interface design on SA, performance, and workload. The IV of interface design consisted of two conditions: (a) traditional—where the environment view and interface view were presented on two separate monitors, and (b) HUD—where the interface view was overlaid on the environment view on a single monitor. The dependent variables consisted of objective SA, subjective SA, performance, and workload. The study utilized a within-subjects repeated measures approach, which was determined to be the best approach to answer the research questions. The order of interface designs was counterbalanced to mitigate order effects. This approach controlled for individual factors such as experience, visual acuity, and previous training.

The target population for the study was U.S. commercial and recreational UAS operators. The target population was then delimited to a smaller accessible population that consisted of Brevard County organizations that currently use UAS commercially in their day-to-day operations and recreational UAS operators (or those with an interest in UAS). Utilizing a convenience sampling and snowball approach, the sample size was $N = 45$. After performing preliminary data analyses, the final sample consisted of $N = 31$ participants. The demographic breakdown of the sample is presented in Chapter 3 (Table 3.2).
The data collection instruments consisted of (a) objective measurement of SA captured via SAGAT queries, (b) subjective measurement of perceived SA captured via the SART, (c) workload captured via the NASA-TLX, and (d) performance captured via the number of correctly detected targets. The reliability and validity of these measures is presented in Chapter 3. Also discussed were the challenges associated with assessing the reliability of the SAGAT measure and thus, reliability of the measure could not be properly assessed in the current study. Any findings relative to the SAGAT measure should be interpreted with caution.

**Summary of Findings**

A total of 45 participants were run through the current study. Five participants were omitted prior to data analysis due to issues encountered during the study. Then, six participants were omitted due to a lack of prior UAS experience. The dataset of 34 participants was then screened with preliminary analyses. Outlier analyses, multicollinearity, and MANOVA assumptions were tested, resulting in a final dataset of \( N = 31 \). A repeated measures MANOVA was performed and revealed no significant effects. However, while working with the data, it was clear that experience effects and order effects were likely present. Therefore, a new analysis was performed. A repeated measures mixed model MANOVA was conducted with between-subject factors of UAS experience and order. The following section outlines a brief summary of the primary analysis. In addition,
Table 5.1
Summary of Hypotheses Tests Results (α = .05)

<table>
<thead>
<tr>
<th>Null Hypothesis</th>
<th>Decision</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. There will be no significant effect of interface design on performance for a visual search task</td>
<td>Failed to Reject</td>
</tr>
<tr>
<td>2a. There will be no significant effect of interface design on objective SA for a visual search task</td>
<td>Rejected(^a)</td>
</tr>
<tr>
<td>2b. There will be no significant effect of interface design on subjective SA for a visual search task</td>
<td>Failed to Reject</td>
</tr>
</tbody>
</table>

Note. N = 31.
\(^a\)Hypotheses were tested using a repeated measure MANOVA strategy with interface design as the IV and SART scores (subjective SA), SAGAT scores (objective SA), workload scores, and performance scores as dependent variables. \(^b\)Hypothesis 2a was rejected as univariate follow-up analyses revealed significance for SAGAT scores. The result should be interpreted with caution due to the lack of proper reliability assessment of the SAGAT measure.

summarizes of the supplementary analyses of workload impacts, qualitative comments, and UAS parameter frequency ratings are also presented.

**Primary analysis: Hypothesis 1 and 2.** An initial repeated measure MANOVA and comparison of means revealed no significant relationship between interface design and performance. A repeated measure mixed model MANOVA with between-subject factors of UAS experience level and interface order revealed significant main effects of interface. Univariate follow-up analyses revealed significant effects of interface design on SAGAT scores with the HUD exhibiting a one point higher mean than the traditional interface (see Table 4.7). The reader should note the lack of a proper reliability assessment for the SAGAT and the result should be interpreted with caution.

**Supplementary analyses 1: Interactions.** Interactions between order and interface were revealed for both SAGAT scores and SART scores. SAGAT scores
and SART scores increased in the second trial, regardless of interface design. Also discovered was a three-way interaction between interface, order, and UAS experience with respect to workload ratings and SART scores. The reader should note the lack of a proper reliability assessment for the SAGAT and the result should be interpreted with caution. Due to the difficulty in interpreting three-way interactions, this interaction will not be interpreted (see Table 4.7 & Figure 4.4).

**Supplementary analyses 2: Impacts on workload.** Included within the repeated measures mixed model MANOVA was workload. Based on the mixed results within the literature, no hypotheses were made relative to workload. Instead, workload was analyzed from an exploratory perspective. Supplementary analyses revealed no significant effects of interface on workload.

**Supplementary analyses 3: Qualitative comments.** Open-ended responses regarding participants’ opinions about each interface revealed specifics on what was liked and disliked about each interface. For the traditional interface, participants liked the full screen views of interface and environment that allowed for easier VLOS and a distributed view of information. However, participants did not like the greater distance between pieces of information and the increased workload it created. For the HUD interface, participants liked that all information was presented on one screen, which required less eye movement and was seen as easier. However, participants did not like that the camera view reduced the area to maintain line of sight, and some participants noted the HUD to be disorienting.
Supplementary analyses 4: UAS parameter frequencies. Participants were asked to rate how frequently they used various parameters (a) in their day-to-day operations, and (b) in the search and rescue task in the current study. For day-to-day operations, the most frequently used parameters included battery life indicators, altitude, camera video feed, and distance. For the simulated search and rescue mission, the most frequently used parameters included camera video feed, altitude, battery life indicator, and GPS map.

Conclusions and Inferences

In the following section, the findings from the study are presented and discussed relative to the research questions and terms defined in Chapter 1. Each section describes the results related to the corresponding research questions, along with interpretations of those findings in the context of the research settings. Plausible explanations for the findings are also presented.

Research question 1: What is the effect of HUD UAS operation on performance for a visual search task compared to traditional UAS operation?

The repeated measures MANOVA revealed insignificant effects related to performance (see Table 4.5). One plausible explanation for these results is relative to the operational definition of performance in the current study. Targets detected may not have been sensitive enough to show differences between interfaces. Other studies have shown differences in performance classified by degree of accuracy, such as time to find targets, or picture accuracy (Calhoun et al. 2007; Hedayati et
al., 2018). Although the original intent was to measure target time, the ability to objectively measure target time detection proved difficult.

A second plausible explanation is that the HUD interface does not improve target detection but may improve other aspects of performance. For example, HUDs in manned aviation have shown to significantly reduce pilot errors, such as lateral and vertical deviations, and improved initial approach accuracy (Kramer et al., 2003; Thomas, 2009). Potentially, performance metrics related to frequency or duration of broken VLOS may have emerged as significant performance impacts. Furthermore, the automated flight mode of the task prevented operator errors from occurring. Manual flight may have allowed for piloting error differences to emerge as a performance difference similar to research by Hedayati et al. (2018).

A third plausible explanation is that a HUD does not significantly impact target detection. It is possible that a HUD simply does not improve the likelihood of finding targets. In the context of the current study, a HUD display did not help a UAS operator find more missing persons. However, the reader should also note that the utilization of a HUD, based on the findings of the current study, would not hinder target detection.

**Research question 2: What is the effect of HUD UAS operation on SA and subjective SA for a visual search task compared to traditional UAS operation?** The repeated measures mixed model MANOVA revealed a significant main effect of interface. A follow-up univariate analyses revealed significant
effects of interface design on SAGAT scores, $F(1, 27) = 4.2, p = .049$, but not on SART scores, $F(1, 27) = 0.00, p = .99$.

One plausible explanation for the findings is relative to Endsley’s model of SA in which interface design is proposed to improve SA (Endsley, 1995a). In the context of the current study, integrating UAS status and sensor information up into the VLOS improved objective SA. However, the results did not show significant differences for subjective SA ratings. This may be due to concerns discussed by Endsley (1995c) regarding subjective measures that capture perceived level of SA; specifically, that operators may not be aware of the SA that they lack. In other words, you don’t know what you don’t know. Endsley argues that subjective SA measures may be more representative of how comfortable operators are in the situation relative to their knowledge, or operator workload relative to how difficult it was to obtain SA. In the context of the current study, it is plausible that operators perceived that they had no gains in their SA and felt similar levels of comfort and workload with both interface designs. However, actual objective SA scores were higher in the HUD condition regardless of operator’s awareness of improved SA.

A second plausible explanation for objective SA score differences is that, due to the reduced distance between information in the HUD condition, participants were able to shift their attention quicker to pieces of information they felt were critical to monitor. This reflects a better ability for operators to collect various pieces of information and therefore gain level 1 SA.
A third plausible explanation for objective SA differences could have been due to measurement error. The lack of proper reliability assessment for the SAGAT measure means that the results associated with SAGAT scored should be interpreted with caution. More research is needed to assess the reliability of the SAGAT queries and confirm the findings.

**Research question 3: What is the effect of HUD UAS operation on workload for a visual search task compared to traditional UAS operation?** The repeated measures mixed model MANOVA revealed a significant main effect of interface. A follow-up univariate analyses revealed no significant effect of interface design on workload scores $F(1, 27) = 3.08, p = .091$.

One plausible explanation is that the HUD exhibited reductions and increases in workload in different ways. The reductions in workload were noted by participants in qualitative comments based on the reduced distance between pieces of information. However, participants also noted it required more effort to maintain VLOS because the camera view occluded a large area of the environmental view. It is plausible that any workload reductions for the HUD were cancelled out by the added workload to maintain VLOS.

A second plausible explanation is that the nature of the task itself did not change. Participants were still given the same tasks, and both conditions required the same inputs and controls to complete the task. It is possible that no significant workload differences emerged due to the similarity between the two tasks.
Implications

The following section presents the implications: (a) relative to the SA model from Endsley (1995a) discussed in Chapter 2, (b) relative to prior research presented in Chapter 2, and (c) relative to the UAS industry.

Implications relative to theory. The theory the current study was grounded on was Endsley’s (1995a) model of SA. Endsley’s theory posited that operators can possess different levels of SA or an understanding of the situation. Operators can exhibit three levels of SA: (a) Level 1—a perception of the elements, (b) Level 2—creating meaning from the elements, and (c) Level 3—projecting to the future. One’s ability to have high levels of SA depends on various individual and task factors. Individual factors can include one’s goals, experiences, training, and memory. Task or system factors can include automation, stress level, workload level, and system design, such as the interface. One who exhibits high SA should be able to make better decisions, which can ultimately lead to more desirable performance and outcomes. However, someone with poor SA may make bad decisions based on inaccurate or incomplete information, ultimately leading to errors, incidents, and accidents.

In the context of the current study, the findings support some specific aspects of the model. Relative objective SA captured via the SAGAT, the findings support the model. Based on SA theory, improved interface design should facilitate improved SA. In the current study, it was discovered that by reducing the distance
between sources of information by utilizing a HUD design, participants were able to acquire higher levels of SA. Relative to subjective SA captured via the SART, the findings did not support the model. Interface design did not impact the participants’ own perceptions of their SA. It is likely that either participants were not aware of the SA they were lacking or that measures and perceptions of SA are not sensitive enough to the small differences observed in this study. Also, the lack of reliability information on the SAGAT could have also led to the results observed in this study and should interpret the results with caution. Lastly, relative to performance, the findings did not support the model. Based on SA theory, improved SA should lead to improved performance. In the current study, participants detected the same number of targets in both interface designs. It is possible that, similar to Endsley’s (1990) findings, the results of the current study reflect that the relationship between SA and mission success is a complex one. It is possible that better SA about the UAS status did not lead to improved performance on detecting missing persons. Endsley notes that improved SA may not lead to improved performance if they are unable to capitalize on it. Because the flight was automated, it is possible that participants could not utilize their increased SA to improve performance, or that the subtle differences in SA did not lead to a significant increase in the type of performance measured.

Implications relative to prior research. The findings from the current study are in line with previous research. The current study unveiled that HUD
design led to improved SA, as measured via a freeze probe technique known as SAGAT. However, due to the lack of proper assessment of reliability in the current study, the implications should be interpreted with caution. This is consistent with findings from various domains. For example, the review of medical research utilizing HUDs and HWDs by Yoon et al. (2018) found similar findings that bringing vital sources of information into view can lead to improved SA during surgical processes. In the automotive domain, Lindermann et al. (2018) researched the impacts of providing a HUD above the steering wheel. Utilizing a freeze probe approach, they also discovered improved SA utilizing a HUD. Furthermore, although the freeze approach is difficult to implement in aviation settings, HUDs have also shown to improve SA utilizing other measures (Bailey et al., 2007; Snow & Reising, 1999).

Research that can be directly compared to the current study is limited as little research has been performed in the UAS industry relative to interface design. The research that has been conducted has centered around BVLOS operations. Research by Hedayati et al. (2018) and Ruiz, et al. (2015) are the only studies that have a fairly similar design. Hedayati et al. (2018) evaluated the impact of AR in manual UAS operations in an enclosed indoor area on performance and accuracy. Participants utilizing AR demonstrated improved accuracy and task completion time. In addition, participants rated the AR condition as more comfortable, easier, and more usable. These results are also in line with qualitative aspects of the
current study in which participants reported that the HUD design was easier to use than the traditional interface. However, unlike Hedayati et al. (2018), the current study did not find differences in measures of performance. As discussed previously, this may be due to the measures not being granular enough for differences in performance to emerge, or due to the automated nature of the task.

For Ruiz et al. (2015), participants acted as a UAS safety pilot in a simulated mission. The UAS was controlled via a ground control station by another pilot while the safety pilot monitored the UAS for VLOS rules and had the ability to take over UAS control in case of an emergency. Participants utilizing the head-worn AR interface exhibited higher SAGAT accuracy compared to verbal communication and tablet interface conditions. Although the AR condition also exhibited lower workload, it was not statistically significant. The results of the current study were in line with the findings of Ruiz et al. The HUD condition results in higher SA as measured by the SAGAT and lower workload, although also not statistically significant.

The current study builds on Hedayati et al. (2018) and Ruiz et al. (2015) in a few ways. First, the simulated scenarios consisted of operationally relevant search and rescue missions that could be applied to real-world applications. Additionally, operators acted as a visual observer and operator in a long-distance operation. These conditions are more representative of the current dynamic of approved UAS operations in the United States. Further, the current study captured both objective
and subjective measures of SA. The current study demonstrated that although subjective perceptions of SA where not statistically significant, the HUD demonstrated an actual increase in an objective measure of SA. Lastly, the simulator and interface mimicked interface designs and technology readily available on the consumer market. Ruiz et al. (2015) utilized custom designed interfaces, whereas the current study mimicked interfaces presented on the DJI partner application, an application that is readily available to operators today. Given this, findings from the current study can be applied to emergency VLOS operations more so than previous research studies.

**Implications for aviation practice.** The implications for the aviation and UAS industries are important to consider, especially as the UAS industry expands. The current study unveiled that utilization of a HUD in automated drone search and rescue missions improved SA. The results also revealed that the HUD had no positive or negative impacts on workload, performance, and perceived levels of SA. This implies that UAS operators using a HUD interface may be able to exhibit a better understanding of UAS status, which could lead to safer operations and reduced incidents.

In the current study, the HUD interface resulted in one more query answered correctly, on average, compared to the traditional interface. However, reader is reminded of the lack of a proper reliability assessment for the SAGAT and more research is needed to confirm the findings. Although, from a practical
perspective, this may seem like an insignificant gain in SA, knowledge of this one piece of information may prove to be the difference between life and death. A total of 382 unauthorized UAS sightings occurred from October 2019 to December 2019 (FAA, 2020). Many of these reports were made by manned aircraft pilots on approach to nearby airports with reported distances of as little as 100 feet between the aircraft and UAV. Incident and accident reports from the NTSB show operator faults as the causes for: (a) crashing a UAS due to pilot misunderstanding of UAS controls (NTSB, Incident Report DCA18IA269, 2018), and (b) the damage of an army helicopter colliding with a UAS operating in restricted airspace due to flying the aircraft too far and also exceeding approved altitudes (NTSB, 2017). As the UAS industry continues to grow, loss of SA by a UAS operator could ultimately lead to collision with a manned aircraft resulting in a fatal crash, or the crash of a UAS into innocent bystanders. The need for increased SA for UAS operations is growing as demonstrated by the number of accidents and incidents caused by poor SA in the medical and manned aircraft domain (Endsley, 1995b; Schulz et al., 2016).

Secondly, the implications from the following study imply that workload and performance are not significantly impacted with the utilization of a HUD. Therefore, the results suggest that operators may be able to transition to a HUD interface without experiencing significant decrements during operations relative to the constructs captured in the current study. Considering that many UAS tasks are
visual search or monitoring tasks, there are several UAS use cases that could potentially benefit from the implementation of HUD interfaces, which could lead to SA gains without negative impacts to performance and workload.

Lastly, the three-way interaction among interface design, order, and UAS experience implies there might be appropriate times to transition to HUD interfaces. The highest workload, lowest SAGAT scores, and low SART scores were experienced by novice operators utilizing the traditional interface in the first trial. This is consistent with previous research that posits that novice operators need more information to derive meaning compared to experts (Endsley, 1995a). In the traditional interface, the greater distance made information gathering more difficult for the novice operators. However, novice operators exhibited their lowest workload, highest SART scores, and higher SAGAT scores when they received the traditional interface in their second trial. Many participants noted that they felt they liked the information being distributed. This implies that novice operators starting out with the traditional interface may be overwhelmed by the task and distributed information initially, but after practice on the task and interface, it becomes easier to digest.

Experienced operators exhibited less variability in workload and SART scores with a four-point range and three-point range, respectively. For novice operators, workload and SART scores exhibited higher variability with 13-point and 8-point ranges, respectively. Therefore, the data suggest novice operators are
more influenced by changes to interface design and order compared to experienced UAS operators. This implies, experienced UAS operators may be able to transition and adapt to HUD interfaces more easily.

**Generalizability, Limitations, and Delimitations**

**Generalizability.** The concept of external validity is related to the extent to which the results from the current study can be applied to other populations and settings. The strength of the study determines how far the results can extend outside of the experimental setting. The first type of generalizability is concerned with population validity, which refers to how likely the results can extend beyond the sampled population. Chapter 3 presents the demographic information of the target population and the sample demographics, which denotes the sample was representative of the parent population. Based on the sample demographics (Table 3.1), the results can generalize to the accessible population of Brevard County and the target population of the United States.

The second type of generalizability is ecological validity and addresses the ability for the conditions of the experimental environment to apply to different settings, conditions, or circumstances. The methods, task design, materials, and setting all impact the ability for the findings to apply to real UAS-led search and rescue tasks. The reader must take into consideration the simulated nature of the task, the automatic UAV flight mode, the simulated weather, and the simulated Florida grasslands. These key features, as well as other constraints of the study,
have been presented throughout the dissertation. Extending the results of this study to a bright, windy, live search and rescue task, in the Carolina mountains may not be suitable. Therefore, the results of the study are most applicable to visual search tasks operating a highly automated UAS on a clear weather day in natural grassland settings.

Study limitations and delimitations. The current study experienced various limitations and delimitations. For the ease of the reader, the limitations and delimitations from Chapter 1 have been replicated in this section to provide a framework, and to set the stage for the next section, which presents recommendations for research and practice relative to the study limitations and delimitations.

Limitations. Limitations are aspects of the study that cannot be controlled and can affect the interpretation and generalizability of the findings. Limitations for the current study include:

1. Low environmental fidelity. The study utilized a desktop simulator with low environmental fidelity to present highly task-relevant targets such as missing persons as real-world emergency situations were not feasible. Although the environment attempted to address task relevancy and environment fidelity for higher generalizability, it was not comparable to real-world emergency situations in terms of workload, stress, environment, and other characteristics. As a result, real-
world operations and subsequent studies utilizing higher fidelity environments may experience different results.

2. Sample demographics. The sample consisted of UAS operators from Brevard County, Florida, which may differ from personnel in other areas of the country. For example, in California, wildfire, and earthquake emergencies are typically experienced, whereas in Florida, hurricane and tropical storm emergencies are more prevalent. Demographic information about the participants will be presented in the study results to allow the reader to make his or her own interpretations regarding generalizability. As a result, future studies utilizing demographic backgrounds different from the sample in the current study, may find different results.

3. Participant technology experience. The current study mimicked a DJI UAS interface and a USB radio controller, which are the most common currently in the UAS industry. However, the participants utilized in the current study may not be familiar with the technology utilized, or even with the simulator computer interaction requirements. Participants’ experience with UAS and camera gimbals, and which UAS information parameters they utilize in their day-to-day operations of UAS, were captured and are presented to the reader to make their own interpretations and generalizations. As a result, similar studies that utilize participants with more or less experienced operators may elicit different results.
4. Search and rescue experience. The current study utilized a search and rescue visual search task as the simulated mission. Participants may not have experience utilizing UAS for this purpose and therefore experience may have impacted their results. Descriptive information on sample occupation and their uses of UAS, and camera operating experience, are presented to allow the reader to make their own interpretations and generalizations. As a result, studies utilizing participants with different search and rescue experience may find different results.

5. Participant motor skills and visual acuity. The current study utilized a simulated search and rescue task, that required maneuvering a camera gimbal using joysticks, viewing a small camera window, and discerning human shapes from distracting targets. As a result, similar studies with participants of different visual acuity and motor skills may find different results.

Delimitations. Delimitations include constraints on the study that I, as the researcher, impose on myself to improve the feasibility of the study, but that may impact interpretations and generalizability. Delimitations of the current study include:

1. Type of UAS and interface. The current study was limited to the use of commercial off-the-shelf UAS systems from DJI and the accompanying interface design. First responders using different systems may experience different impacts on SA and performance. Therefore, studies utilizing different interfaces may experience different results.
2. Sampling approach. The current study included participants from various backgrounds, including commercial and recreational UAS operators. This approach was utilized to increase the generalizability of the findings and to recruit the needed sample size for the study. However, the study did not utilize a homogenous group, nor cover all domains, and therefore similar studies may find different results with different populations. Sample demographics are presented to allow the reader to make his or her own interpretations and generalizations. Therefore, future studies utilizing different sampling approaches may find different results.

3. Sample background. This study utilized participants with varying levels of experience. Although the original intent was to collected participants with 10 hours of experience or higher, access to this population proved difficult. Pilot testing revealed those with little to no UAS experience, and those with extensive UAS experience had similar performance and results. Therefore, the sample was expanded to include individuals with lower levels of UAS experience. These individuals were required to have some prior UAS experience; however, no specific time requirement was put in place. To control for potential experience differences, experience level was then captured as a potential between subjects variable. Therefore, information on sample UAS experience is presented to allow the reader to make their own interpretations on generalizability. Similar studies utilizing participants of different backgrounds may produced different results.
4. **Experience Categories.** The current study categorized operators by his or her level of experience. Based on the average length of training courses, participants were categorized into novices and experienced operators at the ten-hour mark. Similar studies categorizing operators based on experience level using different criteria may find different results.

5. **Performance measurement.** The current study measured performance solely from the classification of correctly detected targets. This was the most feasible, objective, and representative metric of performance given the simulator constraints. To achieve this, pictures were scored as correct as long as a missing person was present within the photo. A photo with a distractor item and a missing person within the photo was still coded as a detected target. However, other metrics of performance could include target detection time or missed targets. If manual flight operation was an option to the participants, search strategy and mission completion time could have also been performance metrics. As a result, studies using other metrics for performance may find different results.

6. **Self-developed queries.** The current study utilized queries made specifically for the context of this mission and for this simulator. The queries were developed utilizing the method presented by Endsley (2000), in conjunction with previously published task analyses and queries, to create 27 queries. However, they may not present a comprehensive assessment of SA due to the limited number of queries and task duration. In addition, as the queries were self-developed for the
purposes of this study, they have not undergone extensive testing to ensure validity and reliability. Therefore, the queries may not have provided the most valid and robust measure of objective SA and future studies using a different set of queries may produce different results.

7. **Change to a mixed model approach.** The current study was originally intended to be analyzed as a repeated measures MANOVA. However, in analyzing the data, it was clear that experience and learning effects were taking place. Therefore, the data analysis approach shifted to a mixed model repeated measures MANOVA approach to account for these differences. Although this approach was still appropriate to answer the a priori hypotheses, similar studies that do not modify the data analysis approach to include between subjects effects may find different results.

8. **Test-retest duration.** The current study measured each of the dependent variables twice. The time between the two measurements was approximately 15–20 minutes, and as observed with order effects, may have impacted the results. Therefore, studies that do not use a repeated measures approach or utilize different durations between measurements may find different results.

9. **Simulator Design.** The simulator monitor setup was designed to keep the following characteristics consistent as information moved across monitors: (a) visual distance of information relative to the participants’ eyes, (b) size of information, and (c) portability and replicability of the simulator setup at various
locations. This helped to ensure that the findings of the study could not be attributed to the simulator nuances and could be attributed to the changed location of information. Therefore, the simulator design consisted of two 19-inch monitors mounted on top of one another with the visual center point located where the two monitors touch. Participants sat approximately 18 inches away from the two screens. However, in a live UAS setting, the operator has no field of view constraints on their environment view, which was represented on the top monitor. Participants could use the arrow keys to “look around”. However, operators in the real world can pan their head left and right and see the whole world around them and are not limited to a view directly in front of them. Additionally, the information view would likely be on a 5-7 inch handheld mobile device located near the operator’s hands. Therefore, the size of the information view in the traditional condition was much larger than real life and was located much closer to the environment view than real UAS operations. The reader should note that findings in a real-life setting may exhibit much larger differences than the subtle differences that emerged in the current study.

10. Scenario Type. The current study utilized two self-developed search and rescue mission designs to represent a visual search task. Although the mission characteristics were derived from similar simulation studies that utilized search and rescue missions, those utilizing different search and rescue missions, or other visual search tasks, may find different results.
11. Training. The current study utilized one five-minute computer-based training slide deck and two three-minute training flight routes. This training may have been insufficient and may have affected their performance. Similar studies utilizing different training strategies may not obtain the same results.

12. Automated flight. The current study utilized an automated flight path to ensure participants were exposed to the same conditions throughout the task. This ensured that correct answers to queries would be consistent for each participant and that all participants would pass over each potential target. However, in a natural search and rescue mission, operators may begin in automated flight but switch to manual flight to investigate and close-in on potential targets. In the current study, operators had to make judgment calls from a distance. Therefore, studies utilizing manual UAS flight may find different results.

Recommendations for Research and Practice

Recommendations for future research relative to study limitations.

1. The experimental task in the current study was conducted on a desktop simulator of low environmental fidelity. A recommendation for future research is to see the impacts of a HUD in a live task setting. The experimental task utilized stationary 3D objects. Therefore, the trees did not sway in the wind, and the human targets did not move. Future research should consider utilizing dynamic 3D objects for more operational relevancy as this may produce different results.
2. The current study utilized Brevard County, Florida UAS operators with varying levels of experience, backgrounds, and training. The commercial operators in this current study used UAS for ocean rescue, space rocket inspections, and hurricane preparedness and response. Future research should include participants from other parts of the world where UAS may be used for different purposes such as wildfires, earthquakes, and search and rescue in snowy conditions as it may produce different results.

3. The current study utilized a radio controller and was similar to the DJI interface. Although, these are the most common forms of UAS interaction, participants had varying levels of experience with this technology—particularly with respect to controlling the UAS gimbal using the joysticks on the controller. Future research should utilize participants from a more homogenous background with more experience with this technology.

4. The design of the scenario was made to simulate a search and rescue mission. The sample revealed that few individuals used UAS for emergency and preparedness. Future research should look at a more representative population of those that primarily use UAS for emergency preparedness and search and rescue.

5. The current study did not capture and assess the participant’s visual acuity or motor skills, which could have impacted his or her performance on the search
and rescue mission. Future research should consider collecting visual acuity and motor skill measures as an influencing factor.

**Recommendations for research relative to study delimitations.**

1. The UAS interface utilized in the current study mimicked a DJI UAS interface. The participants in the study had varying levels of UAS experience and may have utilized various UAS interfaces in the past. Familiarity, or lack of familiarity, with the interface, may have impacted the results. Future research should assess the impacts of HUD operations with other interface designs or layouts.

2. The current study also utilized convenience sampling of commercial and recreational operators and is by no means comprehensive of all forms of UAS operators. Future research should evaluate operators from additional industries such as agriculture, police departments, park rangers, hospital transport, and construction. In addition, populations from various climates such as mountainous regions should be researched as well for the differences in challenges they face. The experimental task was replicated to mimic the Melbourne, Florida area. A recommendation for future research is to explore the effects in various other operational settings such as mountain ridges, urban areas, as well as varying times of day and weather.

3. The sample utilized in the current study consisted of pilots with varying levels of UAS experience. Although this factor was included in the final analyses to
control for these effects, future research should look at homogenous samples of similar background experience and training when evaluating other tasks and interface layouts.

4. Participants were categorized into novice and experienced categories based on the average UAS training course duration. However, ten hours may not be the most representative threshold to distinguish operator experience. Future research should explore different classifications of experience level.

5. Performance was captured in the current study via targets detected. This was the most unobtrusive and feasible way to capture performance with the given study design. Other metrics such as picture accuracy, time to detect target, and missed targets could have been utilized to capture performance instead. Alternatively, time maintaining VLOS or manual flight errors could also be utilized as measures of performance that have shown to be sensitive enough performance metrics in other studies. Future research should consider methods to capture other aspects of performance.

6. The SAGAT queries for the current study were self-developed to align with the simulator and task characteristics. Although sources of previously developed and validate SAGAT queries were referenced as a guide, the queries utilized in the current study could not be validate or deemed reliable. Future research should aim to assess the validity and reliability of the query set used in the current study or develop a query set that can be utilized for a UAS setting.
7. The current study adapted the data analysis approach from a repeated measures MANOVA to a mixed model repeated measures MANOVA. This approach allowed for the control of individual differences of experience level and order. Future research should use more homogenous samples or a between subjects design with larger sample sizes to attempt to remove the need for controlling extraneous variables.

8. The current study allotted approximately 15–20 minutes between measurements. The time duration may not have been sufficient to prevent any memory or testing effects. Future studies should ensure longer durations between measurements to further reduce these effects.

9. The setup of the simulator in the current study kept information size and visual distance consistent to isolate the relationship of information location and the dependent variables. However, in a real-life UAS setting, the traditional condition exhibits larger visual distances and smaller information size. Future research should evaluate if the differences observed in this study become greater when these operational factors are also present.

10. The experimental task focused specifically on search and rescue missions that were self-developed. Although previous research and subject matter experts were utilized to create a realistic and similar search and rescue mission, different missions may produce different results. A recommendation for future
research is to examine the impacts of a HUD in other forms of search and rescue missions as well as other visual search tasks such as inspections.

11. The current study utilized a 5-minute training slide deck and two 3-minute training courses. Although the intent was to make participants familiar enough with the simulator and task to mitigate any order or learning effects, effects were still observed with participants becoming more comfortable and accurate in the second trial. Future research should incorporate a longer training task or a more homogeneous sample that may not require substantive training.

12. The current study utilized solely automated UAV flight so that each participant was exposed to the same parameters, target location, and search path. However, in a live search and rescue task, an operator would likely start on automated flight and then switch to manual control when a potential human was discovered. Future research should allow participants the ability to utilize automatic and manual flight, as this may produce different results.

**Recommendations for future research relative to implications.** The following section discusses recommendations based on the implications discussed within this chapter. The current study suggests that a HUD can improve objective SA, but does not result in improvements in workload, performance, or subjective SA. The reader is cautioned that more research is needed to confirm the findings due to lack of reliability assessment for objective SA. Future research should evaluate the relationship of these factors in other operational settings including: (a)
different tasks, (b) live environments, (c) more representative interface differences such as distance and information size, (d) different populations, (e) more sensitive measures of performance, (f) manual UAS flight modes, and (g) and additional types of UAS operators. Likely all these factors play a role in the dynamic relationships of SA, workload, and performance. The controlled nature of the current study allowed for direct evaluation of integrating information into the field of view while controlling or removing various influencing factors such as information size, wind conditions, and manual flight modes. With the emerging field of UAS research and lack of prior research, this first step was required; however, future research should explore other factors such as the factors mentioned above to determine the appropriate times and use cases for when HUDs are effective.

To build upon Endsley’s (1995a) theory of SA in a UAS setting more research studying the influencing factors presented in the model is needed. These factors could be isolated or combined to determine the unique impact of each, or interactions between influencing factors. Researchers may be able to explore the impacts of UAS interface designs on specific commercial operator populations, in manual flight modes, or in other parts of the country with other operational challenges. Further, these influencing factors could be combined in a regression analysis to determine the unique impact of interface design in the presence of other influencing factors.
Past research suggests that differences in performance, subjective SA, and workload should emerge with interface design changes. Likely, the differences between the two conditions was subtle compared to real-world operational differences in size and positioning of the displays. Future research could study the impact of a HUD in higher fidelity situations with more realistic representation of screen placement and size. Furthermore, future research could explore other measures of performance, workload, and subjective SA to determine if the findings will then better align with previous research in UAS and other domains. Additionally, optimization of information layout can also be explored. The UAS parameters presented in Table 4.9 suggests that different elements are key in a visual search task. Future research could determine if different information layouts are more effective when paired with specific tasks as demonstrated in other UAS research by Hedayati et al. (2018) that examined camera positioning in a HUD.

**Recommendations for practice relative to implications.** The current study demonstrated improved objective SA with no significant differences in workload, performance, or subjective SA. Recommendations discussed within this section are conservative based on these findings as the study was simulated and seminal in nature along with the lack of reliability assessment relative to the SAGAT. The design of the interfaces, task, and the simulated nature of the current study should all be taken into consideration when deriving recommendations for
real-life settings. Recommendations based on the type of reader are presented within this section. The following recommendations are made for UAS operators:

1. Utilization of a HUD interface should be encouraged to improve awareness of various parameters. This recommendation applies to those conducting visual search tasks in relatively unchanging environments with low elevation. More research is needed in mountainous climates and additional task settings to determine HUD impacts in these settings.

2. Operators should remain cognizant of the added workload required to maintain VLOS with the occluded environment view. Current HUD designs may be designed in such a way that position information over the current flight direction of the UAS. Naturally, by overlaying information on the environment view, the window to maintain VLOS becomes smaller. UAS operators should be made aware of this downfall and alter their scan patterns appropriately.

The following recommendations are made for engineers and designers:

1. The ratings of UAS parameter frequency revealed operators performing a search and rescue task use particular pieces of information more frequently when compared to day-to-day operations such as recreational or film purposes. Designers of UAS interfaces should begin developing interface layouts that place emphasis on elements key to specific use cases.

2. Some negative comments on the HUD interface were related to disorientation and confusion. Many other domains provide a declutter mode that allows
operators to see only the most critical pieces of information. This function would benefit those in a moment of disorientation.

3. Other negative comments on the HUD interface were related to the lack of contrast between the parameters display in and the light background. Designers should explore interface designs that allow for ample contrast on various backgrounds while also remaining mindful to prevent too much occlusion of the VLOS.

The following recommendations are made for policy makers and industry:

1. Policies related to the use of HUD interfaces should support the use of these technologies as even incremental gains in SA could aid in the prevention of UAS and manned aircraft accidents. The current study demonstrated no negative impacts of HUD operations. Additionally, improved SA could reduce the number of unauthorized UAS actions such as exceeding approved altitudes and entering restricted airspaces. This could also reduce the number of incidents and prevent future accidents.

2. Research on interface designs to facilitate SA and performance should be funded by the leading industries and agencies. Similar to manned aircraft design regulations, the UAS domain will soon require the same guidance as it enters the national airspace. Designing for optimal performance is key to prevent incidents and accidents.
3. Differences were observed in the present study between novice and experienced operators. However, currently no training related to the operation of a UAS is required to fly a UAS commercially. To lower the threat of incidents and accidents, flight training should be required for all forms of UAS operators. The following recommendations are made for aviation trainers and instructors:

1. For aviation trainers and instructors, integration of HUD interfaces in late stages of training could potentially lead to adoption of these technologies in future practice. As the facilitators for safe practices for UAS operators entering the industry, it is important to equip them with the technology and skills necessary for optimum operational safety. However, the interactions discovered within the study suggest there is a right time to introduce new UAS operators to HUD interfaces. Potentially, HUD interfaces should be introduced in the later stages of training. Research in a live setting is needed to support the findings in the current study; however, exposure to technology, such as a HUD, could lead operators to adopt technology that assists them in their missions.

2. The simulator used within the current study was a representative low-fidelity environment similar to real UAS operations. Participants noted after the study how the SAGAT queries made them aware of their own monitoring strategies. Potentially, simulated environments such as this one could be used as a low-cost training environment to improve scan patterns and mission strategies for search and rescue missions.
References


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Appendix A

Demographic Measures

Age _____

Ethnic Background

- Caucasian
- African American
- American Indian
- Hispanic
- Asian
- Other __________

Sex

- Male
- Female
- I prefer not to answer

What is the highest degree or level of education you have completed?

- Less than high school diploma
- High school diploma or GED
- Trade school
- Some college, but no degree
- Bachelor's Degree
- Master's Degree
- Ph.D. or higher
- Prefer not to say
What is your current occupation? _______________________

What purposes do you use UAS for?

☐ Recreational
☐ Research and Development
☐ Training
☐ Education
☐ Film/Photography
☐ Events
☐ Entertainment
☐ Sports
☐ Industrial
☐ Utility
☐ Environmental
☐ Oil & Gas
☐ Real Estate
☐ Construction
☐ Agriculture
☐ Press & Media
☐ Emergency and Preparedness
☐ None
☐ Other
What level of experience do you have operating a UAS?
  
  o  No experience
  o  Less than 5 hours of experience
  o  6-9 hours of experience
  o  8-10 hours of experience
  o  11-30 hours of experience
  o  31-50 hours of experience
  o  Over 50 hours of experience

How frequently do you operate a UAS?
  
  o  Daily
  o  Weekly
  o  Monthly
  o  Yearly
  o  Never

What level of experience do you have operating a UAS camera gimbal?
  
  o  10 or less hours of experience
  o  11-30 hours of experience
  o  31-50 hours of experience
  o  Over 50 hours of experience
How frequently do you operate a UAS camera gimbal?

- Daily
- Weekly
- Monthly
- Yearly
- Never

What level of experience do you have playing video games?

- Less than 6 months
- 1 year to less than 3 years
- 3 years to less than 5 years
- 5 years or more

How frequently do you play video games?

- Daily
- Weekly
- Monthly
- Yearly
- Never
Appendix B

UAS Information Parameter Experience

Please rate the frequency of use for the following elements of drone information in your day-to-day operation

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Not at all</th>
<th>Rarely</th>
<th>Sometimes</th>
<th>Often</th>
<th>Always</th>
<th>Unsure</th>
</tr>
</thead>
<tbody>
<tr>
<td>GPS Number of Satellites</td>
<td></td>
<td></td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>GPS Signal Strength</td>
<td></td>
<td></td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
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<tr>
<td>Battery Life Indicator</td>
<td></td>
<td></td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>GPS Map</td>
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<td></td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>GPS Track</td>
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<td></td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Altitude/Height</td>
<td>0</td>
<td></td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Distance</td>
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<td></td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Vertical Speed</td>
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<td></td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Horizontal Speed</td>
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<td></td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Compass</td>
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<td></td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
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<tr>
<td>Home Point Indicator</td>
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<td></td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Return to Home Battery Indicator</td>
<td>0</td>
<td></td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Camera Video Feed</td>
<td>0</td>
<td></td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>
Please rate the frequency of use for the following elements of drone information in the search tasks you just completed

<table>
<thead>
<tr>
<th>Element</th>
<th>Not at all</th>
<th>Rarely</th>
<th>Sometimes</th>
<th>Often</th>
<th>Always</th>
<th>Unsure</th>
</tr>
</thead>
<tbody>
<tr>
<td>GPS Number of Satellites</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>GPS Signal Strength</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Battery Life Indicator</td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>GPS Map</td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>GPS Track</td>
<td></td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Altitude/Height</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Distance</td>
<td></td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Vertical Speed</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Horizontal Speed</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Compass</td>
<td></td>
<td></td>
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<td></td>
<td></td>
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<tr>
<td>Home Point Indicator</td>
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<td></td>
</tr>
<tr>
<td>Return to Home Battery Indicator</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Camera Video Feed</td>
<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Appendix C

Performance Measurement

Answer Key Image:

Participant Example Image:
## Appendix D

### SAGAT Query Requirements

#### Unmanned Ground Vehicle SA Requirements

**Level 1 SA**

<table>
<thead>
<tr>
<th>Vehicle status</th>
<th>Weather conditions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Speed of vehicle</td>
<td>Terrain features</td>
</tr>
<tr>
<td>Location of vehicle</td>
<td>Landmarks/barriers</td>
</tr>
<tr>
<td>Heading of vehicle</td>
<td>Clutter</td>
</tr>
<tr>
<td>Past vehicle locations</td>
<td>Debris</td>
</tr>
<tr>
<td>Control actions at interface</td>
<td>Stairwvuneven terrain</td>
</tr>
<tr>
<td>Past control actions</td>
<td>Stage of recovery operations</td>
</tr>
<tr>
<td>Starting position/base</td>
<td>Status of human assets</td>
</tr>
<tr>
<td>Operator location</td>
<td>Location</td>
</tr>
<tr>
<td>Distance from base</td>
<td>Activity</td>
</tr>
<tr>
<td>Battery/fuel level</td>
<td>Vehicle orientation</td>
</tr>
<tr>
<td>Tread on/off</td>
<td>Pitch of vehicle on terrain</td>
</tr>
<tr>
<td>Amperage/voltage level(s)</td>
<td>Roll of vehicle on terrain</td>
</tr>
</tbody>
</table>

**Vehicle characteristics**

- Size (length, width, height)
- Ground clearance
- Tracks/wheels
- Configuration of vehicle
  - Flapper angle
  - Manipulator arm/gripper rotation
  - Body configuration
- Weight

**Objects/obstacles**

- Material (solid, liquid)
  - Size (length, width, depth, height)
- Location of obstacle
- Distance to obstacle

**Tasks/mission objectives**

- Time in current location
- Time on task
- Number of tasks completed
- Time constraints
- Teammate tasks
- Total number of tasks to complete

**Overall status of motor system**

- Flapper motors function
- Motor temperatures

**Quality of communications links**

- With robot operator control unit/station
- With other vehicles
- With mission control station
- Signal strength (current and trends)
  - For GPS

- Number of sensors
- Number reporting
- Type of sensor reporting
- Frequency of reporting

**Detectors**

- Number of sensors detecting target
- Type of sensors detecting target
- Reliability of sensors detecting target
- Information from other sources
- Number of targets identified by humans
- Number of targets identified by system
- Human asset capabilities/limits
- Results of past searches

**Onboard device status**

- Sensors (functional, on/off)
- Cameras (functional)
  - Orientation (pan and tilt)
  - Zoom
- Manipulators/grippers (functional)
  - Size
  - Functional limits
  - Open/closed
- Automation (on/off, level of automation)
- Lights

---

191
<table>
<thead>
<tr>
<th>Bandwidth available</th>
<th>Location of other operators</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bandwidth requirements</td>
<td>Location of other robotic systems/assets</td>
</tr>
</tbody>
</table>

**Level 2 SA**

**Vehicle operations**
- Distance traveled
- Area coverage

**Deviation between aperture size and robot size**
- Impact of orientation on mobility of robot
- Proximity to object/obstacle
- Distance between robot and other assets
- Vehicle capabilities
- Vehicle limitations
- Orientation of robot
- Situatedness of robot

**Likelihood of losing robot/damage to robot**
- Impact of weather and terrain
  - Impact of weather on time to task completion
  - Impact of terrain features on time to task completion
  - Visibility
  - Environmental complexity
  - Impact of terrain on comms
  - Impact of weather on comms
  - Impact of weather on terrain

**Tasking**
- Status of tasks/progress
- Impact on mission plan
- Task priority
- Robot ability to perform mission

**Level 3 SA**

**Projected location of robot**
- Relative to operator
- Relative to stating position
- Relative to other systems

**Projected destination of vehicle**
- Projected control actions
- Projected damage to robot
- Potential for collision
- Projected ability to navigate through space or aperture
- Projected ability to traverse terrain
- Projected ability to complete mission
- Projected need to return to base
- Projected time without comms
- Projected locations without comms

**Projected actions/behaviors of the robot**
- Projected information needs of others
- Projected need to shed tasks
- Projected time to task completion
- Projected next or near future task
- Projected ability to detect targets
- Projected target identify
- Projected target location
- Projected coverage of area
- Projected reliability of sensor coverage
- Projected distance from target/obstacle
- Projected ability to manipulate objects
- Projected time to recovery
- Projected activities of other robots
Appendix E

Example SAGAT Queries from Endsley and Kiris (1995)

1. Enter the location of all aircraft (on the provided sector map)
   - aircraft in track control
   - other aircraft in sector
   - aircraft will be in track control in next 2 minutes
2. Enter aircraft callsign (for aircraft highlighted of those entered in query 1)
3. Enter aircraft altitude (for aircraft highlighted of those entered in query 1)
4. Enter aircraft groundspeed (for aircraft highlighted of those entered in query 1)
5. Enter aircraft heading (for aircraft highlighted of those entered in query 1)
6. Enter aircraft's next sector (for aircraft highlighted of those entered in query 1)
7. Enter aircraft's current direction of change in each column (for aircraft highlighted of those entered in query 1)
   - Altitude change
     - climbing
     - descending
     - level
   - Turn
     - right turn
     - left turn
8. Enter the aircraft type (for aircraft highlighted of those entered in query 1)
9. Enter aircraft's activity in this sector (for aircraft highlighted of those entered in query 1)
   - enroute, inbound to airport, outbound from airport
10. Which pairs of aircraft have lost or will lose separation if they stay on their current (assigned) courses?
11. Which aircraft have been issued assignments (clearances) that have not been completed?
12. Did the aircraft receive its assignment correctly?
13. Which aircraft are currently conforming to their assignments?
14. Which aircraft must be handed off to another sector/facility within the next 2 minutes?
15. Enter the aircraft that are experiencing a malfunction or emergency that is effecting operations.
16. Enter the aircraft which are not in communication with you.
17. Enter the aircraft that will violate special airspace separation standards if they stay on their current (assigned) path.
18. Which aircraft are weather currently an impact on or will be an impact on in the next 5 minutes along their current course?
19. Which aircraft will need a new clearance to achieve landing requirements?
20. Enter all aircraft that will violate minimum altitude requirements in the next two minutes if they stay on their current (assigned) paths?
21. Enter the aircraft that are not conforming to their flight plan.
22. Enter the aircraft and runway for this aircraft.
Appendix F

Example Military SAGAT Queries from Bolstad and Endsley (2003)

<table>
<thead>
<tr>
<th>Query wording</th>
</tr>
</thead>
<tbody>
<tr>
<td>Indicate the location(s) of each element on the map</td>
</tr>
<tr>
<td>Which units are below green level on ammo?</td>
</tr>
<tr>
<td>Which units are below green level on equipment?</td>
</tr>
<tr>
<td>Which friendly units have been detected by the enemy?</td>
</tr>
<tr>
<td>Which enemy units are currently firing/applying weapons?</td>
</tr>
<tr>
<td>Which friendly units are currently firing/applying weapons?</td>
</tr>
<tr>
<td>What is the force capability of this enemy unit?</td>
</tr>
<tr>
<td>What do you expect this enemy unit to do in the next 10 minutes?</td>
</tr>
<tr>
<td>What is this enemy unit’s objective?</td>
</tr>
<tr>
<td>Which friendly units are not able to carry out their assigned tasks?</td>
</tr>
<tr>
<td>What additional assets are needed to carry out your assigned mission?</td>
</tr>
<tr>
<td>Which friendly units need additional fire support?</td>
</tr>
<tr>
<td>Which enemy unit is the highest priority threat?</td>
</tr>
<tr>
<td>How does the status of other Brigades affect your operations?</td>
</tr>
<tr>
<td>How does the status of other Battalions affect your operations?</td>
</tr>
<tr>
<td>How many casualties/wounded has your Brigade suffered?</td>
</tr>
<tr>
<td>How many casualties/wounded has your Battalion suffered?</td>
</tr>
<tr>
<td>Enter the last known location(s) of enemy units/targets which have been destroyed/rendered ineffective?</td>
</tr>
<tr>
<td>Which friendly units are below green level on overall effectiveness?</td>
</tr>
<tr>
<td>Enter the last known location(s) of friendly units which have been destroyed/rendered ineffective?</td>
</tr>
<tr>
<td>Indicate the current location of supply points on this map</td>
</tr>
<tr>
<td>Indicate potential choke points for your supply routes on the map.</td>
</tr>
<tr>
<td>Which friendly units have had changes to their mission requirements since the original OPORD?</td>
</tr>
<tr>
<td>What additional Intel assets do you need to collect the needed Intel data?</td>
</tr>
<tr>
<td>Indicate the current location(s) of your Intel assets on the map</td>
</tr>
<tr>
<td>Is a change in asset deployment/collection plan needed due to unexpected Intel information?</td>
</tr>
<tr>
<td>Indicate the location of HVT/HPTs on the map</td>
</tr>
<tr>
<td>Enter the location(s) of known obstacles, including land mines barriers and Concertina wire.</td>
</tr>
<tr>
<td>Which friendly units are outside their maneuver boundaries?</td>
</tr>
<tr>
<td>What is the maximum range of this unit’s weapons?</td>
</tr>
<tr>
<td>Currently, which unit has the highest priority with regards to calls for fires?</td>
</tr>
</tbody>
</table>
### Appendix G

#### Developed SAGAT Queries

<table>
<thead>
<tr>
<th>Level</th>
<th>Riley and Endsley (2004) UGV SA Requirements</th>
<th>UAS Developed Query</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Task/Mission Objectives: Time on Task</td>
<td>Enter the number of minutes the drone has been in flight.</td>
</tr>
<tr>
<td>1</td>
<td>Detections: Number of targets identified by humans</td>
<td>Enter the number of human targets you have detected.</td>
</tr>
<tr>
<td>1</td>
<td>Quality of communication links: For GPS</td>
<td>Enter the number of satellites you are currently connected to.</td>
</tr>
<tr>
<td>1</td>
<td>Vehicle status: Past control actions</td>
<td>Enter the number of times the drone has turned 180 degrees.</td>
</tr>
<tr>
<td>1</td>
<td>Vehicle status: Heading of vehicle</td>
<td>Enter the cardinal direction that the drone is currently flying (N/E/S/W).</td>
</tr>
<tr>
<td>1</td>
<td>Vehicle status: Location of vehicle</td>
<td>Enter the current height (in FT) of the drone.</td>
</tr>
<tr>
<td>1</td>
<td>Vehicle status: speed of vehicle</td>
<td>Enter the current horizontal speed (in MPH) of the drone.</td>
</tr>
<tr>
<td>1</td>
<td>Vehicle status: speed of vehicle</td>
<td>Enter the current vertical speed (in MPH) of the drone.</td>
</tr>
<tr>
<td>1</td>
<td>Vehicle status: Distance from base</td>
<td>Enter the distance (in FT) of the drone from your location.</td>
</tr>
<tr>
<td>1</td>
<td>Vehicle status: Battery/fuel level</td>
<td>Enter the percentage of battery life remaining.</td>
</tr>
<tr>
<td>1</td>
<td>Quality of communication links: Signal strength</td>
<td>Enter the current number of bars of signal strength.</td>
</tr>
<tr>
<td>2</td>
<td>Vehicle operations: Distance between robot and other assets</td>
<td>Enter the height (in FT) that the drone is currently located above the tree line.</td>
</tr>
<tr>
<td>2</td>
<td>Tasking: Status of tasks/progress</td>
<td>Enter the number of human targets remaining.</td>
</tr>
<tr>
<td>2</td>
<td>Impact of weather and terrain: Visibility</td>
<td>Enter the number of times that your view of the drone has been blocked by the trees.</td>
</tr>
<tr>
<td>2</td>
<td>Vehicle operations: Situatedness of robot</td>
<td>Enter the cardinal direction that the drone is currently relative to you (N/E/S/W).</td>
</tr>
<tr>
<td>2</td>
<td>Vehicle operations: Likelihood of losing robot/damage to robot</td>
<td>Enter the number of times the drone has come within 5 FT of a tree.</td>
</tr>
<tr>
<td>2</td>
<td>Sensor and manipulator operations: Potential for control/communication latency</td>
<td>Enter the current risk of losing GPS connection (at risk/not at risk).</td>
</tr>
<tr>
<td>2</td>
<td>Vehicle Operations: Orientation of robot</td>
<td>Enter the direction (left or right) that the drone must turn to face North.</td>
</tr>
<tr>
<td>2</td>
<td>Vehicle Operations: Area coverage</td>
<td>Enter the number of times the drone has cross a road in the last two search legs.</td>
</tr>
<tr>
<td>3</td>
<td>Projected location of robot: Relative to operator</td>
<td>Enter the distance (in FT) that the drone will be from you in 2 minutes assuming enough battery.</td>
</tr>
<tr>
<td>3</td>
<td>Projected ability to detect targets</td>
<td>Enter the number of human targets you think you will detect by the end of the scenario.</td>
</tr>
<tr>
<td>3</td>
<td>Projected coverage of area</td>
<td>Enter the number of search lines the drone will fly by the end of the scenario.</td>
</tr>
<tr>
<td>3</td>
<td>Projected need to return to base</td>
<td>Enter the number of minutes remaining until the drone will run out of battery.</td>
</tr>
<tr>
<td>3</td>
<td>Projected actions/behaviors of the robot</td>
<td>Enter the cardinal direction that the drone will be flying in 3 minutes assuming enough battery.</td>
</tr>
<tr>
<td>3</td>
<td>Projected destination of vehicle</td>
<td>Enter the distance (in FT) that the drone will have traveled when the battery is at 0%.</td>
</tr>
<tr>
<td>3</td>
<td>Projected need to return to base</td>
<td>Enter the number of minutes remaining until you will need to return to home.</td>
</tr>
<tr>
<td>3</td>
<td>Projected coverage of area</td>
<td>Enter the number of times the drone will cross a road in the next 2 minutes.</td>
</tr>
</tbody>
</table>
Appendix H

SART Questionnaire

Read each statement and then select the appropriate choice which corresponds to how you were feeling during the task you just completed.

Instability of Situation
How changeable is the situation? Is the situation highly unstable and likely to change suddenly (High) or is it very stable and straight forward (Low)?

1  2  3  4  5  6  7
○ ○ ○ ○ ○ ○ ○

Complexity of Situation
How complicated is the situation? Is it complex with many interrelated components (High) or is it simple and straight forward (Low)?

1  2  3  4  5  6  7
○ ○ ○ ○ ○ ○ ○

Variability of Situation
How many variables are changing within the situation? Are there a large number of factors varying (High) or are there very few variables changing (Low)?

1  2  3  4  5  6  7
○ ○ ○ ○ ○ ○ ○

Arousal
How aroused are you in the situation? Are you alert and ready for activity (High) or do you have a low degree of alertness (Low)?

1  2  3  4  5  6  7
○ ○ ○ ○ ○ ○ ○

Concentration of Attention
How much are you concentrating on the situation? Are you concentrating on many aspects of the situation (High) or focused on only one (Low)?

1  2  3  4  5  6  7
○ ○ ○ ○ ○ ○ ○
**Division of Attention**
How much is your attention divided in the situation? Are you concentrating on many aspects of the situation (High) or focused on only one (Low)?

```
1 2 3 4 5 6 7
○ ○ ○ ○ ○ ○ ○
```  

**Spare Mental Capacity**
How much mental capacity do you have to spare in the situation? Do you have sufficient to attend to many variables (High) or nothing to spare at all (Low)?

```
1 2 3 4 5 6 7
○ ○ ○ ○ ○ ○ ○
```  

**Information Quantity**
How much information have you gained about the situation? Have you received and understood a great deal of knowledge (High) or very little (Low)?

```
1 2 3 4 5 6 7
○ ○ ○ ○ ○ ○ ○
```  

**Information Quality**
How good is the information you have gained about the situation? Is the knowledge communicated very useful (High) or is it of very little use (Low)?

```
1 2 3 4 5 6 7
○ ○ ○ ○ ○ ○ ○
```  

**Familiarity with Situation**
How familiar are you with the situation? Do you have a great deal of relevant experience (High) or is it a new situation (Low)?

```
1 2 3 4 5 6 7
○ ○ ○ ○ ○ ○ ○
```
Appendix I

Qualitative Questions

How effective was the *separated* display configuration in completing your task? (environment view and drone on the top display; drone parameters and camera view on the bottom display)

- Not at all effective
- Slightly effective
- Somewhat effective
- Very effective
- Extremely effective

What did you like or dislike about the *separated* display configuration? ____________

Why? ______________________________________________________________________

How effective was the *integrated* display configuration in completing your task? (drone parameters and camera view overlaid on your environment view with drone on the top display)

- Not at all effective
- Slightly effective
- Somewhat effective
- Very effective
- Extremely effective

What did you like or dislike about the *integrated* display configuration? ____________

Why? ______________________________________________________________________
Appendix J

NASA-TLX Workload Measure

Read each statement and then select the appropriate choice which corresponds to how you were feeling during the task you just completed

<table>
<thead>
<tr>
<th>Mental Demand</th>
<th>How mentally demanding was the task?</th>
</tr>
</thead>
<tbody>
<tr>
<td>Very Low</td>
<td>○ ○ ○ ○ ○ ○ ○ ○ ○ ○ ○ ○ ○ ○ ○ ○</td>
</tr>
<tr>
<td></td>
<td>Very High</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Physical Demand</th>
<th>How physically demanding was the task?</th>
</tr>
</thead>
<tbody>
<tr>
<td>Very Low</td>
<td>○ ○ ○ ○ ○ ○ ○ ○ ○ ○ ○ ○ ○ ○ ○ ○</td>
</tr>
<tr>
<td></td>
<td>Very High</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Temporal Demand</th>
<th>How hurried or rushed was the pace of the task?</th>
</tr>
</thead>
<tbody>
<tr>
<td>Very Low</td>
<td>○ ○ ○ ○ ○ ○ ○ ○ ○ ○ ○ ○ ○ ○ ○ ○</td>
</tr>
<tr>
<td></td>
<td>Very High</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Performance</th>
<th>How successful were you in accomplishing what you were asked to do?</th>
</tr>
</thead>
<tbody>
<tr>
<td>Perfect</td>
<td>○ ○ ○ ○ ○ ○ ○ ○ ○ ○ ○ ○ ○ ○ ○ ○</td>
</tr>
<tr>
<td></td>
<td>Failure</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Effort</th>
<th>How hard did you have to work to accomplish your level of performance?</th>
</tr>
</thead>
<tbody>
<tr>
<td>Very Low</td>
<td>○ ○ ○ ○ ○ ○ ○ ○ ○ ○ ○ ○ ○ ○ ○ ○</td>
</tr>
<tr>
<td></td>
<td>Very High</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Frustration</th>
<th>How insecure, discouraged, irritated, stressed, and annoyed were you?</th>
</tr>
</thead>
<tbody>
<tr>
<td>Very Low</td>
<td>○ ○ ○ ○ ○ ○ ○ ○ ○ ○ ○ ○ ○ ○ ○ ○</td>
</tr>
<tr>
<td></td>
<td>Very High</td>
</tr>
</tbody>
</table>
Appendix K

IRB

Florida Institute of Technology
RESEARCH INVOLVING HUMAN PARTICIPANTS
EXPEDITED/FULL APPLICATION

This information listed below should be submitted to Florida Tech's IRB if the proposed research has more than minimal risk (none of the exempt conditions apply), or if the research utilizes a special population (children, prisoners, institutionalized individuals, etc.). Please consult the IRB website for detailed information, or contact the IRB Chairperson.
https://www.fit.edu/research/compliance-regulations/institutional-review-board

Submit via email to FIT_IRB@fit.edu.

IRB Contact Information:
Dr. Lisa Steelman
IRB Chairperson
Lsteelma@fit.edu or FIT_IRB@fit.edu
321-674-7316

PART 1: GENERAL INFORMATION

Title of Project: Evaluation of a Heads-Up Display on Situation Awareness and Performance During Operation of Small Unmanned Aircraft Systems

Date of Submission: 2/26/2020 - Revision

Expected Project Start Date: 11/15/19
Expected Project Duration: 6 months

Principal Investigator: Summer Rebenisky
Title: Graduate Student

Academic Unit: COA

Phone: 321-604-8660
Email: sldney2013@my.fit.edu

List all co-investigators. Please include name, title, academic unit/affiliation and email.

Meredith Carroll, Associate Professor, College of Aeronautics

Florida Institute of Technology - Institutional Review Board
150 West University Boulevard, Melbourne, FL 32901-6977 • 321-674-7310 • Steelman@fit.edu

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PART 2: PROJECT SPONSORSHIP INFORMATION

If any part of this research will be funded by an external source (current or planned), note the funding source and award/solicitation identification number below.

---

PART 3: RESEARCH DESCRIPTION

1. In lay terms, please describe the GENERAL PURPOSE of the study and how human subjects will be involved. List the SPECIFIC AIMS and RESEARCH QUESTIONS or HYPOTHESES. Avoid the use of jargon when describing the purpose of the study.

The goal of the study is to determine the impact that a heads-up interface design has on situation awareness, workload, and task performance for an unmanned aircraft system (UAS) visual search task. Approximately 50 participants will complete two 15 minute search tasks on a computer simulator. It is hypothesized that the heads-up display will lead to increases in situation awareness, workload, and task performance.
2. Outline the INCLUSION CRITERIA for subjects, explaining the rationale for the involvement of any special groups including children, prisoners, pregnant women or subjects with cognitive impairments. Describe the characteristics of the targeted subjects, including gender, age ranges, ethnic background and health/treatment status. If women or minorities are excluded, provide written justification. Give the number of subjects you anticipate including from each targeted group listed above.

Participants will be recruited from the FIT drone club, FIT UAS program, FIT general population, as well as the Brevard County commercial and recreational drone population. The Brevard County drone population will include general UAS operators as well as individuals who use drones in their day-to-day jobs. For example, including personnel from: Brevard County Fire Rescue, Brevard County Sheriff's Office, Kennedy Space Center Facility Inspectors, Brevard County Environmentally Encouraged Lands Program, and Brevard County Ocean Rescue. Minors will not be included in this study. Both males and females will be included as available.

3. Describe sources for potential participants, how subjects will be RECRUITED or the sampling procedure. Attach recruitment advertisements if applicable.

Participants will be recruited via word of mouth and email and Sona Systems. See attached recruitment advertisement.
4. Describe any COMPENSATION the subjects will receive, including course credit. If monetary compensation is offered, indicate how much the subjects will be paid and describe the terms of payment.

For those recruited via Sona Systems, they will receive Sona Credit. Those recruited via email and word of mouth, no set compensation will be offered. Florida Tech Professors may be asked to distribute recruitment information and may offer class credit for participation.

5. Explain how CONFIDENTIALITY and privacy of participant data (and anonymity if appropriate) will be maintained. If the research study involves collection of images or audio recordings of subjects, explain how the material will be used, who will see the images or hear the recordings, and in what setting (refer to the audio/video recording policy).

The informed consent is the only documentation within the study that will contain the name of the subject. The informed consent forms collected will be contained separately from the data collection forms to make sure that the identity of the subjects are kept confidential. Data will be masked by an anonymous identifier code. All study data will remain in the locked office/storage cabinets in the College of Aeronautics or Center for Aeronautics and Innovation (CAI).
7. In the study, unless deception is necessary due to the nature of the study, participants will be debriefed. Deceptive techniques must be justified by the study's scientific claims. Participants must be debriefed and told of the true purpose of the study. Informed consent must be explained to participants. The description will be used.

Florida Institute of Technology

RESEARCH INVOLVING HUMAN PARTICIPANTS

EXEMPT/FULL APPLICATION
8. Describe all SITES where this research will take place and attach documentation of permission from the appropriate source if the study involves subjects from places other than common public spaces.

The CAI building office rooms will be utilized for the simulator portion as this resides closely to the CCA UAS lab making it a familiar and convenient location for participant recruitment. Based on participant availability, the simulator may be brought to the locations of the commercial UAS operators. It will be asked that a similar office or conference room be reserved for the privacy of the study.

9. Describe any POTENTIAL RISKS (physical, psychological, social, legal or other) and the steps that will be taken to minimize risk. Where appropriate, discuss provisions for ensuring necessary medical or professional intervention in the event of adverse effects to the subjects. Also, where appropriate, describe the provisions for monitoring the data collected to ensure the safety of subjects. Research involving children must carefully assess risks and describe the safeguards in place to minimize these risks.

The risks of participating in the study do not exceed the everyday use of a desktop computer and a gaming controller.
10. Discuss the importance of the knowledge that will result from your study and what benefits will accrue to your subjects (if any). Discuss why the risks to subjects are reasonable in relation to the anticipated benefits to subjects.

The benefits of this study include gaining a better understanding of heads-up display impacts on UAS operations. Such an understanding would provide insight and guidance whether or not to incorporate augmented reality technology into UAS operations to improve safety, awareness, and mission success.

11. CONSENT. Informed consent can be in either written or oral format. If you request waiver of informed consent, documentation of informed consent, or of written informed consent, please state your justifications. Attach consent form if applicable. If an oral consent is planned, attach a copy of the text of the statement. If the study will be conducted with minors, provide an assent script. If assent is deemed unnecessary or inappropriate, you must discuss why. (Consent form should contain all eight elements listed in Part 4. Researchers are strongly encouraged to use the formal headers found in Part 4, item #3 to structure the consent document.)

The informed consent form which will be used is attached.
Florida Institute of Technology

RESEARCH INVOLVING HUMAN PARTICIPANTS
EXPEDITED/FULL APPLICATION

PART 4: INSTRUCTIONS FOR DOCUMENTATION OF INFORMED CONSENT

Informed consent is one of the primary ethical requirements underlying human subjects research, reflecting the principle of respect for potential subjects. Informed consent assures that prospective human subjects understand the nature of the research and can decide knowingly and volitionally whether or not to participate.

Informed consent refers to the voluntary choice of an individual to participate in research based on an accurate and complete understanding of, among other things, its purposes, procedures, risks, benefits, alternatives and any other factors that may affect a person’s decision to participate.

The basic concepts of the consent process include:

- Full disclosure of the nature of the research and the subject’s participation, adequate comprehension on the part of the potential subject
- Voluntary choice to participate
- Informed consent must be documented by use of a written consent form approved by the IRB and signed by the participant or the participant’s legally authorized representative. A copy should be given to the person signing the form. Even though the IRB has approved a consent procedure, it is the investigator’s responsibility to ensure that each potential subject understands the information and to take the appropriate steps necessary to gain that comprehension.

Individuals may not be involved as research participants unless a) they understand the information that has been provided and informed consent has been obtained, or b) the IRB has approved a waiver for informed consent.

REMEMBER: If the participant is under the age of 18, parental consent is required. This includes college students under the age of 18.

If the research involves the participation of minors under 18 years of age, read the description of requirements for research involving children. Additional requirements concerning parental consent forms and child assent are discussed.

Please follow the instructions for documentation carefully.

1. The consent form should be written in language that the participants can understand. Whenever possible, simple declarative sentences should be used. Ordinary language should explain technical terms.
2. Avoid the use of uncertain language through which the subject or the representative is made to waive or appear to waive any of his/her legal rights or release the investigator, sponsor or institution or its agents from liability for negligence.
3. Important information that must be included on the Consent Form:
   a. Purpose of the research.
   b. Procedures to be followed (what will the participants be asked to do? Include physical requirements or experimental procedures if applicable)
   c. Reasonable risks or discomforts to the subjects. What are the risks associated with participating and what safeguards are in place? Include the following statement, where appropriate:
   “In the event of physical injury resulting from the research procedures, no form of compensation is available. Medical treatment may be provided at your expense or at the expense of your health care insurer (i.e., Medicare, Medicaid, private pay) which may or may not provide coverage. If you have questions it is your responsibility to contact your insurer.”
   d. Benefits to the subject or others which may reasonably be expected to result.
   e. Alternative procedures or alternatives to participation, if any.
   f. Level of confidentiality of participant records. Is data anonymous? How will data be stored? If audio or visual records are obtained, how will they be maintained? Who will have access to the data?
   g. Primary investigator’s contact information. Point of contact for questions or problems related to this study.
   h. IRB contact. Also note the study was approved by Florida Institute of Technology’s IRB and list the current IRB chair and his/her contact information for questions or the right of people who take part in research.
   i. Voluntary participation, refusal, and withdrawal. Include the following statement:
   “Participation is voluntary. Refusal to participate will involve no penalty or loss of benefits to which you are otherwise entitled. You may discontinue participation at any time without penalty or loss of benefits to which you are otherwise entitled.”
   j. Signatures, if appropriate. Provide a place for:
      a. Signature of the participant (or his/her legally authorized representative)
      b. Date of signature

WAIVER OF INFORMED CONSENT

The IRB may approve a consent procedure that does not include, or which alters, some or all of the elements of informed consent outlined above, or waive the requirements to obtain informed consent provided the IRB finds and documents that the following four conditions have been met:

- The research involves no more than minimal risk to the subjects;
- The waiver or alteration will not adversely affect the rights and welfare of subjects;
- The research could not practically be carried out without the waiver or alteration; and
- Whenever appropriate, the subjects will be debriefed — provided with additional pertinent information — after they have participated in the study.
Florida Institute of Technology

RESEARCH INVOLVING HUMAN PARTICIPANTS
EXPEDITED/FULL APPLICATION

PART 5: SIGNATURE ASSURANCE SHEET
I understand Florida Institute of Technology’s policy concerning research involving human participants and I agree:

1. to accept responsibility for the scientific and ethical conduct of this research study.
2. to obtain prior approval from the Institutional Review Board before amending or altering the research protocol or implementing changes in the approved consent form.
3. to immediately report to the IRB any serious adverse reactions and/or unanticipated effects on subjects which may occur as a result of this study.
4. to complete, on request by the IRB, a Continuation Review Form if the study exceeds its estimated duration.

Pi Signature Date 2/26/2020
Pi Signature (print) Summer Rebsenky

ADVISOR ASSURANCE: IF PRIMARY INVESTIGATOR IS A STUDENT
This is to certify that I have reviewed this research protocol and that I attest to the scientific merit of the study, the necessity for the use of human subjects in the study to the student’s academic program, and the competency of the student to conduct the project.

Major Advisor Signature Date 2/29/20
Major Advisor (print) Meredith Carroll

ACADEMIC UNIT HEAD: IT IS THE PI’S RESPONSIBILITY TO OBTAIN THIS SIGNATURE
This is to certify that I have reviewed this research protocol and that I attest to the scientific merit of this study and the competency of the investigator(s) to conduct the study.

Academic Unit Head Signature Date 2/27/20
Academic Unit Head (print) Deborah S. Carstens

FOR IRB USE ONLY
IRB Approval Date
IRB #
Appendix L

Routes

Route 1

Route 2
Appendix M

SAGAT Scoring Guide

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#### Raw Data

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