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The Bridging Technique: Crossing Over the Modality Shifting Effect

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THE BRIDGING TECHNIQUE: CROSSING OVER THE MODALITY SWITCHING EFFECT

by

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ABSTRACT

Operator responsiveness to critical alarm/alert display systems must rely on faster and safer behavioral responses in order to ensure mission success in complex environments such as the operator station of an Unmanned Aerial System (UAS). An important design consideration for effective UAS interfaces is how to map these critical alarm/alert display systems to an appropriate sensory modality (e.g., visual or auditory) (Sarter, 2006). For example, if an alarm is presented during a mission in a modality already highly taxed or overloaded, this can result in increased response time (RT), thereby decreasing operator performance (Wickens, 1976). To overcome this problem, system designers may allow the switching of the alarm display from a highly-taxed to a less-taxed modality (Stanney et al., 2004). However, this modality switch may produce a deleterious effect known as the Modality Shifting Effect (MSE) that erodes the expected performance gain (Spence & Driver, 1997). The goal of this research was to empirically examine a technique called bridging which allows the transitioning of a cautionary alarm display from one modality to another while simultaneously counteracting the Modality Shifting Effect.

Sixty-four participants were required to complete either a challenging visual or auditory task using a computer-based UAS simulation environment while responding to both visual and auditory alarms. An approach was selected which utilized two 1 (task modality) x 2 (switching technique) ANCOVAs and one 2 (modality) x 2 (technique) ANCOVA, using baseline auditory and visual RT as covariates, to examine differences in alarm response times when the alert modality was changed abruptly or with the bridging technique from a highly loaded sensory channel to an underloaded sensory channel. It was hypothesized that the bridging technique condition would show faster response times for a new unexpected modality versus the abrupt switching condition. The results indicated only a marginal decrease in response times for the auditory alerts and a larger yet not statistically significant effect for the visual alerts; results were also not statistically significant for the analysis collapsed across modality. Findings suggest that there may be some benefit of the bridging technique on performance of alarm responsiveness, but further research is still needed before suggesting generalizable design guidelines for switching modalities which can apply in a variety of complex human-machine systems.

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INTRODUCTION

Background

Multimodal sensation and perception is an intriguing area of research which has been evolving for decades. Sixty-five years ago, the idea was put forth that human brains worked analogous to computers (Craik, 1948). Throughout the 1940s and 1950s research led to the conclusion of a bottleneck or slowing when participants were tasked with responding to two stimuli (Vince, 1949). Alan Welford proposed a single channel hypothesis incorporating the *psychological refractory period* (Welford, 1952), stating this refractory period

> …is due to the processes concerned with two separate stimuli not being able to co-exist, so that the data from a stimulus which arrives while the central mechanisms are dealing with the data from a previous stimulus have to be 'held in store' until the mechanisms have been cleared. (p. 3)

This idea was further refined and explained with Broadbent's bottleneck theory (1958) which suggested a point in information processing where only one piece of information was processed at a time, otherwise known as a serial processing theory. In hindsight it appears obvious that humans can process more than one piece of information at a time, and Moray (1967) and Kahneman (1973) proposed such a notion by suggesting a common pool of mental resources from which all tasks share. Kahneman's capacity theory specifically represented task performance using a mental fuel model. Contrary to previous serial processing theories, this parallel processing theory utilized the concept of different tasks sharing the same collective amount of mental fuel. With enough mental fuel available, an individual could feasibly perform two or more tasks in parallel – devoting a larger portion of mental fuel capacity to a task would yield increased accuracy or speed. The capacity is not a fixed amount; rather, exceeding the mental fuel capacity results in slower and less accurate tasks. With the parallel processing theories showing promise, serial processing theories indeed gave way.

Multiple Resource Theory

Though this evolution in information processing science from serial to parallel processing was supported by the concept of multitasking, it did not explain how some combinations of tasks seemed to conflict with each other, or why other tasks would appear to not affect each other at all. Wickens (1976) suggested Multiple Resource Theory (MRT) which explained these situations with the concept of separate resource structures for separate codes and modalities, such as verbal/spatial or visual/auditory. In this model, time sharing between tasks was more efficient if the two utilized separate structures than if they utilized common structures. He further refined this idea to incorporate structural dichotomies (Wickens, 1980) and eventually design a matrix-like framework, a three-dimensional taxonomy of resources (Wickens, 1984) split into modalities (visual, auditory), codes (spatial, verbal), and stages (perception, cognition, responding) (Figure 1). Two tasks which utilize the same modality, code, or stage will conflict with each other resulting in reduced performance on each. Conversely, two tasks which utilize separate modalities, codes, and stages can likely be performed in parallel resulting in similar accuracy and speed as each would if performed independently.

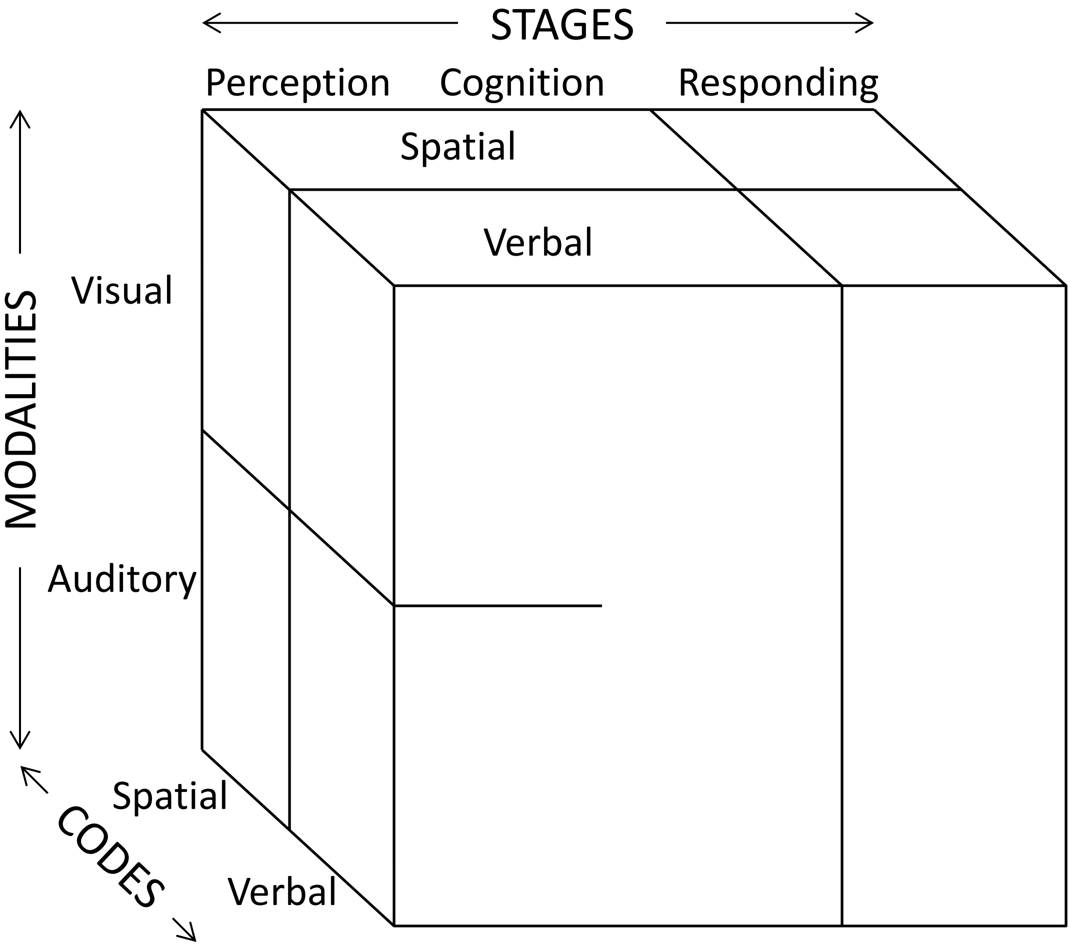


Figure 1. Simplified Multiple Resource Theory framework from Wickens (2008).

A familiar example of MRT in practice is the development of the car GPS unit. Driving a vehicle is a highly demanding visual task, frequently requiring attention through the windshield, rear view mirror and side mirrors. This visual task utilizes the same modality as actively looking at a GPS unit (the visual modality). A driver cannot focus on the road and another display at the same instant. Thus, any time spent looking at the GPS screen is necessarily time spent with only peripheral vision on the road at best. This performance decrement was realized all too often in the form of unintentional and tragic traffic collisions.

To solve this problem, GPS designers added a spoken language element. This auditory presentation of directions utilizes a different modality than the visual presentation, thus, the required channels do not conflict and drivers can successfully navigate highways while listening to directions. Similar reasoning applies for codes (verbal, spatial) and stages (perception, cognition, responding).

Note that in Figure 1 some portions of the model are separated completely by a line, while in other areas there is only a partial demarcation or no line at all. The spatial and verbal codes, for example, are separated by a distinct line through all modalities and stages, thus signifying separate structures and little overlap or conflict. Similarly, a line between the responding stage and the two other stages (perception and cognition) symbolizes an ability to perceive and respond or consider and respond to information at the same time. Importantly, however, there is no line between the perception and cognition stages. This recognizes the notion that there is overlap in structures used for these two stages. Following this logic, the partial horizontal line separating visual and auditory modalities recognizes that visual and auditory tasks activate separate channels during the perception stage but overlapping structures during the cognition stage. Some examples of resource structure conflicts are listed in Table 1.

Table 1. Example resource structure conflicts.

Task A	Task B	Conflict	Alternative
Reading text (visual/verbal)	Listening to spoken words or talk radio (auditory/verbal)	Each utilize the same verbal code	Listen to instrumental or non-verbal music, or silence
Listening to communications over a headset (auditory/verbal)	Listening for a spoken word alarm (e.g., LOW FUEL) (auditory/verbal)	Each utilize the same auditory modality AND the same verbal code	Design the alert as an indicator light (visual/spatial)
Assessing orientation from a map (visual/spatial)	Communicating through chat window (visual/verbal)	Each utilize the same visual modality	Utilize headsets for spoken communication (auditory/verbal)

Though MRT is recognized as an effective and well supported theory, there are criticisms. Meyer and Kieras (1997) suggested MRT lacked sufficient principled constraints, concisely stating "In the absence of such constraints, there is a temptation to hypothesize new sets of resources whenever additional problematic data are collected." Despite this and other criticisms (see Hirst & Kalmar, 1987; Navon, 1984, 1985; Neumann, 1987), MRT remains one of the most reliably predictive information processing theories used today, and is the basis for this research question: *Can we reduce operator workload and improve performance by intelligently interfacing with an operator through multiple sensory modalities?*

Results and findings of MRT research have been applied in many domains including, significantly, complex interface design. Advances in computing technology have led to displays able to present more information than one operator can singly attend to. Future systems will likely be more complex, resulting in interfaces which must be designed with extraordinary consideration to human information processing and cognitive workload. One potential solution is to incorporate MRT principles into the design of the computer interface. The resulting system could provide information to the operator in disparate channels (utilizing multiple modalities and/or codes) in order to not overload any single sensory channel. Previous authors have established preliminary guidelines for such a multimodal interface which can maximize user information processing and mitigate user cognitive overload (Sarter, 2006, Stanney et al., 2004). In addition, Stanney et al. (2004) suggested "creating multimodal display systems that augment or switch modalities to maximize user information processing." This suggestion to switch modalities during operation leads to an avenue of research that is still growing and is the impetus for this effort. Users should expect such a multimodal interface to increase task performance, and the research described here examines this potential performance gain in the context of reduced response times to an infrequent alert.

An Overview of Response Times

Before going further, a field of study relevant to this discussion is the study of response time (RT) to visual or auditory stimuli. The processes involved in simple RT are tightly woven with MRT and multiple modalities, therefore it is essential to understand the knowledge-base of RT research for multiple sensory modalities and how the conclusions help to shape the design of this experiment.

RT Studies as Support for MRT

RT is defined by Shelton and Kumar (2010) as the elapsed time between the presentation of a sensory stimulus and the subsequent behavioral response. At its simplest, RT is consistently lower to auditory stimuli than to visual stimuli. Niemi (1979) examined differences between RT to auditory and visual stimuli when the foreperiod (FP) was held constant in order to investigate the competing *serial-stage theory* and *variable criterion theory*. These conflicting ideas were centrally focused on the relationships of sensory processing stages to each other. Serial-stage theory asserted that the stages were additive and did not interact with each other in the presence of other variables (e.g., number of choices, FP, intensity of stimulus). Conversely, variable criterion theory posited that stimulus intensity must meet a subject's criterion before a response is given, representing an interaction between the central and encoding stages and thus conflicting with serial-stage theory. Niemi's results supported the variable criterion theory, as stimulus intensity had a significant interaction with FP duration for auditory stimuli only (Figure 2).

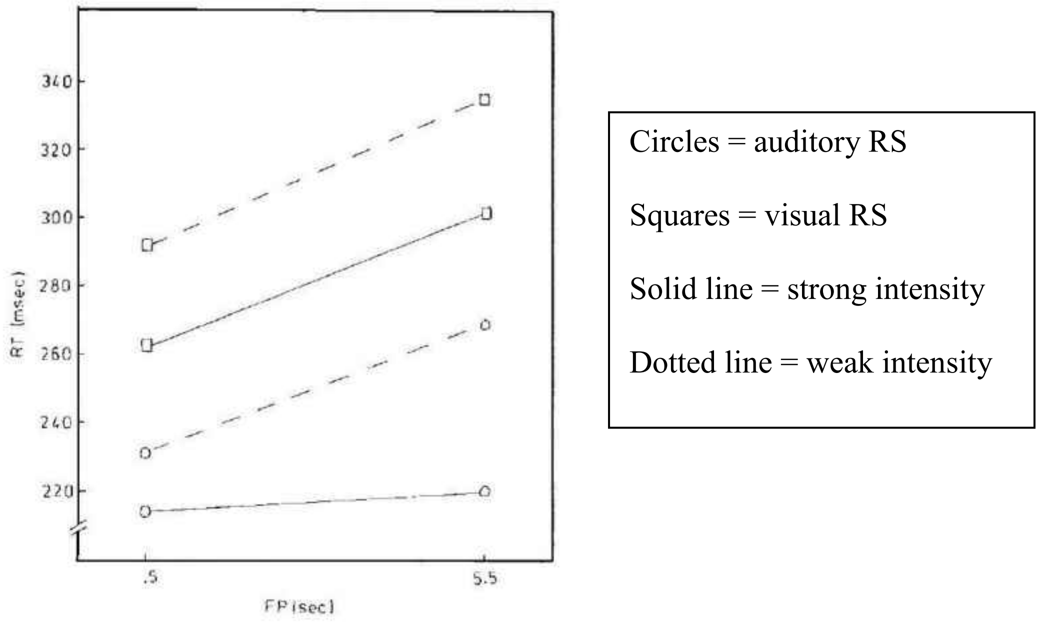


Figure 2. Auditory and visual simple RT as a function of reaction stimulus (RS) intensity and constant FP. (Niemi & Näätänen, 1981).

There was not a significant interaction between the FP duration and stimulus intensity for visual stimuli. Three of the four conditions showed a linear increase in response time as FP increased. Response times to intense auditory stimuli, however, did not significantly increase as FP increased. These results can be interpreted as early support for MRT. A unique result for the intense auditory stimuli suggests separate operating mechanisms, or channels. If auditory and visual stimuli are processed through separate channels, one would expect RT to visual stimuli to behave differently than RT to auditory stimuli in some situations: in this case, based upon an interaction between stimulus intensity and FP duration.

More recent RT experiments continue to support Wickens' MRT with physiological and neurological data. Penhune, Zatorre, & Evans (1998) revealed through Positron Emission Topography (PET) scans that the neurological pathways activated during response time studies differ clearly by modality-specific participation of frontal- and temporal-lobe structures. This furthers the case that MRT is a valid foundation upon which to design a multimodal interface and dictates that experimenters carefully consider modality type when designing RT studies.

The Effect of Foreperiod (FP) Duration on Expectancy

The increase in response time as FP increased in Niemi's study is consistent with earlier research on FP duration. Additionally, the subject's expectancy for the delivery of a stimulus certainly impacts the RT. A constant stimulus rate encourages the highest possible expectancy and consistently yields response times superior to variable stimulus rate conditions, and yet also reveals subjects' flawed internal timekeeping ability. Simon and Slaviero (1975) demonstrated that the presence of a visual countdown timer will reduce response times to stimulus of a fixed interval. In essence, the decreasing number of lights in the countdown timer shortened the FP, reducing it to the short time between the moment the last light of the timer extinguished and the moment the stimulus was presented. This in turn decreased the amount of time the brain relied upon its unassisted internal clock, subsequently reinforcing expectancy, improving accuracy, and thus reducing response times when that expectancy was met.

The FP duration has a more multi-faceted effect on expectancy than simply temporal uncertainty. While typically a longer FP results in greater time uncertainty and thus a longer RT, lengthening the FP does not increase response latency without limit (Niemi & Näätänen, 1981). Research from Bevan, Hardesty, and Avant (1965) provided a threshold, showing that RT did not increase further with an FP greater than 80 seconds. This is useful in instances where the stimuli are relatively infrequent. Response time to an alert that occurs no more frequently than every 80 seconds, with all other variables controlled for, is assumed to be the same for an individual regardless of the amount of time since the last stimulus.

Expectancy Theory in Practice: Introducing the Modality Shifting Effect

Expectancy theory research in driving shows the potential effects of modality expectation. Dilich, Kopernik, and Goebelbecker (2002) compiled many viewpoints from research articles, book chapters, and other relevant sources which showed a consistent, if not consensus position that expectancy plays a significant role in the ability of a vehicle operator to respond successfully to a sudden emergency. A concise example from Davis (1959) is quoted here:

> The conditions under which an engine driver, or pilot or other operator perceives a signal are usually such that he has a strong expectation of what he will perceive, this expectation being derived perhaps from a lengthy experience of

> similar situations and an appraisal of the current situation which is usually both confident and correct. Sometimes he is alert for departures from what he would normally expect. If he is not, he may fail to look out for or fail to perceive correctly, a signal of considerable clarity in terms of strength and duration. Thus he may totally neglect a signal which he does not expect, or misread a signal if what it indicates is contrary to what he expects. He then makes an error because his appraisal or conception of the situation and its probabilities is false. (p. 28)

When applied to a complex operator interface the impact of modality expectancy can be beneficial, as when expecting a cue to appear in a certain modality leads to an enhanced readiness to detect and discriminate information in that sensory channel (Posner & Petersen, 1990; Post & Chapman, 1991; Spence & Driver, 1997). Expectancy can also be undesirable, as is the case when response times increase to cues in an unexpected modality and with modality uncertainty (e.g., Boulter, 1977; Ferstl, Hanewinkel, & Krag, 1994; Zubin, 1975). This detrimental effect is known as the *Modality Shifting Effect* (MSE), defined by Spence & Driver (1997) as a person's strong tendency to respond more slowly to a target in one modality if the preceding target was presented in a different modality than if the preceding target was presented in the same modality. If we are to design systems which maximize user information processing by incorporating multimodal information displays we must account for, mitigate, or eliminate the MSE.

The Benefits of Bridging

Recall from the description of Wickens' Multiple Resource Theory (MRT) that two tasks which utilize the same sensory modality (e.g., visual, auditory) will conflict with each other resulting in reduced performance on each. Conversely, Wickens showed that two tasks which utilize separate modalities can be performed in parallel without the aforementioned reduction in accuracy and speed. This leads to the conclusion that if one modality is already heavily loaded, it should be beneficial to present any additional information in a separate, non-conflicting modality instead. Changing modality abruptly however, with no consideration for expectancy or the MSE, does not maximize the potential of this application. Thus if the interface can switch modality in order to offload cognitive demands to a less taxed channel, and simultaneously prevent the MSE predicted by expectancy theory, the operator may exhibit reduced cognitive workload, decreased response times, and more accurate responses.

To combat MSE, I propose a smooth transition called “bridging” which, when applied to situations where information is presented in multiple modalities, could potentially ameliorate lagging response times due to the MSE. At the appropriate time, rather than switching abruptly and unexpectedly from one modality to another (e.g., visual – auditory), the information would more gradually bridge from one into the other (e.g., visual – visual/auditory – auditory), where the bridge element consists of a stimulus presented in both modalities simultaneously, before the full transition to an alert presented solely in the new modality. In this way the operator would receive a subtle, subconscious cue that would eliminate expectancy in the previous modality and prepare the operator for the next modality without interrupting performance, concentration, or situation awareness. The experiment described below was designed to test this technique in the guise of an Unmanned Aerial System Ground Control System.

Context: Unmanned Aerial System Ground Control Station (UAS GCS)

Some of the most complex interfaces are those facing operators of UASs, often referred to as UAVs or drones, such that volumes have been penned on the human factors issues prevalent in early GCS designs. As UASs continue to evolve, designers must strongly consider several key human factors issues (Mouloua, Gilson, Kring, & Hancock, 2001). The benefits of exploring improved interface design in this emerging field are plentiful because of course the term Unmanned Aerial System is a misnomer. These machines are not truly unmanned, but rather operated remotely. More complex UASs such as the Predator, Fire Scout or Triton are operated by a team of personnel. Though the missions and associated personnel can be different across and even within UAS platforms, many UASs have a similar general teaming arrangement we can use to clarify the roles for the purposes of this experiment. In this dissertation the term *vehicle operator* refers to the personnel primarily responsible for maneuvering the vehicle between points A and B, as used by Calhoun & Draper (2006). This is in contrast to the *sensor operator*, the personnel primarily responsible for monitoring, engaging, and interpreting the information from the various sensor capabilities of the particular UAS platform (e.g., infrared cameras, video feeds, RADAR). For the duration of this dissertation the term *operator* is used interchangeably with *sensor operator*.

While vehicle operators may experience prolonged periods of low to medium level cognitive workload while en route, spikes or bursts of intense workload are quite demanding and can be frequent. The duties of a sensor operator, however, can result in prolonged periods of sustained high workload and thus seem a more fertile ground for multimodal information processing research.

Although the roles of the sensor operator can vary widely between platforms and are dependent upon the platform capabilities, mission requirements and priorities, some tasks are generalizable across multiple platforms. Mangos, Vincenzi, Shrader, Williams, & Arnold (2012) performed an analysis of cross-platform naval unmanned aircraft system task and competency requirements. UAS SMEs provided ratings on operator tasks for frequency, criticality, and difficulty. After reviewing this analysis the author selected three representative sensor operator tasks: identify friend or foe (IFF), confirm and acknowledge communications, and respond to alerts, warnings and alarms. These generalizable tasks were identified as difficult, frequent, and critical and thus provided ecological validity to the participant tasks.

Can we reduce workload and improve performance by intelligently interfacing with the operator through multiple sensory modalities? The phrase *intelligently interfacing* implies a human-centric design in which the interface is modified to meet the needs of the operator rather than vice versa. Military vehicles and weapon systems contain such powerful capabilities that demands for operator attention can reach unsustainable levels with potentially catastrophic results. In such a high-risk environment the display must be intuitive and informative to the operator and nearly any reduction in workload or improvement in performance is worth exploring. These benefits may be accomplished by applying a sound understanding of MRT, modality switching, and MSE to the design of a UAS GCS interface, yielding more capable operators and thus more capable UASs.

Perhaps not surprisingly, a review of the existing research in this emerging domain yields more new questions than answers. Recent research on UAS control tasks has shown that visual displays can be augmented with auditory cues to enhance performance, particularly the response time and accuracy on a secondary monitoring task (Jones, Samman, Stanney, & Graeber, 2005).

Other research has stated that although multimodal displays have value as a method of compensating for sensory information denied to a UAS operator with conventional displays, these displays may carry performance costs as well and argues that future research is necessary to examine the costs and benefits of multimodal displays (McCarley & Wickens, 2005). If so, what is the most effective way to incorporate these modalities to balance the load for multiple sensory channels? How can modality switching be implemented into an interface such as a GCS? When is the most beneficial time to switch modalities in a GCS? Should the system alert the operator to this change? How? The bridging approach proposed here may begin to answer these questions.

In order to test the bridging technique in a UAS context I followed the advice given by Mayhew (1999) who suggested that designers must both utilize structured methods and draw upon well-established design principles and guidelines, adding "Without the benefit of the initial guidance of sound design principles during first passes at design, a particular project with its limited resources may never stumble upon a design approach that works."

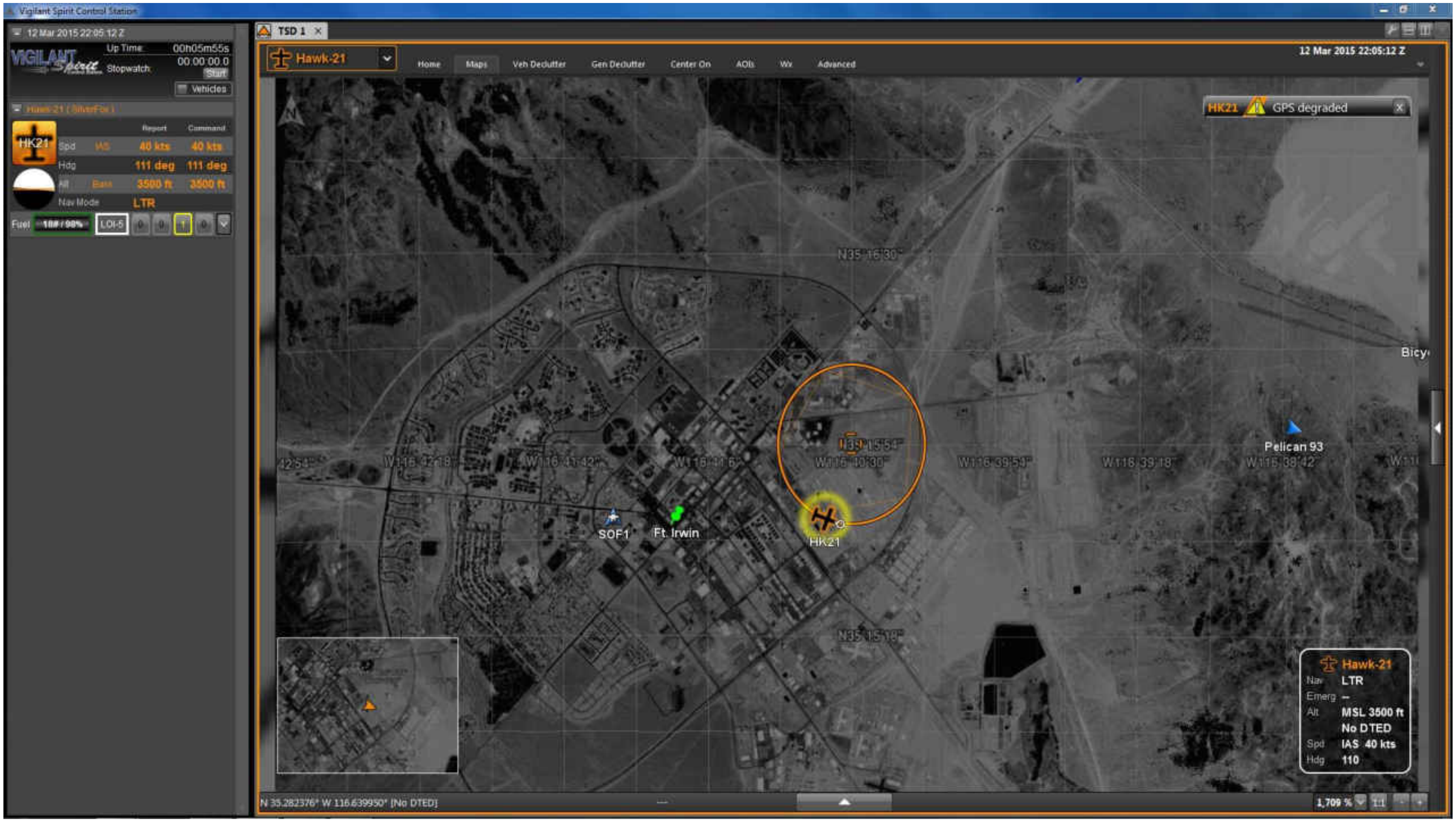
To ensure maximum likelihood of success in this context I referenced the multimodal design guidelines put forth by Sarter (2006). Sarter reviewed existing multimodal design guidelines and split them into four categories. These four categories are (a) selection of modalities, (b) mapping of modalities to tasks and types of information, (c) combination, synchronization, and integration of modalities, and (d) adaptation of multimodal information presentation. The selection and mapping of modalities for this investigation are highlighted here. If successful, future research investigating the third and fourth categories may yield a highly effective and intuitive interface.

Selection of Modalities

Few established design guidelines exist for tactile or haptic display applications in this context (Calhoun & Draper, 2006). Additionally, the sense of touch has unique effects compared to the visual and auditory senses. For instance, it appears to be particularly time-consuming to shift attention to the visual or auditory channel away from rare events that are presented in the tactile modality (Spence, Pavani, & Driver, 2000). Even fewer studies exist investigating the equivalence of the olfactory and gustatory senses. With these considerations in mind, the visual and auditory channels were selected as the most appropriate modalities for this effort.

Mapping of Modalities

The tasks in this experiment were carefully chosen to fulfill the unique cognitive load requirements. The primary task for all participants was to respond to any alert as soon as possible. The visual modality is mapped to the alerts by presenting visual notifications to the participant in three locations simultaneously: a text-box notification in the upper right corner of the primary map, a glowing yellow halo around the vehicle raising the alert, and a yellow outlined numeral on the left side of the screen in the Warning, Cautions, and Alerts (WCA) section of the vehicle pane (see Figure 3 below).



12 Mar 2015 22:05:12 Z

Up Time: 00h05m55s

Stopwatch: 00:00:00.0

Hawk-21 (SilverFox)

		Report	Command
Spd	IAS	40 kts	40 kts
Hdg		111 deg	111 deg
Alt	Baro	3500 ft	3500 ft
Nav Mode		LTR	

Fuel 18# / 98% LOI-5

HK21 GPS degraded

Hawk-21
Nav LTR
Emerg --
Alt MSL 3500 ft
No DTED
Spd IAS 40 kts
Hdg 110

N 35.282376° W 116.639950° [No DTED]

Figure 3. Screenshot of interface depicting locations of visual alerts.

The auditory modality is mapped to the alerts by presenting an auditory siren tone rising and falling in pitch. The volume of the tone was adjusted to a comfortably audible volume, on par with the brightness of the visual alert and presented through standard computer speakers situated in front of the participant.

The secondary tasks needed to produce high cognitive load for a specific sensory channel (and that channel only). As such, the tasks were chosen with the visual and auditory modalities in mind such that the task modality conditions had participants complete a task mapped to either the visual or auditory modality specifically.

The visual task modality condition required a highly loaded visual channel. As such, participants attended to a busy visual display in order to complete an engaging, difficult task of identifying a large number of fast moving unknown entities as hostile or neutral. For the purposes of this experiment, the participants made this decision based upon whether the artificial identification tag ended with an odd or even number. With sufficient and appropriate stimuli the visual channel became highly taxed, as verified by subjective NASA TLX surveys administered post-hoc.

Similarly, the auditory modality was mapped to the auditory task modality condition requiring a highly loaded auditory channel. In these conditions the participant was focusing on pre-recorded communications chatter and asked to acknowledge specific instructions given to them amongst a larger set of communications intended for other virtual air traffic. With a close phonetic resemblance between the participant and virtual player callsigns (e.g., Eraser435, Razor535, Razor553) and the requirement to accurately repeat aloud relevant communications this auditory task was quite challenging and required the participant to focus specifically on the audio channel, as verified again by NASA TLX results. Adhering to these modality selections and mappings allowed for a tightly controlled experiment.

HYPOTHESES

Although previous research efforts have examined applications of multiple resource theory, suggested potential benefits of switching from a highly loaded modality to a lesser taxed modality, shown expectancy to be a key driver in response times, and identified degraded performance due to the modality shifting effect, no literature has previously attempted to counter MSE by mitigating the sudden unexpectedness of the new modality. This effort attempts to do just that by examining the following hypotheses:

Hypothesis I

The AUD-BRI condition will result in greater decrease in response times than the AUD-ABR condition. This hypothesis is comparing visual response times changed from auditory abruptly (ABR condition) or via bridging (BRI condition), while performing an auditory secondary task (AUD condition). It should be noted that the initial alert modality is auditory while performing an auditory task, yet the hypothesis compares the visual response times in the AUD-ABR and AUD-BRI conditions. The comparison is within subjects and examined by comparing the RT for the fifth alert in the AUD-ABR condition with the sixth alert in the AUD-BRI condition (in each case, the first alert presented solely in the new modality). If the bridging technique is successful the RT for the sixth alert in the AUD-BRI condition (the first solely visual alert after the bridge from the auditory modality) should be lower than the RT for the fifth alert in the AUD-ABR condition (the first visual alert presented after the abrupt change from auditory) due to the mitigation of the Modality Shifting Effect via the bridging process.

Hypothesis II

The VIS-BRI condition will result in greater decrease in response times than the VIS-ABR condition due to the mitigation of the Modality Shifting Effect via the bridging process. This hypothesis is comparing auditory response times changed from visual abruptly (ABR condition) or via bridging (BRI condition), while performing a visual secondary task (VIS condition). This hypothesis is examined by comparing the RT for the fifth alert in the VIS-ABR condition with the sixth alert in the VIS-BRI condition. If the bridging technique is successful the RT for the sixth alert in the VIS-BRI condition (the first solely auditory alert after the bridge from the visual modality) should be lower than the RT for the fifth alert in the VIS-ABR condition (the first auditory alert presented after the abrupt change from visual).

Hypothesis III

The *Bridge* condition groups will show significantly greater RT improvement than the *Abrupt* condition groups, when accounting for the variance due to modality specific baseline RT. This will test for the bridging technique effectiveness collapsed across both modalities. This is a between subject comparison as no participant performed both the visual and auditory secondary task. Collapsing the groups requires including both the visual and auditory baseline response times as covariates to account for individual and sensory response time differences.

METHOD

Design

Independent Variables

The experiment consisted of two independent variables, or factors. These factors were Task Modality and Switching Technique. Each factor had two levels as depicted in Table 2.

Table 2. Names and levels of factors.

Factors	Levels
A: Secondary Task Modality	Visual (VIS) Auditory (AUD)
B: Switching Technique	Abrupt (ABR) Bridging (BRI)

The two-by-two combination of these IVs results in four potential conditions. The task modality condition was analyzed between subjects, that is, each participant performed two twelve minute trials of either the challenging visual or auditory secondary task (Factor A).

The first four alerts were distributed in the first half of the scenario and were in the same modality: visual alerts if the participant was assigned to the VIS condition, or auditory alerts if the participant was assigned to the AUD condition. This design was intended to result in overlapping, conflicting modalities and thus an increase in response time (RT) compared to baseline, non-multitasking RT.

The switching technique was analyzed within subjects. Participants in the abrupt switching technique condition (ABR; Factor B) received four alerts after the halfway point in the scenario presented in the second, alternative modality (i.e., auditory for those assigned to the VIS condition, and visual for those assigned to the AUD condition). Participants in the bridging condition received the fifth alert as a combination of visual and auditory modalities before receiving the three remaining alerts in the second modality. This aspect of the design was intended to yield faster response times in the second half of the scenario due to the replacement of an overlapping modality with an orthogonal non-conflicting modality while also facilitating the emergence of MSE in the abrupt condition and mitigating MSE in the bridging condition.

After completing the first trial, the participants completed a second trial with the same tasking in a similar scenario utilizing the opposite switching technique (Factor B). Alerts were presented in the same order with the only difference being the presence or absence of the bridged alert. Participants were not asked to perform two trials of the other secondary task (Factor A) after pilot testing results yielded pattern recognition and learning effects. The order of the two different switching technique trials was counterbalanced across all participants to further mitigate residual variance due to learning, order, or vigilance decrement effects.

Dependent Variables

The dependent variable in this experiment was the participant RT to the first alert presented solely in the second modality. This was the fifth alert for the abrupt condition and the sixth alert for the bridging condition. The RT was assessed by an automated process which logged the scenario time to the millisecond when the alert was presented to the participant and when the alert was acknowledged by key press. In order to account for individual differences, a baseline RT for each modality for each participant was collected and used as a covariate in the analysis (see Procedure section below).

Primary Task

The primary task in all conditions was to acknowledge alerts as soon as possible while performing a secondary visual or auditory task. In all conditions the fifth alert changed modality. In the abrupt conditions (ABR) the fifth alert was simply presented to the alternate sensory channel. If the first four alerts were visual (VIS-ABR), the fifth and subsequent alerts were auditory. If the first four alerts were auditory (AUD-ABR), the fifth and subsequent alerts were visual.

In the bridging conditions (BRI) the fifth alert was a composite of both visual and auditory modalities, while the sixth and subsequent alerts were presented solely in the alternate modality. If the first four alerts were visual (VIS-BRI) the alerts bridged to auditory. Likewise, if the first four alerts were auditory (AUD-BRI) the alerts bridged to visual. In all modalities and conditions the participants acknowledged the alerts by pressing the spacebar key.

Secondary Task – Visual

The secondary task for each participant varied depending on which condition they were assigned to. For the visual task modality (VIS), participants were required to monitor their vehicle within the tactical display of VSCS, be aware of any incoming unidentified entities (tracks), and identify the tracks as hostile or neutral. This process is also known as Identify Friend/Foe, or IFF. This task was challenging due to both the number of tracks that entered the screen throughout the course of the scenario and the series of mouse click actions required to IFF each track. This complexity and volume lead to a highly loaded visual channel.

Secondary Task – Auditory

The auditory task modality (AUD) required participants to listen while a series of simulated communications are relayed (see Table 3 for examples). These communications were developed and scripted by UAS Subject Matter Experts and represent communications from Mission Control, Air Traffic Control, and other nearby UASs. The participants were instructed that their callsign was Eraser435. Any time the participant heard an instruction begin with "Eraser435", "Attention all aircraft", or "Attention all UAS" they were required to repeat the message aloud (minus the callsign) to acknowledge the communication.

Table 3. Examples of scripted audio communications.

"Tower, Razor535 RTB request clearance."
"Spider82 climb and maintain flight level two one zero, traffic ten o'clock, flight level one nine zero, heading west, type UAS, acknowledge."
"Eagle76, you will be on station an additional ten mike, relief has been delayed."
"Eraser435 decrease speed by 15 knots."
"Razor553, expect an updated mission plan, standby."
"Tower, Nitro675 holding short of runway zero one five left, requesting take-off."
"Eagle18 increase speed by five knots."
"Tower, Star922 RTB request clearance."
"Attention all aircraft, severe turbulence reported by Eagle76 at flight level two one zero."
"Gadget indicates weather is moving in, standby."
"Razor553 turn left 30 degrees to avoid weather, then proceed to waypoint three."
"System malfunctioned, but appears to be operating again."
"Eagle76, expect an updated mission plan, standby."
"Eagle18 fly heading zero seven zero."

Requiring the participant to repeat out loud the message required focus on the auditory channel and was consistently subjectively rated as challenging on the post-hoc NASA TLX questionnaires administered (Appendix A).

Participants

Seventy-three participants were recruited from a nearby university using SONA Systems online sign-up tools and were compensated either course credit or ten dollars for their participation in the one hour study. Results of an initial power analysis following the formula provided in Cohen & Cohen (1983) showed 64 participants were needed to detect a medium effect (*f* = .3) at an alpha level of .05 with a power level of .9. Of the 73 participants, nine were excluded from the analysis. Data from the first six participants were collected before the experimenter noticed a mistake in the alert timing and were subsequently discarded. An experimenter error yielded invalid results from the data of one other participant. One participant was dismissed after a testbed malfunction, and one participant chose to end the study early. The sample included 32 males and 32 females ranging in age from 18 to 52 years (*M* = 23.4; *SD* = 7.2). All participants in the sample reported that they were fluent in English, did not have color-deficient vision, had no hearing impairments, and did not have prior UAS experience.

Materials

Vigilant Spirit Control Station

The Vigilant Spirit Control Station (VSCS) is a government-owned software suite developed by a team of researchers and programmers at the Wright Patterson Air Force Base in Dayton, OH for UAS research and applications. VSCS is capable of affording multi-vehicle control and sensor monitoring with varying types and levels of multimodal caution and warning alerts; however this experiment utilized a small subset of these VSCS capabilities. Specifically, the interface presented only one vehicle and one level of alert to monitor in order to eliminate potential response time confounds due to choice and decision making (Figure 4).

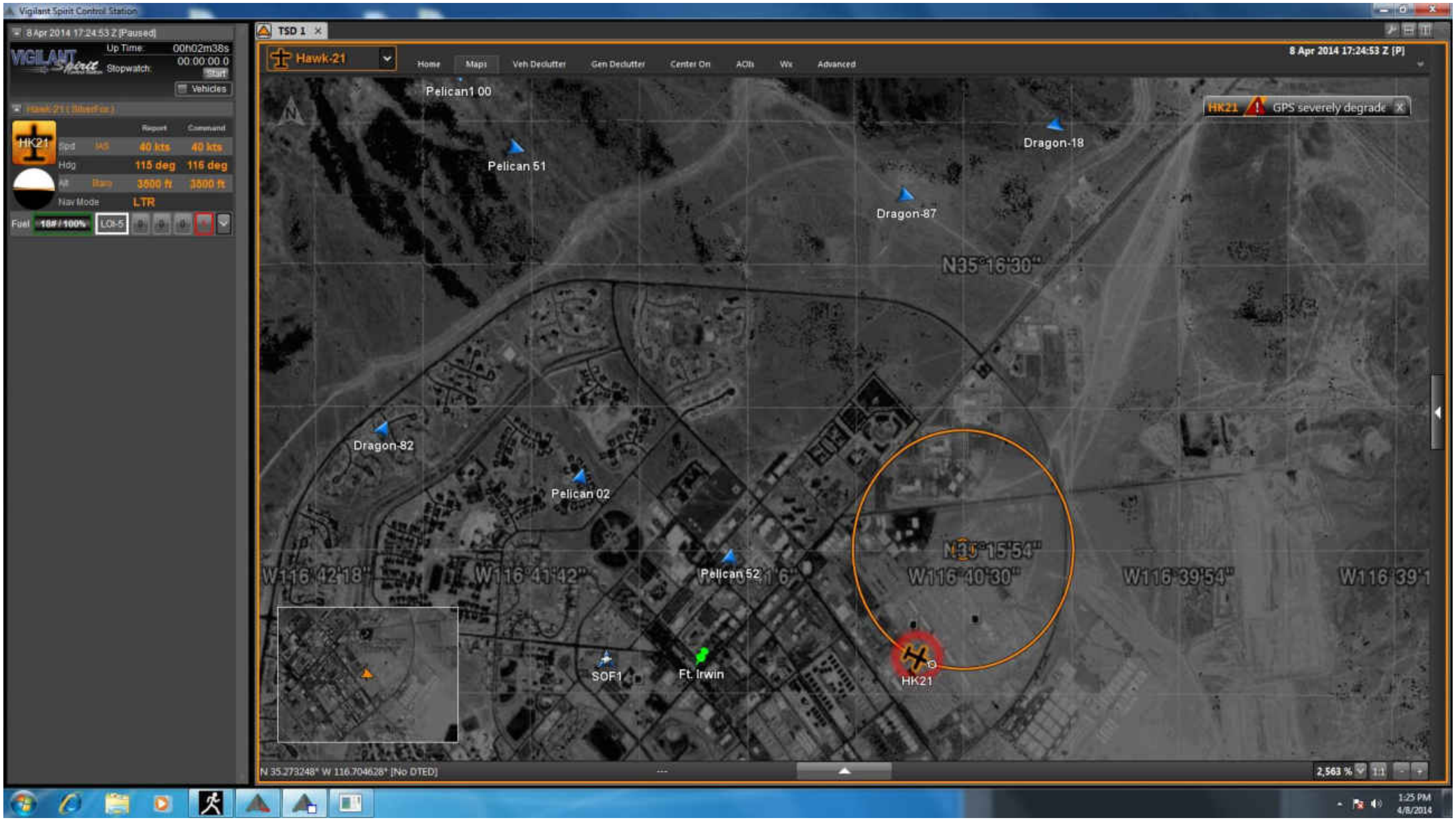


Figure 4. VSCS sample screenshot.

Software plug-ins enabled VSCS to automatically log the scenario time, to the millisecond, when an alert was presented to the participant and when the spacebar key was pressed (which was considered for this experiment to be an alert acknowledgment). Subtracting the former from the latter resulted in the participant RT for each stimulus.

Experimental Scenarios

Three custom scenarios were created for the purposes of this experiment. The first scenario was used during the baseline response time test. In this scenario the UAS flew a circular loiter route with no other vehicles on the map and no events occurring in the scenario (see Figure 5below).

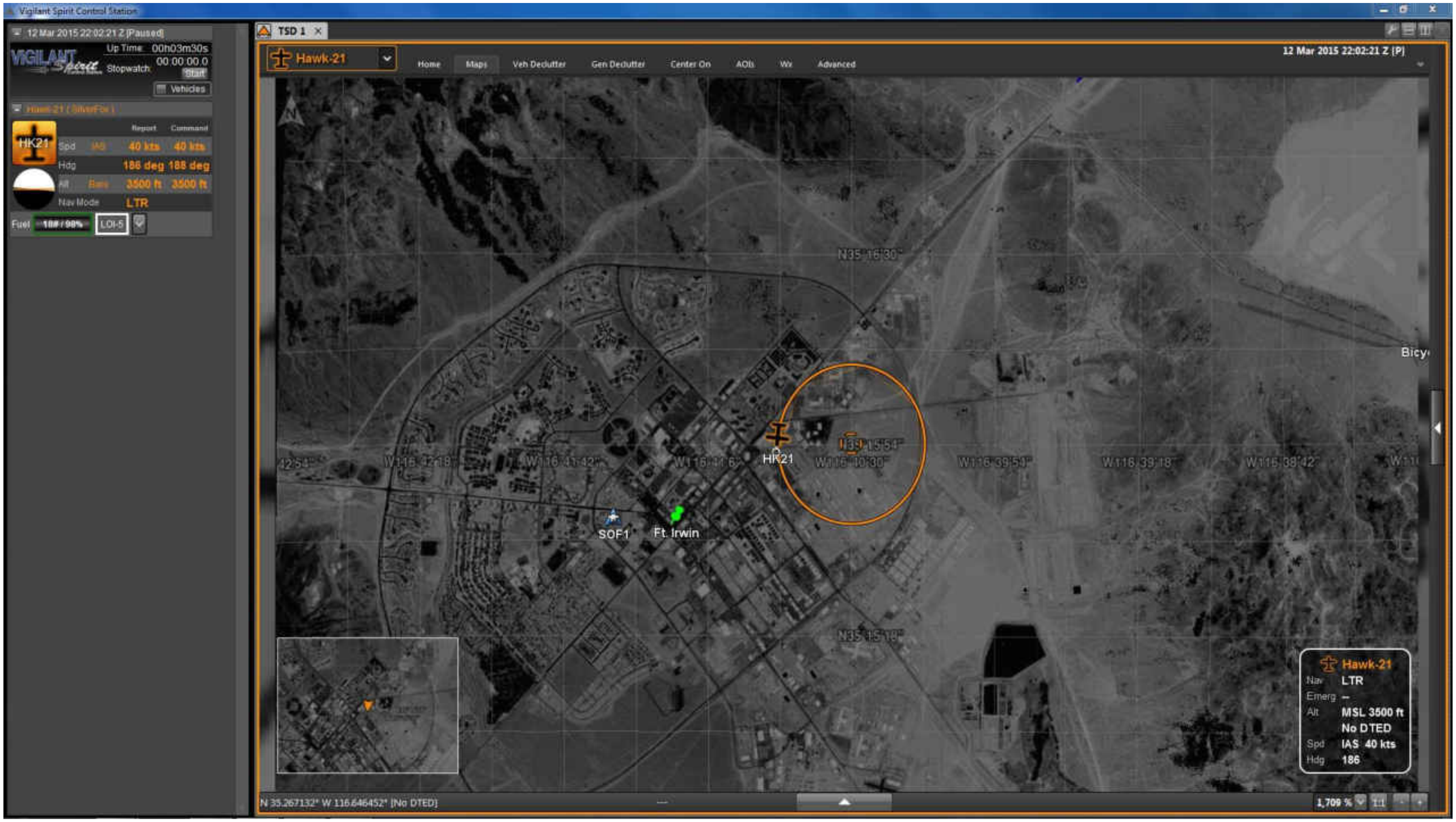
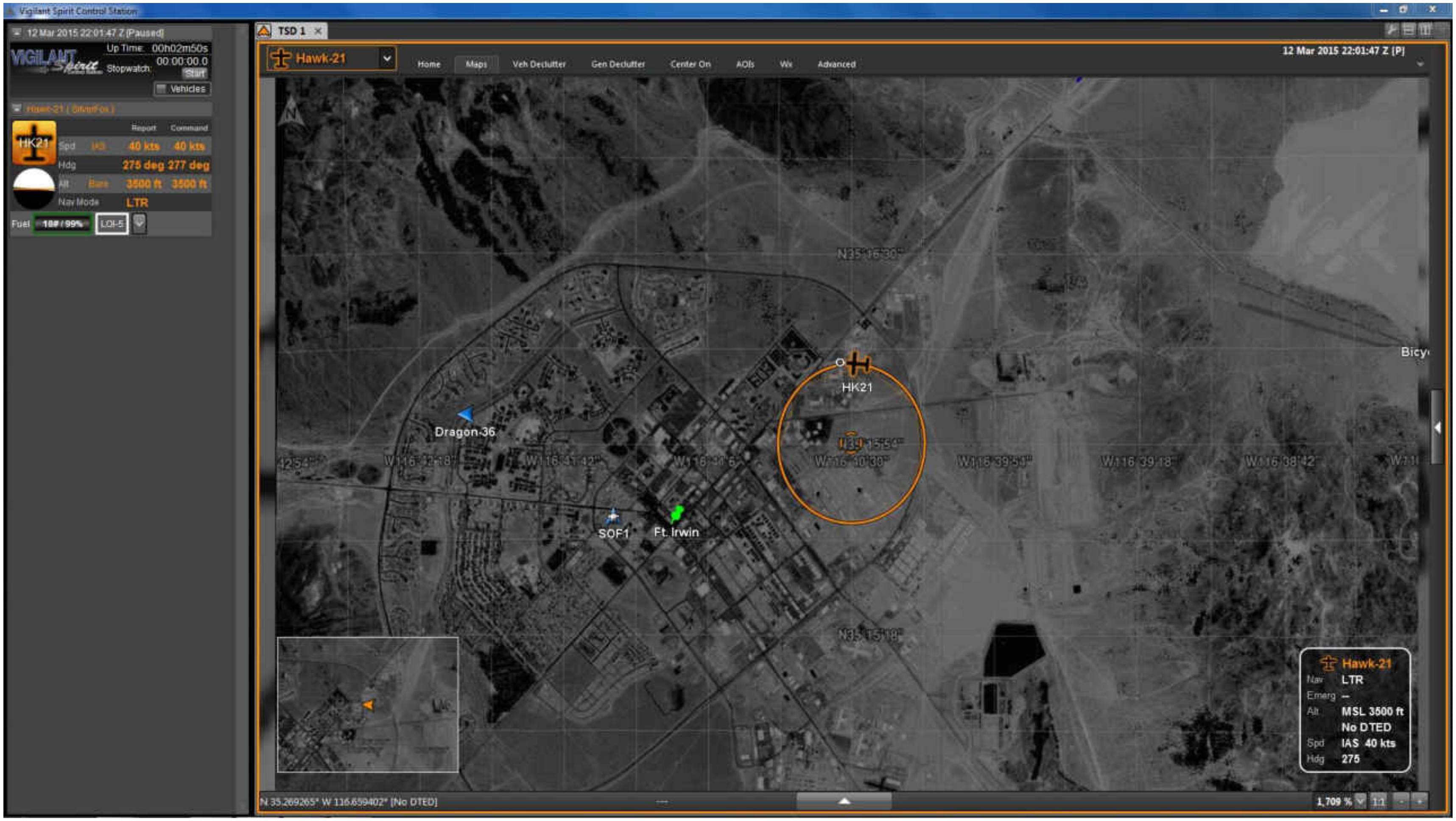


Figure 5. Baseline scenario screenshot.

The second scenario created for this effort was intended to be one step more engaging than the baseline. This was for the auditory task and was not designed to demand a significant amount of visual attention, yet provided stimulation to minimize vigilance degradation between visual alerts (Figure 6).



12 Mar 2015 22:01:47 Z (Paused)

Up Time: 00h02m50s

Stopwatch: 00:00:00.0

Hawk-21 (SilverFox)

		Report	Command
Spd	IAS	40 kts	40 kts
Hdg		275 deg	277 deg
Alt	Baro	3500 ft	3500 ft
Nav Mode		LTR	

Fuel 18# / 99% LOI-5

Hawk-21

12 Mar 2015 22:01:47 Z (P)

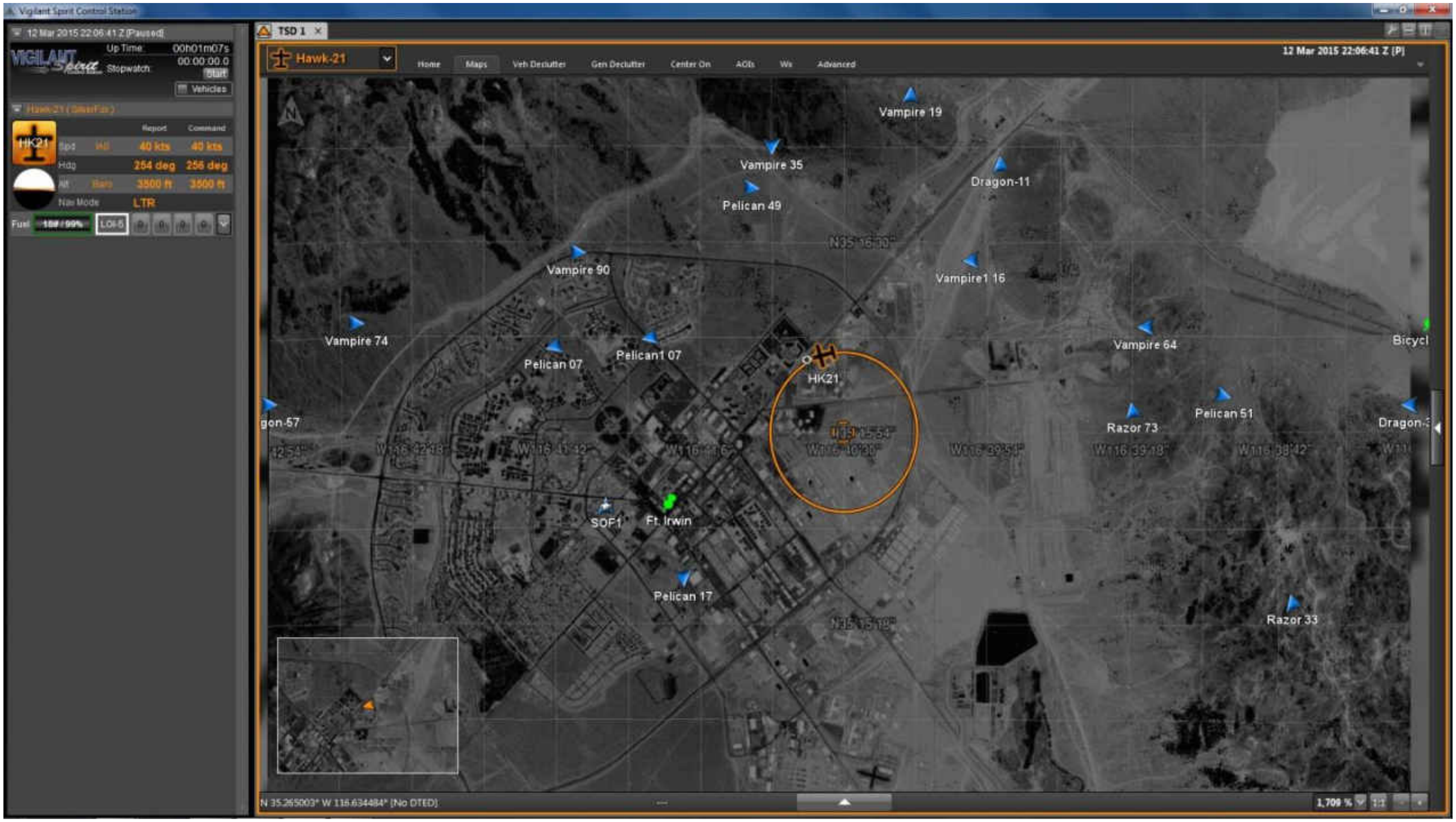
Hawk-21
Nav LTR
Emerg –
Alt MSL 3500 ft
No DTED
Spd IAS 40 kts
Hdg 275

N 35.269265° W 116.659402° [No DTED]

1,709 %

Figure 6. AUD condition screenshot.

The third scenario created was developed for the challenging visual task condition. This scenario depicted a large number of unidentified contacts appearing from all sides in numerous waves (Figure 7).



	Report	Command
Spd Ind	40 kts	40 kts
Hdg	254 deg	256 deg
Alt Baro	3500 ft	3500 ft
Nav Mode	LTR	

Fuel 18# / 99%

Figure 7. VIS condition screenshot.

Questionnaires

Participants completed a demographic questionnaire before beginning the experiment (Appendix B) and a NASA Task Load Index (TLX, Appendix A) subjective workload rating form after completing the scenarios. The NASA TLX information was not collected to provide a validation of the visual or auditory channel taxation; rather to provide a subjective verification that the tasks were indeed challenging as intended, and to compare workload ratings of the visual and auditory tasks.

Procedure

Each participant was asked to sign a consent form and then systematically assigned to either the visual or auditory secondary task with a counterbalanced order of scenario presentation. The experimenter then provided an overview of the experiment schedule to the participant from a script (varying only for a brief description of the upcoming secondary task). The participant subsequently completed a demographic questionnaire (Appendix B) and moved to sit at the computer with VSCS loaded to play the baseline "blank" scenario.

The experimenter identified the primary features of the VSCS interface (i.e., the map panel, the participant's vehicle and route), demonstrated an example of an auditory alert, adjusted the speaker volume as appropriate, demonstrated an example of a visual alert, and instructed the participant to press the space bar one time as soon as possible after they saw or heard any alert during a scenario. The experimenter continued by explaining the first VSCS scenario and informing the participant that the first set of alerts would be visual.

Baseline Condition

Each participant then completed a baseline alarm response time test for auditory and visual stimuli by responding to alerts presented in VSCS during the “blank” baseline scenario. During this twelve minute scenario the experimenter triggered four visual alarms at scheduled intervals during the first six minutes, then notified the participant the next set of alerts would be auditory, and then initiated four auditory alarms in the final six minutes. Responses to these alerts provided a baseline response time for each participant for auditory and visual alarms presented in an expected modality and allowed subsequent analysis to account for individual differences. Once the baseline test was completed the experiment diverged for the two task modality conditions.

Visual condition (VIS)

For participants that were in the visual condition, the scenario continued as an individual contact appeared on the screen. The experimenter demonstrated the IFF task on this contact, which required a series of mouse clicks to proceed through two dialog boxes (Figure 8).

Label: Dragon-32

Affiliation: Neutral

Where: N 35.269191° W 116.664654°

MSL: 24000 ft

Figure 8. IFF dialog boxes.

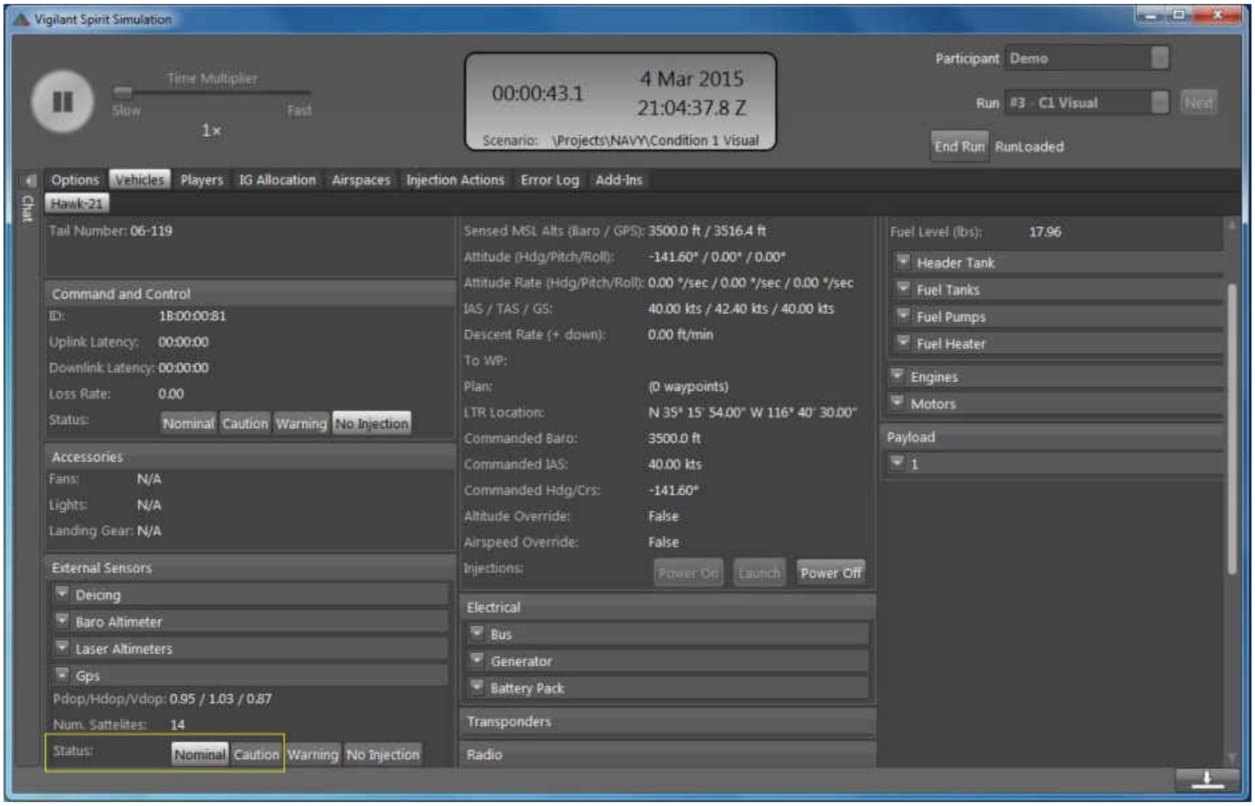
After demonstrating the steps required for the IFF process the participant was instructed to practice IFF on the next group of contacts. A small number of contacts would then appear on the screen, one at a time, allowing the participant to practice the IFF tasking. Once the participant was comfortable with the task, the experimenter loaded either the VIS-ABR or VIS-BRI scenario and described the multitasking aspect to the participant. Participants were instructed to perform the IFF task on any contacts entering the screen. Furthermore, the typical color change from the affiliation identification would not occur, thus requiring the participant to remember which tracks they had already identified and which they had not. Simultaneously they would be expected to respond to any alerts as soon as possible by pressing the spacebar. The experimenter told the participant that performance would be assessed on the number and accuracy of entities identified, as well as the response time to the alerts. This introduced an aspect of deception to the experiment, as due to logistical and software limitations, performance on the secondary tasks was not assessed. The experimenter paused here to answer any questions and then began the twelve minute scenario.

Upon completion of the first VIS scenario the experimenter would load other VIS scenario and confirm to the participant the tasking would be the same. The scenario was similar with the same number of vehicles appearing at the same rate, but they were appearing from different directions than the first scenario. More importantly, the switching technique subtly changed amongst the noise of the surrounding scenario. Several subjects responded to the debriefing saying they had not noticed the single alert presented both visually and auditorily. This supports the idea that the bridging technique, if successful, would indeed provide a subtle, subconscious cue that would not interfere with operator situation awareness or be a distractor.

Auditory condition (AUD)

For participants assigned to the auditory condition the experimenter closed the VSCS scenario and described the upcoming auditory task. Once completed, the experimenter played an example communication sound file to demonstrate how to acknowledge communications by repeating all verbiage out loud (minus the addressee information). The participant was allowed to practice on several communications addressed both directly to their callsign (Eraser435) and to relevant general audiences (“Attention all aircraft” and “Attention all UAS”). Once the participant reported feeling comfortable with the task the experimenter opened the assigned AUD condition of VSCS and queued up the beginning of the first playlist. The experimenter told the participant that performance would be assessed on the number and accuracy of communications acknowledged, as well as the response time to the alerts, again introducing an element of necessary deception. The experimenter paused for any questions, and then simultaneously pressed play on both VSCS and the audio player. In this manner the communications proceeded seamlessly in the background while the experimenter could still remotely trigger alerts from the Simulation panel (

Figure 9) to appear to the participant.



00:00:43.1
4 Mar 2015
21:04:37.8 Z
Scenario: \Projects\NAVY\Condition 1 Visual

Participant: Demo
Run: #3 - C1 Visual
RunLoaded

Tail Number: 06-119
ID: 1B:00:00:81
Uplink Latency: 00:00:00
Downlink Latency: 00:00:00
Loss Rate: 0.00
Status: No Injection
Fans: N/A
Lights: N/A
Landing Gear: N/A
Pdop/Hdop/Vdop: 0.95 / 1.03 / 0.87
Num. Sattelites: 14
Status: Nominal

Sensed MSL Alts (Baro / GPS): 3500.0 ft / 3516.4 ft
Attitude (Hdg/Pitch/Roll): -141.60° / 0.00° / 0.00°
Attitude Rate (Hdg/Pitch/Roll): 0.00 °/sec / 0.00 °/sec / 0.00 °/sec
IAS / TAS / GS: 40.00 kts / 42.40 kts / 40.00 kts
Descent Rate (+ down): 0.00 ft/min
To WP:
Plan: (0 waypoints)
LTR Location: N 35° 15' 54.00" W 116° 40' 30.00"
Commanded Baro: 3500.0 ft
Commanded IAS: 40.00 kts
Commanded Hdg/Crs: -141.60°
Altitude Override: False
Airspeed Override: False
Injections:

Fuel Level (lbs): 17.96

Figure 9. VSCS Simulation panel.

Once the participant completed the first AUD scenario, whether bridged or abrupt, the experimenter loaded the second AUD scenario in VSCS (selecting the opposite switching technique), switched to a second playlist of audio communication files (similar but not identical communications) confirmed the tasking with the participant, and then began the second AUD scenario.

Post-scenario

Due to the aforementioned limitations, performance on the secondary tasks was not assessed and as such, the RT to the alerts was the sole focus of this effort. In order to ensure the intended sensory modality was being heavily taxed the scenario tasks were designed to be particularly difficult, serving two functional purposes: First, it created a ripe environment for an MRT study by heavily loading one sensory channel and not another. Second, it removed the responsibility of timing the modality switching to a spike in workload, or even tracking workload at all. If a task is continuously challenging and taxing to a specific modality then it should always be an appropriate time to switch to a less-taxed modality.

In order to provide some verification that the tasks were actually challenging as intended without utilizing dual task performance results or elaborate physiological measures, the experimenter administered a post-hoc NASA Task Load Index (TLX; Appendix A) questionnaire in order to evaluate participant subjective ratings of the tasking. Once completed the participant received a full debrief informing them of the deception (i.e., not assessing the secondary task) and departed (see Table 4).

Table 4. Experiment composition.

Activity	Duration (min)
Informed consent and pre-brief	5
Demographics questionnaire	3
Alarm response instruction	1
Alarm response baseline test	12
Secondary task instruction	1
Secondary task practice	5
Multitasking trial 1	12
Break	1
Multitasking trial 2	12
NASA TLX	3
Debrief and depart	5
Total time	60

Manipulation Checks

To ensure maximum internal validity several manipulation checks were performed over the course of the pilot study. These checks and modifications were made to ensure a well-designed experiment which negated as many potential confounds and variance contributors as possible. One potential confound to the validity of the RT results is the salience or intensity of the stimulus presented. One aim of the pilot study was to provide baseline RT results that coincide with the literature. Equating visual and auditory response times would not represent equal cue salience, as RT is not consistent across modalities. Given stimuli of equal intensity, RT to an auditory stimulus is consistently faster than RT to a visual stimulus (Niemi & Näätänen, 1981). Although the individual brightness of the visual alert was not adjustable, the experimenter was able to modify the volume of the auditory alert presented. As such, the alert volume was adjusted over time during pilot testing to determine the optimal computer and speaker settings. Optimal volume settings were determined using a titration technique similar to that used by Dawson & Lamond (1999). Dawson & Lamond quantified the effects of alcohol impairment and sleep deprivation by taking multiple measurements and equating the resulting performance levels. For this effort the experimenter utilized baseline RTs to the visual stimulus (fixed brightness), collected auditory response times for multiple volume levels, then compared these results to find the closest match to previously published RT literature; results of this analysis suggested stimuli of equal intensity.

Secondly, the timing of the alerts was deliberately spaced between 80-120 seconds apart. Although the secondary task scenarios appear continuous to the participant, they are nominally divided into separate time elements in accordance with the previously described 80-second limit findings from Bevan, Hardesty, and Avant (1965). Eight alerts were distributed across the duration of the task scenario such that each alert was presented to the participant between 80 and 120 seconds after the previous alert. Within this 40-second alert time element one alert was presented at a time previously determined by a random number generator, resulting in an even yet unpredictable distribution of alerts throughout the scenario. This quasi-random timing prevented the participant from learning a pattern and discouraged participants from trying to use their internal clock to predict the alert timing. Restricting the amount of time between alerts resulted in twelve minute scenarios – these short scenarios helped minimize variance due to potential vigilance decrement effects.

Third, pilot testing revealed that if a participant performed all four conditions (visual and auditory tasks, both bridging and abrupt techniques) then pattern recognition and learning effects crept in. This was revealed when pilot participants began to pick up on the spacing of the alerts. Even the random timing between 80-120 seconds was not enough to overrule a heightened awareness of the time period the alert may appear. As such the participants were assigned to perform either the visual or auditory task, not both. This helped to counter potential confounds due to participant vigilance degradation. Furthermore, to mitigate any remaining variance due to pattern recognition or learning the order of the BRI and ABR conditions were counterbalanced across all participants.

Additionally, the VSCS system was simplified for this study to remove the multi-vehicle control aspect of the tasking. This was done in order to prevent a situation where a participant tries to identify which vehicle is signaling the alert in order to respond properly to the appropriate vehicle. Constricting the testbed to one vehicle removed any variance that may have otherwise been associated with this decision making process.

Finally, to account for the obvious variance due to individual differences in response time, as well as modality specific differences identified in previous RT literature, the experimenter collected baseline response time data for visual and auditory stimuli for each participant before beginning the multitasking scenarios.

RESULTS

Manipulation Checks

The results of the manipulation checks described above and additional checks presented below yield significant insight into the interpretation of the hypothesis testing results as well as the internal and construct validity of this study. These checks and modifications were made to ensure a well-designed experiment in which the variables manipulated relate to their constructs as accurately as possible.

First, the mean baseline RT for each modality (four visual and four auditory alerts with no secondary task) was calculated for each individual (see Table 5) in order to be used as a covariate in the subsequent hypothesis tests. The resulting baseline response times for each modality were consistent with previous RT literature results with the computer speaker volume adjusted to a pre-set level as previously described.

Table 5. Mean baseline RT - auditory and visual (s).

	N	Min	Max	Mean	Std. Dev.
Mean baseline auditory RT	64	0.332	1.317	0.572	0.183
Mean baseline visual RT	64	0.403	1.435	0.684	0.242

Secondly, since the participants performed only one of the secondary tasks (visual or auditory), an ANOVA comparison was performed to check for differences in demographics across the visual and auditory conditions. There were no significant differences between the visual and auditory groups on any of the collected demographic variables: Age: *F*(1, 60) = .789, *p* = .378; Gender: *F*(1, 60) = .000, *p* = 1.000; Highest level of education: *F*(1, 60) = 1.606, *p* = .210; Handedness: *F*(1, 60) = .000, *p* = 1.000; Frequency of PC use: *F*(1, 60) = .152, *p* = .698; Experience with computers: *F*(1, 60) = .187, *p* = .667; or Hours per week playing video games: *F*(1, 60) = 1.065, *p* = .306.

Third, the experimenter investigated the correlation of the baseline auditory RT to the VIS condition post-switch RT, and the baseline visual RT to the AUD condition post-switch RT. The baseline visual and auditory RTs were collected as covariates for their respective post-switch RTs. In other words, as the alarm modality switches from visual to auditory while a participant is performing a visual task, the resultant auditory RT should be correlated to that individual participant's baseline auditory RT. These correlation analyses did yield significant results for the auditory alert as expected (see Table 6).

Table 6. Auditory covariate correlations.

Measure	1	2
1. Mean baseline auditory RT		
2. VIS-ABR post-switch1 RT	.691**	
3. VIS-BRI post-switch1 RT	.557**	.556**

Note: **=*p*<.01 (1-tailed)

The baseline visual RT, however, was significantly correlated with only the abrupt visual alert results, not the bridged visual alert (Table 7). This suggests there was additional variance for visual RT not explained by the baseline data, and is explored further in the discussion section.

Table 7. Visual covariate correlations.

Measure	1	2
1. Mean baseline visual RT		
2. AUD-ABR post-switch1 RT	.448**	
3. AUD-BRI post-switch1 RT	.196	.173

Note: **=*p*<.01 (1-tailed)

Next, if the experimental setup relies on MRT principles to create the emergent MSE, then the experiment design should result in the basic principles being supported by the data in other ways as well. For instance, the visual conditions (both VIS-ABR and VIS-BRI) require the participant to respond to visual and auditory alerts while performing a challenging visual task. Thus, the response times to the visual stimuli should be higher than the response times to the auditory alerts (with the possible exception of the first alert in the unexpected new modality, not included in this manipulation check) due to the conflicting nature of the task and alarm modalities. This was indeed shown to be the case, as seen in Table 8.

Table 8. VIS condition RT data (s).

	Visual alarm RT	Auditory alarm RT
Mean	1.515	0.766
N	32	32
Std. Dev.	0.494	0.198
Median	1.358	0.727
Std. Error of Mean	0.087	0.035
Minimum	0.807	0.526
Maximum	2.495	1.263

Note: RTs listed are while also performing IFF (Visual) task.

The same manipulation check was performed for the auditory task conditions, with results shown in Table 9.

Table 9. AUD condition RT data (s).

	Auditory alarm RT	Visual alarm RT
Mean	0.893	0.974
N	32	32
Std. Dev.	0.297	0.445
Median	0.801	0.822
Std. Error of Mean	0.053	0.079
Minimum	0.600	0.557
Maximum	1.777	2.527

Note: RTs listed are while also performing communications (Auditory) task.

In this case the visual RT was not lower than the auditory RT. Rather than immediately interpreting this as an argument against MRT principles, the experimenter examined these response times compared to the baseline RT data for each modality, shown previously in Table 5. This cursory analysis revealed that both visual and auditory RT increased while multitasking, as expected; however, auditory RT did not increase more than visual RT when performing an auditory task. This was interpreted as the first suggestion that the salience of the visual and auditory cues were not equivalent to participants performing the auditory task.

Hypothesis I Results

Hypothesis I stated that *the AUD-BRI condition will result in greater decrease in response times than the AUD-ABR condition.* This hypothesis was analyzed using a 2 (bridging versus abrupt) by 1 (AUD only) repeated measures ANCOVA using baseline visual RT as the covariate. Specifically, the analysis compared the RT for the first visual alert in the AUD-ABR condition (alert 5) with the first visual alert in the AUD-BRI condition (alert 6). Although mean response times were faster for the visual alerts when modality switched using the bridging technique (*M* = 0.986, *SD* = 0.561) than the abrupt technique (*M* = 1.341, *SD* = 1.000), results did not reach significance, *F*(1, 30) = 1.044, *p* =.315. The large standard deviation associated with the abrupt technique is due to a very wide range in response times to the unexpected visual alert. It should be noted also that there is one case not reflected in this output as one person missed the unexpected visual alert entirely and thus was not included in this analysis. Hypothesis I was not supported.

Hypothesis II Results

Hypothesis II stated that *the VIS-BRI condition will result in greater decrease in response times than the VIS-ABR condition*. This hypothesis was analyzed using a 2 (bridging versus abrupt) by 1 (VIS only) repeated measures ANCOVA using baseline auditory RT as the covariate. Specifically, the analysis compared the RT for the first auditory alert in the VIS-ABR condition (alert 5) with the first auditory alert in the VIS-BRI condition (alert 6). Again, the mean RT for the bridging technique (*M* = 0.735, SD = 0.269) was not significantly faster than the mean RT for the abrupt technique (*M* = 0.740, *SD* = 0.181), *F*(1, 31) = 0.369, *p* = .548. Thus, Hypothesis II was not supported.

Hypothesis III Results

Hypothesis III stated that *the bridge condition groups will show significantly greater RT improvement than the abrupt condition groups, when accounting for the variance due to* *modality specific baseline RT.* This hypothesis was tested by utilizing a 2 (visual versus auditory) by 2 (abrupt versus bridging) repeated measures ANCOVA using baseline visual and auditory RT as covariates, comparing the fifth alert in abrupt conditions with the sixth alert in bridging conditions. Again, results were not significant with the collapsed data set *F*(3, 61) = 0.139, *p* = .711 and thus the null hypothesis cannot be rejected.

DISCUSSION

Interpretation of Results

None of the three primary hypotheses were supported with statistical significance, yet the data may still suggest the bridging technique has merit. Examination of the mean RTs for each condition (Figure 10) helps reveal why.

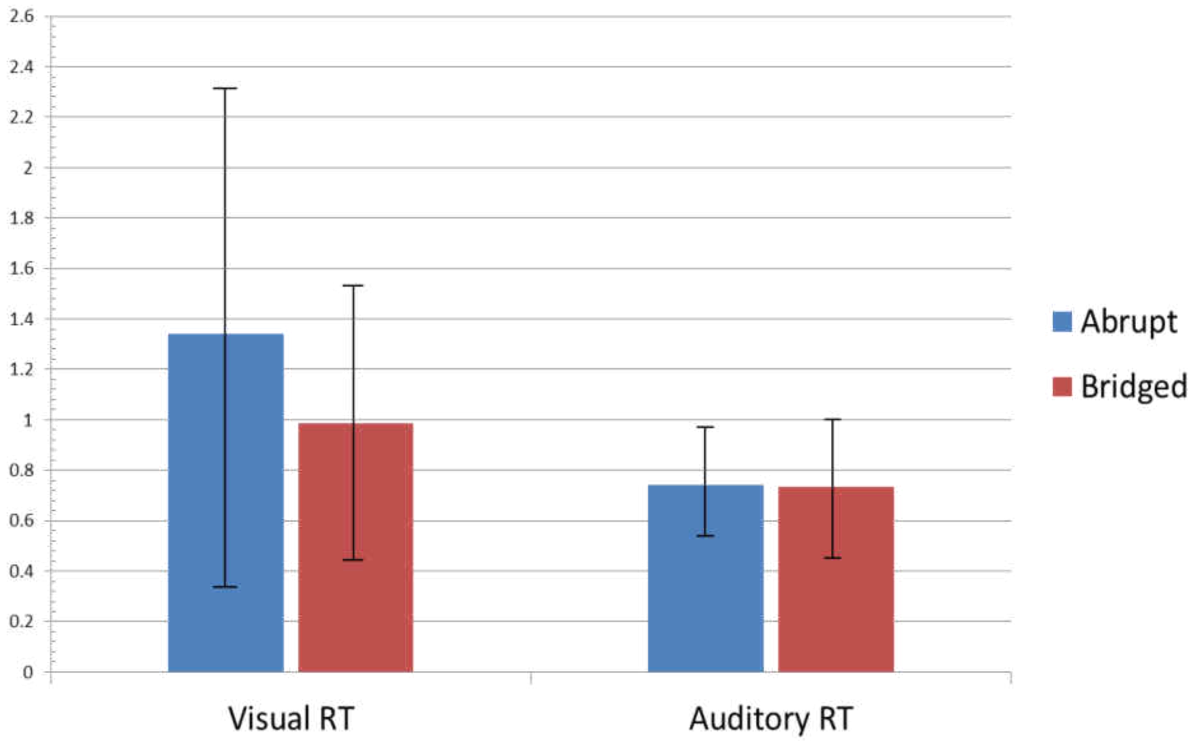


Figure 10. Mean RTs for each condition (s) with standard deviation bars.

The data show a larger difference among mean visual RT than mean auditory RT. Unfortunately the standard deviation is very large indicating a large amount of unidentified variance (recall Table 7 which showed low correlation between the baseline visual RT covariate and the multitasking visual RTs). This isn't the case with the auditory RT, which shows much smaller standard deviation indicating a narrower window of response times, and a much smaller difference as well between the bridging and abrupt conditions. Why is the variance so much greater for the visual response times than the auditory response times? Multiple Resource Theory may again provide an answer.

First, recall that the visual RTs were assessed while performing the auditory secondary task. In the auditory task a participant was required to store in short term memory up to six seconds of a communication and repeat the words back verbatim. This task proved to be particularly challenging for many participants, some of whom would give up on a communication after very little effort if they did not remember it accurately. The difficulty or ease with this participants performed this task was noticeably different across participants. Recall from the discussion of Wickens' (2008) MRT that the cognition and perception stages conflict with each other (i.e., are not separated by a line, refer to Figure 1). The widely varying cognitive component of the auditory task led to a varying level of conflict with the perception of the visual alert, producing a variance in the resulting RT.

This was not the case with the visual secondary task. The visual IFF task asked the participant to recognize odd or even numbers and remember which tracks had already been identified without a change in appearance. This memory challenge was lessened as the tracks did not return on screen once they left. Thus most of the challenge for the visual task was the series of mouse clicks and menu selections required to complete the task – still taxing to the visual channel yet not cognitively challenging.

Further, the auditory condition had three participants who resorted to a strategy of beginning to repeat the message before the communication had completed, resulting in lower cognitive effort. While this can be interpreted as further credit for Wickens and MRT (i.e., perception and responding are two different, non-conflicting stages of information processing), it also served to decrease the reliance on memory and cognition for those three participants. This led to improved performance, providing evidence that the demanding cognitive component of the task may have had an adverse effect for the other auditory condition participants and adding to the variance in the mean visual RT, but not auditory. This interpretation was supported by the results of the NASA TLX which showed greater standard deviations for the auditory task compared to the visual task for both *Mental Demand* and *Effort* (Table 10).

Table 10. NASA TLX ratings.

	Mental Demand		Effort	
	Mean Rating	Std. Dev.	Mean Rating	Std. Dev
Visual Task	71.2	21.3	73.0	17.0
Auditory Task	61.5	25.1	60.3	22.6

This difference is presented as a possible explanation of unidentified variance in the results, as well a primary reason why the visual covariate correlations did not reach significance (see Table 7). The cognitive component of this auditory task conflicted with the perception of an alert, influencing the response time such that the baseline visual RT was no longer correlated to the multitasking visual RT while performing this specific auditory task. In short, the challenging cognitive component of the auditory task resulted in a large variance in response time to visual alerts.

Although this may provide explanation for the difference in standard deviation between the visual and auditory response times, there is also a difference in the switching technique effect between the visual and auditory response times. The visual RT showed a non-significant, yet noticeable difference while the auditory RT showed visible effect whatsoever (Figure 11).

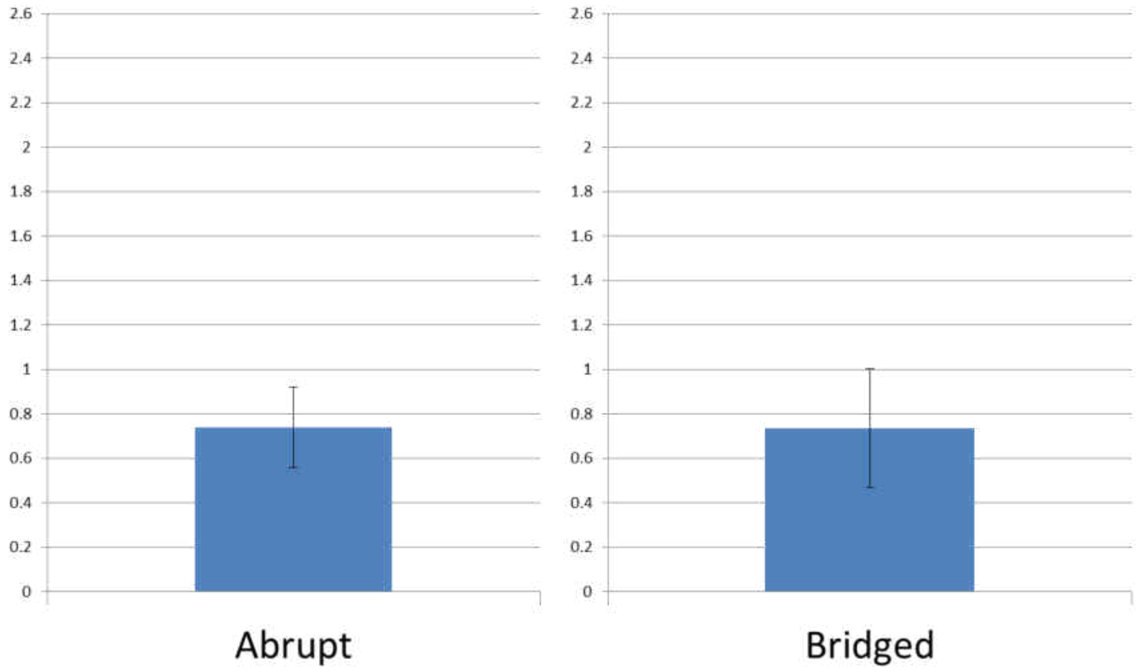


Figure 11. Mean auditory RT (s).

This lack of improvement in mean RT may be related to the salience of the signal. The "whoop whoop" of the auditory alert pierced the otherwise silent testing condition while the participant was performing the visual secondary task. Meanwhile, the visual indicators were presented on an active (though not busy) visual display. Although the visual alerts were displayed in three different locations onscreen, the siren/silence contrast was much greater than the visual/visual contrast of the display. Because the auditory alert was so distinctive and salient, the RT was consistently faster than expected during multitasking performance. This lack of a difference between the two switching technique conditions may represent a ceiling effect such that there was no real room for improvement to the auditory alerts via the bridging technique.

In short, the challenging cognitive component of the auditory task interfered with the alarm perception performance resulting in a large variance in response time to visual alerts, while the distinct and salient nature of the auditory alert encouraged faster auditory response times while multitasking with little room for improvement.

Missing Data Points

In many types of studies a score of zero is considered a negative occurrence or a non-response. Thus, a missing data point can often be replaced with a zero and analysis can proceed as normal. Response time studies are a different animal, in that a missing data point cannot be replaced by a zero without consequence. Lower response times are the desired outcome and so including a zero is in effect adding a data point of the best possible result – this is clearly not the case if the alarm was missed in its entirety!

In the final ANCOVA analyses for hypothesis testing, only one data point was missing amongst the variables of interest (one missed AUD-ABR visual alert), yet in other instances many other alarms were missed completely. All responses were recorded if they occurred less than ten seconds after the alert was presented. Thus, a missed alarm signifies an individual did not react to the alert for at least ten seconds while performing a secondary task. Replacing this blank space with a ten second response time would be inaccurate since the participant did not notice the alert after ten seconds. Replacing the blank with a higher response time (99 seconds for instance) would only skew the data artificially. Thus the blank data point was left as blank and excluded from analysis. When examining the number of missed alerts throughout all of the possible responses during the multitasking scenarios, these missed data points reinforce MRT principles by providing evidence for conflicting modalities (see Table 11).

Table 11. Missed alerts.

	Auditory tasking	Visual tasking
Auditory alerts missed	1	1
Visual alerts missed	1	31
Bridge alerts missed	0	0

This table helps to complete the picture. While the auditory alerts were salient enough to be noticed nearly every time, the visual alerts were frequently missed when participants were performing the visual task. This effectively demonstrates MRT for the visual/visual conflict and illuminates the non-existent auditory/auditory conflict in the AUD conditions (again, likely due to increased auditory signal salience). This would logically result in speedy reaction times for the auditory alert whether expected or unexpected during multitasking and much slower response times (or complete misses) for visual alerts when presented while performing the visual task. This too is corroborated in Table 12 and lends support to the notion that a different testing environment may yet reveal the hidden benefits of the bridging technique which were not shown to be statistically significant in this study.

Table 12. Mean RTs while multitasking.

	Visual task	Auditory task
Mean visual RT	1.515	0.766
Mean auditory RT	0.974	0.893

Limitations of Study

One of the most noticeable limitations of this study is the identified unequal alert salience during multitasking. The salience of the visual and auditory alerts was examined as a manipulation check during pilot testing; however, the salience was measured using RT during the baseline scenario. Once the secondary tasking became involved the auditory alert appeared to retain approximately the same level of saliency while the visual alert seemed to become less noticeable.

Another factor considered a limitation is the balance of a tightly controlled laboratory study and a realistic, operationally valid testing environment. Many scientific principles observed in a laboratory are confounded or masked in an operational environment. This study was not performed with a true operational UAS interface however in trying to provide a plausibly realistic operational environment I may have inadvertently made it more difficult to support the bridging technique by introducing additional confounds.

Future Research Considerations

As noted by Sarter (2006), providing a set of design guidelines without including justifications misses the opportunity to help the reader understand why a recommendation is made and therefore under what circumstances it will be appropriate to apply the guideline. This effort was undertaken in part to provide the justification for bridging design guidelines, yet was unable to statistically do so. The experimenter was able to find encouragement during the data collection process however. During one early run the experimenter forgot to warn the participant of the upcoming change in alert modality during the baseline scenario. As the alert unexpectedly changed from visual to auditory the participant acknowledged aloud and unprompted that the change had caught them off guard. The baseline scenario was halted as the experimenter realized the error, and a subsequent examination of the incorrectly run data log revealed that the unexpected modality had in fact yielded a much longer response time.

Furthermore, one goal of the bridging technique was to provide a subtle, subconscious cue that the modality would shift without distracting the participant. This was often shown to be the case during the debrief session. When the participants were informed of the hypotheses and the difference between the two scenarios, they often said they had not even noticed that one of the alerts had been presented with both modalities. These types of anecdotal support statements fostered an optimistic outlook for data. Nevertheless, the author has several potential recommendations on how to further this intriguing avenue of research.

The first suggestion is of course to correct the failed manipulation checks in this experiment. Any future investigation must be especially careful that the distractor tasks are sufficiently challenging to increase response time to like modality alerts with care taken to ensure these tasks do not produce additional cognitive load due to memory, decision making, or other similar cognitive requirements. In an operational setting UAS sensor operators do perform many different cognitive tasks simultaneously; however, the bridging technique benefits may not be extracted as a signal amongst the noise unless variance due to the cognitive element is accounted for in a controlled setting first.

This experiment required a balance between external validity and tight experimental control. The investigation was carried out in the context of a scenario and the alerts, whether auditory or visual, carry with them informational value about what is happening in the scenario. A pure laboratory stimulus-response testing situation may have shown a significant effect for the bridging technique or may not have. Yet a true GCS environment is even less like a laboratory environment. For instance a UAS GCS is not silent during a SO's tasking. Rather there are communications over the headset as well as among team members within the GCS itself. Thus, an auditory alert may not stand out amongst the silence because there would be very little if any silence. Additionally there are many more visual stimuli present besides a map screen (e.g., sensor displays, chat windows). A visual alert may need to be brighter than the surrounding visual stimuli to elicit an SO's perception and response as quickly as possible; multiple locations may still be overlooked.

Second, the alerts must be equal saliency throughout the entirety of the research study. This confound was exhibited in this study when the response times did not vary for auditory cues during auditory tasking due in part to high cue saliency, while many visual alerts were missed entirely during visual tasking due to low cue saliency.

Other than ensuring the manipulation checks are valid, the modality switching domain remains a verdant pasture of research and exploration. For instance, this study did not assess dual task performance in real time. Modality switching may be an effective approach to prevent sensory overload as measured by alarm response time but a situation with multiple competing task priorities may highlight benefits of bridging or other switching techniques besides (or in addition to) pure response time.

Additionally, future research may utilize trained UAS operators. Novices such as the student sample used for this study may result in a larger variance in task performance. Trained UAS operators experiencing similar curriculum may perform more similarly to each other, reducing variance.

Finally, this study examined response times to alerts spaced approximately between every one and two minutes apart. If a cue or piece of information requires more frequently than every eighty seconds, foreperiod duration will have an impact on the response times. This does not mean that this area should remain unexamined however, as potential response time delays would only be magnified in situations where alerts are more frequent. If an experiment is designed incorporating the lessons learned in this study and the guidelines described above, modality switching may yet become a common practice amongst designers of complex interfaces.

CONCLUSION

In conclusion, several methodological and experimental oversights may have prevented the bridging technique from exhibiting statistically significant effects. This lack of significant results does not necessarily signify that the bridging technique is without merit – experimental refinement or redesign may yield successful results as originally hypothesized. While multitasking, it should still be beneficial to discover the optimal stimulus modality to alert the operator. Alerts presented in a conflicting modality have been shown to result in delayed responses or misses as the signal becomes lost in the noise; therefore a non-conflicting modality is the clear choice. This preferred modality may change periodically and so switching modalities should be a viable technique to improve response time performance. Additional research is still needed in this area in order to examine the true benefit of switching alarm modality during task performance and provide solid design guidelines which can be justified and applied in a complex domain such as that of a UAS Ground Control Station. With UAS prevalence increasing in military settings the consequences of a missed alert or a delayed response can be quite dire. Successfully incorporating a modality switching technique into the information display of a UAS GCS may result in increased task performance and faster operator response times, potentially resulting in fewer vehicle mishaps and a greater number of lives saved.

APPENDIX A:
NASA TASK LOAD INDEX QUESTIONNAIRE

NASA Task Load Index

Place a mark on each scale that represents the magnitude of each factor in the task you just performed. Indicate your answer by typing an X in the appropriate spot on each line.

Mental demand Low |____| High

Physical demand Low |____| High

Temporal demand Low |____| High

Performance Good |____| Poor

Effort Low |____| High

Frustration level Low |____| High

Rating-scale descriptions for your reference:

Title	Endpoints	Descriptions
Mental Demand	Low, High	How much mental and perceptual activity was required (e.g., thinking, deciding, calculating, remembering, looking, searching, etc.)? Was the task easy or demanding, simple or complex, exacting or forgiving?
Physical Demand	Low, High	How much physical activity was required (e.g., pushing, pulling, turning, controlling, activating, etc.)? Was the task easy or demanding, slow or brisk, slack or strenuous, restful or laborious?
Temporal Demand	Low, High	How much time pressure did you feel due to the rate or pace at which the task elements occurred? Was the place slow and leisurely or rapid and frantic?
Performance	Good, Poor	How successful do you think you were in accomplishing the goals of the task? How satisfied were you with your performance in accomplishing these goals?
Effort	Low, High	How hard did you have to work (mentally and physically) to accomplish your level of performance?
Frustration level	Low, High	How insecure, discouraged, irritated, stressed and annoyed versus secure, gratified, content, relaxed, and complacent did you feel during the task?

APPENDIX B:
DEMOGRAPHICS QUESTIONNAIRE

Demographics Questionnaire

ID#_______

How old are you? __________

Gender (circle one): Male Female

What is your highest level of education (circle one)?

High School Diploma Some College Associate's Degree Bachelor's Degree

Some Graduate School Master's Degree Doctoral Degree

What was your major/focus area? ____

Are you left or right handed (circle one)? Left Right I use both equally

How often do you work with personal computers?
_____ I've never worked with a personal computer
_____ Only a couple of times ever in my life
_____ Several times a year
_____ Several times a month
_____ Several times a week
_____ At least once a day, everyday
_____ For several hours every day (over 4 hours a day)

Rate your experience with personal computers:
_____ Little or none
_____ Know a little; know Internet access, know some word processing and other software (e.g., Microsoft Word and Microsoft PowerPoint).
_____ Know quite a bit; know Internet access, know word processing well, used other software packages (e.g., Microsoft Access, FTP, SPSS, Photo Shop, etc.), and/or have done some programming (e.g., HTML).
_____ Expert; know Internet access, word processing, other software, and have much experience with different programming languages (e.g., Flash, VB, C, and Java).

How many hours per week do you play video games? _____________

Do you have color-deficient vision (color blindness)? YES NO

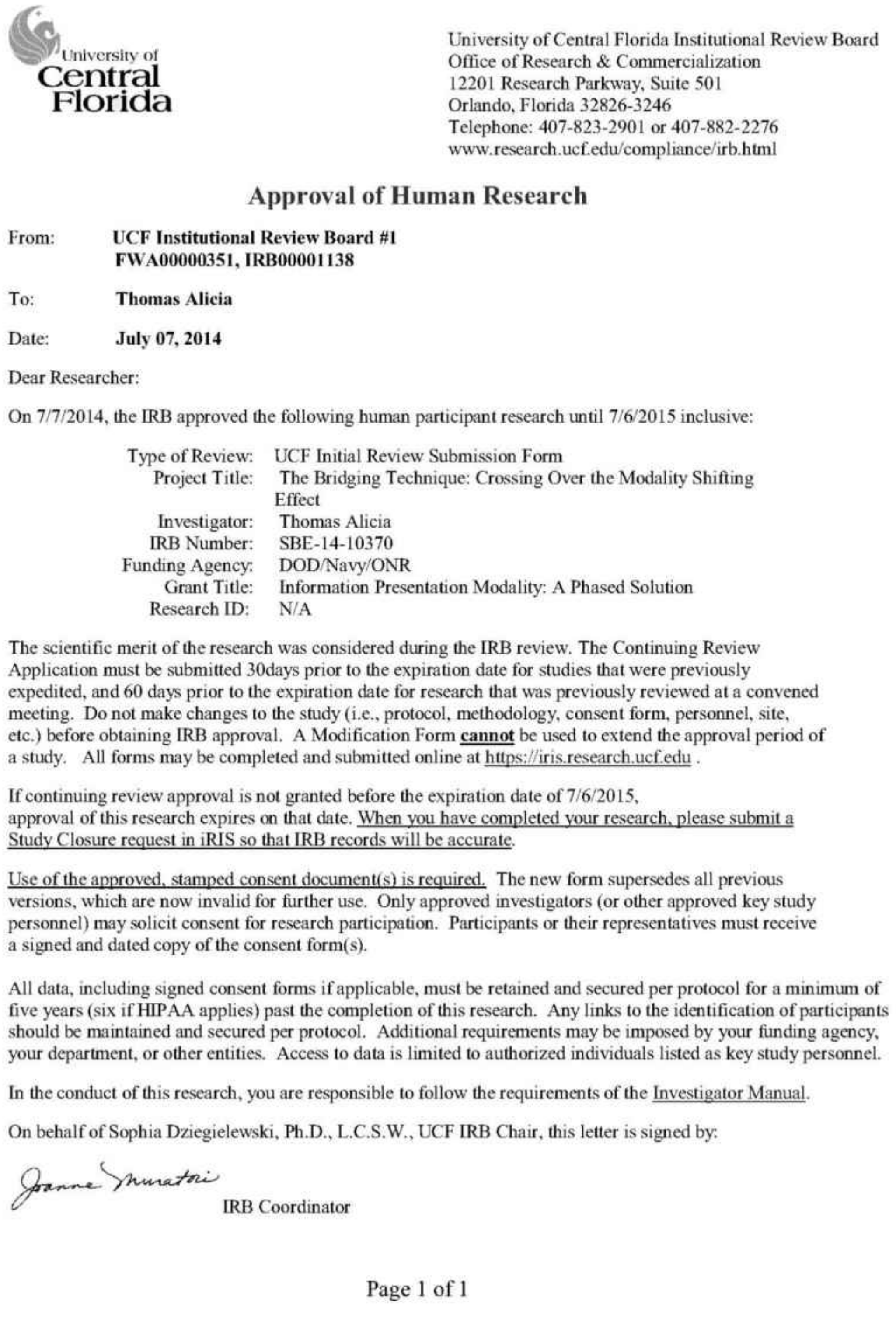
Do you currently or have you previously served in the military? YES NO

If yes, what is your current status? ACTIVE RESERVIST DISCHARGED

Rate your fluency level in English by placing an X on the scale below in the appropriate location:

Low (unfamiliar) |_______________________|_________________________| High (native speaker)

APPENDIX C:
UCF IRB APPROVAL LETTER



University of Central Florida

University of Central Florida Institutional Review Board
Office of Research & Commercialization
12201 Research Parkway, Suite 501
Orlando, Florida 32826-3246
Telephone: 407-823-2901 or 407-882-2276
www.research.ucf.edu/compliance/irb.html

Approval of Human Research

From: **UCF Institutional Review Board #1**
FWA00000351, IRB00001138

To: **Thomas Alicia**

Date: **July 07, 2014**

Dear Researcher:

On 7/7/2014, the IRB approved the following human participant research until 7/6/2015 inclusive:

Type of Review:	UCF Initial Review Submission Form
Project Title:	The Bridging Technique: Crossing Over the Modality Shifting Effect
Investigator:	Thomas Alicia
IRB Number:	SBE-14-10370
Funding Agency:	DOD/Navy/ONR
Grant Title:	Information Presentation Modality: A Phased Solution
Research ID:	N/A

The scientific merit of the research was considered during the IRB review. The Continuing Review Application must be submitted 30days prior to the expiration date for studies that were previously expedited, and 60 days prior to the expiration date for research that was previously reviewed at a convened meeting. Do not make changes to the study (i.e., protocol, methodology, consent form, personnel, site, etc.) before obtaining IRB approval. A Modification Form **cannot** be used to extend the approval period of a study. All forms may be completed and submitted online at https://iris.research.ucf.edu .

If continuing review approval is not granted before the expiration date of 7/6/2015, approval of this research expires on that date. When you have completed your research, please submit a Study Closure request in iRIS so that IRB records will be accurate.

Use of the approved, stamped consent document(s) is required. The new form supersedes all previous versions, which are now invalid for further use. Only approved investigators (or other approved key study personnel) may solicit consent for research participation. Participants or their representatives must receive a signed and dated copy of the consent form(s).

All data, including signed consent forms if applicable, must be retained and secured per protocol for a minimum of five years (six if HIPAA applies) past the completion of this research. Any links to the identification of participants should be maintained and secured per protocol. Additional requirements may be imposed by your funding agency, your department, or other entities. Access to data is limited to authorized individuals listed as key study personnel.

In the conduct of this research, you are responsible to follow the requirements of the Investigator Manual.

On behalf of Sophia Dziegielewski, Ph.D., L.C.S.W., UCF IRB Chair, this letter is signed by:

Joanne Muratori
IRB Coordinator

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REFERENCES

Bevan, W., Hardesty, D., & Avant, L. (1965). Response latency with constant and variable interval schedules. *Perceptual & Motor Skills, 20,* 969-972.

Broadbent, D. E. (1958). *Perception and communication.* Elmsford, NY: Pergamon Press.

Boulter, L. R. (1977). Attention and reaction times to signals of uncertain modality. *Journal of Experimental Psychology: Human Perception and Performance, 3*, 379–388.

Calhoun, G. L., & Draper, M. H. (2006). Multi-sensory interfaces for remotely operated vehicles. In E. Salas (Series Ed.) & N. J. Cooke, H. L Pringle, H. K. Pedersen, & O. Connor (Vol. Eds.), *Advances in human performance and cognitive engineering research: Vol. 7. Human factors of remotely operated vehicles,* (pp. 149-163). Oxford: Elsevier.

Cohen, J., & Cohen, P. (1983). *Applied multiple regression/correlation analysis for the behavioral sciences* (2nd ed.). Hillsdale, NJ: LEA.

Craik, K. J. W. (1948). Theory of the human operator in control systems: II. Man as an element in a control system. *British Journal of Psychology, 38,* 142-148.

Davis, D. R. (1959). Human errors and transport accidents. *Ergonomics, 2,* 24-33.

Dilich, M. A., Kopernik, D., & Goebelbecker, J. (2002). Evaluating driver response to a sudden emergency: Issues of expectancy, emotional arousal and uncertainty. *Safety Brief, 20*(4).

Ferstl, R., Hanewinkel, R., Krag, P., 1994. Is the modality-shift effect specific for schizophrenic patients? Schizophrenia Bulletin 2, 367–373.

Hirst, W., & Kalmar, D. (1987). Characterizing attentional resources. *Journal of Experimental Psychology: General, 116,* 68-81.

Jones, D., Samman, S. N., Stanney, K. M, & Graeber, D. A. (2005, July). Speech, earcons, auditory spatial signals (SEAS): An auditory multi-modal approach. *First International Conference on Virtual Reality,* Las Vegas, NV.

Kahneman, D. (1973). *Attention and effort.* Englewood Cliffs, NJ: Prentice Hall.

Kahneman, D., Beatty, J., & Pollack, I. (1967). Perceptual deficit during a mental task. *Science, 157,* 218-219.

Dawson, D., & Lamond, N. (1999). Quantifying the performance impairment associated with fatigue. *Journal of Sleep Research, 8*, 255-262.

Mangos, P., Vincenzi, D., Shrader, D., Williams, H. & Arnold, R., (2012). *Analysis of cross-platform naval unmanned aircraft system task and competency requirements.* Unpublished technical report, Naval Air Systems Command.

Mayhew, D. J. (1999). The usability engineering lifecycle: A practitioner's handbook for user interface design. San Francisco, CA: Morgan Kaufmann Publishers, Inc.

McCarley, J. S., & Wickens, C. D. (2005). *Human factors concerns in UAV flight.* University of Illinois Human Factors Division Technical Report (AHFD-05-05/FAA-05-1).

Meyer, D. E., & Kieras, D. E. (1997). A computational theory of executive cognitive processes and multiple-task performance: Part 1. Basic mechanisms. *Psychological Review, 104,* 3-65.

Moray, N. (1967). Where is capacity limited? A survey and a model. *Acta Psychologica, 27,* 84-92.

Mouloua, M., Gilson, R., Kring, J., & Hancock, P. (2001). Workload, situation awareness, and teaming issues for UAV/UCAV operations. *Proceedings of the Human Factors and Ergonomics Society 45th annual meeting,* 162-165.

Navon, D. (1984). Resources – A theoretical soup stone? *Psychological Review, 91,* 216-234.

Navon, D. (1985). Attention division or attention sharing? In M. I. Posner & O. S. M. Marin (Eds.), *Attention and performance XI* (pp. 133-146). Hillsdale, NJ: Erlbaum.

Neumann, O. (1987). Beyond capacity: A functional view of attention. In H. Heuer & A. F. Sanders (Eds.), *Perspectives on perception and action* (pp.361-394). Hillsdale, NJ: Erlbaum.

Niemi, P. (1979). Stimulus intensity effects on auditory and visual reaction processes. *Acta Psychologica, 43,* 299-312.

Niemi, P., & Näätänen, R. (1981). Foreperiod and simple reaction time. *Psychological Bulletin, 89,* 133-162.

Penhune, V. B., Zatorre, R. J., & Evans, A. C. (1998). Cerebellar contributions to motor timing: A PET study of auditory and visual rhythm reproduction.

Posner, M. I., & Petersen, S. E. (1990). The attention system of the human brain. *Annual Review of Neuroscience 13*, 25–42.

Post, L. J., & Chapman, C. E. (1991). The effects of cross-modal manipulations of attention on the detection of vibrotactile stimuli in humans. *Somatosensory and Motor Research 8*(2), 149–157.

Sarter, N. (2006). Multimodal information presentation: Design guidance and research challenges. *International Journal of Industrial Ergonomics, 36*, 439-445.

Shelton, J. & Kumar, G. (2010). Comparison between auditory and visual simple reaction times. *Neuroscience & Medicine,* 1, 30-32. doi: 10.4236/nm.2010.11004.

Simon, J. R., & Slaviero, D. P. (1975). Differential effects of a foreperiod countdown procedure on simple and choice reaction time. Journal of Motor Behavior, 7, 9-14.

Spence, C., & Driver, J., (1997). Crossmodal links in attention between audition, vision, and touch: Implications for interface design. *International Journal of Cognitive Ergonomics, 1*(4), 351–373.

Spence, C., Pavani, F., & Driver, J. (2000). Crossmodal links between vision and touch in covert endogenous spatial attention. *Journal of Experimental Psychology: Human Perception and performance 26*, 1298-1319.

Stanney, K., Samman, S., Reeves, L., Hale, K., Buff, W., Bowers, C., et al. (2004). A paradigm shift in interactive computing: Deriving multimodal design principles from behavioral and neurological foundations. *International Journal of Human-Computer Interaction, 17*(2), 229-257.

Vince, M. A. (1949). Rapid response sequences and the psychological refractory period. *British Journal of Psychology, 40,* 23-40.

Welford, A. T. (1952). The "psychological refractory period" and the timing of high speed performance: A review and a theory. *British Journal of Psychology, 43,* 2-19.

Wickens, C. D. (1976). The effect of divided attention on information processing in manual tracking. *Journal of Experimental Psychology: Human Perception and Performance, 2,* 1-13.

Wickens, C. D. (1980). The structure of processing resources. In R. Nickerson & R. Pew (Eds.), *Attention and performance VIII* (pp. 239-257). Hillsdale, NJ: Erlbaum.

Wickens, C. D. (1984) Processing resources in attention. In R. Parasuraman, J. Beatty, & R. Davies (Eds.), *Varieties of attention* (pp. 63-101). New York: Wiley.

Wickens, C. D. (2008). Multiple resources and mental workload. *Human Factors, 3,* 449-455.

Zubin, J. (1975). Problems of attention in schizophrenia. In M. L. Kietzman, S. Sutton, & J. Zubin (Eds.), *Experimental Approaches to Psychopathology* (pp. 139–166). New York: Academic Press.