# Task Relatedness and Spatial Distance of Information:

# Considerations for Medical Head Mounted Displays

by

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ABSTRACT

The medical field is constantly looking for technological solutions to reduce user-error and improve procedures. As a potential solution for healthcare environments, Augmented Reality (AR) has received increasing attention in the past few decades due to advances in computing capabilities, lower cost, and better displays (Sauer, Khamene, Bascle, Vogt, & Rubino, 2002). Augmented Reality, as defined in Ronald Azuma's initial survey of AR, combines virtual and real-world environments in three dimensions and in real-time (Azuma, 1997). Because visualization displays used in AR are related to human physiologic and cognitive constraints, any new system must improve on previous methods and be consistently aligned with human abilities in mind (Drascic & Milgram, 1996; Kruijff, Swan, & Feiner, 2010; Ziv, Wolpe, Small, & Glick, 2006). Based on promising findings from aviation and driving (Liu & Wen, 2004; Sojourner & Antin, 1990; Ververs & Wickens, 1998), this study identifies whether the spatial proximity affordance provided by a head-mounted display or alternative heads up display might benefit to attentional performance in a simulated routine medical task. Additionally, the present study explores how tasks of varying relatedness may relate to attentional performance differences when these tasks are presented at different spatial distances.

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CHAPTER 1

# INTRODUCTION

Augmented reality (AR) has become a topic of great interest in the fields of technology and engineering. These fields have recently seen major trends towards wearable devices and have benefitted from significant improvements in computing and hardware capabilities (Zhou, Duh, & Billinghurst, 2008). Augmented Reality, as defined in Ronald Azuma's initial survey of AR, combines virtual and real-world environments in three dimensions and in real-time (Azuma, 1997). With faster computing and better display technologies, AR visualization is becoming increasingly more practical and inexpensive (Sauer, Khamene, Bascle, Vogt, & Rubino, 2002). This combination of synthetic, simulated virtual environments and actual real-world environments has numerous commercial applications in varied fields as it can extend the perceptual faculties of a human user beyond their normal sensory limitations.

The use of AR in medicine is particularly promising as health-care professionals are often required to perform very complicated physical tasks based on large quantities of virtual data such as biometrics and imaging (Weinger & Slagle, 2002). In this field the cost of errors is immense, so any significant improvement in ergonomics benefitting the accuracy and efficiency of medical procedures should be well received by the healthcare system. A 1998 study on Medical Device Reporting records found that in the US, 60% deaths and serious injuries related to devices and radiologic health were attributable to operator error (Lin, Isla, Doniz, Harkness, Vincente, & Doyle, 1998). The authors claim that much of this error stemmed from medical devices failing to incorporate good human factors design principles. Therefore, there is a necessity to develop technology that can improve operator performance by being more intuitive and comprehensive.

This paper examines the current use of AR visualization in different areas of the medical field, delineates human factors limitations and areas that could be improved, and reports a study to elucidate potential visual-perceptual limitations involved with head-mounted AR techniques in medicine. Specifically, it examines whether head-mounted AR information displays could provide benefits to attentional performance for medical professionals by increasing the spatial proximity of information sources. Additionally, it assesses whether task relatedness is an important factor to consider when trying to establish distance thresholds for the presentation of biometric monitoring information. The purpose of this study is to determine whether the perceived benefit of AR visualization using head mounted displays, that they can allow a medical professional to access critical information without needing to avert their visual attention at any great distance, provides an observable advantage to attentional performance.

## AR Visualization and Display Types

While the definition of AR can extend across all facets of sensory perception, most innovation has been directed towards AR visualization. Bichlmeier and colleagues have outlined a number of requirements for visualization in medical applications of AR (Bichlmeier, Wimmer, Heining, & Navab, 2007). First, the visualization must provide a clear view of the intended anatomical location and conceal obstructing regions so that the operation site can be easily attended. Second, visualized data must provide some sort of positional perspective so that distances and relative locations can be easily and intuitively perceived by the surgeon. Finally, for AR to be used during surgical operations, the system must track and display surgical instruments so their relative positions to bodily structures can be easily perceived.

There are currently several different types of AR display in use in medicine. The Head-Mounted Display (HMD), designed to augment the two dimensional image received by an individual's retina to create the illusion of a three dimensional object, was invented in 1967 by Ivan E. Sutherland and has since been a major focus of AR innovation (Carmigniani, Furht, Anisetti, Ceravolo, Damiani, & Ivkovic, 2010; Sutherland, 1968). There are two types of HMDs: "video-see through" displays which use a screen to project recorded real world images and augmentations directly onto the retina and "optical see-through" displays which project these images onto a semi-transparent lens (Schwald, Seibert, & Weller, 2002). Recently, companies such as Google and Microsoft have developed the latter type head-mounted display devices for consumer and industrial applications. These feature a semi-transparent display screen that allows the user to view virtual, computer-generated images overlaid on top of their natural visual environment. Head mounted displays generally use mounted video cameras and sensors to track the user's head movements and surrounding environment. One limitation of HMDs is that they must either be battery-powered or connect the user via wire to a power source. Also, to keep size and battery consumption low, current HMDs tend to have some sort of remote computing unit. However, the proximity of the HMD screen to the eyes and strong motion tracking capabilities seem to provide benefits over monitor displays.

**Augmented Reality in Medicine**

Potential medical applications for AR are numerous and promising, and with sufficient development they could provide considerable assistance to healthcare professionals. Bichlmeier and colleagues presented a methodology with which a surgeon, using a HMD, could see a three-dimensional representation of the interior of a patient’s body, organs and bone-structures as well as the movements of any tools they had inserted into the body (Bichlmeier et al., 2007). This study found the visualization method, interface, and instrument integration to be accurate, but the system faces a processing speed-visualization quality tradeoff that will need to be addressed with technological improvements.

There has been substantial research aimed at developing the imaging techniques, body tracking, data rendering and hardware necessary to put AR successfully into the operating room, but it is necessary to examine the human factors involved with these devices to come up with systems that are more integrated and usable while prioritizing performance and patient safety. For example, the Da Vinci surgical device not only results in improved patient outcomes from laparoscopic surgery, but also provides comprehensive visual and haptic affordances for the operator that improve upon the laparoscopic system (Song, Kang, Oh, Hyung, Choi, & Noh, 2009). For the present study, we will take this approach while focusing on simpler medical tasks and how they may be improved by AR devices.

AR displays have also been adapted to improve the ergonomics of more basic tasks in the healthcare system including communication and coordination between medical professionals, the accessing of patient records and medical informatics data, and the monitoring of patient biometrics. Following the release of Google's Glass HMD, Muensterer and colleagues studied the use of this device as a communication, information accessing, and recording tool within a pediatric surgery unit (Muensterer, Lacher, Zoeller, Bronstein, & Kübler, 2014). Google Glass is a battery powered, optical-see through HMD with telephone and camera capabilities. In their clinical trial, surgeons used the device for photo documentation and video recording, online search of syndromes and diagnosis, for looking up procedure codes, and as a hands-free telephone. The device was well-received by staff but has issues with data-privacy, app development, battery life (because surgeons can work more than 12 hours a day), and video-conferencing capabilities. Glass has also been found to be a useful tool for training. It makes it possible for student or medical intern could to observe a procedure directly through the eyes of the surgeon during an operation instead of observing from elsewhere in the room (Schreinemacher, Graafland, & Schijven, 2014). The capability of these devices to consolidate different types of information into a single, portable source could aid in simplifying the tasks required of various medical professionals.

**AR for biometric monitoring.** Ormerod and colleagues studied the Nomad HMD for use in anesthesia as a way for an anesthesiologist to monitor biometric information about a patient while looking in that patient's direction (Ormerod, Ross, & Naluai-Cecchini, 2002). This study claimed that the advantage provided by the HMD, that anesthesiologists did not have to look from a monitor to a patient to access biometric information, resulted in improved attention and situational awareness of biometric information and patient features. While this theory seems plausible, Ormerod and colleagues measured visual attention by the amount of time an anesthesiologist spent looking in the direction of the patient. This measure does not take into consideration that the HMD and the patient are still discrete information sources that must be attended to separately via attentional shifting. In 2011, Liu and colleagues studied a newer model of the Nomad HMD and had similar findings, but again focused only on the amount of time the anesthesiologist was able to spend looking at the patient (Liu, Jenkins, Sanderson, Fabian, & Russell, 2010). The purpose of this study is to better understand how spatial location and relatedness of information may impact an anesthesiologist's ability to pay attention to multiple information sources.

**Augmented Reality in Aviation and Driving**

Head-up displays (HUDs) are a type of AR device, similar to optical-see through HMDs, that project virtual information on a transparent screen on top of the user's normal visual field. HUDs differ from HMDs in that they are often fixed to the windshield of a vehicle or other location and are not worn on the head. These devices, which have been widely researched and implemented in automobiles and aircraft, rely on the same principle as Ormerod and colleagues' Nomad device, that the spatial proximity of information provided by these types of displays is advantageous to attention and information processing. For example, a HUD can make it possible for a driver to see their driving speed and navigation projected on the windshield rather than on the dashboard or center stack (Head-Down Displays). Studies have shown that HUDs displaying certain types of information may lower "mental load", improve driving and perceptual task performance, and reduce fatigue (Liu & Wen, 2004; Sojourner & Antin, 1990). In application, there seem to be situations where a reduction in the distance between visual focus locations can have observable benefits on attention during dual-task performance in driving and in aviation. The current study will help to determine whether these attentional benefits may generalize to medical contexts.

Another consideration from aviation that may be relevant to medical applications is the potential for HUD information to distract from the natural environment. Ververs and Wickens mention an attentional tunneling effect when one sensory pathway is overloaded (Ververs & Wickens, 1998). When a pilot's visual channel has been overloaded with information from a HUD as well as the natural environment, they can have inattentional-blindness or reduced situational awareness of unexpected events (Crawford & Neal, 2006). This issue may be exacerbated by the visual masking of objects in the natural environment by virtual features of the display (Foyle, McCann, Sanford, & Schwirzke, 1993). To deal with these issues, HUD displays are often designed to present essential information "just in time" for that information to be necessary.

## Human-Related Technical Limitations of AR

There are other perceptual and physiologic limitations that must be considered to better understand how HMDs may impact attention in medical environments. It is still not fully understood how these types of displays impact perception, interact with the visual channel, and what sensorimotor alterations might be necessary for people to use them (Kim, Lee, & Park, 2014). In 1996, Drascic and Milgrim provided a comprehensive assessment of the visual-perceptual limitations of AR at the time (Drascic & Milgram, 1996). The resolution of depth cues was an area of visual perception they identified as a necessary component of AR. Types of relevant depth cues included: pictoral depth cues (features such as interposition and linear perspective that aid in the perception of distance), kinetic depth cues (such as relative motion of an object to give the kinetic depth effect of three dimensionality), and physiological depth cues (such as the learned response of convergence eye movements to signify the distance of an object).

Another key facet of visual perception identified was binocular disparity: the ability of humans to exploit the differences between the two eyes in order to perceive three-dimensionality in two combined two-dimensional images (Drascic & Milgram, 1996). These aspects of visual perception must be resolved in AR overlaid images because the position of the virtual image will always be closer than the position at which it is intended to be perceived. At the time of the paper, calibration errors, calibration mismatches, inter-pupillary distance mismatches, registration mismatches, restricted field of view and image clarity were major technological limitations inhibiting AR systems from effectively cooperating within the constraints of human perceptual faculties.

To account for technological advances since 1996, Kruijf, Swan and Feiner provided an updated assessment of perceptual issues involved with AR (2010). At the time of their paper, many of the previous technological limitations, such as calibration and image clarity, had been greatly improved upon. However, there are still issues such as occlusion (the visual blocking of objects), color fidelity, and vergence-accommodation conflict that may impact the usability of these devices. Vergence accommodation conflict occurs when the eyes converge on an overall image that is, in the natural environment, occurring in two spatially offset locations. This issue is specific to optical-see through devices as video-see through devices show an image only on the plane of the projected video screen.  Since the paper was written, some HMDs have been developed to use real-time environment tracking to make the projected images appear as holograms in the natural environment. This helps to mitigate some of the vergence accommodation issues and the depth cue issues mentioned in previous surveys of AR. One such device is the Microsoft Hololens. These technologies are relatively new and their strategies to improve upon perceptual limitations have not been sufficiently researched.

Another technological limitation that has been observed is in the augmentation of objects in cluttered environments. This limitation is caused by the mechanism that augmentation software uses to recognize objects or patterns in the environment.  This process that tends to make more errors in a complicated scene because of pattern recognition mismatches. Other factors identified as limitations of AR include the risk of approaching cognitive load thresholds and the visual fatigue that stems from switching between areas of different distance (Gupta, 2004). Acknowledgement of cognitive requirements, improved data visualization, and improvements in environment recognition must be made if AR is to be used properly in medical contexts.

The advancement of AR systems will be defined by the interdependent improvement in technological capabilities such as: video and display equipment, computational processing capabilities, software and interface improvements, and advanced research in the understanding of human perceptual limitations. It is likely that many of these technological limitations will be addressed by improved technology. So long as future designs of AR attempt to use the technological advancements to design systems in a way that fully corresponds with the scientific understanding of perceptual limitations, the accuracy and usability of AR devices will continue to improve.

## Physiologic Aspects of Attending Multiple Sources

To further understand the human-factors involved with the use of AR devices, it is necessary to focus on individual areas of human physiology and visual perception that may aid in the improvement of future AR systems. The following study examines one perceived benefit of AR HMDs, that there are systems that do not require the user to avert their gaze to different parts of a room to access biometric data which saves time and aids in performance of medical tasks. The advantages of this type of display over other display types is described in Table 1. (del Rio, Branaghan, & Gray, 2016). For this feature to be considered truly beneficial, it is necessary to examine the physiological and cognitive mechanisms involved with this sort of activity, and to test whether the system truly aids performance and efficiency during attentional shifting by reducing the distance between information sources.

**Head movements and eye movements during dual tasks.** The apparent advantage of using a HMD in the operating room is that a doctor does not need to turn their head or move their eyes towards distant points in a room such as monitors in order to receive necessary information. This assumption, described in Ormerod;s paper and above, has a few nuances (Ormerod et al., 2002). In this study, “focus of attention” was operationalized as the percentage of operating time spent with the user’s direction of focus (presumably head direction) aimed at the monitor and patient. The purpose of

Ormerod and colleagues' study, to reduce the amount of time an anesthesiologist spends with their attention diverted from a patient, has important safety implications, but the methodology here seems to assume that the doctor can simultaneously attend to the Nomad display and the patient at the same time.  To further understand the utility of HMD versus monitor displays in an operating room, it is necessary to examine the physiological and cognitive tasks involved with switching attention and detecting signals in this specific scenario

The perceived advantage that HMDs will reduce the duration of eye movements necessary to attend to virtual and physical visual information, by combining them into one visual field, relies on two main assumptions. The first assumption is that the eye movements required to switch between a virtual projected image near the eyes and a more distant physical target (HMD) happen more quickly than attending to two separate physical targets (patient/monitor). The second assumption is that a faster physiological switch between targets will come with cognitive benefits such as improved attention and working memory. Therefore, the purpose of this study is to create a simulation to determine whether latencies in eye movements favor HMD or monitor displays and to further measure whether the shorter distance eye movements are accompanied by improved performance in visual attention.

**Vergence and saccadic eye movements.** Two of the basic eye movements, involved with switching attention between displays in different positions and depths, are vergence movements and saccade movements. Proximal *Vergence* is a muscular-derived movement of the eyes in opposing directions in order fixate on objects of different depths

(Kruijff et al., 2010). The latency of vergence eye movements is around 160-180ms in normal adults (Yang, Bucci, & Kapoula, 2002). *Saccade* is a rapid muscular-derived movement of the eyes from one direction to another and has a longer latency of 200-250ms (Yang et al., 2002). The mechanisms for triggering a vergence eye movement and a saccade are distinct (Yang et al., 2002) but the movements also occur in unison (Takagi, Frohman, & Zee, 1995). There has been research to support that while vergence eye movements may occur in a continuous fashion, there also seem to be multi-step pre-defined motor responses similar to those observed saccadic eye movements (Semmlow, Hung, Horng, & Ciuffreda, 1994). The presence of a saccade increases vergence velocity regardless of depth cues in the room (Oohira, 1993). There are other factors in visual focus that are important in AR such as occlusion (Kruijff et al., 2010). In the current study we attempted to isolate long and short saccadic eye movements to compare features of HMDs and spatially separated information sources.

How would one expect eye movements to differ in a HMD and monitor display systems? When a doctor is using a HMD in the operating room they will likely be using many large vergence eye movements to shift between the distant patient and the closer HMD as well as short saccadic eye movements between targets on the screen. There is research to support that vergence (or convergence) eye movement is an essential factor in the perception of depth in AR (Drascic & Milgram, 1996). On the other hand, when a doctor is switching between a patient and an adjacent monitor display, they will be presumably be making long saccades or head movements because of the increased distance between the patient and monitor, but smaller vergence eye movements because the targets are of a similar distance from the eyes. Eye tracking methodologies have improved greatly in the past few decades with improved digital video equipment and video analysis software. Researchers have designed algorithms to characterize and measure saccadic (Behrens, MacKeben, & Schröder-Preikschat, 2010; Duchowski, 2007; Salvucci & Goldberg, 2000) and vergence eye movements (Neveu, Philippe, & Priot, 2012). While the shorter duration of vergence eye movements (Takagi et al., 1995; Yang et al., 2002) would suggest that an individual using HMD would require less time to physically switch focus between patient and display, it is possible that the nature of oculomotor activities requires a longer time before fixation. This study did not observe eye-movements directly, but there seems to be a theoretical basis to predict that longer saccadic eye movements required to switch between information sources of differing distances will result in longer latencies between fixations.

With the occurrence of HMDs that present virtual information as a hologram, the length of vergence eye movements needed to switch between a patient and a HMD is drastically reduced. If the virtual image can be projected at the same distance from the user as the patient, then the vergence eye movements required would be no longer than those required by a monitor of equal distance. Therefore, the research supporting shorter duration of shorter distance saccades would suggest that eye movements required using a hologram HMD would have shorter durations than using a traditional monitor display. Because this hologram technology exists and will likely be commonplace, the design of this simulation controls for vergence eye movements by placing all information sources at the same distance from the participant. By increasing the distance between information sources, this study was effectively manipulating the length of lateral saccadic eye movements and lateral head movements required to attend the multiple information sources.

### Cognitive and Perceptual Aspects of Attending Multiple Sources

**Shifting attention.** The assumption of the Ormerod study, that an anesthesiologist using the Nomad device can simultaneously attend to the patient and display because they are in the same field of vision, seems to contend with current models of human attentional awareness. Early models of dual-process attention limited human consciousness to be able to process only one stimulus at once (Broadbent, 1958; Wickens, 1981). Furthermore, it is necessary to address the difference between visual attention and attentional awareness, where feature detection is followed by some level of perceptual recognition (Lamme, 2003). For practical purposes, it will be necessary to elicit stimulus recognition in any simulation of a HMD rather than basic signal detection. This is because the anesthesiologist not only needs to detect a change in either information source, but must also perceptually encode that change and use it to make a decision. In the case of the anesthesiologist, the shift between stimuli must be an overt shift in attention. However, while saccadic eye movements are essential to quickly and accurately attend to stimuli in a different region, covert attentional shifts have also been observed. Covert attentional shifts happen when an individual visually attends to an area outside their gaze, an activity that has been shown to improve visual processing of the area attended (Posner, 1992; Belopolsky & Theeuwes, 2009; Mangun et al., 2001; Posner, 1980). While covert attentional shifting will no doubt be present, the gaze shift we are trying to elicit is an overt attentional shift, where gaze is re-directed in response to the detection of a visual signal in a different region.

One important consideration for study design is that the retina can detect unexpected luminance stimuli equally whether they be foveal or peripheral (Posner, Snyder, & Davidson, 1980). Therefore, to activate a true shift in gaze during this experiment rather than a peripheral detection of the stimulus, it was necessary to add some sort of content to the stimulus. If a correct response is required following detection of the stimulus, people must consciously or overtly attend to the alternate direction. This study did not examine whether HMDs allow a user to simultaneously attend to two targets, but rather determined whether users can quickly and accurately shift their attentional awareness between targets. Additionally, the tasks were designed so that the participant must detect, perceive, and make a decision based on the content of the stimulus.

Aviation research has supported the theory that rapid attention shifting is more likely the strategy for dual task scenarios than simultaneous attention sharing. A 2009 study showed that fighter pilots with proficient situational awareness utilize a rapid attention switching behavior strategy rather than a strategy of sharing attention (Endsley & Bolstad, 2009). It is possible that this sort of strategy is key in professions such as anesthesiology where the ability to fully attend to multiple sources is so important. In such sensitive environments, it is not enough to partially and simultaneously attend to multiple areas at the same time because of the perceptual load required to appropriately encode and respond to the stimuli.

There is also a proposed processing bottleneck which suggests that attentional capacity is limited and diminishes as multiple information sources are attended to (Strayer & Drews, 2007; Wickens, 1984). It seems that as information from multiple sources gets more complex, attention approaches a bottleneck and performance deteriorates. This study used only two information sources, simulating the monitor and the patient, to maintain consistency with the anesthesiology context. The following section looks at design principles that attempt to reduce the workload of attending multiple sources.

**The Proximity Compatibility Principle.** The main benefit that will be examined in this study is whether the closer proximity of information afforded by heads up displays improves the speed and accuracy of attentional switching between information sources. The proximity compatibility principle (PCP) as it relates to displays, predicts that the more connected or proximal two information sources are perceptually, the closer in *spatial proximity* they should appear on a display for optimal attention sharing in dual task scenarios (Wickens & Carswell, 1995). *Spatial proximity* refers to the spatial distance between information sources from an individual's point of view. *Perceptual proximity* is a combination that defines a spectrum of task proximity as a combination of spatial distance and a variety of perceptual metrics.

The PCP has been largely supported by research in computer and aviation controls and displays (Bailey, 1989; Bonney & Williams, 1977; Schons & Wickens, 1993; Seidler & Wickens, 1995), as well as in basic 2D cognitive tasks (Garner & Felfoldy, 1970). Research has also shown that the information access cost of increased distance can have negative impact on performance when tasks are related to each other perceptually (Liu & Wickens, 1992; Martin-Emerson & Wickens, 1992; Vincow & Wickens, 1993). A better understanding of how proximity compatibility relates to the dual task scenario of an anesthesiologist attending to a patient and monitor could lead to better design of these devices.

In their 1995 paper, Wickens and Carswell provide an exhaustive list of definitions, parameters, and characteristics related to proximity compatibility, many of which need to be considered for the present study (Wickens & Carswell, 1995). The following metrics fall under a wide variety of measures for perceptual proximity. Many of these metrics have been derived from Gestalt grouping principles. The following sections define the metrics of perceptual proximity that are relevant to the present study.

One of the metrics mentioned by Carswell and Wickens, *Processing Proximity,* is defined by the level at which multiple information sources are required to perform the same task. An example of high processing proximity would be the relationship between the speed limit sign and speedometer, as information sources, in a driver's task of maintaining the speed limit. Low processing similarity would be a visual text message notification and the speed limit sign for the same task. In this case, the text message notification is distant from the speed limit sign in its necessity for completing the task of maintaining the speed limit. The PCP states that if information sources have high processing proximity, they should be placed closer together spatially.

Another metric mentioned, *Task Proximity*, constitutes a spectrum of task integration ranging from integrated, to independent. An example of integrated or high task proximity would be when drawing on a tablet: one task would be monitoring the position of the stylus and another task would be watching the feedback of the drawing appearing on the tablet. These tasks are fully integrated, happen at the same time, in the same place, with the same causality. Low integration or independence would be the tasks of a driver watching the road to drive safely and the driver looking at the radio to see what station they are on. These tasks are independent of each-other spatially and temporally and they have different goals and outcomes. This spectrum also includes intermediate levels of integration. For example, when a bicyclist is putting air in a tire: they have the task of watching the tire pressure gauge and the task of feeling the tire to make sure that it is filling. These tasks are integrated in that the information comes from the similar source of the tire and the tasks have a similar goal or processing proximity, but they are independent in spatial location and in the code of the information being received. The PCP states that in tasks with higher integration of task proximity, attention will be improved by decreasing the spatial distance between the information sources.

A third metric mentioned, *Code homogeneity*, refers the level at which the two information sources have similar types or units of information. For example, the speed limit sign and the speedometer have high code homogeneity in that they both use the unit miles per hour. An example of low code homogeneity would be in the task of adjusting the volume and adjusting the bass on a radio. The units of volume and the units of bass are different and thus have different codes. Based on the PCP, information sources with high code homogeneity should be placed in higher spatial proximity.

A fourth relevant metric, *Source Similarity*, refers to the level at which two information sources relate to the same concept or entity. For example, the bicyclist is receiving information from the tire directly and the tire pressure gauge. These information sources share a similar source, the air pressure in the tire, and thus have high source similarity. An example of low source similarity would be when a driver performing the task of checking the dashboard and reading the speedometer and the fuel level gauge. This situation has low source similarity because the source of one display is the movement of the vehicle and the source of the other display is the amount of fuel present in the tank. The PCP states that when source similarity is high, information sources should be grouped in closer spatial proximity to optimize performance.

**PCP in the anesthesiology context.** While the scenario of an anesthesiologist encompasses the mentioned facets of perceptual proximity, there are other facets of this construct may not be relevant. Therefore, the present study will attempt to separate the construct of spatial proximity from other PCP constructs. Processing proximity, task proximity, code homogeneity, and source similarity seem to be intrinsic to these particular tasks and thus will be combined into the construct of *Task Relatedness*. By attempting to locate the anesthesia task scenario along these metrics of perceptual proximity, we can better define the construct of task relatedness.

In this scenario, processing proximity is generally high over a series of tasks, as both the patient and the monitor are necessary to appropriately respond to changes in the patient’s health. However, depending on the event, one of these sources may indicate the patient’s condition has changed and a response is required. Alternatively, there may be cases where information from both the patient and the monitor could be necessary for an appropriate response to be assessed.

Task proximity in this context is somewhat uncertain, but seems to fall somewhere between integration and independence. The tasks should not be fully integrated because they do not possess code homogeneity. The information coming from the patient is related to facial expression detection and color coding. The information from the monitor deals with numeric representations of health condition such as heart rate and blood pressure. However, because there is generally high task proximity and source similarity, some level of integration seems to be required. Source similarity is known to be high because the information from both the patient and the monitor are exclusively derived from the condition of the patient.

Because this scenario seems to fall somewhere along a spectrum of task relatedness, there is some theoretical uncertainty behind the strategy of increasing the spatial proximity of these information sources. The present study looks at how attentional performance might be different given different levels of task relatedness. By better understanding the level of task relatedness in this scenario, improvements could be made to the theoretical bases for decreasing the distance of information sources using a HMD.

## The Present Study

In the context of the anesthesiologist attending to a patient and monitor, during an operation that may last several hours, actual signals where the anesthesiologist may be required to respond to the monitor or patient's changes may be relatively infrequent and dispersed.  These sort of tasks are known as vigilance tasks, and can have a significant impact on performance in attending to displays (Baker, 1959).  A cognitive task analysis of clinical performance identified vigilance, task sharing, and rapid decision making as some of the most demanding elements of the anesthesia domain, especially during non-routine events (Weinger & Slagle, 2002) . To study the effects of spatial and perceptual proximity in the anesthesiology context, a vigilance task was selected to best simulate the types of tasks that these doctors may be required to perform.

We predicted patterns based on: the attentional benefits observed in aviation and driving, on the duration and combinations of eye and head movements, and on previous work suggesting that spatial location of information can improve attention and accuracy in certain tasks (Bashinski & Bacharach, 1980; Yeshurun & Carrasco, 1998). The hypotheses are consistent with Ormerod and colleagues' assumption that when the information sources are in closer spatial proximity, the lower information access cost will result in improved reaction time and accuracy during the signal detection task. It was predicted that performance (reaction time/accuracy) would improve when task relatedness was increased and spatial distance was decreased.

**List of hypotheses.** The first hypothesis ($H_1$) was that when information sources were closer spatially, participants would have faster reaction times in their responses. The second hypothesis ($H_2$) was that when information sources were more related to each other, participants would have faster responses. The third hypothesis ($H_3$) was to find an interaction: as spatial distance between information sources was decreased, the impact of increased task relatedness on reaction time would be more pronounced. This hypothesis would be consistent with the PCP because when task relatedness is higher, it is more important to group information sources spatially. The fourth hypothesis ($H_4$) was that when information sources were closer spatially, participants would have more accurate responses. The fifth hypothesis ($H_5$) was that when information sources were more related to each other, participants would have more accurate responses. The sixth hypothesis ($H_6$) was to find an interaction: as spatial distance between information sources was decreased, the impact of increased task relatedness on accuracy would be more pronounced. Again, this is because higher task relatedness of information sources suggests that spatial grouping will improve attentional performance. The exploration of the impact of distance on performance could reveal an ideal distance or distance thresholds for displays presenting biometric information to anesthesiologists. Additionally, the exploration of the impact of task relatedness on performance could lead to a better understanding of how proximity compatibility might be a factor in these sorts of tasks.

The present study was also interested in what effect the time interval before an event may have on reaction time, and how this may differ between the different spatial and relatedness conditions. Consistent with Baker's theory on vigilance tasks, the seventh hypothesis ($H_7$) was that longer time intervals would result in slower reaction times (1959). However, the addition of relatedness and distance as factors in this comparison begged an additional exploratory research question. The question ($E_1$) was: what was the interaction of time intervals and spatial conditions on reaction times? Because anesthesiologists often have very long intervals between events, exploration of how time intervals between events may relate to performance in these tasks, and whether distance of information sources is a factor, could help relate the findings to the anesthesiology context.

CHAPTER 2

# METHOD

## Participants

13 participants were recruited and participated in the study. One participant's data contained unprecedented outliers and was removed from analysis. Of the 176 false alarms observed in the original data, 48.3% were observed within this participant's data. The counterbalanced task order for this participant was repeated by the thirteenth participant. Therefore, 12 participants were included in the analysis. Participants were recruited from an ASU undergraduate psychology student subject pool (SONA) and received partial course credit for their participation. Participants were screened on criteria of having normal or corrected vision. Participant age ranged from 18 to 31. Additional participant demographic characteristics can be found in Table 2. As this was a repeated measures design, participants were not randomized into separate groups but were assigned to a counterbalanced order of conditions as they arrived at the laboratory.

## Design

The study featured a five by two independent variable repeated measures design. There were five spatial proximity conditions and two task-relatedness conditions. The 5 distance conditions were selected to require varying lengths of eye and head movements. The dependent variables measured were reaction time in milliseconds and accuracy in number of incorrect responses. Targets would appear on the monitors at randomly selected intervals. A secondary exploration into how time interval before a target event may have impacted reaction time.

**Spatial proximity.** The within subject conditions of spatial proximity, depicted in Appendix A, included five arrangements of monitors differing in spatial proximity from each other and by horizontal angle from the participant. For each condition, two monitors were placed 1m. away from the participant and at angles ranging from 22.5° to 112.5°. The order in which participants would receive trials on the spatial proximity conditions was determined using a Williams incomplete, balanced Latin-square design for 5 conditions to account for possible order and training effects.

**Task relatedness.** The task relatedness conditions were based off whether the target of the task occurred on one of the two monitors or both as shown in Appendix B. "Related" tasks involved targets appearing on both monitors simultaneously. "Independent" tasks involved a target appearing on one monitor or the other. The dependent variables of performance were measured on both the biometric signal detection task and the face recognition task. The task relatedness conditions appeared in a randomly selected sequence in each trial to account for order and training effects.

## Apparatus and Materials

**Recruitment.** Participants were recruited to the study over the web-based client, SONA, used by the Arizona State student subject pool. The description included the name, screening criteria, and a brief description of the study.

**Consent and instructions.** Participants were given a consent form explaining the study and their voluntary participation, shown in Appendix C. Participants received verbal instructions read from a script by the experimenter (Appendix D) and accompanied by printed instructions delineating target and non-target stimuli (Appendix E). Before the practice trial, participants were also given on-screen instructions about the task (Appendix F.)

**Monitors and input.** All five spatial conditions consisted of two monitors placed at varying distances from each-other at intervals of 22.5°. The closest spacing was at 22.5° and the farthest being 112.5° (as seen in Appendix A). These distances were chosen: partially to accommodate for the size of the monitors and also to account for a wide variety of distances. Both monitors were always placed 1m away from the participant's face. This controlled the visual angle of the stimuli between distance conditions. Monitors used were 15-inch Dell monitors. Participants sat at a desk in a stationary chair and were asked to center themselves on a line to keep them at a 1m distance from the monitors. Participants input their responses using either button on a standard Macintosh mouse.

**Program and computing.** The task program was written in Inquisit by Millisecond Software and was programmed to collect response inputs at a 1ms sensitivity. The program was run on a 2016 iMac desktop computer.

**Stimuli.** The vigilance task was designed with different types of stimuli specific to each monitor (Appendix G). On monitor 1, non-target stimuli featured a .gif of a video of a resting face. During a target event, the .gif would change so that the face appeared to open its eyes. On monitor 2, non-target stimuli featured a .gif of changing blood pressure and heart rate values that fell within normal thresholds. During a target event, the .gif would change to begin showing changing blood pressure and heart rate values outside of normal thresholds.

**Stimulus sets.** When there was not a target event, the non-target .gif images would always be on the screen. For target events stimuli were programmed to appear on the monitors in a randomly selected order of three combinations. The first “Independent” combination included a target .gif appearing on monitor 1 while the non-target .gif remained on monitor 2. The second “Independent” combination included a target .gif appearing on monitor 2 while the non-target .gif remained on monitor 1. The “Related” combination included a target .gif videos appearing on monitor 1 as well as monitor 2.

**Reaction time feedback.** Following a response, monitor 1 would present the reaction time to the response in milliseconds for about 1 second. If the participant responded before a target stimulus set had occurred, the reaction time displayed would be a negative number.

**Trials.** Each trial was 8 minutes long and consisted of a series of randomly selected stimulus sets. Each of the three stimulus combinations had an equal weight in the selection process so the chances of getting a given combination was approximately 1 in 3. These sets were programmed to appear at a randomly selected interval (1s, 2s, 3s, 4s, 5s, 6s, 7s, or 8s) for the duration of the trail. Random time intervals were used to prevent a strategy of anticipated regular responses by participants. Each trial was repeated for all five spatial distances.

**Data collection.** The task program was designed to record: participant number, time, spatial condition, stimulus combination, trial number, interval before a target, and reaction time (RT) in milliseconds. If RT was a negative number, it was coded as a false alarm or incorrect response.

**Demographics questionnaire.** Participants were given a demographic questionnaire on Google Forms (Appendix H). The questionnaire recorded reported: gender, age, race or ethnicity, and handedness.

### Procedure

Participants entered the laboratory and received an informed consent form (Appendix C). They received a verbal briefing on the purpose of the study (Appendix D) as well as printed materials to better understand the material (Appendix F).  They then completed a brief, two minute signal detection and response practice trial on whichever spatial condition they were assigned to as the first condition. They were asked to respond as quickly as possible to each target event. They then received a series of five, 8 minute signal detection trials for each spatial condition as described above.  A photograph of a pilot participant during the closest distance condition can be found in Appendix J. Between trails they were asked to rest while the monitors were repositioned. Before starting the next trial, they were shown their mean reaction times to the previous trial and told to respond as quickly as possible to all target stimuli.

### Scoring

RT was aggregated into a mean reaction time for each combination of conditions per participant. For example: all the responses to the “Related” stimulus set in the nearest spatial condition were averaged for each participant. Accuracy was measured by number of incorrect responses or false alarms per condition set. The number of incorrect, false alarm responses to each combination of conditions were counted as a sum for each participant.

**Statistical Analysis**

This design used two 5 x 2 repeated measures factorial ANOVA to test the interaction between task-relatedness and spatial distance on reaction time and accuracy respectively, as well as the main effects of each condition on reaction time and accuracy for each distance condition and stimulus combination. Linear and Quadratic components were assessed for the five distance conditions. Secondary analysis included an ANOVA see whether interval was a predictor for reaction time between distance conditions.

CHAPTER 3

# RESULTS

## Descriptive Statistics: Reaction Time

Table 3 outlines the descriptive statistics for the averaged mean reaction times for each of the 12 participants. At first glance, the reaction times appear to be markedly slower in the independent condition, and the reaction time in 22.5 degree distance condition seems to be much faster than in the 112.5 degree condition for both the independent and related task types.

## $H_1$: Main Effect of Distance on Reaction Time

In $H_1$, a main effect of angle distance on reaction time was predicted. Specifically, the prediction was that as angle between the monitors was increased, reaction times would be slower.

The results of the ANOVA (Table 4) show that this predicted relationship seems to be supported by these data, $F(4,44) = 3.228$, $p = .019$, $\eta^2 = .230$. In fact, in the comparison of means plotted in Figure 1, it appears as if reaction times were substantially faster in the 22.5 degree and 45 degree conditions and were slower at distances beyond that. It is also apparent from Figure 1 that participant reaction times were more varied at greater distances.

Post hoc tests using Fisher's LSD were performed to evaluate this observation (Table 5). These data suggest differences between 22.5 degrees and the following distance conditions: 90 degrees, $SE = 58.117$, $p = .004$, and 112.5 degrees, $SE = 58.956$, $p = .020$. There also seems to be a difference between the 45 degrees and 90 degrees, $SE = 61.001$, $p = .026$. The analyses did not support the presence of a quadratic relationship between distance and reaction time.

### $H_2$: Main Effect of Relatedness on Reaction Time

In $H_2$, a main effect of task relatedness on reaction time was predicted. Specifically, the prediction was that reaction time would be faster when tasks were related than when they were independent.

The results of the ANOVA (Table 4) show that this predicted relationship seems to be supported by these data, $F(1,11) = 140.958$, $p = .000$, $\eta^2 = .230$. In the comparison of means plotted in Figure 1, it is apparent that reaction times were markedly faster when the tasks were related.

### $H_3$: Interaction of Distance and Relatedness on Reaction Time

In $H_3$, an interaction of distance and relatedness on reaction time was predicted. Specifically, the prediction was that in the related condition, there would be a positive relationship (increase in reaction time) as distance was increased that was more pronounced than the effect of distance in the independent condition.

The results of the repeated measures factorial ANOVA (Table 4) show that these data do not support this prediction, $F(4,44) = .473$, $p = .755$, $\eta^2 = .041$. In fact, in the comparison of means plotted in Figure 1., it appears that the pattern followed in both relatedness conditions related to changes in reaction time very similarly across the distance conditions.

**Descriptive Statistics: Accuracy**

Table 6 outlines the descriptive statistics for the mean number of incorrect responses for each of the 12 participants. The more incorrect responses a participant made, the less accurate they were. At first glance, it is apparent that the average number of incorrect responses per condition was rarely greater than 1. Also, by the number of incorrect responses per number occurrences of each condition set, there seemed to be a floor effect where very few mistakes were made overall. The descriptive statistics do not reveal any notable patterns between the conditions.

**$H_4$: Main Effect of Distance on Accuracy**

In $H_4$, a main effect of angle distance on accuracy was predicted. Specifically, the prediction was that as the angle between the monitors was increased, participants would have more incorrect responses.

The results of the ANOVA (Table 7) show that this prediction is not supported by these data, $F(4,44) = 1.172$, $p = .336$, $\eta^2 = .096$. The comparison of means plotted in Figure 2. reveals no obvious relationship between distance and accuracy. In this comparison, it does appear as if participants responded with more variable accuracy as distance was increased in the independent condition. Post hoc Fisher's LSD analysis performed on the data also did not support a relationship between any distance comparisons on accuracy (Table 8). The analyses also did not support the presence of a quadratic relationship between distance and accuracy.

### $H_5$: Main Effect of Relatedness on Accuracy

In $H_5$, a main effect of task relatedness on accuracy was predicted. Specifically, the prediction was that participants would have fewer incorrect responses when tasks were related than when they were independent.

The results of the ANOVA (Table 7) show that this predicted relationship seems to be marginally supported by these data, $F(1, 11) = 4.632$, $p = .054$, $\eta^2 = .296$. In the comparison of means plotted in Figure 1, it seems as if, in most distance conditions, participants had fewer incorrect responses when the tasks were related.

### $H_6$: Interaction of Distance and Relatedness on Accuracy

In $H_6$, an interaction of distance and relatedness on task accuracy was predicted. Specifically, the prediction was that in the relatedness condition, there would be a positive relationship (fewer errors, improved accuracy) as distance was increased that was more pronounced than the effect of distance in the independent condition.

The results of the repeated measures factorial ANOVA (Table 7) show that these data do not support this prediction, $F(4,44) = .750$, $p = .563$, $\eta^2 = .064$. In fact, in the comparison of means plotted in Figure 2, it appears that the pattern followed in both relatedness conditions related to changes in accuracy with a similar pattern across the distance conditions.

## $H_7$: Interval and Reaction Time

In $H_7$, a relationship between interval before a target and reaction time was predicted. Specifically, the prediction was that participants would have slower reaction times when intervals were longer.

The 5 x 8 factorial ANOVA (Table 9) performed on the data supported this prediction, $F(1, 6) = 9.594$, $p = .002$. However, it is apparent from Figure 3. that the differences in reaction time related to interval are likely explained by the greater variation of reaction times when intervals were short.

## $E_1$: Interval Before Target on Reaction Time

The question of $E_1$ elaborates on this hypothesis and looks at what the effect of distance might be on this interaction?

The 5 x 8 factorial ANOVA (Table 9) performed on the data did not support this prediction, $F(1, 4920) = .727$, $p = .648$. In fact, in Figure 4, it appears that all distance conditions had similar patterns of responses based on reaction time.

Separate linear regression models for each distance condition to see how interval predicted reaction time performance. While almost all the coefficient estimates had p-values less .001, the $R^2$ values for all the regression models were less than .01, meaning they explained very little of the variance in reaction times.

Because intervals were selected randomly, not all intervals occurred with equal frequency. When the frequencies of interval occurrences per interval group were plotted

(Figure 5) they seemed to match the pattern of distributions in Figure 3 and Figure 4 Table 10. shows the frequency of occurrence and mean reaction time for each interval. A regression was performed to access frequency of interval occurrence as a predictor for reaction time, $F(1, 6) = 3.076$, $p = .13$, $R^2 = .34$. While this relationship is not statistically strong, it is possible that the number occurrences of intervals may explain more of the variance in performance over different intervals than the length of the intervals themselves.

CHAPTER 4

# DISCUSSION

The purpose of this study was to attempt to isolate some of the perceptual and attentional demands an anesthesiologist experiences while attending to a patient and biometric monitor, and to explore how manipulating the difference between these information sources may benefit or detract from attentional performance. The reason for this exploration was to supplement previous research recommending the use of HMDs by anesthesiologists to display biometric and other patient information (Liu et al., 2010; Ormerod et al., 2002). The experimental design, a low-fidelity simulation of this dual task scenario, sought to answer research questions about: how distance of information sources may relate to differences in attentional performance in this context, how task relatedness between information sources may affect attentional performance, and about how the effect of distance may change when task relatedness is manipulated.

In summary, the findings of this study contribute to several inferences about the overall research questions as well as implications regarding the construct validity of this novel experimental design. *First*, the data seemed to support an effect of distance on attentional performance based on the measure of reaction time. *Second*, the data seemed to support an effect of task relatedness for both attentional performance measures. *Third*, the data collected failed to support an interaction between distance and task relatedness for either of the attentional performance outcomes. *Fourth,* the data seemed to show an effect of interval before a stimulus where shorter intervals resulted in slower reaction times.  This section will: explore these inferences in the order the results were presented, explain how they may relate to previous research findings, examine potential limitations of this experimental design, discuss potential design implications for patient monitoring displays, and propose future study directions that could lead to a more complete understanding of the subject matter.

**Distance**

As the literature review suggests, there are a variety of potential reasons why a main effect of distance was observed in this experiment. Factors contributing to the main effect of distance could include physiological factors, such as eye and head movements. Perceptual, attentional, and cognitive factors may have contributed such as: attention shifting or sharing, cognitive workload or demand, and proximity compatibility.

The pattern of the main effect found for distance seems to suggest that there was a marked improvement to attentional performance when the visual separation was 45 degrees or less, and that at distances of 67.5 degrees or greater performance was reduced. One inference could be that there is a threshold around 45 degrees where anything greater will detract from attentional performance in this sort of task.

It is very likely that simple physiological constraints such as eye and head movements contributed to participants improved performance at shorter distance conditions. Previous clinical studies of HMDs in anesthesiology would suggest attentional performance was improved at shorter distances because participants spent more time looking in the direction of both information sources (Liu et al., 2010; Ormerod et al., 2002). Physiologic research of human saccadic and vergence eye movements supports the relationship between distance and increased reaction time because long eye movements take more time overall and require more time for adjustments (Kruijff et al., 2010; Yang et al., 2002). The combination of long eye movements and head movements likely contributed to this finding.

One interesting pattern visible in Figure 1 is that reaction time seemed to actually be lower in the 112.5 degree condition than in 67.5 and 90 degree conditions. While this pattern was not supported statistically, it may be touching on the type of physical movements used between the different distance conditions. It is possible that at distances of 67.5 and 90 degrees, participants had slower reaction times because their strategies included a choice between a head movement or just an eye movement. In the longer condition, they were forced into a strategy of a long head movement which may have resulted in improved reaction time. Eye and head-tracking methods could be used to identify which of these strategies may have been in play.

However, it seems unlikely that time of physical movements alone would account for the main effect of distance. For one thing, the effect of distance on reaction time was supported within the related condition which means that attentional performance was diminished even when the participant didn't need to move their eyes or head to detect a target. There is also substantial literature to support the notion that attending to multiple data sources is influenced by perceptual and cognitive factors as well.

One explanation would be that participants did a better job of rapid attentional switching when the monitors were closer together. While the students tested were not trained on this sort of task, they still may have employed the rapid attention switching strategy described by Endsley and Bolstad (2009). A few studies have found attentional shifting across distances can be achieved with covert visual attentional shifts (Itti & Koch, 2000; Posner, 1980). These involve shifting attention to the periphery of the visual field towards stimuli that are very salient. Salient stimuli to the periphery include stimuli that change in luminance, color, movement, or other distinct changes. However, the present study was designed with changes in stimuli subtle enough to require more direct focal attention.

Cognitive demand and proximity compatibility also likely played a role in the effect of distance on reaction time because the tasks required participants to not only switch attention between sources, but also required some perceptual encoding of the stimuli and the decision to respond. Research has shown that greater distance between information sources can increase the cognitive demand or workload required to complete a task (Liu & Wen, 2004; Sojourner & Antin, 1990). The proximity compatibility principle also supports this effect of distance provided that task similarity is high enough interference between tasks will not affect performance (Wickens & Carswell, 1995; Wickens et al., 1993).

**Task Relatedness**

The purpose of manipulating task relatedness in this study was to try and better understand where the anesthesiology task fell on the spectrum of task relatedness and proximity compatibility. Because the interaction between relatedness and distance was not supported, the main effect of relatedness does not, by itself, yield any substantial inferences. The related tasks were predicted to have lower reaction times because if a participant happens to be looking at one screen when a target occurs, they will not have to shift their attention to the other screen to react.

One solution in the experimental design to control for this strategy would have been to require participants to provide responses that were specific to the monitor in which a target occurred. For example, if both monitors showed targets simultaneously, a participant would have to respond separately to each monitor at the same time. However, this solution was not used because it would have added a task complexity that would have caused both the independent and related conditions to have less relatedness. It would be interesting to see the results of a variation of this study with the addition of separate response requirements. This variation would also likely result in accuracy scores with a higher incorrect response to occurrence ratio per condition set.

**Interaction of Distance and Relatedness**

By observing the differences between the manipulations of task relatedness and distance, the present study was attempting to answer the question of *why* decreasing the spatial distances of the information sources might improve attentional performance in this context. If $H_1$ had been supported and the effect of spatial distance on attentional performance was more pronounced when task relatedness was high, then one interpretation would be that spatial proximity of this type of task should be increased *because* the tasks have high relatedness.

However, the findings seem to suggest that the manipulation of relatedness resulted in a similar pattern of attentional performance at all distance conditions. If the relevant features of the PCP are generalizable to this dual task scenario, then it is possible that the experiment did not sufficiently manipulate task relatedness to evoke this interaction. As the PCP has been well validated in many domains and there is no evidence or basis to claim that it would not extend to this sort of task, it seems that insufficient manipulation of relatedness is likely the reason that an interaction was not observed (Liu & Wen, 2004; Liu & Wickens, 1989; Wickens & Carswell, 1995; Wickens, Martin-Emerson, & Larish, 1993).

The manipulation of relatedness was defined in this study design as an event occurring in one information source independently (independent) or in both sources simultaneously (related). This manipulation essentially altered the processing similarity of the tasks by changing whether attending to both monitors or one monitor would be sufficient to complete the task. The manipulation also altered the task proximity by changing whether the patient's health status was conveyed in a way that was integrated across both monitors or independently conveyed by one monitor. However, the code homogeneity was continuous across both the related and independent conditions. In both task relatedness conditions, the monitors used different units to convey information about the patient to participants. Additionally, the source similarity was continuous across task relatedness conditions. In both conditions the source of the information for both monitors was simulated to be from a single patient. Therefore, it is possible that the reason no interaction was observed is that these continuous aspects of the relatedness manipulation placed the independent and related task combinations too close together on the task-relatedness spectrum.

These continuities were not accounted for in the study design because they are essential to the simulation of the anesthesia task. To account for code homogeneity and source similarity, it may have been possible to present separate series of tasks where both monitors featured the biometric information, or both monitors featured blood pressure and heart rate information with targets on either or both screens and similar distance conditions. While this may have more successfully manipulated the level of relatedness between task conditions, it would have further diminished fidelity of the experiment.

Another explanation for the failure to find an interaction could be that too few observations were made for the interaction to be supported statistically. The effect sizes and observed power for both RT ($\eta^2$ = .041, observed power = .151) , and accuracy ($\eta^2$ = .041, observed power = .155) were relatively low. However, because the pattern between conditions was so marked in RT measure (Figure 1.) and the main effects were supported it seems unlikely that there would have been an interaction with more participants.

**Interval**

Perceptual vigilance can be a considerable factor in performance of visual attention tasks. This is the reason present study evaluated interval before a stimulus as predictor for reaction time. Reaction time has been found to deteriorate over longer periods of monitoring (Baker, 1959; Saltzman & Garner, 1948; Buck, 1966). In the anesthesiology context, intervals between target events could be very long, even hours. In such conditions, it could be expected that interval would influence reaction time, but what is not certain is what the relationship between interval and distance of information sources would have been. The design of this study only included intervals ranging from one to eight seconds so it is not surprising that reaction time did not deteriorate substantially. However, it would be interesting to run a variation on this study with an increased range of intervals between target stimuli to see if there is an interaction.

**Study Limitations**

The present study was a low fidelity simulation that attempted to control for the of shifting attention between two information sources, similar to that required of an anesthesiologist. While the findings may have elucidated some key variables of human performance at attending to multiple information sources at varying distances, there are various limitations of this design in attempting to validate the use of HMDs in anesthesiology.

First, university undergraduate students were used instead of trained anesthesiologists or nurse anesthetists. Research on pilots has shown that expertise can be a factor in attentional switching performance during multiple simultaneous tasks (Endsley & Bolstad, 2009). It is possible that this factor of expertise would extend to the tasks in this study and yield different results than with a naïve population. However, as these tasks were simple and relied on simple physical, perceptual, and cognitive mechanisms, it is also possible that expertise would not play much of a role in a between-subjects design.

Another limitation, an artifact of the task program, was that certain observations were not collected in equal quantities. For example, the relatedness condition appeared about half as often as the independent condition because the program randomly selected between two independent conditions and one relatedness. This limitation should have been addressed in the program design. Also, because certain factors such as interval and task type were selected randomly, they did not occur the same number of times per condition. However, because many observations were collected, it is likely that these limitations did not affect the reliability of the data collected.

Another limitation is that while the two-monitor design encompasses a wide range of angle distances, a HMD could accommodate proximities closer than 22.5 degrees. In practice, it is possible to even transpose the monitor on top of the patients face. The impact of distances that are closer than 22.5 degrees of angle are not accounted for in this design. Using an analogous design with distances possible using an actual HMD would be an interesting and potentially useful direction for further study

Finally, while the findings suggest that showing similar information sources closer to each other would likely provide an attentional benefit, there are other features of the anesthesiology environment that should be considered. Future research into longer time intervals would help to reproduce the duration between events during an operation. Anesthesiologists must also attend to multiple auditory displays. The addition of an auditory attention task to this design would further help generalize findings.

**Design Implications**

The main design question behind this study was: is the increased spatial proximity afforded by a HMD advantageous to attentional performance over conventional monitor displays in an anesthesiology scenario?  Based on the findings of this study, it seems there is an implication that increased spatial proximity to distances under 45 degrees of visual distance would likely be a benefit to attention in this sort of task. So long as there is not an additional benefit of making information sources closer than an angle of 22.5 degrees, it is possible that developing a costly HMD system would not even be necessary. HMDs are improving at an accelerated rate but remain costly to purchase, somewhat invasive to users, and are limited by some of their technological characteristics mentioned earlier in the paper. It may be possible to instead use some sort of tablet or monitor display that is portable and can be placed within an angle of 45 degrees from the patient without being an obstruction to the anesthesiologist or other medical personnel.

**Conclusions and Future Study Directions**

In conclusion, this study begins to lend empirical support to the theoretical basis for implementing HMDs into the operating room. These devices certainly have the capability to position patient biometric information closer to the patient. Given the findings of this study, field research performed in the automotive and aviation fiends, and the theoretical basis established in the literature, it seems these devices could also improve the attentional performance of anesthesiologists in the operating room. However, there are many other factors relating to the surgery environment that should be assessed before these devices are put in the operating room.

Given the limited scope of this study, the first direction proposed for further inquiry involves replicating this study design with trained anesthesiologists and nurse anesthetists. Because the time of these medical professionals is so valuable, it was necessary to use a naïve sample to begin to validate this experimental design. Now that there is an observed to be a pattern between distance of information sources and attention, it is necessary to see if this pattern extends to the target population. Further examination of this pattern may also lead to a better understanding of how different distances may affect attention.

One of the shortcomings of the present study is, in attempting to control for the individual task of switching between information sources, many of the facets of an anesthesiologists workload and environment were not considered. To better understand the conditions in which task sharing between a monitor and patient is necessary, a promising direction of study would be to perform a cognitive task analysis. A task analysis similar to that performed by Weinger and Slagle, but that more specifically observes the anesthesiologists reliance on patient and monitor cues, would help to identify the conditions in which this task shifting is necessary (Weinger & Slagle, 2002). The addition of eye-tracking could further identify circumstances when attending the monitor and the patient is crucial to accurate decision making and patient safety.

Once a strong theoretical and empirical foundation is established for the use of HMDs by anesthesiologists, research must be conducted to strengthen the practical aspects of the device. It will be important to understand what information should be displayed on the HMD given the temporal conditions of a surgical procedure. If too much information is displayed on an HMD, an interference effect as has been observed with aviation HUDs, might be distracting and detract from performance (Crawford & Neal, 2006; Foyle et al., 1993). Therefore, design research techniques such as participatory design and formative usability testing should be carried out to ensure that essential information is being presented “just in time” for it to be relevant to the user’s decision making process.

With improved understanding of the cognitive aspects of AR in the operating room and continuing advancement of the technology, it is reasonable to predict that these devices will see widespread adoption in the coming years. However, it is essential that this transition occurs with proper attention towards developing systems that take the user's limitations into account. A better understanding of the complex cognitive and perceptual mechanisms of human involved with using AR will lead to devices that are useful, save, and make a positive contribution to the healthcare system.

# TABLES

**Table 1.** *Human Factors Analysis of Information Displays* (del Rio, Branaghan,& Gray, 2016)

| | |
|---|---|
| *Conventional: Information Displays on Monitors and Instruments* | |
| Advantages | • User preference: most professionals have been trained using this method.<br>• Multimodal signals: Incorporates visual and auditory cues to reduce cognitive load.<br>• Allows operator to choose what data they receive and when (This could be a disadvantage). |
| Disadvantages | • Time-motion issue: information is displayed in different places and on different instruments.<br>• Operator must look to different areas of the room to access data, cannot look at patient and information without moving head or eyes (Ormerod et al., 2002). |
| *Video See-Through Head Mounted Display* | |
| Advantages | • Operator can see both natural world and virtual information on one plane (monitor) so eyes do not need to converge between depths.<br>• Head tracking: allows information to be displayed in any focus direction.<br>• Operator does not need to move head to access information display |
| Disadvantages | • May cause motion sickness (Kim, Lee, & Park, 2014a).<br>• Video monitors may not provide sufficient depth cues at this time (Kruijff et al., 2010).<br>• Monitor failure would obscure vision entirely. |
| *Optical See-Through Head Mounted Display* | |
| Advantages | • Head tracking: allow information to be displayed in any focus direction.<br>• Allows operator to see real-world relatively normally.<br>• Operator does not need to move head to access information display |
| Disadvantages | • Eyes must converge to focus on information display. |
| *AR Window* | |
| Advantages | • Operator and patient tracking: more accurate display of complex image overlay on top of body (Navab, Blum, Wang, Okur, & Wendler, 2012; Schwald et al., 2002).<br>• Uses a swivel arm that can be moved over the patient. |
| Disadvantages | • Not wearable, the operator can only use this when it is above the patient.<br>• Difficult to see through screen unless there is sufficient light below (Dorfmüller, 1999).<br>• Useful when doctor must be able to remove display to get very close to the patient’s body. |

**Table 2.** *Demographic Characteristics of Study Participants*

| *Characteristic* | *Number of Participants* | *%* |
|---|---|---|
| *Gender* | | |
| Male | 12 | 100.0% |
| | | |
| *Race or Ethnicity* | | |
| White | 8 | 66.7% |
| Hispanic or Latino | 2 | 16.7% |
| Asian | 1 | 8.3% |
| Black or African American | 1 | 8.3% |
| | | |
| *Handedness* | | |
| Right | 11 | 91.7% |
| Left | 1 | 8.3% |

**Table 3.** *Descriptive Statistics: Reaction Time (ms)*

| *Relatedness* | *Distance* | *Mean RT (ms)* | *SD* | *N* | *Number of Occurences* |
|---|---|---|---|---|---|
| Related | 22.5° | 648.23 | 172.21 | 12 | 361 |
| | 45° | 687.06 | 140.55 | 12 | 337 |
| | 67.5° | 750.96 | 131.10 | 12 | 331 |
| | 90° | 829.79 | 293.89 | 12 | 341 |
| | 112.5° | 768.45 | 333.08 | 12 | 345 |
| Independent | 22.5° | 998.59 | 197.36 | 12 | 707 |
| | 45° | 1062.01 | 161.72 | 12 | 704 |
| | 67.5° | 1208.79 | 397.35 | 12 | 662 |
| | 90° | 1233.45 | 335.90 | 12 | 685 |
| | 112.5° | 1199.31 | 312.19 | 12 | 647 |

**Table 4.** *Factorial ANOVA of Within Subject Effects: Distance, Relatedness, Reaction Time*

| *Factor(s)* | *Type III Sum of Squares* | *Degrees of Freedom* | *Mean Square* | *F* | *Sig.* | *Partial Eta Squared* | *Observed Power[a]* |
|---|---|---|---|---|---|---|---|
| Distance x Relatedness | 44043.456 | 4 | 11010.864 | .473 | .755 | .041 | .151 |
| Error (Distance x Relatedness) | 1024112.505 | 44 | 23275.284 | | | | |
| **Distance** | **714751.064** | **4** | **178687.776** | **3.288** | **.019*** | **.230** | **.683** |
| Error(Distance) | 2391514.976 | 44 | 54352.613 | | | | |
| **Relatedness** | **4885155.210** | **1** | **4885155.210** | **140.958** | **.000***** | **.928** | **1.000** |
| Error (Relatedness) | 381224.028 | 11 | 34656.730 | | | | |

* $p < .05$
** $p < .01$
*** $p < .001$
*a. Computed using alpha = .05*

**Table 5.** *Fisher's LSD Comparisons of Distance on Reaction Time*

| *Distance I* | *Distance II* | *Mean Difference (I-2)* | *Std. Error* | *Sig.* | *Interval for Difference* | |
|---|---|---|---|---|---|---|
| | | | | | *Lower Bound* | *Upper Bound* |
| 1 | 2 | -51.121 | 44.675 | .277 | -149.449 | 47.207 |
| | 3 | -156.465 | 82.690 | .085 | -338.464 | 25.533 |
| | **4** | **-208.214*** | **58.117** | **.004*** | **-336.128** | **-80.300** |
| | **5** | **-160.474*** | **58.956** | **.020*** | **-290.235** | **-30.712** |
| 2 | 1 | 51.121 | 44.675 | .277 | -47.207 | 149.449 |
| | 3 | -105.344 | 60.782 | .111 | -239.124 | 28.436 |
| | **4** | **-157.093*** | **61.001** | **.026*** | **-291.356** | **-22.830** |
| | 5 | -109.352 | 66.054 | .126 | -254.737 | 36.032 |
| 3 | 1 | 156.465 | 82.690 | .085 | -25.533 | 338.464 |
| | 2 | 105.344 | 60.782 | .111 | -28.436 | 239.124 |
| | 4 | -51.749 | 74.033 | .499 | -214.695 | 111.197 |
| | 5 | -4.008 | 100.366 | .969 | -224.913 | 216.897 |
| **4** | **1** | **208.214**** | **58.117** | **.004**** | **80.300** | **336.128** |
| | **2** | **157.093*** | **61.001** | **.026*** | **22.830** | **291.356** |
| | 3 | 51.749 | 74.033 | .499 | -111.197 | 214.695 |
| | 5 | 47.741 | 47.686 | .338 | -57.216 | 152.698 |
| **5** | **1** | **160.474*** | **58.956** | **.020*** | **30.712** | **290.235** |
| | 2 | 109.352 | 66.054 | .126 | -36.032 | 254.737 |
| | 3 | 4.008 | 100.366 | .969 | -216.897 | 224.913 |
| | 4 | -47.741 | 47.686 | .338 | -152.698 | 57.216 |

* $p < .05$
** $p < .01$
*** $p < .001$

**Table 6.** *Descriptive Statistics: Accuracy*

| *Relatedness* | *Angle* | *Mean Frequency of False Alarms* | *SD* | *N* | *Total Number Of False Alarms* | *Number of Occurrences* | *%* |
|---|---|---|---|---|---|---|---|
| Related | 22.5° | 0.58 | 0.67 | 12.00 | 7 | 334 | 2.10% |
| | 45° | 0.67 | 1.15 | 12.00 | 8 | 310 | 2.58% |
| | 67.5° | 0.25 | 0.45 | 12.00 | 3 | 307 | 0.98% |
| | 90° | 0.42 | 1.16 | 12.00 | 5 | 313 | 1.60% |
| | 112.5° | 0.75 | 1.22 | 12.00 | 9 | 313 | 2.88% |
| Independent | 22.5° | 0.58 | 0.90 | 12.00 | 7 | 638 | 1.10% |
| | 45° | 1.00 | 1.71 | 12.00 | 12 | 656 | 1.83% |
| | 67.5° | 0.92 | 1.24 | 12.00 | 11 | 611 | 1.80% |
| | 90° | 1.00 | 1.04 | 12.00 | 12 | 635 | 1.89% |
| | 112.5° | 2.25 | 4.16 | 12.00 | 27 | 590 | 4.58% |

**Table 7.** *Factorial ANOVA of Within Subject Effects: Distance, Relatedness, Accuracy*

| *Factor(s)* | *Type III Sum of Squares* | *Degrees of Freedom* | *Mean Square* | *F* | *Sig.* | *Partial Eta Squared* | *Observed Power*[a] |
|---|---|---|---|---|---|---|---|
| Distance x Relatedness | 7.467 | 4 | 1.867 | .750 | .563 | .064 | .222 |
| Error (Distance x Relatedness) | 109.533 | 44 | 2.489 | | | | |
| Distance | 14.033 | 4 | 3.508 | 1.172 | .336 | .096 | .337 |
| Error(Distance) | 131.767 | 44 | 2.995 | | | | |
| Relatedness | 11.408 | 1 | 11.408 | 4.632 | .054 | .296 | .501 |
| Error (Relatedness) | 27.092 | 11 | 2.463 | | | | |

* $p < .05$
** $p < .01$
*** $p < .001$
*a. Computed using alpha = .05*

**Table 8.** *Fisher's LSD Comparisons of Distance on Accuracy*

| Distance I | Distance II | Mean Difference (I-2) | Std. Error | Sig. | Interval for Difference Lower Bound | Upper Bound |
|---|---|---|---|---|---|---|
| 1 | 2 | -.250 | .298 | .420 | -.907 | .407 |
| | 3 | 5.551E-17 | .204 | 1.000 | -.449 | .449 |
| | 4 | -.125 | .255 | .633 | -.686 | .436 |
| | 5 | -.917 | .699 | .216 | -2.454 | .621 |
| 2 | 1 | .250 | .298 | .420 | -.407 | .907 |
| | 3 | .250 | .250 | .339 | -.300 | .800 |
| | 4 | .125 | .269 | .651 | -.467 | .717 |
| | 5 | -.667 | .700 | .361 | -2.207 | .874 |
| 3 | 1 | -5.551E-017 | .204 | 1.000 | -.449 | .449 |
| | 2 | -.250 | .250 | .339 | -.800 | .300 |
| | 4 | -.125 | .186 | .515 | -.534 | .284 |
| | 5 | -.917 | .743 | .243 | -2.553 | .719 |
| 4 | 1 | .125 | .255 | .633 | -.436 | .686 |
| | 2 | -.125 | .269 | .651 | -.717 | .467 |
| | 3 | .125 | .186 | .515 | -.284 | .534 |
| | 5 | -.792 | .775 | .329 | -2.497 | .914 |
| 5 | 1 | .917 | .699 | .216 | -.621 | 2.454 |
| | 2 | .667 | .700 | .361 | -.874 | 2.207 |
| | 3 | .917 | .743 | .243 | -.719 | 2.553 |
| | 4 | .792 | .775 | .329 | -.914 | 2.497 |

* $p < .05$
** $p < .01$
*** $p < .001$

**Table 9.** *Factorial ANOVA of Within Subjects Effects: Interval, Distance, and Reaction Time*

*Factorial ANOVA of Within Subjects Effects: Interval, Distance, and Reaction Time*

| Factor(s) | Sum of Squares | Degrees of Freedom | Mean Square | F | Sig. |
|---|---|---|---|---|---|
| Distance x Interval | 2875000 | 1 | 410709 | .727 | .648 |
| Error (Distance x Interval) | 2223221 | 4920 | 136154 | | |
| **Distance** | **5419000** | **1** | **5418613** | **13.272** | **.000*** ** |
| Error(Distance) | 12735044 | 6 | 12735044 | | |
| **Interval** | **52470000** | **1** | **21448836** | **9.594** | **.002** ** |
| Error (Interval) | 128693018 | 6 | | | |

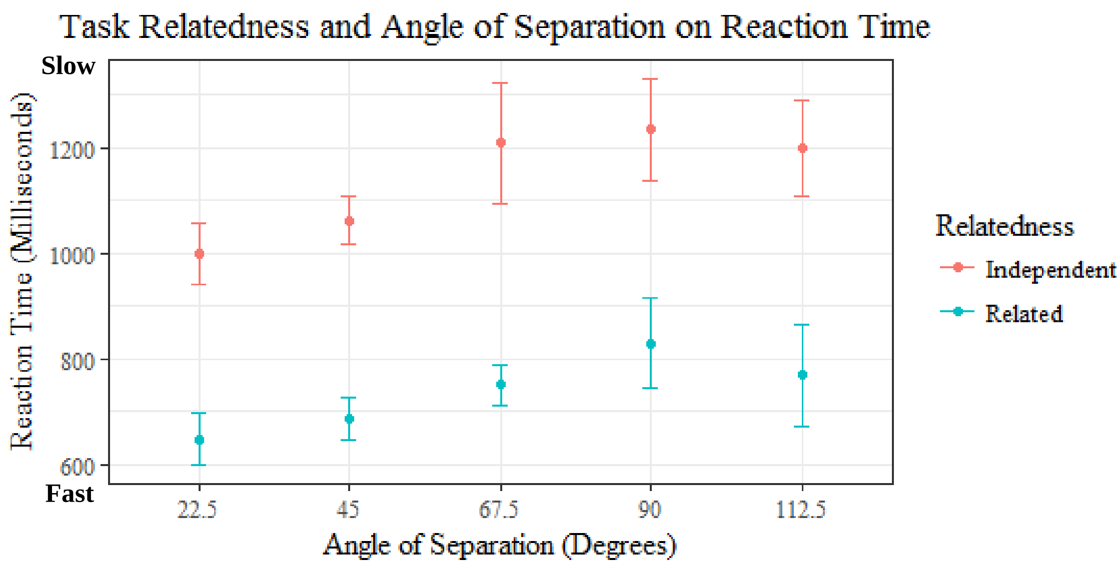
* $p < .05$
** $p < .01$
*** $p < .001$
*a. Computed using alpha = .05*
*Note: Unlike Table 4. and Table 7., this analysis was performed on all data rather than aggregate means.*

**Table 10.** *Mean Reaction Time and Number of Occurences per Interval*

| *Interval (ms)* | *Mean (ms)* | *Number of Occurrences* |
|---|---:|---:|
| 1000 | 1417.44 | 662 |
| 2000 | 1197.17 | 625 |
| 3000 | 1010.50 | 647 |
| 4000 | 1041.06 | 583 |
| 5000 | 893.79 | 609 |
| 6000 | 867.50 | 630 |
| 7000 | 806.99 | 620 |
| 8000 | 812.58 | 576 |

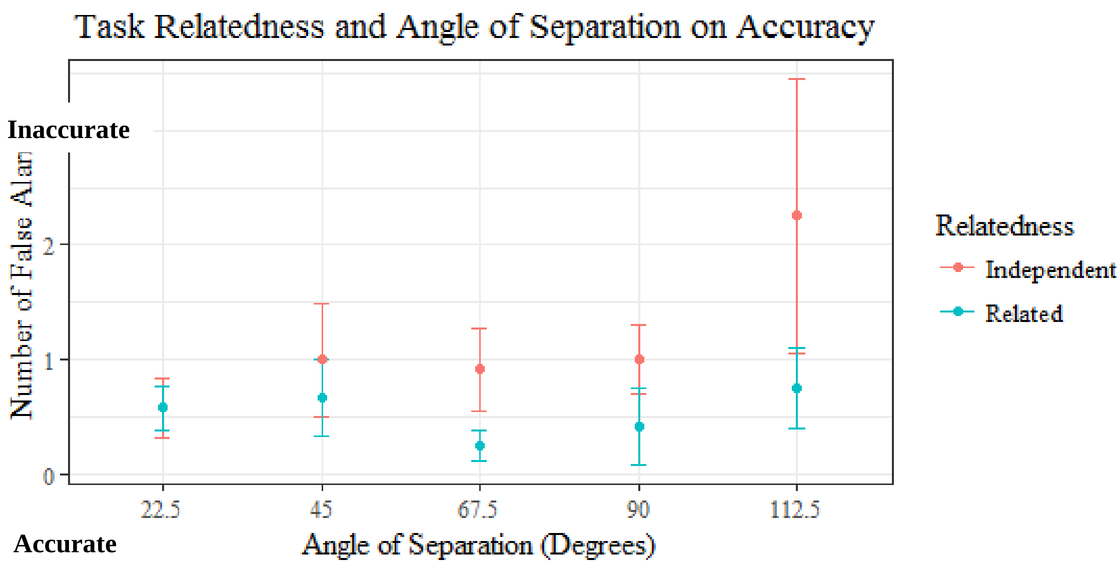
## FIGURES

**Figure 1.** *Task Relatedness and Angle of Separation on Reaction Time*



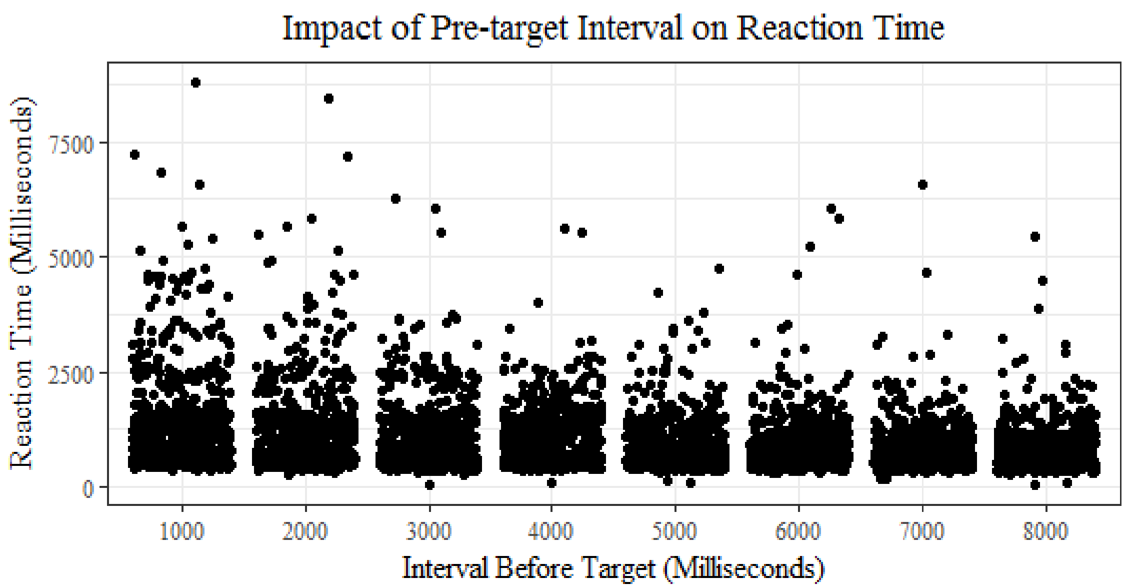

*Further distances seem to relate to slower reaction times.*
*Error bars represent standard error from the mean*
*Note: Lower reaction times indicate higher performance*

**Figure 2.** *Task Relatedness and Angle of Separation on Accuracy*




*Error bars represent standard error from the mean.*
*Note: higher false alarms indicate poor performance.*

**Figure 3.** *Impact of Pre-target Interval on Reaction Time*




*Longer intervals seem to relate to less variation, faster reaction times.*

**Figure 4.** *Impact of Pre-Target Interval on Reaction Time Between Distances*

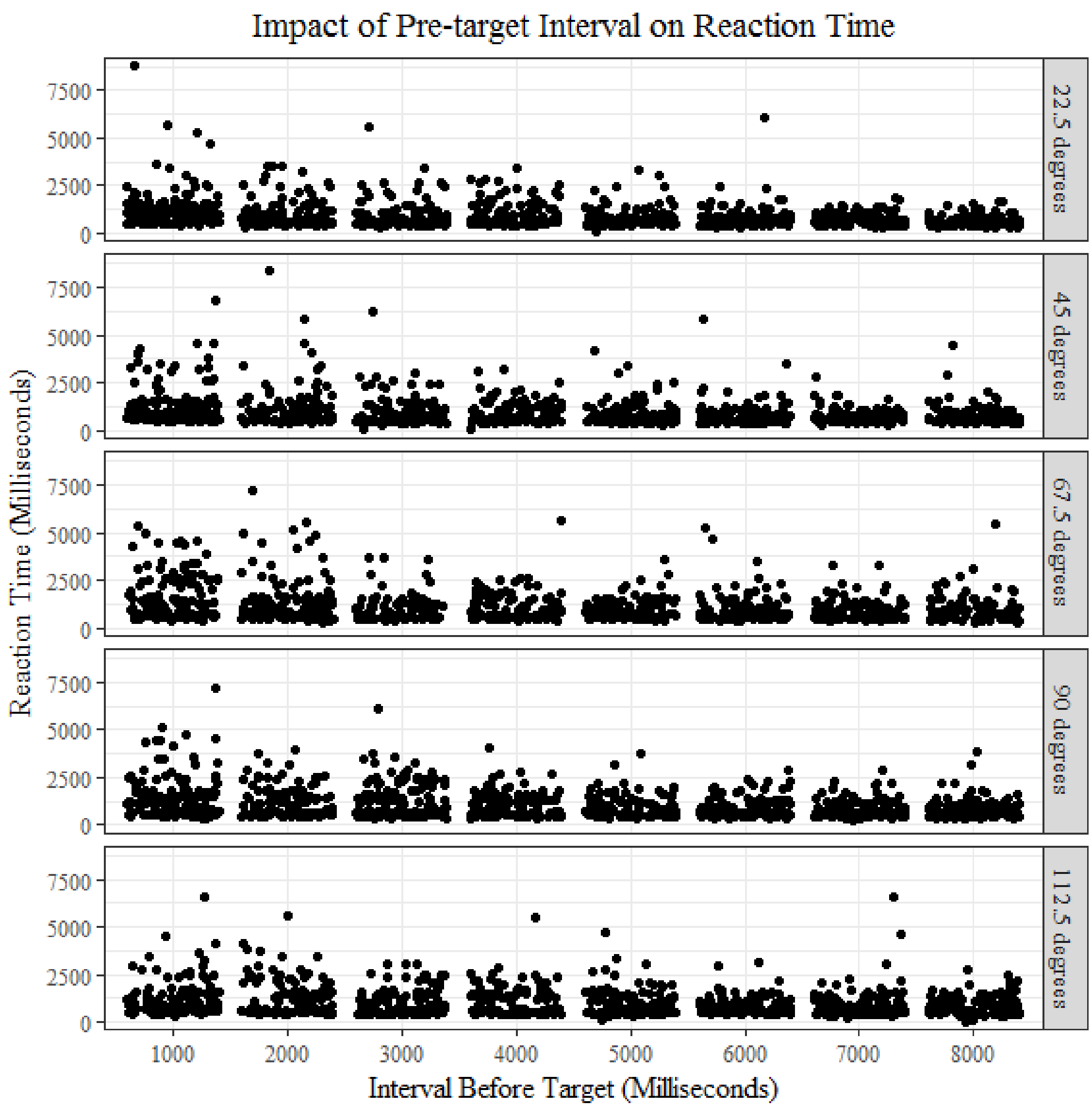


**Figure 5.** *Frequency Distribution of Interval Occurrences*

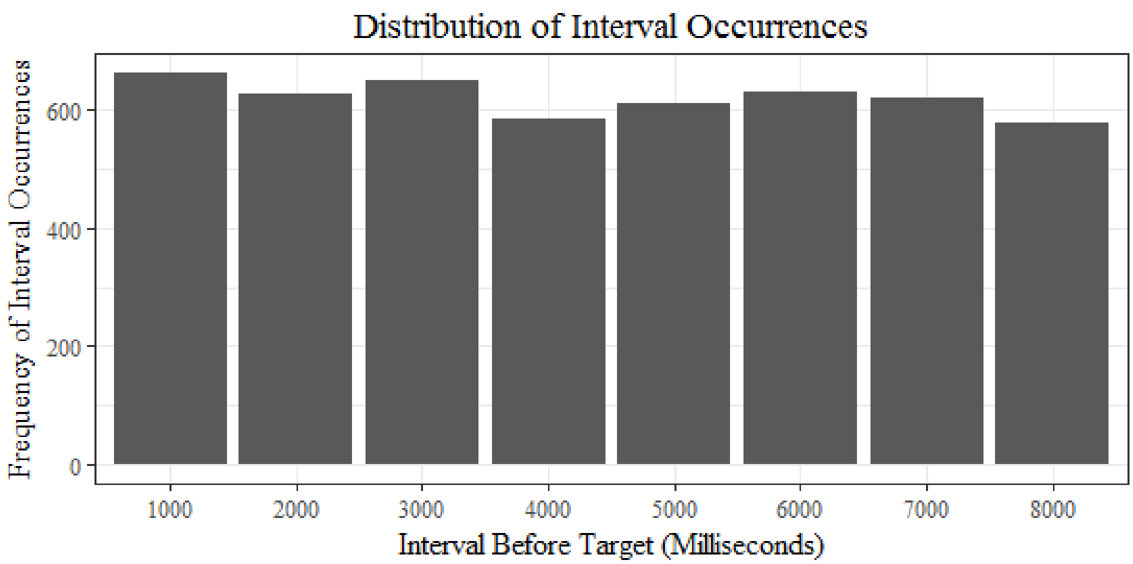



*Figure shows that intervals did not all occur the same number of times in the study.*

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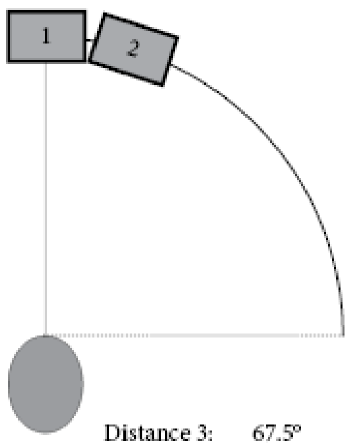
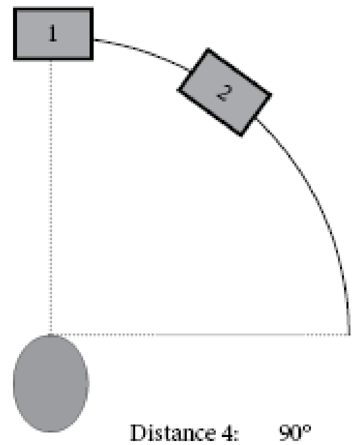
# APPENDIX A

## WITHIN-SUBJECTS SPATIAL PROXIMITY CONDITIONS. (MONITORS 1 AND 2)

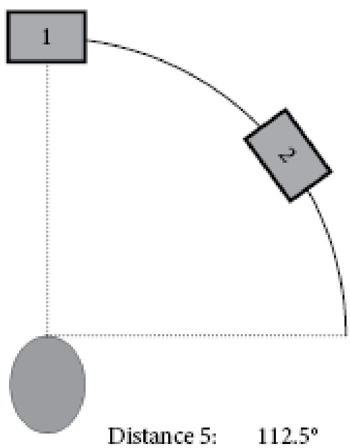
Distance 1: 22.5°



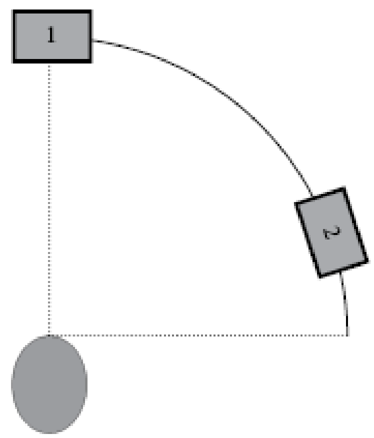

Distance 2: 45°



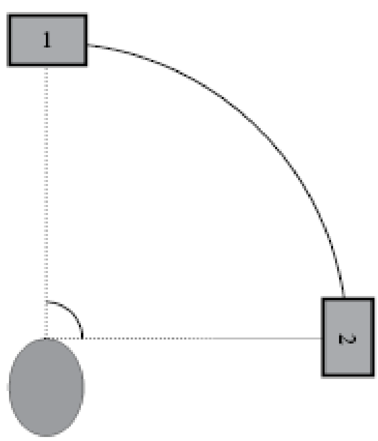

Distance 3: 67.5°




Distance 4: 90°




Distance 5: 112.5°



# APPENDIX B

# WITHIN-SUBJECTS TASK RELATEDNESS CONDITIONS

| | **Monitor 1: Patient** | **Monitor 2: Biometric** |
|---|---|---|
| **Independent:**<br><br>Target appears on Monitor 1 | **Target** | Non-Target |
| **Independent:**<br><br>Target appears on Monitor 2 | Non-Target | **Target** |
| **Related:**<br><br>Target simultaneously appears on Monitor 1 and 2 | **Target** | **Target** |

# APPENDIX C

# INFORMED CONSENT FORM

**Spatial Distance of Tasks**

I am a graduate student under the direction of Professor Russell Branaghan in the Human Systems Engineering program of Ira A. Fulton Schools of Engineering at Arizona State University. I am conducting a research study to examine how doctors pay attention to patients during surgery. You will receive 1 credit for **HSE** 101 for participation in this experiment.

I am inviting your participation, which will involve a 60 minute session consisting of completing tasks on two computer monitors. During these tasks, you will be asked to respond to specific changes in the images on each monitor. You have the right not to answer any question, and to stop participation at any time.

Your participation in this study is voluntary. If you choose not to participate or to withdraw from the study at any time, there will be no penalty, (for example, it will not affect your grade). You must be 18 or older to participate in the study and have normal vision or corrected vision.

The benefits of participating in this type of research will be to understand the impact of distance on your ability to complete tasks on two different monitors. There are no foreseeable risks or discomforts to your participation. If you feel any discomfort you may take a break at any time or end your participation.

We will ensure the protection of your confidentiality by assigning you a subject number in which your name and this consent form will not be tied to your data and will be kept in a separate location. Your responses will be confidential. The results of this study may be used in reports, presentations, or publications but your name will not be used. Results of this study will only be shared in the aggregate form.

If you have any questions concerning the research study, please contact the research team at: Richard del Rio: rdelrio164@gmail.com or Russell Branaghan: Russell.Branaghan@asu.edu. If you have any questions about your rights as a subject/participant in this research, or if you feel you have been placed at risk, you can contact the Chair of the Human Subjects Institutional Review Board, through the ASU Office of Research Integrity and Assurance, at (480) 965-6788.

By signing below you are agreeing to be part of the study.

Name:

Signature: Date:

# APPENDIX D

# VERBAL INSTRUCTIONS FOR PARTICIPANT

**For this study, your task is to monitor a patient who is going through surgery. Your goal will be to keep your medical patient healthy by responding with the mouse when the patient appears to be getting sick. You will see images appear on the two monitors. On the left, monitor you will see a patient's face, and on the right monitor you will see blood pressure and heart rate. Most of the time, the patient's face will be in a normal resting position and their blood pressure and heart rate will be normal. However, occasionally either of these images or both will become abnormal. When this happens, I would like you to respond by clicking the mouse and help get the patient back to normal.**

***direct attention to printed instructions for Monitor 1***

**In this diagram, you can see that when a patient is normal, they have their eyes closed and their mouth relaxed. Whenever the patient's eyes start to open, please respond with the mouse.**

***direct attention to the Monitor 2 instructions***

**In this diagram, you can see that when a patient is normal, their blood pressure and heart rate are within these ranges. Whenever the patient's blood pressure or heart rate go outside of these ranges, I would like you to respond with the mouse.**

**Any Questions?**

**During this study, you will participate in 5 trials of this task that will last 8 minutes long.**

**First, we will do a brief practice run for you to get used to the tasks.**

**When you are ready to begin, please read the instructions on the screen.**

APPENDIX E

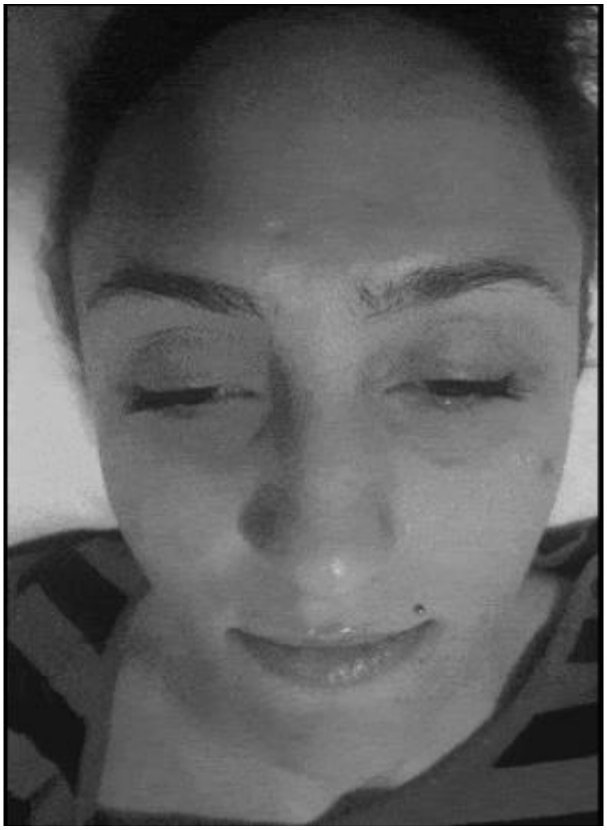
PRINTED INSTRUCTIONS:

*Monitor 1a:*

Don’t Click! Patient is Normal

*Monitor1b:*

Click! Patient is waking up.



*Monitor 2:*

# DON'T CLICK

Normal Blood Pressure (Don't click)

| Systolic | Diastolic |
|---|---|
| Less Than **120** | Less than **80** |

**100/70**

is a normal blood pressure reading

Normal Heart Rate is More than **60**

Normal Heart Rate is Less than **100**

# CLICK!

Abnormal Blood Pressure (Click)

| Systolic | Diastolic |
|---|---|
| More Than **120** | More than **80** |

**130/85**

Is an abnormal blood pressure reading

Abnormal Heart Rate is less than **60**

Abnormal Heart Rate is more than **100**

# APPENDIX F

## ON SCREEN INSTRUCTIONS:

In this test you will be presented with changing images on two monitors.

On the monitor on the left, you will be presented with a face that will change facial expressions.

When the face opens its eyes or frowns, please click the mouse.

On the monitor on the right, you will be presented with blood pressure and heart rate.

When the blood pressure or heart rate go outside of the normal thresholds (posted next to the monitor), please click the mouse.

Please click the mouse as quickly as possible when you have seen a change.

Once you have responded to either monitor or both, the computer will display

your reaction time for 1.5s.

If you respond before there has been a concerning change in blood pressure and heart rate, the reaction time posted will be a negative number. This will tell you that you have responded incorrectly.

The test will take 8 minutes to complete.

</page>

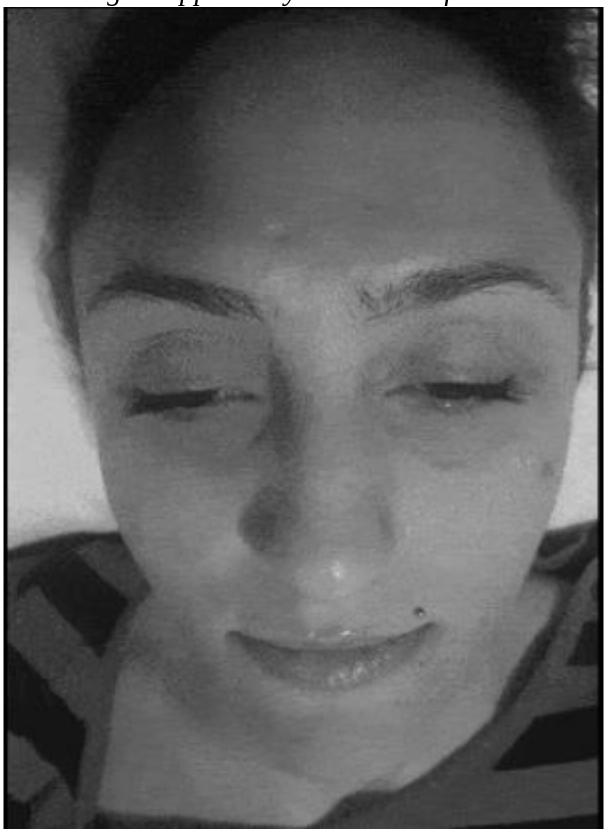
# APPENDIX G

## MONITOR 1 STIMULI: NON-TARGET .GIF

*Note: .gif was a moving image that showed breathing and minor eyelid movement.*

*Monitor 2 Stimuli: Non-Target .gif*

*Note: .gif was a moving image that showed breathing, when target happened eyelids moved from closed to open..*



*Monitor 2 Stimuli: Non-Target .gif*

*Note:.gif was a moving image where numbers changed within Normal thresholds*

| | |
|---|---|
| Blood Pressure: | 117/75 |
| Heart Rate: | 70 |

*Monitor 2 Stimuli: Non-Target .gif*

*Note:.gif was a moving image where numbers changed within Normal thresholds*

| | |
|---|---|
| Blood Pressure: | 121/76 |
| Heart Rate: | 60 |

# APPENDIX H

## DEMOGRAPHIC QUESTIONNAIRE:

# Spatial and Perceptual Distance: Consideration for Medical Head Mounted Displays

Demographics Questionnaire

* Required

Age (years) *

Your answer

Gender *

- ◯ Male
- ◯ Female
- ◯ Other: ____________

Race and Ethnicity *

- ◯ White
- ◯ Asian
- ◯ Black or African American
- ◯ Native Hawaiian or Other Pacific Islander
- ◯ American Indian or Alaska Native
- ◯ Hispanic or Latino
- ◯ Non Hispanic or Latino
- ◯ Prefer not to answer

Right or Left Handed? *

- ◯ Right Handed
- ◯ Left Handed

SUBMIT

# APPENDIX I

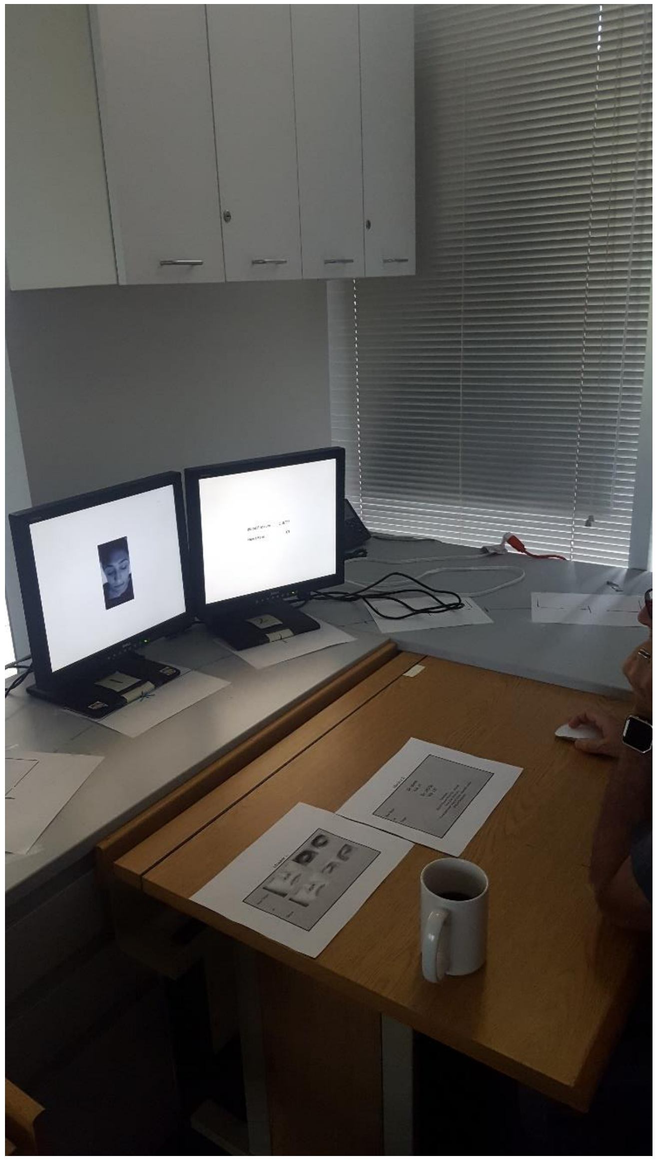
## WILLIAMS INCOMPLETE PARTIAL LATIN SQUARE DESIGN.

*Order of Distance Conditions*

| *Participant* | *1st* | *2nd* | *3rd* | *4th* | *5th* |
|---|---|---|---|---|---|
| 1 | 22.5° | 45° | 112.5° | 67.5° | 90° |
| 13 | 45° | 67.5° | 22.5° | 90° | 112.5° |
| 3 | 67.5° | 90° | 45° | 112.5° | 22.5° |
| 4 | 90° | 112.5° | 67.5° | 22.5° | 45° |
| 5 | 112.5° | 22.5° | 90° | 45° | 67.5° |
| 6 | 90° | 67.5° | 112.5° | 45° | 22.5° |
| 7 | 112.5° | 90° | 22.5° | 67.5° | 45° |
| 8 | 22.5° | 112.5° | 45° | 90° | 67.5° |
| 9 | 45° | 22.5° | 67.5° | 112.5° | 90° |
| 10 | 67.5° | 45° | 90° | 22.5° | 112.5° |
| 11 | 22.5° | 45° | | 67.5° | 90° |
| 12 | 45° | 67.5° | 22.5° | 90° | 112.5° |

APPENDIX J

PHOTOGRAPH OF PILOT PARTICIPANT AT APPARATUS



# APPENDIX K

## IRB APPROVAL

**ASU Knowledge Enterprise Development**

APPROVAL: EXPEDITED REVIEW

Russell Branaghan
IAFSE-PS: HSE Programs
480/727-1390
Russell.Branaghan@asu.edu

Dear Russell Branaghan:

On 3/20/2017 the ASU IRB reviewed the following protocol:

| | |
|---|---|
| Type of Review: | Initial Study |
| Title: | Spatial Distance and Attention: Consideration for Medical Head-Mounted Displays |
| Investigator: | Russell Branaghan |
| IRB ID: | STUDY00005931 |
| Category of review: | (7)(b) Social science methods, (7)(a) Behavioral research |
| Funding: | None |
| Grant Title: | None |
| Grant ID: | None |
| Documents Reviewed: | • Instruction script, Category: Participant materials (specific directions for them);<br>• Monitor 1 Target Stimulus, Category: Measures (Survey questions/Interview questions /interview guides/focus group questions);<br>• Monitor 2 non-target Stimulus, Category: Measures (Survey questions/Interview questions /interview guides/focus group questions);<br>• Recruitment paragraph on SONA, Category: Recruitment Materials;<br>• Monitor 2 non-target Stimulus, Category: Measures (Survey questions/Interview questions /interview guides/focus group questions);<br>• Monitor 1 Non-Target Stimulus, Category: Measures (Survey questions/Interview questions /interview guides/focus group questions);<br>• On Screen Instructions, Category: Participant |

Page 1 of 2

| | |
|---|---|
| | materials (specific directions for them);<br>• Consent Form, Category: Consent Form;<br>• Spatial Distance and Attention, Category: IRB Protocol; |

The IRB approved the protocol from 3/20/2017 to 3/19/2018 inclusive. Three weeks before 3/19/2018 you are to submit a completed Continuing Review application and required attachments to request continuing approval or closure.

If continuing review approval is not granted before the expiration date of 3/19/2018 approval of this protocol expires on that date. When consent is appropriate, you must use final, watermarked versions available under the "Documents" tab in ERA-IRB.

In conducting this protocol you are required to follow the requirements listed in the INVESTIGATOR MANUAL (HRP-103).

Sincerely,

IRB Administrator

cc: Richard del Rio
Erin Chiou
Robert Gray
Richard del Rio