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Assessment of Visual Field Performance Asymmetries While Utilizing Aircraft Attitude Symbology

George A. Reis

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ASSESSMENT OF VISUAL FIELD PERFORMANCE ASYMMETRIES WHILE UTILIZING AIRCRAFT ATTITUDE SYMBOLOGY

DISSERTATION

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DEPARTMENT OF THE AIR FORCE
AIR UNIVERSITY

AIR FORCE INSTITUTE OF TECHNOLOGY

Wright-Patterson Air Force Base, Ohio

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George A. Reis, BS, MS

Civilian, USAF

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Abstract

Research was conducted to understand the effect of symbology placement in augmented reality displays, such as head-mounted displays for piloting and dismount operators. Two experiments were conducted to examine visual performance asymmetries when perceiving complex, meaningful visual stimuli, such as the Arc Segment Attitude Reference (ASAR). The ASAR symbology represents an aircraft's vertical flight path and roll angles. Experiment 1 examined participants' performance while recalling and reporting various attitudes of ASAR symbology and a Gabor patch, which were briefly presented in the peripheral visual field. This presentation required the participants to rely on covert attention to assess the visual stimuli. Performance was assessed for coordinate and categorical judgments at various display locations. The results were consistent with the horizontal-vertical anisotropy literature, which implies that performance is better for stimuli placed on the horizontal meridian as compared to stimuli placed on the vertical meridian. Experiment 2 assessed asymmetries for continuously presented stimuli, which permit the participants to flexibly attend to the peripherally located stimulus using overt or covert attention. Participants performed a visual psychomotor task using stimuli in the center of a display while monitoring peripherally located ASAR or Gabor patches. The visual stimulus in the periphery was displayed constantly and observers could move their gaze on such stimuli. This experiment sought to understand if eye movement is paired better between a center task and the various peripheral locations. No performance differences were found among the different peripherally located stimulus placements, but eye tracking data suggested efficient visual processing for the horizontal meridian.

Acknowledgments

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George A. Reis

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List of Abbreviations

AE	Absolute Error
AOE	Absolute Offset Error
A-PI	Aggregated Percent Incorrect
A-AE	Aggregated-Absolute Error
A-RT	Aggregated-Response Time
ANOVA	Analysis of Variance
ASAR	Arc Segment Attitude Reference
AR	Augmented Reality
AV	Augmented Virtuality
CGI	Computer-generated Imagery
DV	Dependent Variable
FOV	Field of View
FPD	Flight Parameter Directions
FLANDERS	Flinders Handedness Survey
HMD	Head-mounted Display
HVA	Horizontal-Vertical Anisotropy
IV	Independent Variable
LSD	Least Significant Difference
M	Mean
MOT	Multiple Object Tracking
NED	Near-eye Display
NA	Non-applicable
NDFR	Non-Distributed Flight Reference
RT	Response Time
SA	Situation Awareness
SE	Standard Error
TSD	Tactical Situation Display
TPD	Total Performance Decrement
VFP	Vertical Flight Path
VMA	Vertical Meridian Asymmetry

ASSESSMENT OF VISUAL FIELD PEROFRMANCE ASYMMETIES WHILE USING AN AIRCRAFT ATTITUDE SYMBOLOGY

I. Introduction

General Issue

Pervasive *augmented reality* (AR) is poised to drastically expand the computing platforms that humans use to acquire and interact with information, as well as communicate and collaborate with other human-machine systems (Grubert, Langlotz, Zollmann, & Regenbrecht, 2017). In an AR system, the user perceives both the real world and overlaid computer-generated information on a display that can be hand-held at arm's length (e.g., a smartphone, tablet) or on a near-eye display (NED). NEDs encompass displays that can be held near the eyes (e.g., night vision scopes) and head-mounted displays (HMDs). In the case of an HMD, the real world view may be observed either with an optical see-through display or a real-time video display wherein video is obtained from sensors proximal to the user's eyes and presented in near real-time on electronic displays near to the eyes (Azuma, 1997). Azuma describes AR as a system that is:

(1) combined of real and virtual information

(2) interactive in real-time

(3) registered in the three dimensional (3-D) environment

AR bridges the gap between the real world and virtual environments and can be classified under the term of *mixed reality*, which spans the *virtuality continuum*, with real environments on one end and virtual environments on the other end (see Figure 1). AR is situated closer to real environments as real world objects comprise the majority of the perceived visual stimuli (Milgram, 2006). Likewise, *augmented virtuality* (AV), presides closer to virtual environments as virtual information comprises the majority of the perceived stimuli.

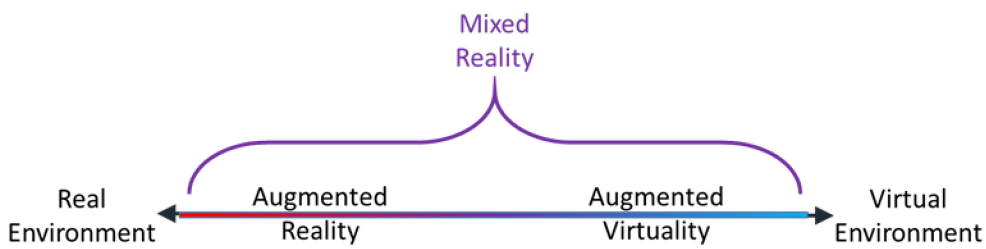


***Figure 1*. The virtuality continuum—adapted from Milgram (2006).**

In an AR context, operators visually perceive the real world to execute the foundational task and concurrently perceives virtual information, computer-generated imagery (CGI), or symbology of varying amount and complexity to gain additional information which enhances their *situation awareness* (SA) of, and interaction with, the real-world foundational task. Additionally, the CGI information may provide information relevant to some distant or non-viewable person, place, or object, unrelated to the foundational task at hand. To better illustrate such situations, consider the following scenario. An operator is navigating on foot from waypoint to waypoint. The operator may be a military dismount operator, a recreational hiker, a member of a search-and-rescue team, or a tourist exploring a large city. The foundational task at hand is to move from point to point while avoiding hazards and determining how to navigate potential obstacles. The operator is focused and attentive to near and far objects in the environment. When using an AR display, these individuals may additionally perform the concurrent task of understanding the information on an HMD, which may aid short or long term path planning. For example, a compass on the HMD may provide directional orientation or cues indicating the direction to the next way point. Figure 2 illustrates this scenario.

***Figure 2*. Example scenario demonstrating utility of AR symbology and potential placement on display.**

The concurrent perception and understanding of the AR information in the periphery may be obtained through *covert attention*. In applying covert attention to the periphery, our ocular focal point remains still while our attentional focal point orients to another location somewhere in the peripheral visual field (Posner, 1980). That is, our attention shifts without any discernible movement in body, head, or eyes, to better perceive a stimulus. Conversely, in *overt* attention, we move our head, body, or eyes to align with the stimulus with which we are interested (for reviews of overt and covert attention see Wickens & McCarly, 2008a, and Wright & Ward, 2008).

Considering the scenario mentioned above, in essence, there are two visual information flows: 1) information from the real world, attended to overtly and 2) AR information, i.e., alphanumeric characters, shapes, and strokes of lines or curves, which may be attended to overly or covertly. The current research is concerned with how well an operator can divide and control attention to perceive, understand, and respond to both information flows. Unfortunately, human visual attention is limited. The degree to which the operator can process both tasks in parallel will be degraded compared to processing of the individual tasks. Thus performance will vary, depending upon the operator's success in distributing attention to the peripheral information while concurrently attending to the real world elements. It is possible that the operator may covertly attend to the peripheral information while concurrently attending to the real world information. However, the environment or the tasks' requirements may preclude parallel processing, forcing the operator to engage the tasks sequentially and cyclically, employing attention switching (Wickens & McCarley, 2008b). Therefore, it is possible for the operator to attend to the information within one of these visual flows without attending to the other at any moment in time. As a result, the operator risks attending to one of these visual flows at a point when time critical information is displayed within the other visual flow. In the scenario, the individual may attend to the augmented information at the time they encounter a tree limb or a dip in terrain, potentially causing a loss of balance, a fall, and injury. In terms of an attention resource pool, the real world information may be favored by foveal vision and the peripheral AR information may be processed ambiently. These two aspects of visual processing, focal and ambient vision, are supported by separate resources as evidenced by efficient time sharing, being processed by different brain structures, and differing in the type of information processing that is engaged (Wickens & McCarley 2008c).

How well an operator can visually process and formulate appropriate actions based on these two sources of information, it is postulated, will depend greatly on the design and placement of the symbols within the HMD. Unfortunately, the hardware development of various HMDs, particularly for military use, is outpacing the rate of human factors knowledge to facilitate robust application of AR information. This issue should concern many if the requirement to wear HMDs is introduced across various career fields (e.g., warehouses, factories, maintenance, first responders, and military personnel) without suitable knowledge on how to design the systems to enhance, rather than degrade, human performance. To meet the needs of designers of HMD interfaces, application of principles that enhance the effectiveness of visual displays should be developed.

Indeed display design has been conducted to understand the legibility, saliency, coding, display arrangement and grouping of information in traditional, direct-view display systems—for summary, see Proctor and Van Zandt (2018). In addition, research has explored methods for determining the information requirements for traditional displays (Bisantz & Roth, 2016), leading to various display design approaches and methods for optimizing the representation of information (e.g., graphical arts, psychophysical, attention-based, problem solving/decision, and meaning-processing) (Bennett, Nagy, & Flach, 2012). While not originally designed for AR systems in mind, much of this knowledge and many of these methods may be extended to the design of AR systems. However, lacking in the display design literature, and particularly significant to AR displays, is an understanding of how perceptual asymmetries in the human visual system may impact design. Perceptual asymmetries are a characteristic of our perceptual system to sample environmental information unevenly. These asymmetries may result from the human eye-brain system's ability to more efficiently sample visual stimuli in one specific spatial location over other spatial locations or responding differently to the visual stimulus at different locations in the visual field. It is believed that this phenomena results from the evolution of our visual system to enhance our ability to perform everyday tasks, with the limited, available neural circuitry in the eye-brain system (Gunturkun & Ocklenburg, 2017; Rogers, Zucca, & Vallortigara, 2004; Toga, Narr, Thompson, & Luders, 2009; Vallortigara & Rogers, 2005) .

A commonly known asymmetry is that of foveal versus peripheral visual acuity. This functional asymmetry is due primarily to the asymmetric distribution between cone and rod photoreceptors in the retina and their connections to retinal ganglion cells. Visual acuity excels towards the center fovea because of the residing tightly packed cones, specialized for very high spatial resolution, and the fact that relatively few cones are connected to corresponding retinal ganglion cells. Acuity systematically degrades away from this central point, into all other parts of the retina as the cone density decreases and the number of rods and cones connected to each retinal ganglion cell increases (Bedell, 2002). However, we must understand the interplay between this asymmetry and others in the larger eye-brain system. For example, another inherent property of our visual system is an asymmetry resulting from our brain's two hemispheres responding differently to a visual stimulus and its projected placement on the retina (Hellige, 1993; Rogers & Vallortigara, 2017).

While these and other asymmetries have been studied extensively in the visual science and perception literature, this research often utilizes basic visual stimuli such as Gabor patches (Frederickson, Bex, & Verstraten 1997; Graham, 1989, Chapter 2). Little research has explored the effect of these asymmetries with more meaningful, more complex visual stimuli, such as the symbology designed for use in NEDs.

A variety of real world symbology designs are present across various HMDs. Symbology of particular interest to the U.S. Air Force is the Arc Segment Attitude Reference (ASAR) (Fischer & Fuchs, 1992). The ASAR was created to represent an aircraft's roll and vertical flight path (VFP) angles in a coordinated fashion. The ASAR includes a fixed 'ownship' symbol that represents the aircraft's roll and VFP angles by its relation to a half-circle arc surrounding the ownship, as shown in Figure 3. A modified version of the original ASAR, which was designed specifically for use in HMDs, is the Non-Distributed Flight Reference (NDFR) (Geiselman, Havig, & Brewer, 2000). In the NDFR, the same ASAR symbology is accompanied by digital information to communicate heading, speed, and altitude, as shown in Figure 4. Independent of the ASAR or NDFR location in the display, its interpretation as an attitude reference is consistent.

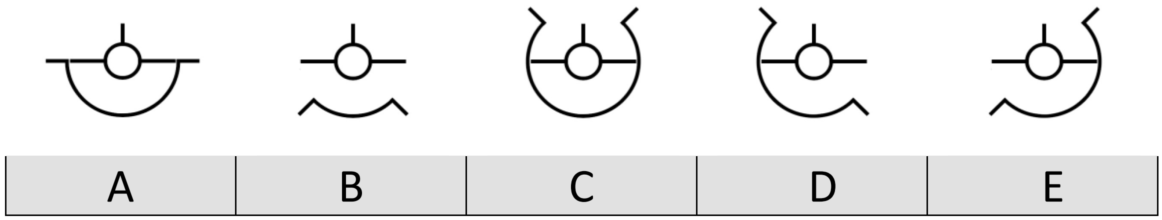


Figure 3. **The ASAR showing climb, dive, rolling left and right. The ASAR representing (A) straight and level flight. (B) 45° climb (C) 45° dive (D) 45° roll left (E) 45° roll right. Note: the ASAR can represent deviations in both roll and VFP at the same time but is not shown here.**

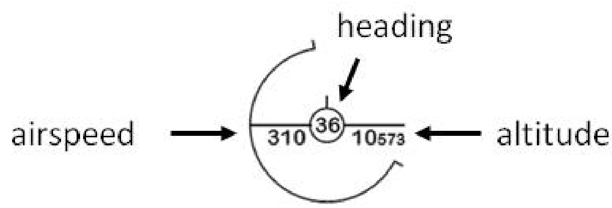


Figure 4. **Non-Distributed Flight Reference (NDFR). The NDFR showing roll and VFP angles in analog fashion and heading, air speed and altitude through digital information. Note: here the NDFR is representing deviations in both roll and VFP at the same time.**

Problem Statement

The ASAR's implementation in HMDs for off-boresight line-of-sight positioning has been researched and has been found to produce performance benefits over more traditional symbology under some contexts (Geiselman et al., 2000; Jenkins, Thurling, Havig, & Geiselman, 2002). Under this past research, however, the placement of the ASAR was usually somewhere on the center vertical meridian of the test display. Any effects due to the placement of the ASAR on this meridian were not studied. More recent research (Geiselman, Williams, & Schnell, 2017) has assessed the ASAR and NDFR in studying spatial disorientation and providing situation awareness, with the attitude symbology only displayed in the upper right part of the HMD.

The problems we wish to better understand are:

1) "How do visual field asymmetries influence visual processing performance of symbology, such as the ASAR, within a display?" and
2) "Can we take advantage of these asymmetries to determine guidelines for placement of symbology on displays in such a way to enhance human performance?"

Research Objectives/Questions/Hypotheses

The research questions are tied to the context of aircraft control in conjunction with asymmetries observed in the vision science literature. These asymmetries relate to the placement of visual stimuli in visual field and the type of visual spatial processing that an observer employs. It is hypothesized that we spatially process information in either a categorical or coordinate manner (Kossyln, Koenig, Barrett, & Backer Cave, 1989). In categorical processing, we relate objects to each other categorically—in gross, global relations. For example, in categorical processing we assess if an object is above or below another object, if an object is to the left or right of another, if an object is in or out of some defined area, or if an object is on or off another object. In coordinate processing, we relate objects to each other through a measuring system. For example, in coordinate processing, we assess that object A is 10 meters to the left of object B. In terms of assessing the ASAR under categorical processing, we might interpret the ASAR symbology rolling left or right. We might also interpret the ASAR along its vertical flight path and say if the ASAR is climbing or diving. In terms of assessing the ASAR under coordinate processing, we might interpret the ASAR's roll deviation or climb/dive deviation from straight and level flight; for example, 45 degree roll or 30 degree dive. Specifically, the research questions are:

1) What is the difference in visual processing performance due to the placement of the ASAR and a Gabor patch at various peripheral locations, under the contextual combinations of flight attitude and type of spatial processing employed:
    a. Flight Attitude:
        i. Rolling left at low angles
        ii. Rolling left at high angles
        iii. Rolling right at low angles
        iv. Rolling right at high angles
        v. Climbing up at low angles (NA to the Gabor stimulus)
        vi. Climbing up at high angles (NA to the Gabor stimulus)
        vii. Diving down at low angles (NA to the Gabor stimulus)
        viii. Diving down at high angles (NA to the Gabor stimulus)
    b. Spatial Processing Employed:
        i. Categorical
        ii. Coordinate

And

2) Are these differences sustained as one moves from experimental paradigms intended to explore visual function to more realistic conditions which include multitasking and free eye movements within a fixed visual field.

This research is not interested in the differences between categorical and coordinate conditions as both types of spatial processing are deemed important in the realm of spatial disorientation and aircraft control. However, within categorical and within coordinate conditions, it is important to understand if left visual field placement of symbology is processed differently than right visual field placement. Similarly, the four flight parameter directions (FPDs)—rolling left, rolling right, climbing up, diving down—are equal in importance as well. However, as mentioned above, the ASAR's various roll and climb/dive angles may affect how it is perceived, thus ASAR roll and VFP angles should be assessed at different levels. Lastly, as this research seeks to extend the visual science literature, which predominantly employed Gabor patches as stimuli, the Gabor will act as a baseline to compare against the ASAR, provide validation of the experimental set-up, and help explain experimental results. The Gabor and ASAR stimuli can be easily compared for roll. That is, the degree tilt in a Gabor patch can be related to the degree of roll (i.e., tilt) of the arc in the ASAR. However, there is no easy comparison for the change in vertical flight path for the Gabor patch which corresponds to a change in the ASAR; hence, no analyses will be conducted with the Gabor under the FPD of climb up or dive down.

Research Hypotheses in Null Form

To understand and describe asymmetries of interest, it is useful to characterize the visual field. Here we will use a polar coordinate system in which the polar angle with respect to a horizontal line extending to the right of the center of the visual field is referred to as the 0 degree ***hemimeridian.*** The research hypotheses, incorporating the independent variables *hemimeridian* and *angle* are listed below.

For ASAR and Gabor as the peripheral stimulus processed under **covert** attention:
H_0: There are no differences in visual processing performance due to the interaction effect between hemimeridian (locations of the ASAR or Gabor) and angle **(the degree of the roll).**
H_0: There are no differences in visual processing performance due to the main effect of hemimeridian (locations of the ASAR or Gabor).
H_0: There are no differences in visual processing performance due to the main effect of Angle **(the degree of the roll)**.

For ASAR only as the peripheral stimulus processed under **covert** attention:
H_0: There are no differences in visual processing performance due to the interaction effect between hemimeridian (locations of the ASAR) and angle **(the climb/dive angle).**
H_0: There are no differences in visual processing performance due to the main effect of hemimeridian (locations of the ASAR).
H_0: There are no differences in visual processing performance due to the main effect of angle **(the climb/dive angle).**

For ASAR and Gabor as the peripheral stimulus processed under free-viewing **(overt and covert attention)** and with the additional demand of performing a central task:
H_0: There are no differences in visual processing performance of the combined central and peripheral tasks the due to the main effect of hemimeridian (locations of the ASAR or Gabor).
H_0: There are no differences in the gaze time within the central task region when the ASAR or GABOR is presented across various peripheral locations, represented through the variable hemimeridian
H_0: There are no differences in the gaze time within the peripheral region when the ASAR or GABOR is presented across various peripheral locations, represented through the variable hemimeridian.
H_0: There are no differences in the gaze time within the in-between region when the ASAR or GABOR are presented across various peripheral locations, represented through the variable hemimeridian.
H_0: There are no differences in the gaze time within the non-applicable region when the ASAR or GABOR is presented across various peripheral locations, represented through the variable hemimeridian.

Investigative Questions

The major overarching investigative question of this dissertation is: Are visual performance field asymmetries, from the vision science literature, evident and to what degree, in operationally relevant stimuli and under more operationally relevant experimental conditions. We can outline several more concise questions from this inquiry as it pertains to the experimental set-up, the stimuli, and variables chosen in this research.

(1) Will a Gabor patch stimulus produce similar results as past asymmetry research with the current experimental set-up?

(2) What are the best positions for processing a Gabor patch with the current experiment set-up?

(3) What are the best positions for processing an ASAR with the current experiment set-up?

(4) Does visual processing performance of an ASAR trend in the same manner as a Gabor patch?

(5) What are the consequences on visual processing performance when engaging with Gabor and ASAR stimuli at various angle representations?

(6) How well does the categorical\coordinate spatial processing dichotomy hold with the ASAR and Gabor under the current experimental conditions?

(7) What can we infer between the results from Experiment 1, where the task was designed so covert attention would be employed with no central task and from Experiment 2, where the experiment allowed the participants to use overt attention and contained an extremely attention drawing task?

(8) From Experiment 2, what can we infer from where participants were looking?

Methodology

The methodology employed to accomplish this dissertation involved first reviewing the vision science literature and determining what were appropriate and interesting variables to explore. Concurrently, there was an examination of Air Force relevant symbology. An intersection of the vision science literature in visual field performance asymmetries and the symbology review yielded the current experimental set up.

A pilot study was conducted and the results were published in the International Symposium of Aviation Psychology, 2019 (Reis, Geiselman, Miller, 2019). In this dissertation, a more robust experiment building from that pilot study is presented as Experiment 1 and a complementing study incorporating more realistic perceptual and cognitive functioning is presented as Experiment 2. The first experiment observed visual performance when people employ covert attention. The second experiment observed participants' behavior and performance when they could employ covert or overt attention to view the ASAR.

The first experiment was designed to follow a common protocol for studying visual asymmetries in which stimuli were presented briefly in the peripheral visual field to preclude eye movements fixating on the stimuli. To accomplish this study, the visual field was constrained within a circular area with a diameter of 28.5 degrees of visual angle. Participants fixated at a target at the center of the circular area and stimuli were presented at an eccentricity of 13 degrees of visual angle from the point of fixation along one of eight hemimeridians. Figure 5 shows the geometries of the locations of where visual stimuli in the study appeared.

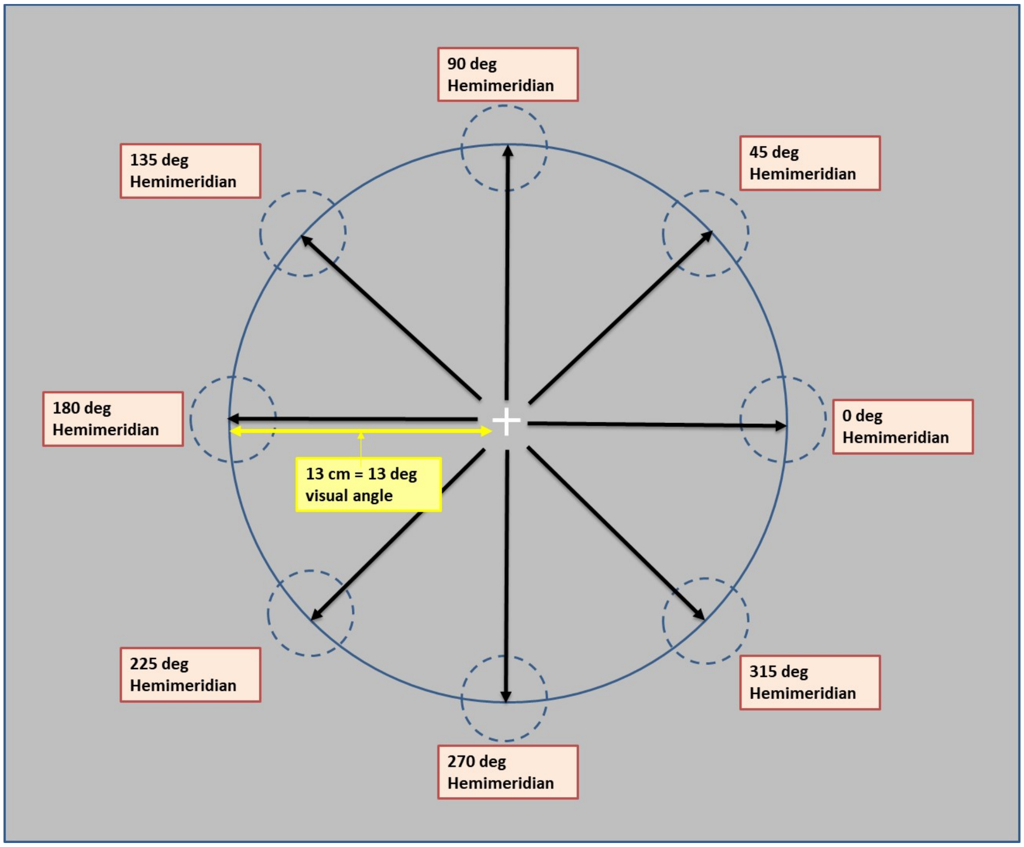


***Figure 5*. Geometries of the on-screen task. The dotted blue circles indicate the locations in the field of view where a visual stimulus could be presented. The hemimeridians are shown as the black arrowed-ended lines. The eccentricity of the locations will be at 13° of visual angle from center gaze (with a 57 cm eyes-to-screen distance the locations correspond to 13 cm from center).**

In Experiment 2, the problem to understand was if asymmetries exist when overt attention is employed. In other words, the visual stimulus in the periphery is constantly displayed and the participants could move their eyes and gaze on such stimuli. If people are engaged in a dual task scenario where they have to monitor the center of a display and a stimulus in the periphery, does it matter if the eye movement is paired between the center task and the various other peripheral locations (i.e., is there an optimal pairing of the center task and the location of where a visual stimulus is in the periphery). In the 2nd experiment, a tactical situation display (TSD) was used as a center task, having a diameter of 8 cm (equaling 8 deg of visual angle). Visual stimuli were tested in the same eight hemimeridian locations as in the first experiment (see Figure 6).

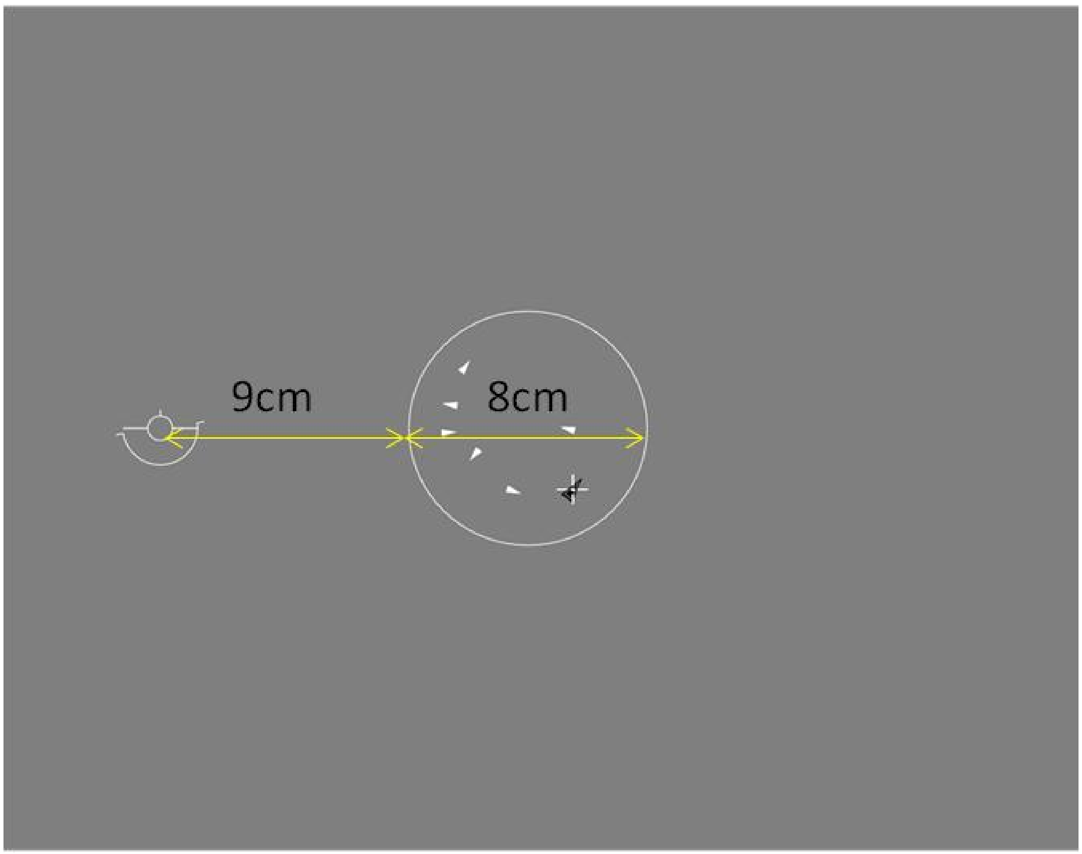


Figure 6. **Example display in Experiment 2. Tactical situation display is located in the center of the screen while the peripheral visual stimuli were tested in each of the eight hemimeridian locations – here shown at the 180 deg hemimeridian location.**

Assumptions/Limitations

A potential limitation of the proposed research is that the actual display is not an HMD but rather a desktop display. The use of the two experiments' display was necessary to obtain a baseline understanding of the variables of interest, as existing HMDs may exhibit imaging artifacts (e.g., ghosting, blur, misalignment) which often increase in magnitude with eccentricity from the center of the display. Therefore, the use of a display with better optical control is necessary to avoid confounding the variables of interest with these display artifacts. It is the hoped that future systems will have reduced artifacts making it possible to verify these results on actual HMDs. Although Experiment 2 mimicked a real operational type task in the central part of the display, we are still exploring behavioral performance in a laboratory setting. It is not clear if results obtained from this current research would truly represent those obtained in a real operational environment. However, simplifying the task makes it more likely that participants who are naïve to the domain of aircraft control and symbology will respond similarly to aircraft pilots or other individuals who are experts in the domain of application for any setting. The use of virtual reality for supplying a potential more realistic environment may need to be explored as this would allow for control of variables, but at the same time provide the essence needed to understand how people react to the nuances of real environments.

Implications

The results from this research should provide evidence for or against the general premise that visual field asymmetries will significantly affect human performance while using an AR system and should, therefore, play a role in the design of information for these systems, especially those including HMDs. The information obtained from this research should help guide the design of various information sets in HMDs across multiple operational domains (aircraft control, ground trekking). Moreover, the results could help guide the design of interface displays on common desktop monitors where operators may have a central panel that must be continually observed and ancillary information is displayed in the periphery.

Preview

A literature review follows in Chapter II. This review provides the basis and motivation for the research presented. Chapters III and IV present two experiments that were designed and derived from elements that the literature review provided. These two chapters will individually discuss their participants, experimental set-up, methodology, results, and conclusions. Following, in Chapter V, a general discussion will be presented for the collective results from the experiment conducted in this dissertation. Lastly, Chapter VI will end with recommendations and conclusions.

II. Literature Review

Chapter Overview

This chapter provides an overview of existing research which was influential on the research methods. The review describes various perceptual asymmetries in the visual domain and their potential application for improving visual processing of AR symbols, such as the ASAR.

Brain Asymmetries

The brain may appear as a single structure, but it is divided into the left and right hemispheres, connected by the corpus callosum, a bundle of commissural fibers which enable communication between the two hemispheres. Although the two hemispheres may appear similar in physical structure, there is considerable evidence that they are functionally asymmetric. The earliest collection of data supporting functional asymmetry was that of Marc Dax in the mid-18th century (Buckingham, 2006). He observed loss of speech in patients who experienced trauma to the left hemisphere of the brain without similar loss of functionality in patients who experienced right brain trauma. These findings and similar ones by Paul Broca spawned brain asymmetry research (Manning, Thomas-Antérion, 2011). By the latter part of the 19th century, it was becoming clear that the left hemisphere was associated with various language functions.

Fast-forwarding to the 1900's, studies of individuals with damage to one of the two hemispheres indicated that damage to the left hemisphere reduced verbal ability while damage to the right hemisphere reduced an individual's ability to manipulate geometric figures, work spatial puzzles, and perform tasks involving spatial relations.

Research during the latter half of the 20th century demonstrated these asymmetries with patients who had their corpus callosum severed for various medical reasons (Ocklenburg and Güntürkün, 2018a). In the last 40 years, advances in functional imaging methods, including EEG, PET, and fMRI, have added new knowledge and evidence of brain asymmetries (Lalor, & O'Connell, 2015; Newman et al., 2017; Loughnane, Shanley, Ocklenburg and Güntürkün, 2018b). Brain hemispheric specialization studies involving human and non-human species has been performed to improve our understanding the human brain in development, behavior, disease, and injury (for general review, see Rogers and Vallortigara, 2017).

Evidence suggests that brain asymmetries, as manifested in handedness, have been demonstrated since the Neanderthal era (Volpato et al., 2012). Theories on the advantages of brain laterization revolve around the notion of brain efficiency (Levi, 1969; Rogers et al., 2004; Vallortigara, 2006). The functional asymmetry of the brain's hemispheres can be seen in manifestations in muscle motor asymmetry (e.g., handedness, more expressive emotions in the left side of the face, head turning for kissing) as well as in the resulting performance in decision accuracy and responses attributed to asymmetries in cognition and perception. The research in perceptual asymmetries entails not just the visual domain but also the auditory and somatosensory systems.

Perceptual Asymmetries in Vision

Between-field and Within-field Asymmetries

Although our consciousness may see the world in a unified manner, visual asymmetries are dependent upon which particular brain hemisphere is activated. The degree of the "spatial" nature of a visual stimulus impacts how it is processed when presented in the left visual field versus the right visual field. The left visual hemi-field projects onto the right brain hemisphere and the right visual hemi-field projects onto the left brain hemisphere. This contralateral projection is due to the cross-over of optic fibers in the brain (see Figure 7).

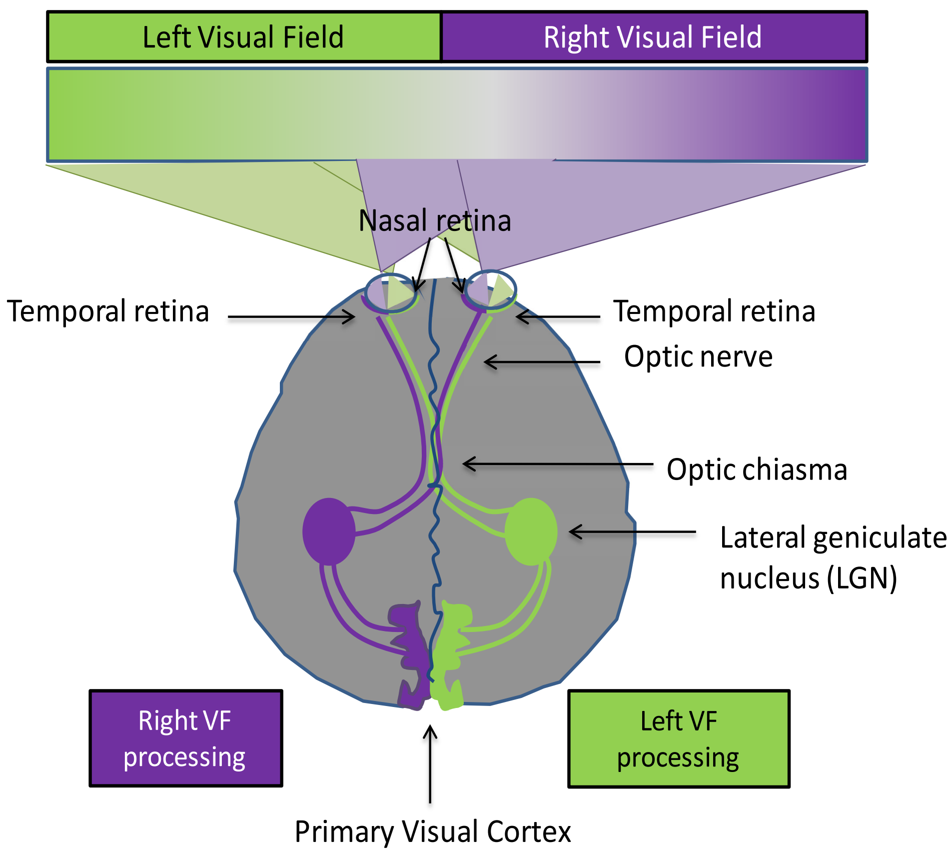


***Figure 7*. Diagram of the brain, showing the paths of visual input reaching the contralateral parts of the visual cortex.**

The right hemisphere, which is primarily responsible for processing information from the left visual field has been found to facilitate better processing of line orientation, Vernier offset, and size discrimination (Corballis , Funnell, & Gazzaniga, 2002). The left hemisphere which is primarily responsible for processing information from our right visual field facilitates the processing of temporal and linguistic information, as well as elements involving judgments of cognitive utility (Corballis, 2003; Okubo & Nicholls, 2008).

Asymmetry research in the visual domain has demonstrated asymmetries beyond that of the left versus right asymmetries. A commonly known asymmetry is that of foveal versus peripheral vision; due to the makeup of receptors in the retina and representations of visual input in the visual cortex, there are increasing performance decrements in visual acuity (De Valois & De Valois, 1990) and contrast sensitivity (Rovamo, Franssila, & Nasanen, 1992) with increasing distance from the fovea. Asymmetries have also been observed in the visual processing of stimuli located in the upper versus the lower field of view (FOV). At the same eccentricity, visual acuity, temporal and contrast sensitivity (Skrandies, 1987), as well as detection of differences in hue and motion (Levine & McAnany, 2005) are higher for stimuli located in the lower field of view; visual search is more efficient (Previc & Blume 1993), object recognition is faster (Chambers, McBeath, Schiano & Metz, 1999), and apparent size is more accurate (Ross, 1997) for stimuli presented in the upper visual hemi-field.

Asymmetries in vision are not just location dependent. The make-up of a visual stimulus, i.e., the various characteristics of a stimulus, may contribute to how it is visually processed. The relevant characteristics of the stimuli, as discussed in the visual science literature, includes its spatial frequency, orientation, color, and if moving, its direction of motion. The distinction of perceptual asymmetries in vision is specified as being location-dependent or characteristics-dependent has been termed *between-visual field* and *within-visual field* asymmetries, respectively (Karim & Kojima, 2010).

Disassociations in Visual Asymmetries

In any asymmetry research, it behooves the researcher to account for interactions among between-visual field and within-visual field asymmetries. For example, consider the *meridonial effect* asymmetry (a.k.a. the *radial bias effect*) (Rovamo, Virsu, Laurinen, & Hyvarinen, 1982; Sasaki et al., 2006). In the meridonial effect, a more efficient visual processing of stimuli is observed when the stimuli's directional components are congruent with the meridian on which it lies in the visual field (see Figure 8).

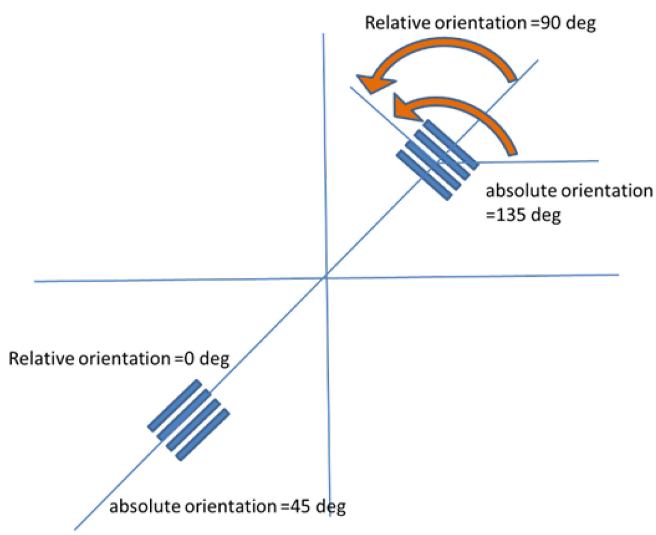


Figure 8. The meridional effect. The meridional effect suggests that resolution acuity is greater for radially oriented gratings (relative orientation = 0 deg) than for other orientations.

Also, consider the spatial frequency of a stimulus and its location between the left and right visual field. Stimuli with high spatial frequency components are better processed in the right visual field whereas stimuli with low spatial frequency components are better processed in the left visual field (Christman, Kitterle, & Hellige, 1991; Kitterle & Selig, 1991; Peyrin, Chauvin, Chokron, & Marendaz, 2003). Related to this high versus low spatial frequency processing disassociation, is the asymmetry in processing global versus local information in the left versus right visual fields.

Global and local information is characteristically expressed by low and high spatial frequencies, respectively, and therefore, in the left visual field, global information is better processed than local information and vice versa in the right visual field (Delis, Robertson, & Efron, 1986; Van Kleeck, 1989). Figure 9 shows an example of a typical visual stimulus employed to study the global/local asymmetry. The stimulus is hierarchical in that the smaller 'E's make up the larger 'H'. In divided visual field studies of global versus local information processing, typical experimental methods ask participants to report either the global structure, the 'H,' or the local structure, the 'E.' This asymmetry is a bit different from the previous ones mentioned in that the participants are *directed* to employ a certain mode of perceiving to obtain the required target (i.e., local-directed or global-directed).

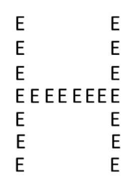


Figure 9. Stimulus patterns employed in global vs. local research contain smaller elements, the "local" features that make up a larger "global" element.

Another asymmetry that results from a top down process is the *categorical* versus *coordinate* spatial processing distinction. It has been proposed that we use two types of processes when making spatial relations, namely, a categorical system and a coordinate system (Kosslyn, 1987; Kossyln et al., 1989). When employing the categorical system, we do not think of or perceive exact distances between objects but rather assign equivalence classes based on spatial position of an object relative to another, expressed as verbal locatives (e.g., left/right, above/below, on/off, in/out). When employing the coordinate system, we relate objects to each other in space with metric units and determine finer-grained numeric relationships between the objects.

In the categorical versus coordinate asymmetry, the processing of visual stimuli may be performed differently in the left and right visual fields based upon which of the two spatial relationships is being employed. Generally, categorical processing is performed better when stimuli are in the right visual field and coordinate processing is performed better when the stimuli are in the left visual field. The stimuli employed in such research have been relatively simple. For example, Hellige and Michimata (1989) used dots placed above and below a line as illustrated in Figure 10. For example, one of the dots would appear above or below the line and in one of "near" (e.g., within 2 cm of line) or "far" (e.g., greater than 2 cm of line) groups. In this experimental paradigm, stimuli are presented briefly in either the left or right visual field and the observer is asked if the dot is above or below the line in categorical trials and they are asked if the dot is within 2 cm of the line in coordinate trials.

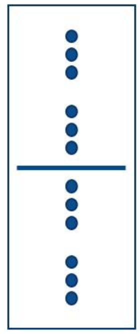


***Figure 10*. Example stimuli used in Categorical vs. Coordinate asymmetry research. Adapted from Hellige and Michimata (1989).**

A review by Jager and Postma (2003) on the hemispheric specialization for categorical and coordinate spatial relations found that in general, there is a strong relative right hemisphere/left visual field advantage when encoding coordinate spatial relations and weaker support for left hemispheric/right visual field categorical specialization. In addition, some of the modulating factors that may affect the categorical-coordinate dichotomy include:

- Handedness: right-handed individuals have a greater lateralization of categorical and coordinate tasks.
- Practice: coordinate advantage of right-handed individuals is diminished with more practice
- Task difficulty: difficult tasks show more lateralization than simple tasks.

Horizontal-Vertical Anisotropy / Vertical Meridian Asymmetry

The evaluation of between-field asymmetries will address how the ASAR will be interpreted between the eight locations (cardinal and intercardinal). In addition to observing if the left and right visual field locations are different from each other in categorical and coordinate taskings, we are also interested in seeing if the left and right positions, in a collective sense, are visually processed better than the top and bottom locations in the visual field.

Overall, the general findings in the literature suggest that performance of the visual system when perceiving stimuli located on one of the main cardinal directions around the visual field is best on the horizontal meridian, second best in the lower vertical meridian, and last is the upper vertical meridian. These past results have been termed the *horizontal-vertical anisotropy* (HVA) and *vertical meridian asymmetry* (VMA) (Abrams, Nizam, & Carrasco, 2012; Fuller, Rodriguez, & Carrasco, 2008; Talgar & Carassco, 2002). The causes of the HVA and the VMA may be multifaceted. Cone and gangiolon density in the retina is correlated with eccentricity and polar angle. Another factor may be that of asymmetries in the amount of neural matter devoted to the lower versus the upper visual field in the lateral geniculate nucleus and in cortical processing (Perry & Cowey, 1985; Kupers, Carrasco, & Winawer, 2019). Lastly, Karim and Kojima (2006), posited that lower visual field asymmetries may partly be due to learned mechanisms, experienced and perceiving of the world primarily towards the lower hemifields.

Literature Summary and Implications for Research

Brain asymmetries have fascinated medical practitioners, scientists, and researcher for years. From the reporting of Marc Dax and Paul Broca in the 1800's research persists which attempts to understand the brain's functional hemispheric asymmetries and associated perceptual asymmetries in vision which arise from the larger eye-brain system. This research has been primarily conducted to expand knowledge through basic research. However, applied research to understand how visual field asymmetries may impact display interface design is lacking. In the past research, stimuli were primitive. For example, Gabor patches entail a very specific prominent spatial frequency, provided through alternating dark and light bars, and the Gabor patch is composed of a distinct directional component (the orientation of the bars). The generalization of this research to display design requires additional research with more complex, real-world visual stimuli in similar experimental conditions, and the application of simple or complex stimuli in more complex experimental paradigms.

In the current research, the ASAR will be observed in various configurations due to the many attitudes the ASAR will be representing. Further, the ASAR will be presented in various locations in the field of view, allowing between field asymmetries to be explored. The various presentations of the ASAR may in fact contain different spatial frequency and orientation components, and the different spatial frequency and orientation components may interact with the between-field asymmetries. However, in an effort to scope the research in this proposal, the ASAR visual stimulus will be evaluated for only between-visual field asymmetries at each of the spatial relations under categorical coordinate taskings. Any potential effect of varying spatial frequency in the tested stimuli was not assessed specifically as a variable.

Pilot Study

A largely unexplored area in the visual asymmetry research is that of understanding how robust these asymmetries are when more real world, meaningful, visual stimuli are applied and the application of these stimuli in more realistic environmental contexts. As was mentioned in the Introduction, one such suitable context for which visual asymmetries may have an impact is in the display of information in an HMD and the ASAR is an example symbology that serves as the information that might be placed on the HMD. Reis, Geiselman, and Miller (2019) explored how observers interpreted the ASAR symbology in peripheral vision. They randomly presented the ASAR for 80 ms in one of the cardinal and inter-cardinal positions, 13° visual angle away from the center of a display, as shown in Figure 11. It is important to note that the literature suggests that the fastest saccades may be lower bounded by about 80 ms (Kingstone & Klein, 1993; Knox, 2017). These extremely short latency saccades have been referred to as express saccades (Fischer & Ramsperger, 1986; Fischer & Weber, 1993), and are often fostered in visual psychophysical experimentation where the fixation stimulus is extinguished around 200 ms prior to an eccentric target onset (Reuter-Lorenz, Hughes, Fendrich, 1991; Saslow, 1967). Therefore, the selection of an 80 ms presentation time should preclude eye movements from the fixation to the target before it is removed from the display.

The attitude of the ASAR represented the aircraft being in a left or right roll and was positioned anywhere from 5º to 85º in increments of 10º, and likewise for climb up or dive down VFP positions. The participants were required to report the attitude of the ASAR in either a Categorical manner, i.e., left or right if ASAR showed a roll deviation, up or down if ASAR showed a VFP deviation, or in a coordinate manner, i.e., reporting the exact angle of the roll or the VFP. In the categorical and coordinate trials, the dependent variables were, respectively, the response time (RT) to report the correct attitude and the absolute offset error (AOE) between the actual attitude and the reported attitude. The means of RTs and AOEs from the trials in each participant x position cells were chosen to be analyzed. Figures 12 and 13 present AOEs and RTs for VFP and roll parameters, respectfully, as a function of position in the FOV. In general, across all angular deviations and directions in VFP and roll, the data suggests no performance differences between the 180° and 0° positions, e.g., left vs. right or the horizontal meridian in either the coordinate or categorical taskings. However, there appear to be visual processing differences of the ASAR across the FOV. In particular, the 180° position showed decreased RT and offset error when compared to some other positions. It may be the case that this effect results from *pseudo neglect* (Jewell & McCourt, 2000), i.e., the tendency to shift attention to the left side of space in the FOV. The results here trend in line with the HVA as the 0° and 180° positions showed some performance advantages over the 90° and 270° positions.

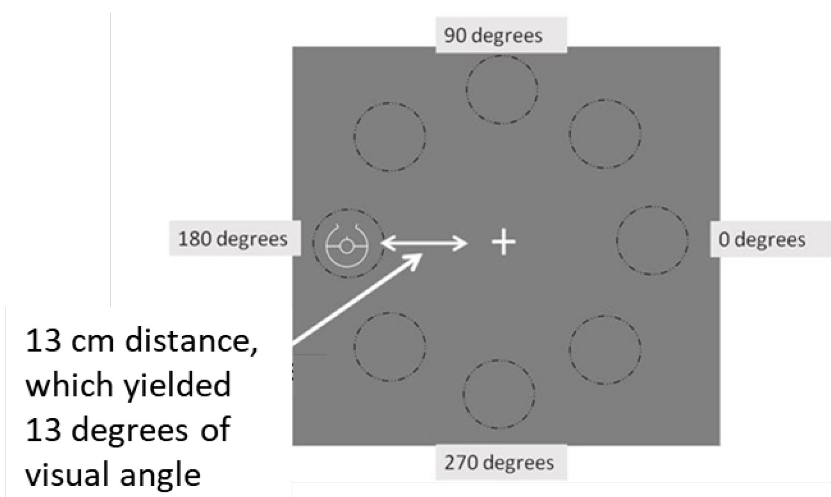


***Figure 11*. Experimental display configuration in Reis et al., 2019.**

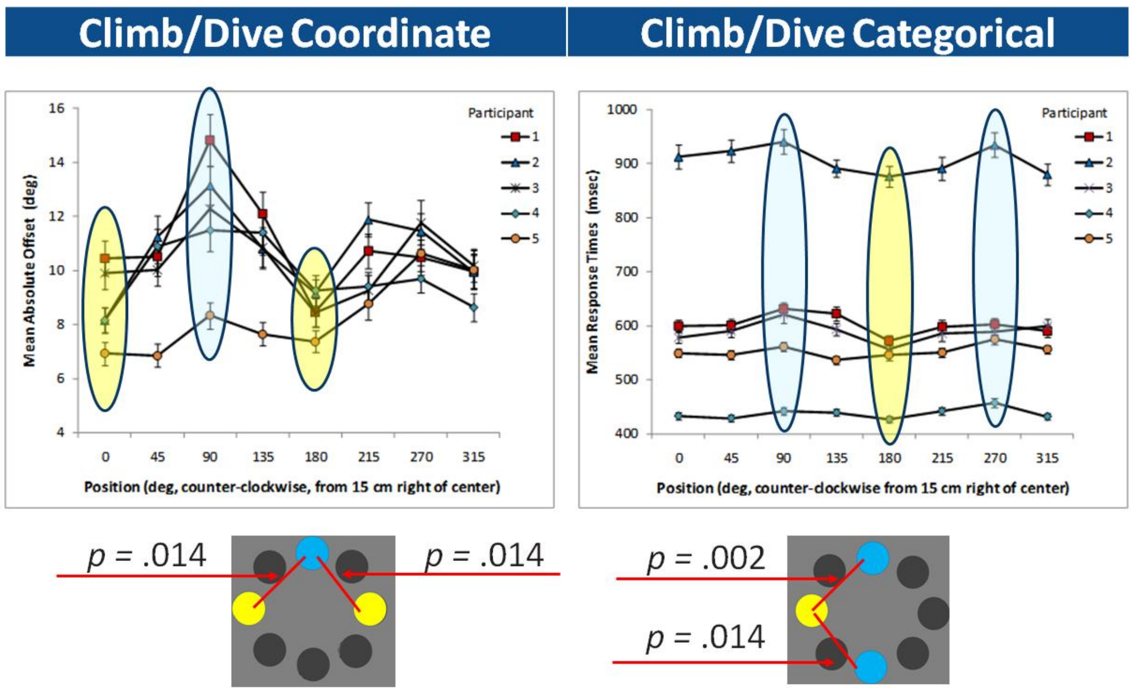


Figure 12. **Data from Reis et al. 2019; Climb/Dive Conditions. Each point represents the mean across climb and dive deviations for a particular participant. Left graph: At coordinate trials, the mean absolute offsets plotted as a function of position in the FOV. Right graph: At categorical trials, response times plotted as a function of the position in the FOV. The yellow and blue ellipses group and highlight the data points for certain positions in the display. The grouped points are all of one hemimeridian—but just called position here. The ellipses in the graphs correspond to the yellow and blue display locations shown below the graphs. In both graphs, the analyses suggest that data grouped by the yellow ellipse, as a group, have lower Mean Absolute Offset and Mean Response Time than the data grouped by the blue ellipse. Errors bars represent ± 1 standard error of the mean. Note Climb/Dive in the graphs refers to VFP.**

The Reis et al. study spring boarded the current research presented in Chapters III and IV. Although the results from Reis et al. suggest that the ASAR location in the FOV may affect how it is visually processed, some context must be given. The study had a small number of participants as the study was conducted as a pilot experiment. All participants were males. Testing was performed in a rigid experimental manner and there was not a great deal of semblance of an operational environment. Lastly, the participants' responses were input strictly with the left hand. Experiments 1 and 2, presented below, attempted to address these matters, and examine the robustness of the Reis et al pilot study.

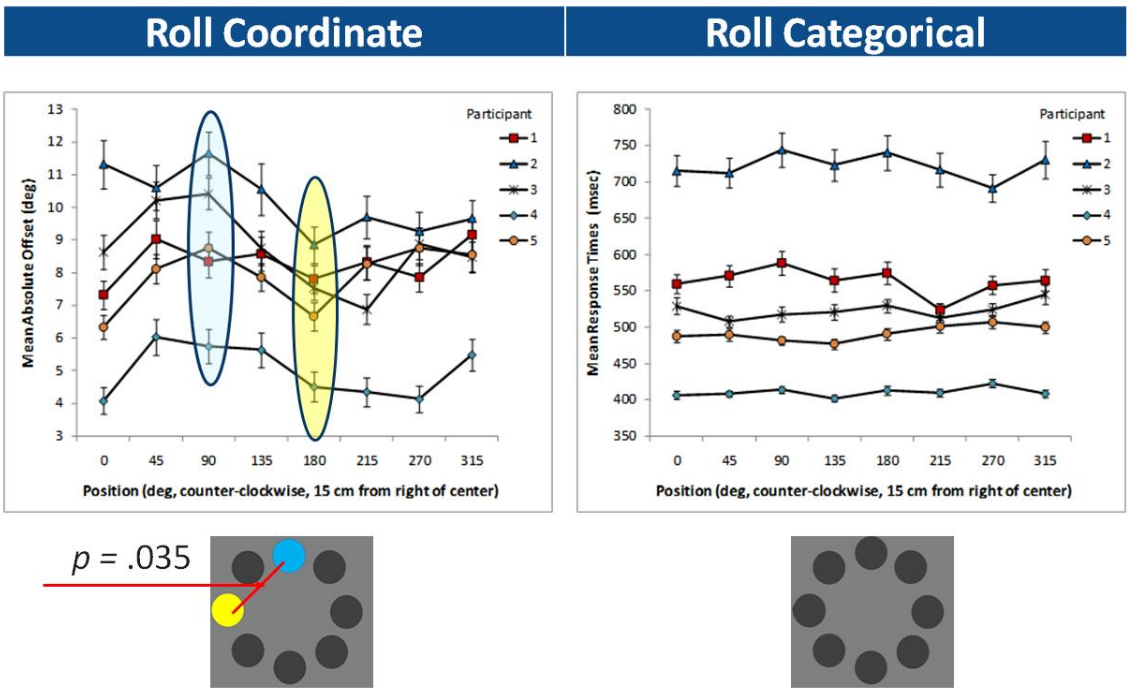


Figure 13. **Data from Reis et al. 2019; Roll Conditions. Each point represents the mean across both left and right roll deviations for a particular participant. Left graph: At coordinate trials, the mean absolute offsets plotted as a function of position in the FOV. Right graph: At categorical trials, response times plotted as a function of the position in the FOV. The yellow and blue ellipses group and highlight the data points for certain positions in the display. The grouped points are all of one hemimeridian—but just called position here. The ellipses in the graph correspond to the yellow and blue display locations shown below the graphs. The analyses suggest that data grouped by the yellow ellipse, as a group, have lower Mean Absolute Offset than the data grouped by the blue ellipse. There were no statistically significant differences among position pairwise comparisons for Mean Response Time. Errors bars represent ± 1 standard error of the mean.**

Summary

In this literature review section, a variety of visual perceptual asymmetries were discussed. All these asymmetries may have some impact on the way the ASAR, or any other visual stimulus, is processed. Unfortunately, not all asymmetries can be studied due to limitations in resources and study complexity. However, we can methodologically create a study that minimizes the effects of artifact in coming to our conclusions. The next sections discuss the design of this research.

III. Experiment 1

Chapter Overview

This chapter describes the design, execution, analysis, and results of Experiment 1. Experiment 1 employed a method similar to a previously published pilot study (Reis et al, 2019).

Introduction

Reis, Geiselman, and Miller (2019) explored performance differences utilizing the ASAR at cardinal and ordinal locations in the visual field. As mentioned, the ASAR exemplifies a meaningful, real-world, symbology by representing aircraft roll and vertical flight path angles relative to a natural horizon. The results from Reis et al. are in concordance with the horizontal-vertical anisotropy (Carrasco, et al., 2001). Specifically, performance was better in the “west” and “east” locations (left and right from center of display) over the “north” and “south” locations (top and bottom from center). The current study explored the robustness of the Reis et al. (2019) study by analyzing the ASAR with more participants, a switch of response handedness, and a more compact set of ASAR angles.

The current research study switched the input response from the left hand to the right to better map interactions to inputs required in modern fighter aircraft, which require the pilot to utilize their right hand for primary inputs. This difference is significant as it may introduce artifacts in understanding the pure perceptual constructs of the visual asymmetries as operation with a certain hand competition may compete with a visual asymmetry for the same functional space within a hemisphere (Dalen & Hugdahl, 1987). If use of the right hand introduces artifacts, the results of the study will mimic the contextual environment of modern day fighter aircraft.

Reis et al. tested ASAR attitude angles ranging from 5º to 85º, in increments of 10º. In general, the participants' performance curves leveled off around 50º, for both climb/dive and roll attitudes. Therefore, the ASAR attitudes in the current experiment were bounded to a range between straight and level and 50º angle deviation in attitude.

Including a Gabor patch stimulus provides a more direct comparison to a common stimulus used in past asymmetry research and a representative real world stimulus. The inclusion of a Gabor stimulus also provided a method to validate the experimental methodology against previous asymmetry research.

Method

Participants

Twelve participants (6 males, 6 females) completed the study and had an age range of 22-53 years (*M* = 37.5, *SD* = 11.0). All participants were right-handed except for one female (left-handed) and one male (no hand preference) as determined using the FLANDERS skilled hand preference test (Nicholls, Thomas, Loetscher, and Grimshaw, 2013) and the Purdue Pegboard test (see Lafayette Instrument Company, 2021). One male and one female had experience piloting aircraft. All participants reported normal or corrected-to-normal vision. Appendix A summarizes the participants' demographical data. The institutional review board from the Air Force Research Laboratory approved the study and participants gave informed consent prior to participation.

Experimental Set up and Stimuli

The experiment was run on a Dell Precision 5820 X-series with a 24.5" Sony PVMA250 Professional OLED Production Monitor (1920 x 1080 pixel resolution, 60 Hz refresh rate). The experiment was administered in the Unity programming environment. Participants' heads were stabilized with chin and head rests while they binocularly viewed the display at a distance of 57 cm, as shown in Figure 14. Their responses were registered on a ZD-V+ USB wired gaming controller gamepad as shown in Figure 15.

***Figure 14*. Experiment 1 set-up. Participants sat 57 cm from display with an eye height aligned to the center of the display. Their head was stabilized in chin and head rest. Here the participant is 'flying' an aircraft while observing the corresponding ASAR attitude representations.**

The test stimuli consisted of a Gabor patch at various roll (slant) orientations and the ASAR at various representations of an aircraft rolling left, rolling right, diving, and climbing. Gabor patches of dimension 100 horizontal x 100 vertical pixels were generated by multiplying 12 cycles of a sinusoid with a Gaussian function (see Figure 16). This stimulus subtended a visual angle of 3.5 degrees, providing a Gabor with a frequency of about 3.4 cycles per degree of visual angle.

***Figure 15.* Experiment 1 input device. Participants entered their inputs with a gamepad controller. The left hand index finger progressed the participant through the testing while the right handed thumb input the test responses.**

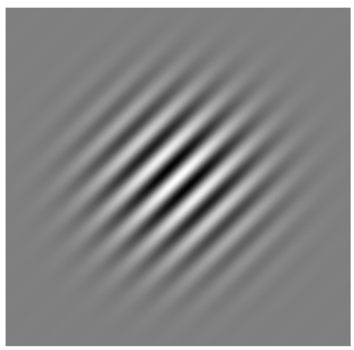


Figure 16. **Gabor patch, rolling right.**

The ASAR includes a fixed ‘ownship’ symbol that represents the VFP (climb/dive) angle by its relation to a half-circle arc surrounding the symbol. During straight-and-level flight, the upper portion of the circle is not visible and represents the area above the horizon as shown in Figure 17-A. The visible arc represents the area below the horizon. As the climb angle increases, the visible angle area of the arc narrows in proportion to the angle, as shown in Figure 17-B. Conversely, as the dive angle increases, the arc closes towards a circle, as shown in Figure 17-C. During rolling maneuvers, the arc rotates about the ownship symbol as shown in Figure 17-D and 17-E. The ASAR's lines in this study were white, and both the Gabor patch and the ASAR were presented against a gray background. The exact luminance and chrominance values (as measured by a Minolta Chromo meter CS100) of the black, gray and white elements on the monitor are shown in Table 1.

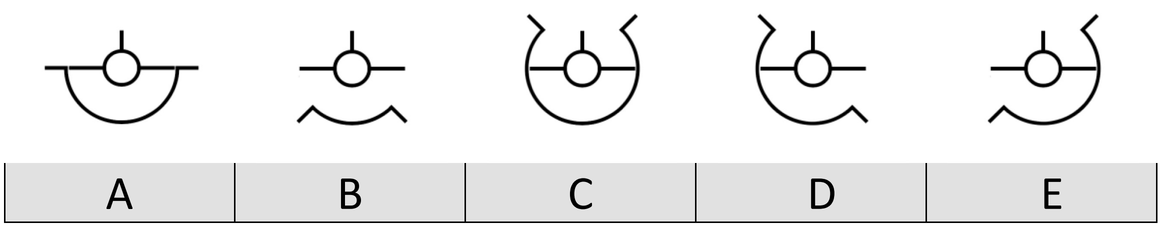


Figure 17. **The ASAR showing vertical flight path and roll directions. The ASAR representing (A) straight and level flight, (B) 45° climb, (C) 45° dive, (D) 45° roll left, (E) 45° roll right. At a climb/dive of 0° (panels A, D, E), the half-circle subtended 3.5° of visual angle.**

Table 1. Luminance and Chrominance values of screen elements.

	Y	x	y
Black	0 cd/m^2	NA	NA
Gray	19.4 cd/m^2	.310	.325
White	100 cd/m^2	.310	.325

Gabor roll orientations of 3°, 6°, 9°, 12°, 15°, 18°, 21°, 24°, 27°, 30°, 33°, 36°, 39°, 42°, 45°, and 48°, left and right, were presented to the observers. These degree increments were also tested for ASAR roll (left/right) and VFP (climb/dive) depictions as shown in Figure 18.

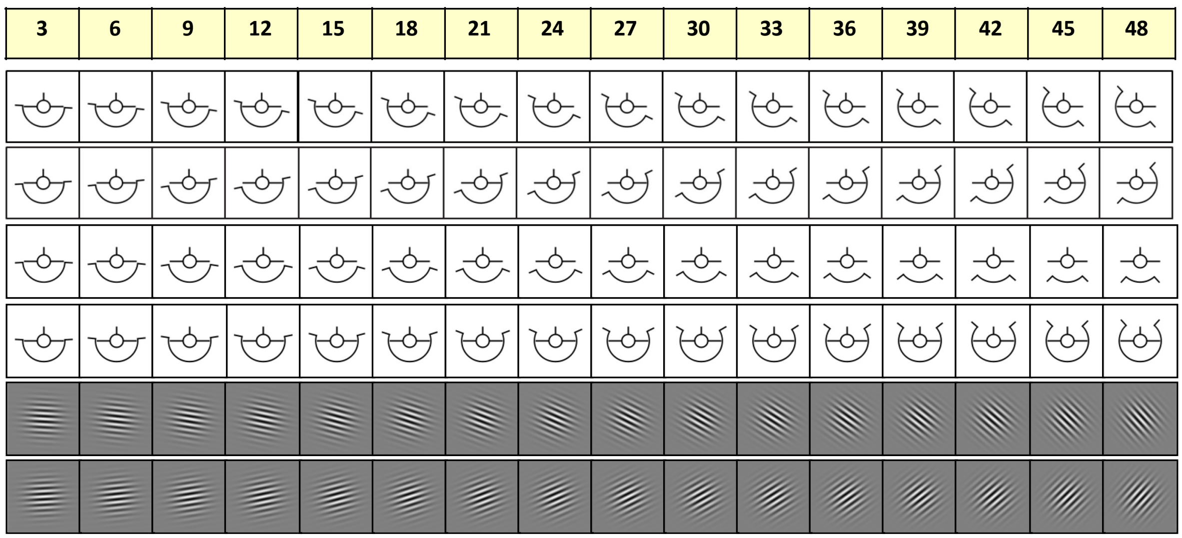


Figure 18. **Angles of deviation from straight and level flight as represented in the ASAR symbology and in the Gabor patches. The top row shows the angle of deviation. The next two rows show the ASAR rolling left and then right. The two rows after that show the ASAR climbing and then diving. The last two rows show the Gabor patch rolling left and then right. The Gabor patches' roll orientations correspond to the ASAR roll orientations.**

Procedure

Before testing occurred, participants completed a demographic questionnaire, the FLANDERS handedness test, the Purdue Peg Board Test, and they had their vision checked with the Optec 5500 vision tester to assess for major deviations from normal vision. Participants performed six different 'situation' blocks (see Table 2), each with its own type of trials, repeated three times, totaling 18 blocks. The order of these six types of blocks across participants and three repetitions was presented using balanced Latin squares. This design helped to minimize immediate carry-over effects by having every condition preceded another condition the same number of times across participants. A ten day window was allowed to complete the totality of the 18 blocks.

Table 2. The six different types of situation blocks.

(1) Gabors rolling left or right and responding in a categorical manner.
(2) Gabors rolling left or right and responding in a coordinate manner.
(3) ASAR representations showing rolling left or right and responding in a categorical manner.
(4) ASAR representations showing rolling left or right and responding in a coordinate manner.
(5) ASAR representations showing climbing or diving and responding in a categorical manner.
(6) ASAR representations showing climbing or diving and responding in a coordinate manner.

A training session was administered at the beginning of the study to explain the mechanics of the ASAR. At the beginning of every test session, the participants spent one minute on a simulator, maneuvering an aircraft with the coupled ASAR behavior on the screen. Preceding any block of test trials, the participants performed 20 random trials from that block's situation type for familiarization.

Each situational block contained 256 trials where the stimulus was presented for 80 ms with a random interstimulus interval between 50 and 200 ms. Each block was formed by randomly sampling from the factorial combination of **8** hemimeridian locations on the monitor, i.e., polar coordinate angles of 0°, 45°, 90°, 135°, 180°, 225°, 270°, 315° and **2** flight parameter directions (left or right if block contained roll trials; dive or climb if block contained VFP trials) without replacement. The stimuli appeared at 13° of visual angle from center (Figure 19) and had one of **16** angle deviations from straight and level, which was selected in a random order from among 3°, 6°, 9°, 12°, 15°, 18°, 21°, 24°, 27°, 30°, 33°, 36°, 39°, 42°, 45°, and 48°. Participants performed three repetitions of every combination of block, and angle deviation, responding for all 16 angle deviations sequentially within each block and completing all blocks within a repetition before proceeding to the next repetition. Participants took a 10 minute break after every block of trials.

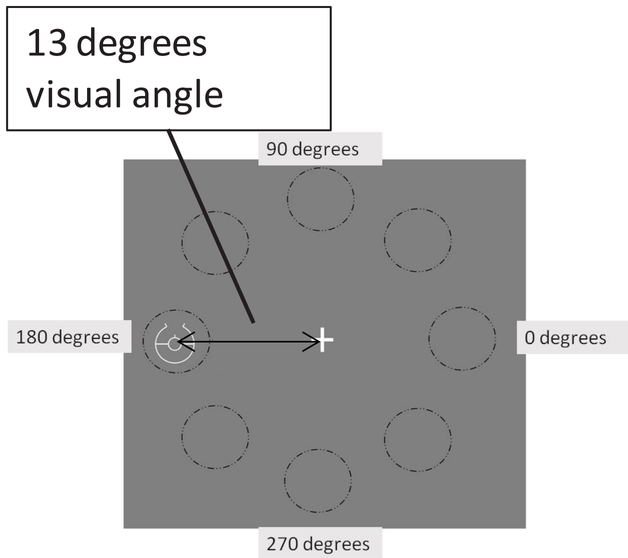


***Figure 19*. An example ASAR stimulus is shown in the 180 degree hemimeridian location. Dotted lines indicate the other possible presentation locations but were not visible during testing.**

For each trial, participants were instructed to fixate on a crosshair symbol centered on the display. They initiated a trial by pressing a button on the left side of the controller and provided responses with their right thumb on the right joystick of the controller. The ASAR was presented for 80 msec in one of the hemimeridian locations. After presentation, the gray screen was replaced with a mask of static Gaussian noise to reduce visual persistence. If the situational context was roll/categorical, participants were instructed to respond by pushing the joystick in the appropriate direction to match the actual roll direction indicated by the ASAR or Gabor. Likewise, if the situational context was VFP/categorical, the participants responded by pushing the joystick distally, reporting that the symbology represented aircraft dive, or proximally, representing aircraft climb, which maps their response to the mechanization of aircraft control stick input to correct the flight condition to straight and level. In roll and VFP categorical trials, response time (RT) and accuracy (reporting representation correctly or incorrectly) were recorded for each trial. After a response, the Gaussian noise disappeared and the crosshairs reappeared to begin the next trial. For all trials, participants were instructed to prioritize accuracy. Figure 20 shows the sequence of categorical trials.

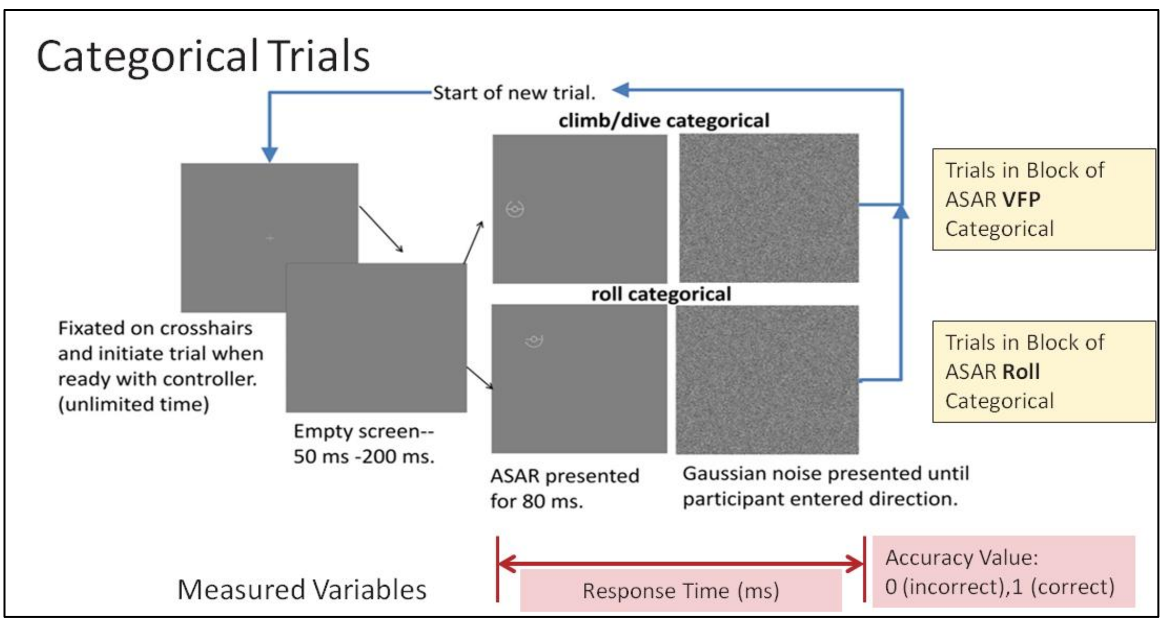


Figure 20. Shown is the sequence followed in categorical roll and VFP trials.

If the situational context was roll/coordinate, after the ASAR or Gabor disappeared in the periphery, the stimulus reappeared in a straight and level attitude in the middle of the screen with Gaussian noise as a backdrop. The participants then attempted to match the exact roll angle of the stimulus by moving the joystick left or right. Likewise, if the context was VFP/coordinate, after the ASAR disappeared, the participants changed the straight and level ASAR by moving the joystick proximally or distally to match the climb or dive angle. After the participants obtained the attitude they thought they observed, they pressed a button on the left side of the controller with their left index finger and the crosshairs reappeared. Absolute error (AE) was the dependent variable (DV) of interest: i.e., the absolute value between the actual ASAR/Gabor attitude presented and the participants' attitude responses. Figure 21 shows the sequence of coordinate trials. Figure 22 shows an example of how absolute error was measured. Figure 23 summarizes the left and right hand inputs into the gamepad controller for categorical and coordinate trials.

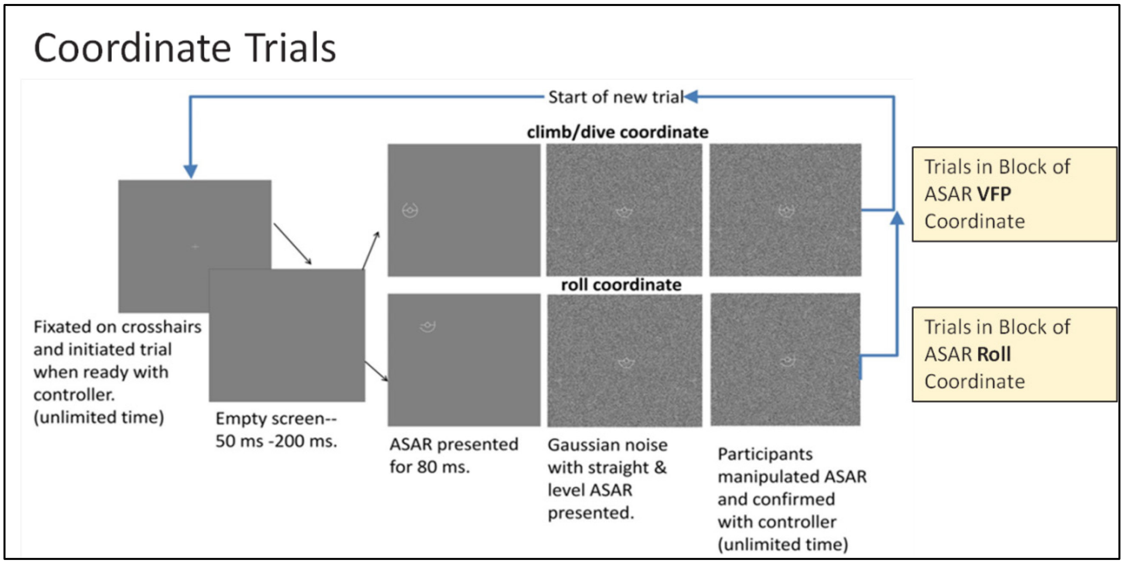


Figure 21. **Shown is the sequence followed in coordinate roll and VFP trials.**

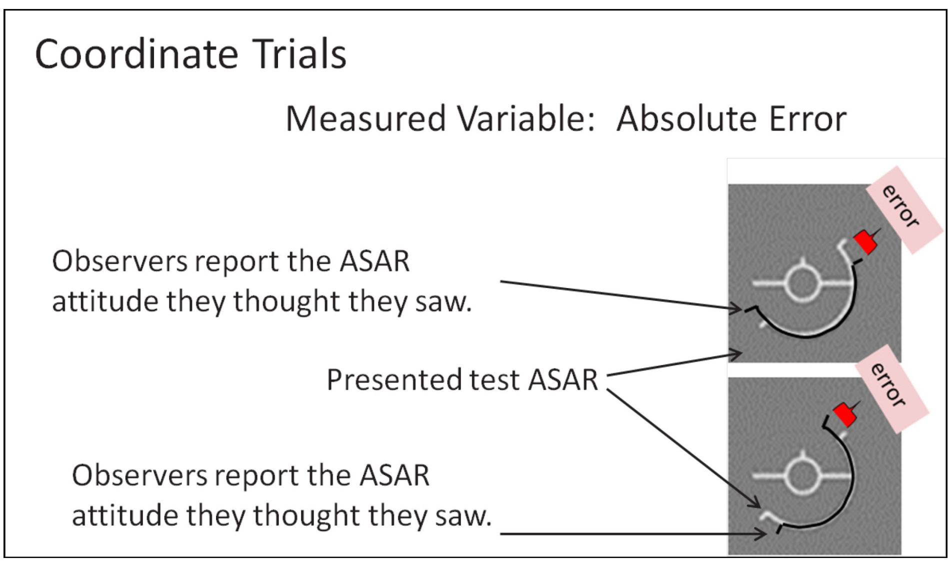


Figure 22. **A demonstration of how Absolute Error for coordinate trials was obtained.**

1. Gabor Roll Categorical → Identify the Gabor's roll: **Left** or **Right**
2. Gabor Roll Coordinate → Match the Gabor's roll angle
3. ASAR Roll Categorical → Identify the ASAR's roll as **Left** or **Right**
4. ASAR Roll Coordinate → Match the ASAR's roll angle
5. ASAR VFP Categorical → Identify the ASAR's VFP: **Diving** or **Climbing**
6. ASAR VFP Coordinate → Match the ASAR's VFP angle

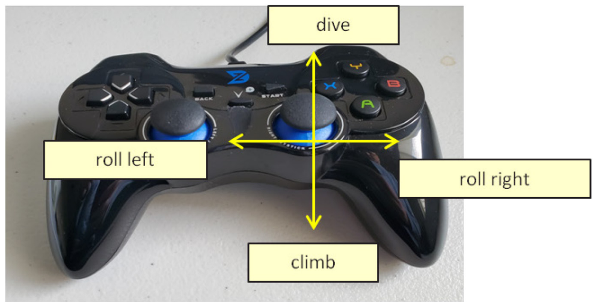


***Figure 23*. A summary of the hand inputs required on the controller for each of the six different blocks.**

Data Analysis

Data were analyzed with IBM SPSS Statistics 22. A 2 x 8, within-participant design was employed to analyze the data. The independent variables were angle (low, high) and hemimerdian (0º, 45º, 90º, 135º, 180º, 225º, 270º, 315º). The angle level of low represented angle attitude deviation angles of 3°, 6°, 9°, 12°, 15°, 18°, 21°, and 24°. The high level represented the angle attitude deviations of 27°, 30°, 33°, 36°, 39°, 42°, 45°, and 48°. This split was simple cut in the middle of the entire range. The analysis sought out differences in performance field asymmetries at these two levels of angle deviation. Various flight operations may require varying angles of roll or VFP. Thus, it is important to understand if any differences in asymmetries vary across lower and higher angle deviations and determine if asymmetries should be considered for varying operations.

Moreover, it might be undesirable for larger aircraft to experience climb and dive angles greater than 15° and rolls greater than 30°, whereas, more nimble fast jets can experience a wide range of the angles in climb/dive and roll.

To remedy possible attentional lapses and anomalous anticipatory responses, the dependent variable response data set (absolute errors, response times, and accuracy values) was curtailed to the median values from the three repetitions at each combination of situational block x hemimeridian x angle deviation x direction. These median values were then binned into two groups, the low and high levels of the angle variable. Within each bin, the medians of the response data set were averaged across all angle deviations at each situational context x hemimeridian x direction combination.

The derived DVs for categorical trials were labeled aggregated-response time (A-RT) and aggregated percent incorrect (A-PI), for the accuracy data. For coordinate trials, the DV was labeled aggregated-absolute error (A-AE). The 'A' signifies that the value represents an aggregate of the attitude angles presented.

Six two-way (8 hemimeridian x 2 angle) within-participant analysis of variance (ANOVA) procedures were applied to assess A-AE (from coordinate trials). These ANOVAs were applied to trial sets of the following:

(1) Left rolling ASAR symbols

(2) Right rolling ASAR symbols

(3) Left rolling Gabor patches

(4) Right rolling Gabor patches

(5) Climbing vertical flight path ASAR symbols

(6) Diving vertical flight path ASAR symbols

Six two-way (8 hemimeridian x 2 angle) within-participant ANOVA procedures were applied to assess A-RT (from categorical trials). These ANOVAs were applied to trial sets of the following:

(1) Left rolling ASAR symbols

(2) Right rolling ASAR symbols

(3) Left rolling Gabor patches

(4) Right rolling Gabor patches

(5) Climbing vertical flight path ASAR symbols

(6) Diving vertical flight path ASAR symbols

Twelve Friedman tests were used to analyze the A-PI data (from categorical trials) in which the participants were used as blocks. The Friedman test is a non-parametric alternative to the repeated measures ANOVA and is applied here as the data violates of the ANOVA assumptions. The test is used to determine whether or not there is a statistically significant difference between the means of three or more groups in which the same participants are present in each group (Conover, 1999, pp.367-373). To apply the Freidman test, the values for the variable of interest are ranked across the levels of the variable of interest and these ranks are then analyzed. See Appendix D for an example calculation of the mean ranks. Here, the tests are applied to analyze the effect of hemimeridian at each level of angle separately, i.e., at low angles which represented 3°-27° and at high angles which represented 27°-48°. These Friedman tests were applied to trial sets of the following:

(1) Left rolling ASAR symbols at the low angle bin

(2) Left rolling ASAR symbols at the high angle bin

(3) Right rolling ASAR symbols at the low angle bin

(4) Right rolling ASAR symbols at the high angle bin

(5) Left rolling Gabor patches at the low angle bin

(6) Left rolling Gabor patches at the high angle bin

(7) Right rolling Gabor patches at the low angle bin

(8) Right rolling Gabor patches at the high angle bin

(9) Climbing vertical flight path ASAR symbols at the low angle bin

(10) Climbing vertical flight path ASAR symbols at the high angle bin

(11) Diving vertical flight path ASAR symbols at the low angle bin

(12) Diving vertical flight path ASAR symbols at the high angle bin

Results

All test results were assessed at $\alpha = .05$. This level was chosen to provide a guide for performing subsequent analysis and to provide confidence in recommendations that stem from the trends in the analysis. The results are discussed separately for data where participants performed coordinate and categorical trials. Any degrees of freedom marked by an asterisk were the result of having been corrected using Greenhouse-Geisser estimates of sphericity, i.e., Mauchly's test indicated that the assumption of sphericity had been violated (Keppel and Wickens, 2004, pp.376-379). Post-hoc comparisons will be reported from Least Significant Difference (LSD) tests due to the exploratory nature of this research. However, due to the large number of comparisons among the hemimeridian locations, it should be noted of the increased occurrence of a Type I (false positive) error—for example, stating that there are significant differences in the A-RT dependent variable when compared across the hemimeridians and in actuality there are no significant differences. For results with coordinate data, Appendix B shows the comparisons among hemimeridians in any significant main effect of hemimeridian from omnibus F tests or stemming from simple main effect analyses. Appendix B shows the *p*-values for the LSD tests as well as adjusted *p*-values using the Holm's-Bonferroni method (Holm, 1979; Wright, 1992). It should be noted that in this Results section that comparisons may be discussed in general locations being different than other general locations (e.g., top vs the left and right sides of the display). To see exact hemimeridian location comparison differences see Appendix B. Likewise, for results with categorical data, Appendix C contains the comparisons among hemimeridians in any significant main effect of hemimeridian from omnibus F tests (Keppel and Wickens, 2004, pp 60-62), simple main effect analyses (Keppel and Wickens, 2004, pp 195-209), or Friedman tests (Conover, 1999, pp.367-373).

In the results below, the F and χ^2 statistics allow us to investigate the null hypothesis. Larger F and χ^2 values imply rejection of the null hypothesis, however other parameters must be considered in conjunction to the magnitude of these statistics (Keppel and Wickens, 2009, pp. 36-46). The *p*-value is simply a measure of the strength of evidence against the null hypothesis (Dorey, 2010). Smaller *p*-values indicate stronger evidence against the null hypothesis. Partial eta squared, (η_p^2), is a measure of effect size. Partial eta squared is expressed as a proportion and higher values indicate a greater amount of the variability accounted for by that particular effect (Fritz, Morris, and

Richler, 2012). Kendall's *W* is used for assessing agreement among raters (Sheshken, 2004).

Notes on the plots to follow in the analysis of the data:

In the categorical data analyses with A-RT as the DV, if there was no significant interaction effect between hemimeridian and angle, thus only one line is shown, the mean A-RT as a function of hemimeridian. In all polar plots, the perimeter points signify the hemimeridian and the axes are ranged to auto fit the A-AE in the coordinate data and the A-RT in the categorical data. This was done to provide a better visualization of the differences among the hemimeridians within the condition of interest. The ordinate range in the line plots are scaled consistently to observe differences between the different conditions.

Coordinate Tasking

For trials required to be answered in a coordinate manner and responding to Gabor stimuli rolling *left*, analysis of variance revealed significant main effects of angle, $F\,(1, 11) = 25.4$, $p < .001$, $\eta_p^2 = .70$, and hemimeridian, $F\,(2.31, 25.5)^* = 4.66$, $p = .018$, $\eta_p^2 = .29$; however these main effects were qualified by a significant interaction effect between angle and hemimeridian, $F\,(3.18, 35.0)^* = 3.45$, $p < .001$, $\eta_p^2 = .24$. The effect of this interaction is illustrated in the top panels of Figure 24. Simple effects analysis produced a marginal effect at the low level of angle, $F\,(3.08, 33.9)^* = 2.71$, $p = .059$, $\eta_p^2 = .20$, however at the high level, $F\,(2.41, 26.49)^* = 4.42$, $p = .017$, $\eta_p^2 = .29$, it was found that the top position, i.e., the 90 deg hemimeridian location, was significantly higher, in A-AE, than the 0, 180, and 135 deg locations.

For trials required to be answered in a coordinate manner and responding to **Gabor stimuli rolling *right***, analysis of variance revealed significant main effects of angle, F (1, 11) = 9.69, p = .010, η_p^2 = .47, and hemimeridian, F (2.35, 25.9)* = 4.66, p = .001, η_p^2 = .46; however these main effects were qualified by a significant interaction effect between angle and hemimeridian, F (7, 77) = 5.45, p < .001, η_p^2 = .33. This interaction is illustrated in the bottom panels of Figure 24. Simple effects analysis produced a significant effect at the low level of angle, F (2.64, 29.00)* = 3.64, p = .029, η_p^2 = .25, and at the high level, F (2.23, 24.6)* = 8.88, p = .001, η_p^2 = .45. In both levels of low and high angle, it was found that the top position, the 90 deg hemimeridian location, was the primary cause for differences in hemimeridian, in general, the 90 degree position had higher mean A-AE than positions to the left and right and this difference was much more substantial in the high angle condition.

For trials required to be answered in a coordinate manner and responding to an **ASAR stimulus rolling *left***, ANOVA revealed non-significant main effect of angle, F (1, 11) = .188, p = .673, η_p^2 = .02 and a significant main effect of hemimeridian, F (7, 77) = 4.45, p < .001, η_p^2 = .29; however, these main effects were qualified by a significant interaction effect between angle and hemimeridian, F (7, 77) = 2.36, p < .031, η_p^2 = .18. The effect of this interaction is illustrated in the top panels of Figure 25. Simple effects analysis produced a significant effect at the low level of angle, F (7, 77) = 5.23, p < 001, η_p^2 = .32, but not at the high level, F (3.18, 35.02)* = .723, p = .553, η_p^2 = .06. The interaction was driven by difference in the low angle level having, in general, lower mean A-AE values at 0 and 180 deg than the upper hemimeridians.

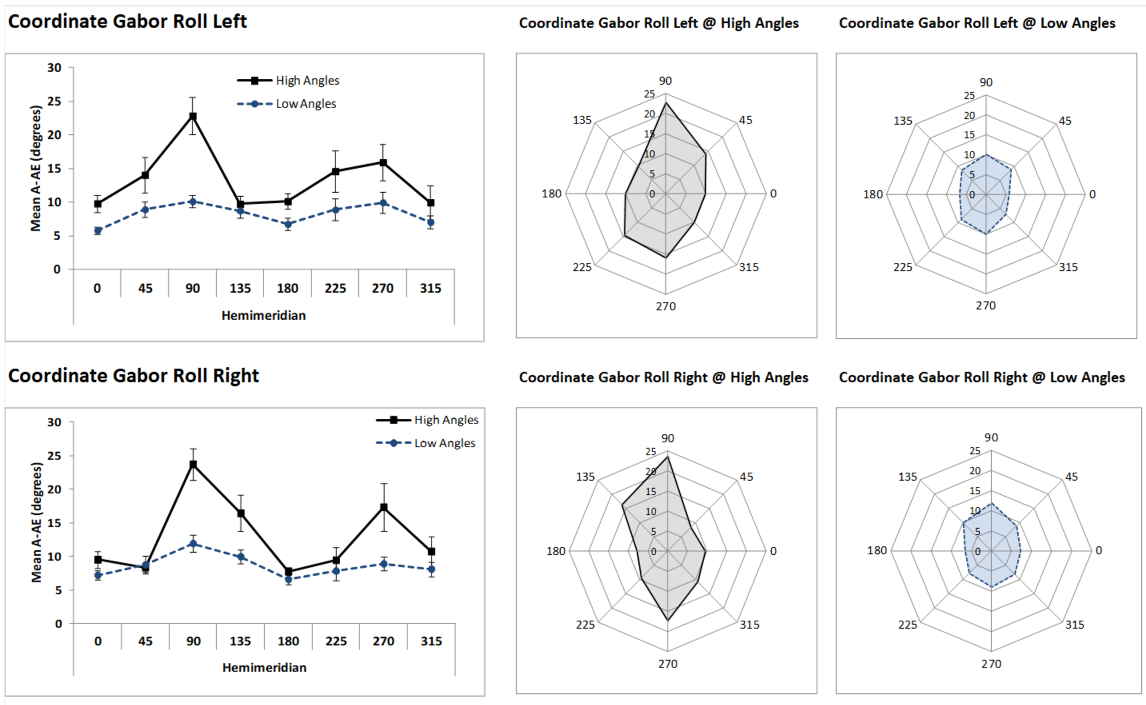


Figure 24. **Data plots for coordinate Gabor roll left and right conditions. The top row contains results from trials required to be answered in a coordinate fashion and with the Gabor stimulus when it was rolling left. The bottom row contains results from trials required to be answered in a coordinate fashion and with the Gabor stimulus when it was rolling right. The leftmost panels in both rows contain the mean A-AE across hemimeridian with data in the solid black line showing values from the high angle level and data in the dotted blue lines from the low angle level. The middle panels contain polar plots for the mean A-AE at high angles, corresponding to the solid black line in the leftward plot. The rightmost panels contain polar plots for the mean A-AE at the low angles, corresponding to the dotted blue line in the leftmost plots.**

For trials required to be answered in a coordinate manner and responding to an **ASAR stimulus rolling *right***, ANOVA revealed non-significant main effects of angle, *F*

(1, 11) = .589, p = .459, η_p^2 = .05 and hemimeridian, F (7, 77) = 1.95, p = .073, η_p^2 = .15; however, these main effects were qualified by a significant interaction effect between angle and hemimeridian, F (7, 77) = 3.79, p = .001, η_p^2 = .26. The effect of this interaction is illustrated in the lower panels of Figure 25. Simple effects analysis produced a significant effect at the low level of angle, F (7, 77) = 3.78, p = 001., η_p^2 = .26, but not at the high level, F (7, 77) = 1.43, p = .205, η_p^2 = .12. The interaction was driven by difference in the low angle level having, in general, higher mean A-AE values in the upper hemimeridians over the rest of the field.

For trials required to be answered in a coordinate manner and responding to an **ASAR stimulus VFP *climb***, ANOVA revealed non-significant main effect of angle, F (1, 11) = .809, p = .388, η_p^2 = .069 and a significant main effect of hemimeridian, F (7, 77) = 2.62, p = .018, $\eta_p{}^2$ = .192; however these main effects were qualified by a significant interaction effect between angle and hemimeridian, F (7, 77) = 3.02, p = .007, η_p^2 = .216. The effect of this interaction is illustrated in the top panels of Figure 26. Simple effects analysis produced a significant effect at the low level of angle, F (7, 77) = 3.50, p = .003, η_p^2 = .241, and at the high level, F (7, 77) = 2.34, p = .032, η_p^2 = .175. The interaction was driven primarily by difference in the low angle level having, in general, higher mean A-AE values at the 270 degree position over various other parts of the field and, in general, in the high level of angle, the 0 and 315 hemimeridian positions having lower A-AE values over various other parts of the field.

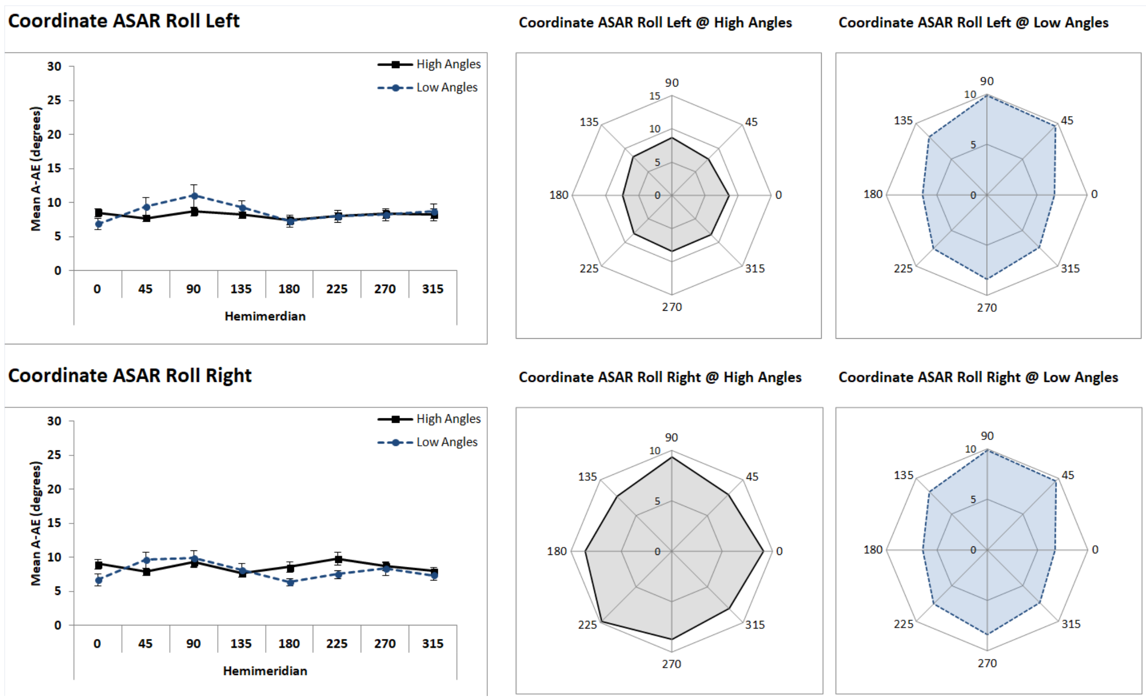


Figure 25. **Data plots for coordinate ASAR rolling left and right conditions. The top row contains results from trials required to be answered in a coordinate fashion and with the ASAR stimulus when it was rolling left. The bottom row contains results from trials required to be answered in a coordinate fashion and with the ASAR stimulus when it was rolling right. The leftmost panels in both rows contain the mean A-AE across hemimeridian with data in the solid black line showing values from the high angle level and data in the dotted blue lines from the low angle level. The middle panels contain polar plots for the mean A-AE at high angles, corresponding to the solid black line in the leftward plot. The rightmost panels contain polar plots for the mean A-AE at the low angles, corresponding to the dotted blue line in the leftmost plots.**

For trials required to be answered in a coordinate manner and responding to an **ASAR stimulus VFP *dive***, analysis of variance revealed significant main effects of angle, F (1, 11) = 5.78, p = .035, η_p^2 = .35 and hemimeridian, F (2.37, 26.05)* = 4.11, p = .023, η_p^2 = .27; however these main effects were qualified by a significant interaction effect between angle and hemimeridian, F (7, 77) = 2.82, p = .011, η_p^2 = .204. The effect of this interaction is illustrated in the lower panels of Figure 26. Simple effects analysis produced a significant effect at the low level of angle, F (7, 77) = 2.83, p = .011, η_p^2 = .21, and at the high level, F (2.06, 22.65)* = 4.49, p = .022, η_p^2 = .29. The interaction was driven primarily by difference in the low angle level having, in general, lower mean A-AE values in 0 and 180 degree hemimeridians over various positions in the rest of the field and in the high angle level having, in general, higher A-AE values at the 90 degree position over various positions in the rest of the field.

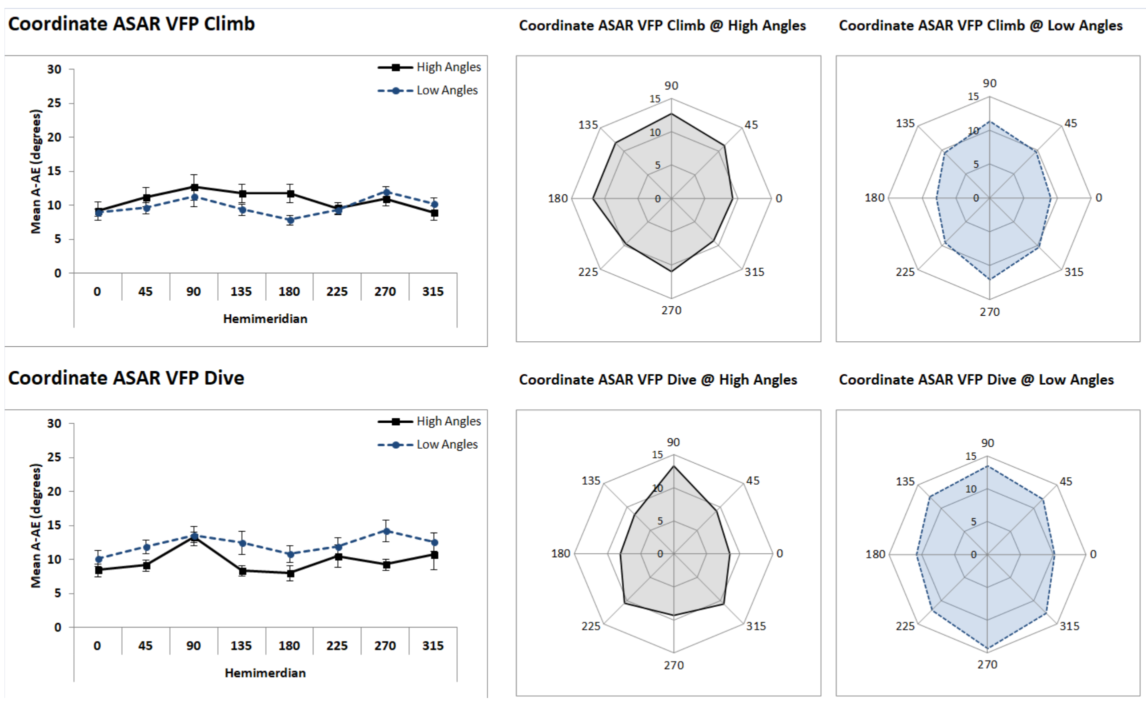


Figure 26. **Data plots for coordinate ASAR VFP climb and dive conditions. The top row contains results from trials required to be answered in a coordinate fashion and with the ASAR stimulus when it was in a VFP climb. The bottom row contains results from trials required to be answered in a coordinate fashion and with the ASAR stimulus when it was in a VFP down. The leftmost panels in both rows contain the mean A-AE across hemimeridian with data in the solid black line showing values from the high angle level and data in the dotted blue lines from the low angle level. The middle panels contain polar plots for the mean A-AE at high angles, corresponding to the solid black line in the leftward plot. The rightmost panels contain polar plots for the mean A-AE at the low angles, corresponding to the dotted blue line in the leftmost plots.**

Categorical Tasking

For trials required to be answered in a categorical manner and responding to a **Gabor stimulus rolling *left*** and A-RT as the dependent variable, analysis of variance revealed a non-significant main effect of angle, F (1, 11) = .752, p = .404, η_p^2 = .06; however, the main effect of hemimeridian was significant, F (2.85, 31.36)* = 4.25, p = .014, η_p^2 = .28. These main effects are illustrated in Figure 27. The main effects were not qualified by an interaction effect, F (7, 77) = 0.461, p = .860, η_p^2 = .04. Pairwise comparisons in the hemimeridian variable revealed that the differences were mainly driven by the 90 and 225 (lower-left) having higher A-RT values than various other parts of the field (Figure 27). Towards analyzing the A-PI, a non-parametric Friedman test of differences among repeated measures was conducted and at the low angles rendered χ^2 (7) = 15.90, which was significant, p = .026, W = .189, and at the high angles, rendered χ^2 (7) = 25.98, which was also significant, p = .001, W = .309. Pairwise comparisons at the low angles revealed that the differences were between the top, 90 degree hemimeridian, having higher A-PI than the left (180 degree position), right (0 degree position) and top-left (135 degree position); at the high angles, the 90 degree position had higher A-PI than the 135 position and the right side of the field.

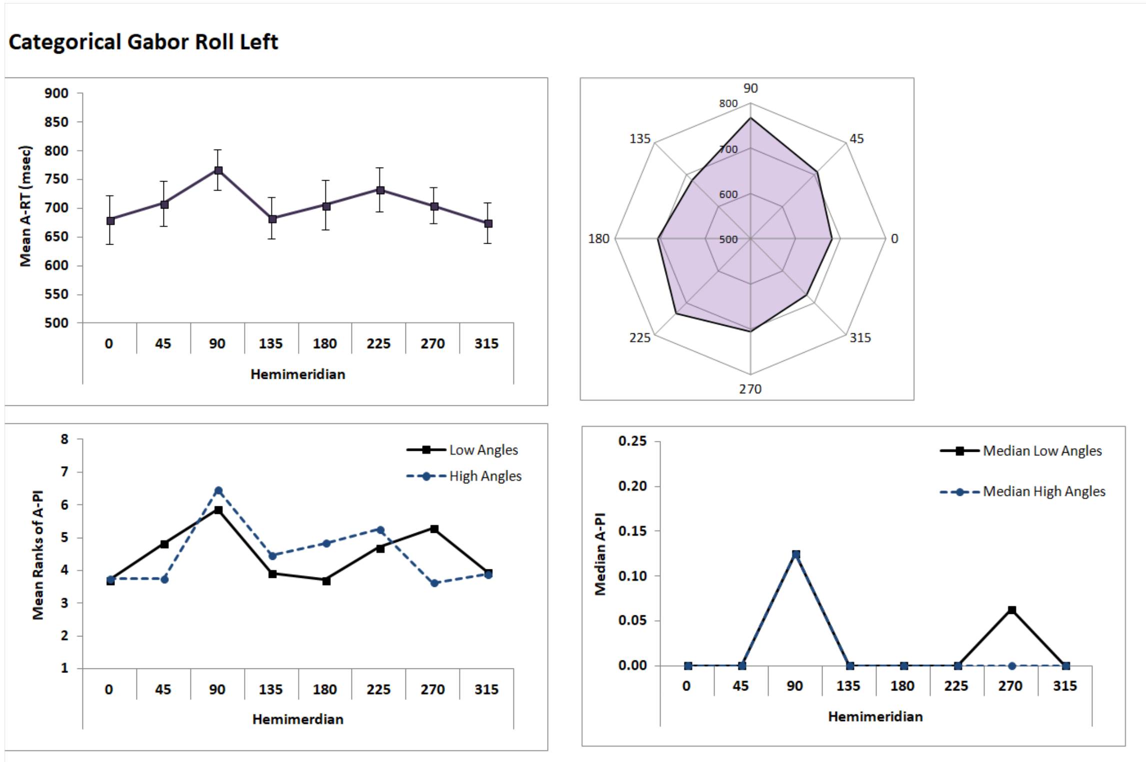


Figure 27. **Data plots for categorical Gabor rolling left condition. Plots contain results from trials required to be answered in a categorical fashion and with the Gabor stimulus when it was rolling left. Top-left panel contains the mean A-RT plotted as a function of hemimeridian. The right panel is a polar plot corresponding to the mean A-RT values in the leftward plot. The bottom left panel has the mean ranks from the Friedman test plotted as a function of hemimeridian and the bottom right panel contains the median A-PI values plotted as a function of hemimeridian.**

For trials required to be answered in a categorical manner and responding to a **Gabor stimulus rolling *right*** (Figure 28) and A-RT as the dependent variable, ANOVA revealed significant main effects of angle, *F* (1, 11) = 7.223, *p* = . 396, η_p^2 = .40, (low angles: *M* = 696 msec, *SE*= 32.90; high angles: *M* = 673.81 msec, *SE*= 36.49) and hemimeridian, *F* (3.128, 34.41)* = 5.342, *p* = .004, η_p^2 = .327. The main effects were not qualified by an interaction effect, *F* (2.27, 25.00) = .1.343, *p* = .281, η_p^2 = .109. These main effects are illustrated in the Figure 28. Pairwise comparisons in the hemimeridian variable revealed that the differences were mainly driven by the right side of the field having lower A-RT values than various other hemimeridian positions in the field. Towards analyzing the A-PI, a non-parametric Friedman test of differences among repeated measures was conducted and at the low angles rendered χ^2 (7) = 26.15, which was significant, $p < .001$, $W = .311$, and at the high angles, rendered χ^2 (7) = 19.34, which was also significant, $p = .007$, $W = .23$. Pairwise comparisons at the low angles revealed that the differences were driven by the 90 and 270 degree hemimeridians, having higher A-PI than the various other positions in the field, and at the high angles, the 90 degree position had higher A-PI than the various other parts of the field.

For trials required to be answered in a categorical manner and responding to an **ASAR stimulus rolling *left*** and A-RT as the dependent variable, analysis of variance revealed a significant main effect of angle, F (1, 11) = 56.04, $p < .001$, $\eta_p^2 = .84$, and a non-significant main effect of hemimeridian, F (3.12, 34.16)* = 9.58, $p = .426$, $\eta_p^2 = .080$. However, the main effects were qualified by an interaction effect, F (3.37, 37.01)* = 3.39, $p = .024$, $\eta_p^2 = .24$. The effect of these interactions is illustrated in Figure 29. Simple effects analysis uncovered a non-significant effect at the low level of angle, F (7.00, 34.30)* = 1.706, $p = .112$, $\eta_p^2 = .13$, but a significant effect at the high level, F (7, 77) = 4.13, $p = .001$, $\eta_p^2 = .27$. The interaction was driven primarily by differences in the high angle level having, in general, lower mean A-RT values in 90, 135, and 180 degree positions (top-left quadrant) compared to the bottom right quadrant (270 and 315 degrees). Towards analyzing the A-PI, a non-parametric Friedman test of differences among repeated measures was conducted and at the low angles rendered χ^2 (7) = 18.32, which was significant, $p = .011$, $W = .218$, and at the high angles, rendered χ^2 (7) = 7.73, non-significant, $p = .357$, $W = .092$. Pairwise comparisons at the low angles revealed that the differences were driven by the 135 degree hemimeridian, having higher A-PI than the various other positions in the field.

***Figure 28*. Data plots for categorical rolling right condition. Plots contain results from trials required to be answered in a categorical fashion and with the Gabor stimulus when it was rolling right. Top-left panel contains the mean A-RT plotted as a function of hemimeridian. The right panel is a polar plot corresponding to the mean A-RT values in the leftward plot. The bottom left panel has the mean ranks from the Friedman test plotted as a function of hemimeridian and the bottom right panel contains the median A-PI values plotted as a function of hemimeridian.**

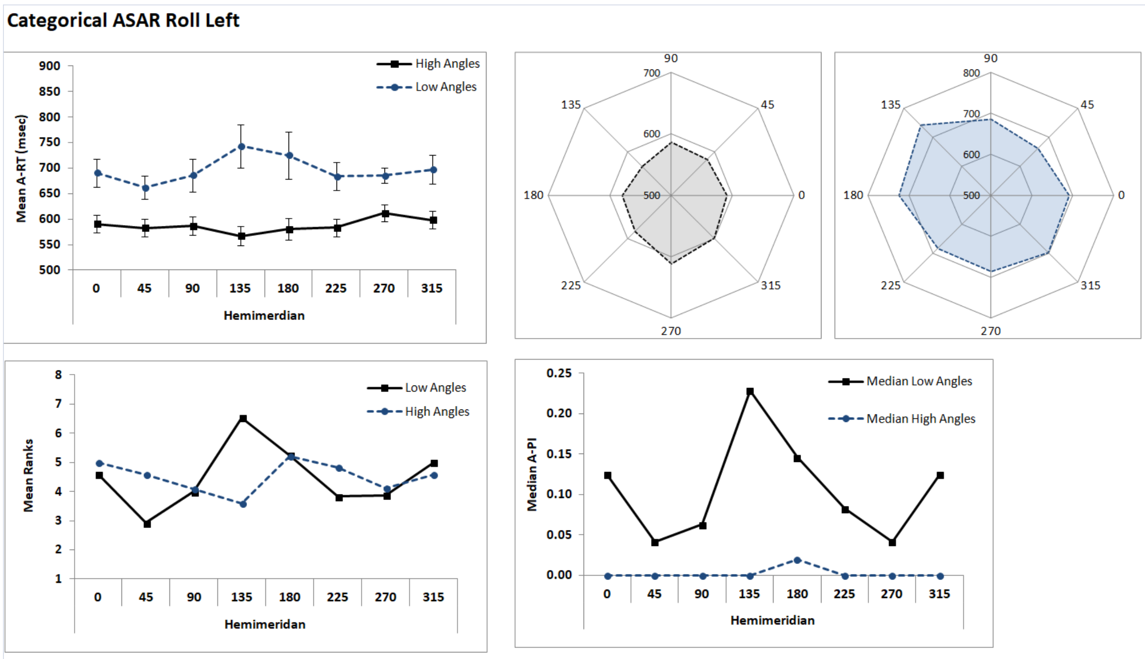


***Figure 29*. Data plots for categorical ASAR rolling left condition. Plots contain results from trials required to be answered in a categorical fashion and with the ASAR stimulus when it was rolling left. Top-left panel contains the mean A-RT plotted as a function of hemimeridian. The panels to the right are polar plots for the high angles, top middle panel, and the low angles, top rightmost panel -- corresponding to the mean A-RT values in the leftward plot. The bottom left panel has the mean ranks from the Friedman test plotted as a function of hemimeridian and the bottom right panel contains the median A-PI values plotted as a function of hemimeridian.**

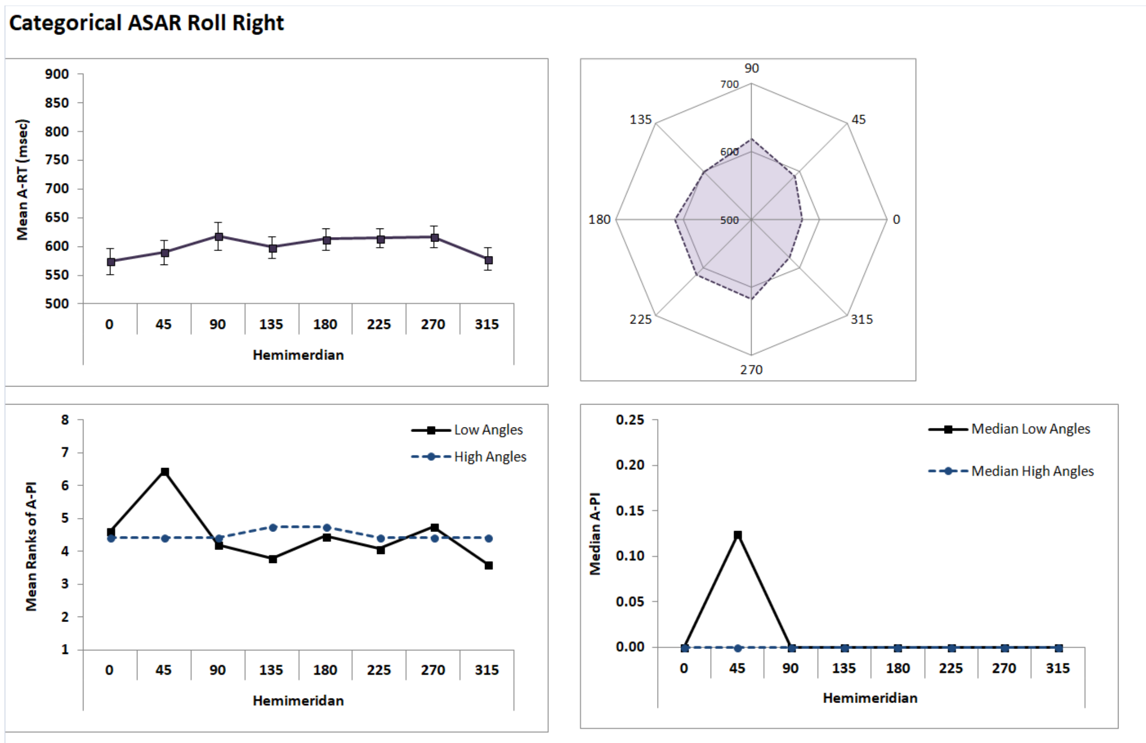


Figure 30. **Data plots for categorical ASAR rolling right condition. Plots contain results from trials required to be answered in a categorical fashion and with the ASAR stimulus when it was rolling right. Top-left panel contains the mean A-RT plotted as a function of hemimeridian. The right panel is a polar plot corresponding to the mean A-RT values in the leftward plot. The bottom left panel has the mean ranks from the Friedman test plotted as a function of hemimeridian and the bottom right panel contains the median A-PI values plotted as a function of hemimeridian.**

For trials required to be answered in a categorical manner and responding to an **ASAR stimulus rolling *right*** and A-RT as the dependent variable, analysis of variance revealed significant main effects of angle, $F\ (1, 11) = 52.184$, $p < 0.001$, $\eta_p^2 = .83$; at low angles, $M = 643$ msec, $SE = 21.97$, at high angles, $M = 558$ msec, $SE = 16.76$, and hemimeridian, $F\ (3.12, 34.34)^* = 4.70$, $p = .007$, $\eta_p^2 = .30$; the main effects were not qualified by an interaction effect, $F\ (7, 77) = .771$, $p = .613$, $\eta_p^2 = .065$. These main effects are illustrated Figure 30. Pairwise comparisons between the hemimeridian positions revealed positions on the left side of the field plus the top and bottom positions, had in general, higher A-RT values than the positions in the right part of the field. Towards analyzing the A-PI, a non-parametric Friedman test of differences among repeated measures was conducted and at the low angles rendered χ^2 (7) = 20.20, which was significant, p = .005, W = .24 and at the high angles, rendered χ^2 (7) = 6.00, non-significant, p = .540, W = .069. Pairwise comparisons at the low angles revealed that the differences were driven by the 45 degree hemimeridian, having higher A-PI than the various other positions in the field.

For trials required to be answered in a categorical manner and responding to an **ASAR stimulus having a VFP *climbing*** and A-RT as the dependent variable, analysis of variance revealed a significant main effect of angle, F (1, 11) = 27.16, p < . 001, η_p^2 = .71 but not at the hemimeridian variable, F (3.19, 77)* = 1.38, p = .265, η_p^2 = .11; however, the main effects were qualified by a significant interaction effect, F (7, 77) = 2.75, p = .013, η_p^2 = .20. The effect of this interaction is illustrated in the Figure 31. Simple effects analysis uncovered a non-significant effect at the low level of angle, F (7, 77) = 1.72, p = .116, η_p^2 = .14, and a marginally significant effect at the high level, F (7, 77) = 1.85, p = .089, η_p^2 = .14. At the high angles, pairwise comparisons between the hemimeridian positions suggest that the 90 and 180 degree positions had higher A-RT values over the right field positions. Towards analyzing the A-PI, a non-parametric Friedman test of differences among repeated measures was conducted and at the low angles rendered χ^2 (7) = 11.93, non-significant, p = .103, W = .142, and at the high angles, rendered χ^2 (7) = 7.00, non-significant, p = .429, W = .083.

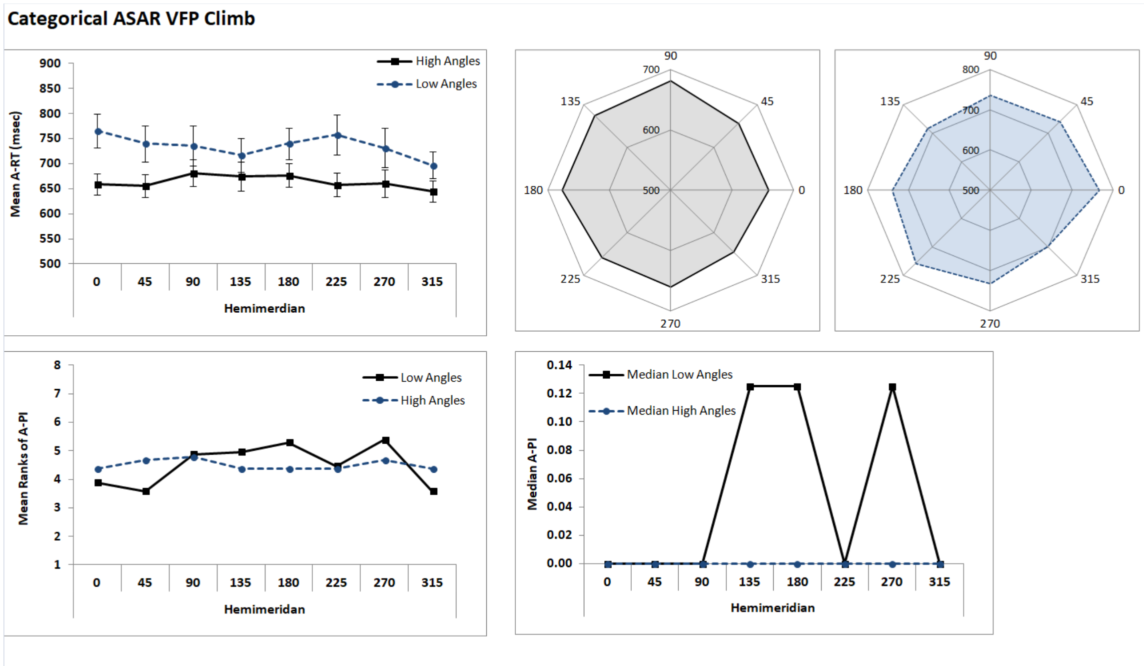


Figure 31. **Data plots for categorical ASAR VFP climb condition. Plots contain results from trials required to be answered in a categorical fashion and with the ASAR stimulus when it representing a VFP climbing. Top-left panel contains the mean A-RT plotted as a function of hemimeridian. The panels to the right are polar plots for the high angles, top middle panel, and the low angles, top rightmost panel -- corresponding to the mean A-RT values in the leftward plot. The bottom left panel has the mean ranks from the Friedman test plotted as a function of hemimeridian and the bottom right panel contains the median A-PI values plotted as a function of hemimeridian.**

For trials required to be answered in a categorical manner and responding to an **ASAR stimulus having a VFP *diving*** and A-RT as the dependent variable, analysis of variance revealed a significant main effect of angle, F (1, 11) = 21.18, $p < .001$, $\eta_p^2 = .66$ but not at the hemimeridian variable, F (3.62, 39.85)* = 1.46, $p = .236$, $\eta_p^2 = .17$. However, the main effects were qualified by a significant interaction effect, F (7, 77) = 2.58, $p = .019$, $\eta_p^2 = .19$. The effect of this interaction is illustrated in Figure 32. Simple effects analysis uncovered a non-significant effect at the low level of angle, F (3.77, 41.47)* = 1.35, p = .270, $\eta_p{}^2$ = .109, and a significant effect at the high level, F (7, 77) = 6.06, p < .001, $\eta_p{}^2$ = .36. At the high angles, pairwise comparisons between the hemimeridian positions suggest that the differences were mainly driven by the 45 degree position having lower A-RT values than various other parts of the field. Towards analyzing the A-PI, a non-parametric Friedman test of differences among repeated measures was conducted and at the low angles rendered χ^2 (7) = 7.48, non-significant, p = .381, W = .089, and at the high angles, rendered χ^2 (7) = 7.00, non-significant, p = .429, W = .083.

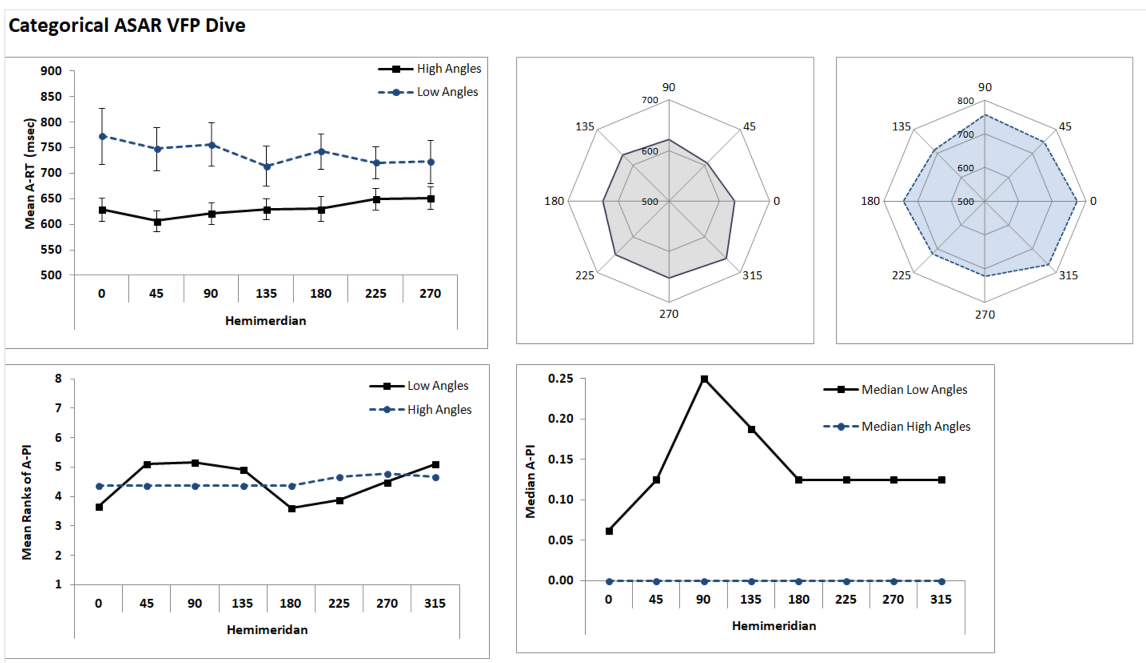


***Figure 32*. Data plots for categorical ASAR VFP dive condition. Plots contain results from trials required to be answered in a categorical fashion and with the ASAR stimulus when it representing a VFP diving. Top-left panel contains the mean A-RT plotted as a function of hemimeridian. The panels to the right are polar plots for the high angles, top middle panel, and the low angles, top rightmost panel -- corresponding to the mean A-RT values in the leftward plot. The bottom left panel has the mean ranks from the Friedman test plotted as a function of hemimeridian and the bottom right panel contains the median A-PI values plotted as a function of hemimeridian.**

Discussion

In Experiment 1, the effects of eight hemimeridian locations (placement of the ASAR or Gabor stimulus in the periphery), two angle levels (one level representative of low attitude angles deviating from a straight and level and another level representing high angles) and the interaction between hemimeridian and angle were assessed on the visual processing performance and the resultant behavioral performance. This evaluation was performed to observe if any visual field performance asymmetries (biases in response) would manifest themselves in the same manner as that of perceptual asymmetries from past literature.

It should be noted that the inclusion of the Gabor stimulus served as a baseline to validate to the experimental set-up. As will be discussed below, effects of stimulus hemimeridian placement were observed with the Gabor as a stimulus in this experiment and corresponded to past visual perceptual asymmetry research using similar stimuli, thus validating the experimental set-up.

The experiment was designed so that aspects of piloting an aircraft would correspond with aspects of research performed in the asymmetry research. These included assessing visual stimuli in:

1. coordinate verses categorical tasking
2. at various positions in the field of view

3. at various orientations (rolling) or component makeup (climb or dive) while placed in various positions in the field of view—the angle of deviation change from straight and level.

Items 1 and 2 are somewhat related in that differences were expected between the 0 and 180 degree hemimeridians, i.e., the left and right positions, while reporting in either categorical or coordinate taskings. We did not find evidence of differing visual processing performance between the left or right positions under coordinate or categorical taskings. This result might have come about due to the departure from traditional coordinate/categorical stimuli. Missing from the coordinate/categorical asymmetry literature are stimuli that are rotated, i.e., rolling, or dilating, as occurred during climbing or diving.

Assessment of the ASAR and Gabor at the eight different hemimeridians diverged between coordinate and categorical data in terms of the effects observed through the horizontal-vertical anisotropy. In general, more differences between hemimeridian positions were found at the low angle condition for the coordinate tasking and more differences between hemimeridian positions were found at the high angle condition for the categorical tasking. Over both coordinate and categorical taskings, these effects sometimes appeared as the 90 degree or the 270 degree (top and bottom) positions having worse performance than the rest of the field or as the 0 degree or 180 degree (left or right) positions having better performance than other parts of the visual field. These results, separately or coinciding, are considered to be elements of the HVA.

For coordinate data, elements of the HVA stood out mostly for high angles in the Gabor roll conditions, for low angles in the ASAR roll conditions, and for low and high angles in the ASAR VFP conditions. Across the board, the highest difference values of A-AE in the HVA effect were among the high angles with the Gabor rolling stimulus. It appears that the oblique effect (Appelle, 1972) is more pronounce in the 90º (top) position. In the oblique effect, the human visual system is more efficient in processing stimuli possessing horizontal and vertical directional contours as compared to stimuli possessing oblique elements. It can be argued that the roll angles presented, 3 to 48 by steps of 3, represented more directional elements that were towards the horizontal direction and hence less oblique.

For categorical data, the results were more mixed and not as conclusive. Interactions between angle and hemimeridian played a role in half the contextual situations. For Gabor rolling left and right stimuli, A-RT was higher at the 90 degree position and the lower left position than the rest of the field and the A-PI was significantly higher in the top position. The results for Gabor rolling left and right thus trended in a manner which was similar to those reported due to the HVA. For ASAR rolling left and right, results suggested the 90 and 270 hemimeridian positions followed HVA characteristics in A-RT but not so much in A-PI. For ASAR with VFP climb and dive stimuli, the results were markedly different than the rolling stimuli of Gabor and the ASAR. In the results for ASAR VFP climb and dive, there was little to no evidence of any trends of the HVA effect. This difference between the ASAR VFP contexts versus the ASAR/Gabor roll contexts could be due to the difference in the structure of the climbing/diving versus rolling stimuli. In an ASAR climb or dive, the number of visible pixels in the symbol changes with changes in angle. There are more pixels visible with increasing dive angle and fewer pixels visible with increases in climb angles. This can be thought of as dilation in the geometry of the ASAR's arc. In rolling conditions, the arc simply rotates clockwise or counter-clockwise. This can be thought of as a rotation in the geometry of the ASAR's arc. At a general level, it could very well be that asymmetries are more apparent when comparing rotations of any given stimulus over those of dilations of a stimulus.

An overall assessment of all contexts shows that results from performing the coordinate task produces trends more like that of the HVA in the literature over that of performing the categorical task, and the Gabor stimulus showed the highest A-AE at the 90 degree hemimeridian (~ a mean A-AE of 25 degrees) and at the 270 degree hemimeridian (~ a mean A-AE of 15 degree). The effects at the ASAR rolling left and right and ASAR VFP climbing and diving were much more subdued but nevertheless in some cases still significant enough to support recommendations on placement of the ASAR on an HMD. In general, the least desirable placement of the ASAR would be at the 90 degree position and second least desirable location would be at the 270 degree position. In terms of best possible placement of the ASAR, it can be argued that the right and left positions (0 and 180 degrees) will lead to improved performance when the pilot attempts to obtain this information using covert attention.

Summary

This chapter detailed Experiment 1's design, execution, analysis, and results. The results stemming from Experiment 1 were encouraging towards the exploitation of visual field asymmetries for recommendation of the placement of the ASAR in an HMD, or other symbology for that matter. However, this experiment employed an experimental protocol which was similar to previous laboratory research on visual anisotropy. Therefore, the question remains as to whether these effects will persist in conditions which are more representative of the real-world, for example, conditions in which users are presented with visual stimuli which compete for visual attention, that is stimuli which require the user to both focus their attention on the central part of the display while simultaneously maintaining awareness of visual stimuli in the peripheral regions. In following chapter, Experiment 2 will address some of these issues.

IV. Experiment 2

Chapter Overview

This chapter describes the design, execution, analysis, and results of Experiment 2. Experiment 2 was designed to better understand if asymmetries exist when participants have the flexibility to employ overt or covert attention. In other words, the visual stimulus in the periphery is constantly displayed and observers could move their eyes and gaze on such stimuli. If people are engaged in a dual task scenario where they have to monitor the center of a display and a stimulus in the periphery, does it matter if the eye movement is paired between the center task and the various other peripheral locations.

Introduction

Experiment 1 (presented in Chapter III) sought to compare if visual field performance asymmetries, as observed in the vision science literature with basic laboratory stimuli, were observable with more real-world stimuli that have purpose and meaning. Experiment 1 methodology was therefore designed to mimic that of past vision science research. The major methodological element of such research was to present peripheral stimuli for a very brief amount of time such that the eyes could not gaze onto it, thus tapping into the appropriate brain hemisphere thought to cause a certain perceptual phenomenon which shaped the resulting performance level.

We observed in Experiment 1 that there are elements of visual field performance asymmetries which influence the participant's ability to use the ASAR as a peripheral stimulus. Further, the methodology was validated by producing results with the Gabor patch which was consistent with the earlier research on visual field anisotropy. Although this research demonstrated that a real world stimulus such as the ASAR can produce similar trends in performance as appears in the vision science literature on visual asymmetries, the contextual tasking under which the participants were tested was very simple. There was no central task to engage and the ASAR was presented very briefly, each of which differ from the conditions that would occur in our imagined real world scenario (i.e., the ASAR would be constantly present and available to be observed if needed). Therefore, the question that needed to be asked was this: Are there performance differences in observing the ASAR when placed in different parts of the peripheral visual field, with the ASAR being constantly displayed, while the individual is engaged in a central attention-demanding task. With such a scenario, the observers could employ a mix of overt and covert attention towards the peripheral stimuli. These levels would most certainly be modulated by the attention demands on the central task.

Depending on the level of attention demands of the central task, various levels of covert and overt attention may be employed to the peripheral task. Experiment 1 could perhaps be thought of as having the simplest of central tasks as participants were asked to gaze in the center of the display where nothing was displayed. It can be argued that 100%, or near that, of attention resources were employed as covert attention, permitting individuals to attend fully to the ASAR or Gabor patch that was to be briefly presented in the periphery. In an effort to frame the understanding of visual field asymmetries with real world stimuli, in particular the ASAR, the design of Experiment 2 sought to employ a visually demanding central task such that it required the user to gaze upon the central field while directing attention to it. Thus, the observer would be required to employ overt attention to the central task and since attentional resources are limited, this may require the participants to minimize the use of covert attention to remain aware of the stimuli placed in the periphery. Hence, participants may find it advantageous to employ overt attention for the peripheral task as well as the central task. Thus, participants in this study may switch their combined gaze and direction of attention between that of a central task and each of eight different hemimeridian positions. Note that under this condition, the visual asymmetries do not specifically apply. However, a similar effect may exist if, for example, observers perform better when they switch attention between a central task and the left periphery over that of the center and right periphery. This type of visual field asymmetry has not been explored in the literature but it provides the other extreme case for how attention may be employed between a central task and a peripheral task.

Additionally, in the Reis et al., 2019, the study presented more “roll” trials than climb/dive trials. This was due to the Gabor stimulus not having a climb/dive equivalent to the ASAR. In Experiment 2, it was sought to better control for this potential artifact. Thus, only roll attitudes for the ASAR and the Gabor were tested. It was deemed more important to include the Gabor patch over a condition of ASAR climb/dive due to the exploratory nature of this research.

Method

Participants

Twelve participants, 11 males and 1 female, with an age range of 22-55 years age (*M* = 37.1, *SD* = 12.3) completed the study. Three of the male participants were also tested in Experiment 1. All participants were right-handed except for one male (left-handed) as assessed by the FLANDERS skilled hand preference test (Nicholls et. al, 2013) and the Purdue Pegboard test (Lafayette Instrument Company, 2021). One male had experience piloting aircraft. All participants reported normal or corrected-to-normal vision. Appendix A summarizes the participants' demographical data. The institutional review board from the Air Force Research Laboratory approved the study and participants gave informed consent prior to participation.

Experimental Set up and Stimuli

Experiment 2 used the same room set up, display, and computer as Experiment 1; however the input device was a standard computer mouse and a Tobii Pro/Fusion eye tracker was used to assess the participants' gaze location. The Gabor patch and ASAR visual stimulus from Experiment 1 was also incorporated in Experiment 2 and had the same dimensions, composition and hemimeridian locations as Experiment 1. Experiment 2 included a continuous tracking task in place of the fixation target from Experiment 1. A representative image of the visual stimuli employed in the tracking task is shown in Figure 33. The tracking task display mimicked a tactical situation display (TSD), where in real operational displays, the aircraft entities indicated by the triangles are monitored and selected for information.

In the peripheral task, the ASAR or Gabor stimulus represented a left or right roll attitude and as soon as the ASAR's or Gabor's roll attitude crossed into the opposite roll, i.e., crossing over a level roll attitude, the participants were required to acknowledge this event by clicking the left mouse button. Simultaneously, with equal importance, the participants were required to place crosshairs over a black-highlight aircraft in the tracking display and to track the aircraft while it moved within the TSD circle using the mouse. On occasion the black highlight would change to another aircraft and the participant would have to move the crosshairs to that aircraft and track it.

There were trials where the participants only performed the TSD task or the ASAR/Gabor task. In these single task trials, the ASAR or Gabor were placed in the middle of the display.

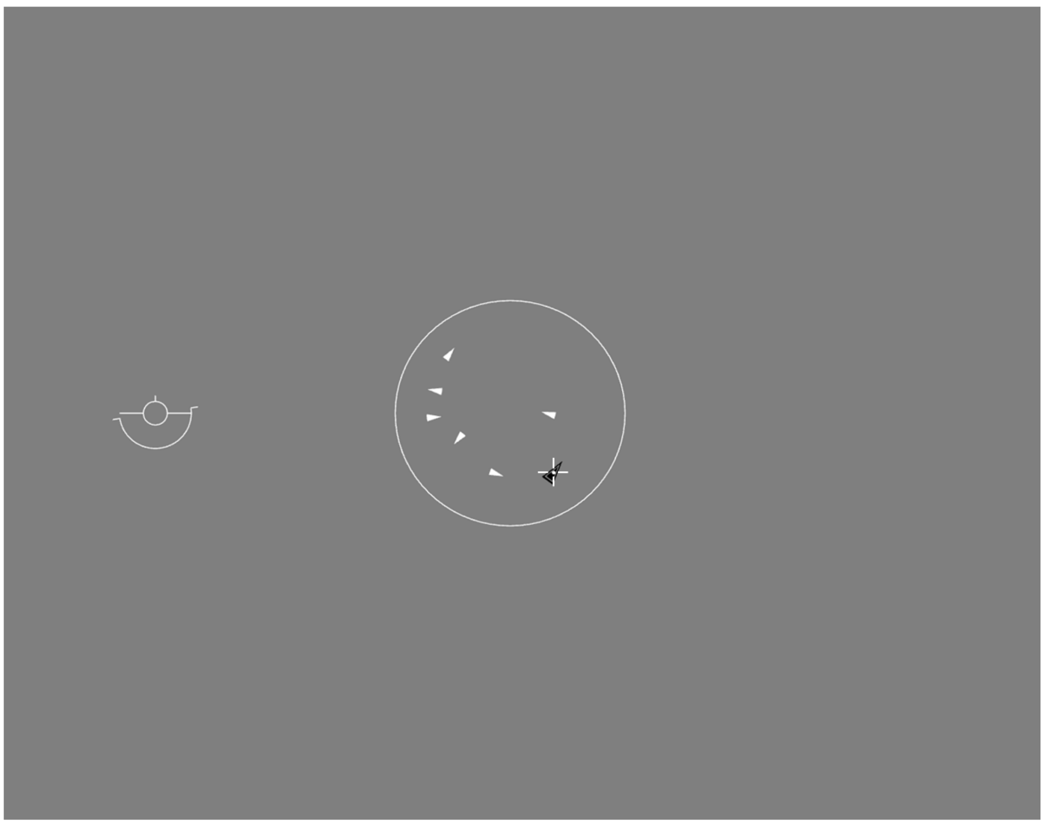


***Figure 33*. Experimental task in Experiment 2, showing central TSD task and peripheral visual stimulus. In this figure, the ASAR symbology is representing a right roll. The ASAR is located at the 180 deg hemimeridian location. The highlighted aircraft always contained a white dot in the center of the aircraft symbol and when the crosshairs contained the white dot a black outline surrounded the aircraft for visual feedback that the aircraft was being tracked properly.**

Procedure

The experiment required approximately two hours for each participant. Participants completed a demographic questionnaire, the FLANDERS handedness test, the Purdue Peg Board Test, and they had their vision checked with the Optec 5500 vision tester to assess for major deviations from normal vision. The participants were then seated at the experimental workstation and the Tobii eye tracker was calibrated for each participant.

Participants then completed three tasks. The participants first performed the tracking task by itself, as shown in Figure 34. The participants then performed the attitude task by itself as shown in Figure 35, using the ASAR and Gabor. Finally, the participants performed both tasks simultaneously by interacting with a display as shown previously in Figure 32. The participants were shown examples of these three types of tasks and the required inputs.

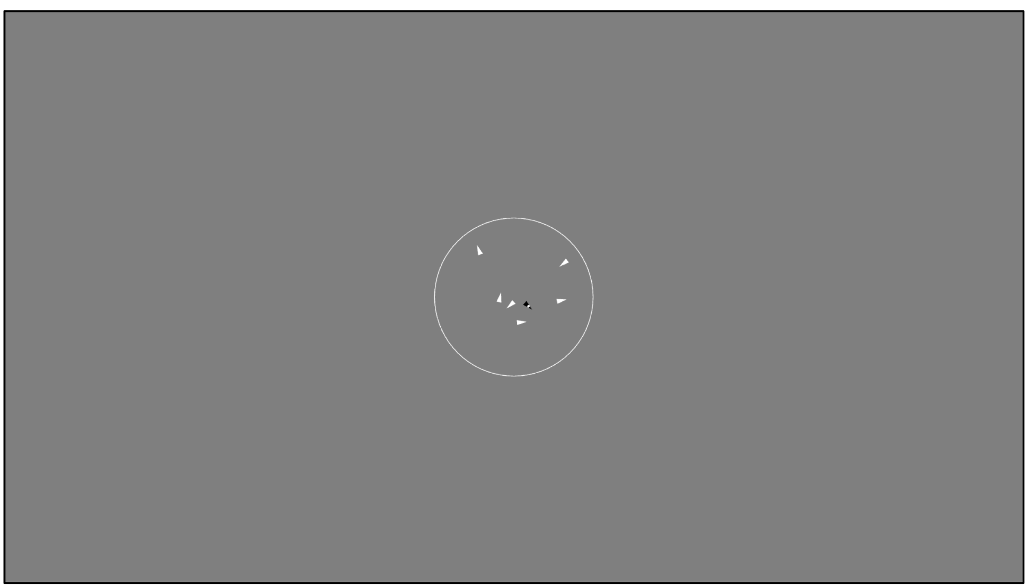


***Figure 34*. The TDS task shown as a single task.**

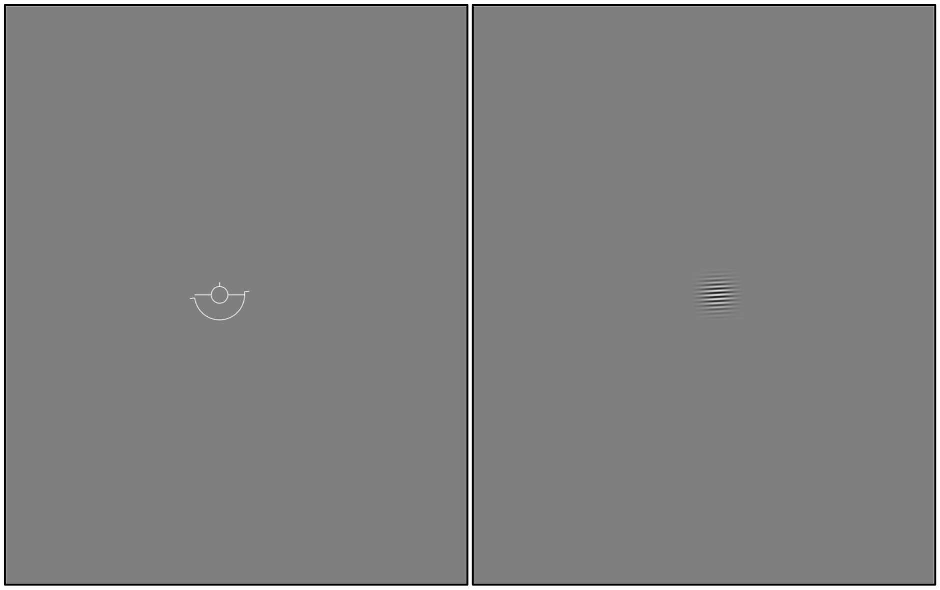


Figure 35. **The ASAR and Gabor stimuli in single tasks. The ASAR (on left) and the Gabor (on right) attitude tasks shown as single tasks -- in the middle of the display. Here, both the ASAR and the Gabor are showing slight right rolls.**

In both the single TSD and in the dual tasks, there were seven triangles, each representing a different aircraft, randomly placed in the circle of the tracking task. The circle was eight degrees of visual angle in diameter. The aircrafts' bases and lengths subtended 0.1667 and 0.5 degrees of visual angle, respectively. The aircraft were white in color and traveled at a rate of 0.5 degree of visual angle/sec. All aircraft changed heading at some random angle selected from a uniform distribution between 10 and 15 degrees to the left or right of its trajectory and this change in direction occurred at a uniformly distributed random time between 1 and 2 seconds. In the single task trials, the TSD task lasted one minute. In the dual task, the TSD task lasted as long as the attitude task in the periphery. In both the single and dual task trials, the performance measure in the TSD was “percent of time off target.” This measure calculated the percent of the time when the mouse cursor was not tracking the highlighted aircraft.

In the attitude task, the stimulus (ASAR or Gabor) was presented in a left or right roll and perturbated randomly between 1 and 10 degrees in its initial roll direction at a rate of 3 deg/second. At some random time between 6 and 14 seconds from the start of a trial, the ASAR or Gabor started making a flip in the roll direction. This was defined as a “flip event.” When the participant acknowledged that the ASAR or Gabor had just crossed over the level mark they were to press the left mouse button. At the point when the participants pressed the mouse button, the angle (degrees) and time (milliseconds) from when the ASAR or Gabor crossed over level was recorded. When the flip event was acknowledged, the ASAR or Gabor would then reset into the original roll direction in which it started the trial. This flip event occurred a total of five times in a trial and the trial ended once the left mouse button was pressed for the fifth event. In single task trials, the five events occurred in the middle of the display. One single task trial containing these five events was performed at the beginning of the session and one trial towards the end of the session. For dual task trials, the five flip events were presented in one trial at each hemimeridian.

Practice trials were administered before each trial. In the single tracking task trials, the practice trial was 10 seconds in length and was followed by a 60 second experimental trial. For the single attitude task, the ASAR or Gabor practice trial had only included one flip event.

In summary, the single tasks were:

1. TSD Single Task
    a. Practice: The TSD task lasting 10 seconds—no peripheral attitude task.
    b. Test: The TSD task lasting 10 seconds—no peripheral attitude task.
2. ASAR Rolling Left
    a. Practice: No TSD task and ASAR positioned in the middle of display The ASAR starting in a rolling left attitude and acknowledging when the ASAR changed into a rolling right attitude—*occurring one time*.
    b. Test: No TSD task and ASAR positioned in the middle of display The ASAR starting in a rolling left attitude and acknowledging when the ASAR changed into a rolling right attitude—*occurring five times*.
3. ASAR Rolling Right
    a. Practice: No TSD task and ASAR positioned in the middle of display The ASAR starting in a rolling right attitude and acknowledging when the ASAR changed into a rolling left attitude—*occurring one time*.
    b. Test: No TSD task and ASAR positioned in the middle of display The ASAR starting in a rolling right attitude and acknowledging when the ASAR changed into a rolling left attitude—*occurring five times*.
4. GABOR Rolling Left
    a. Practice: No TSD task and GABOR positioned in the middle of display The GABOR starting in a rolling left attitude and acknowledging when the GABOR changed into a rolling right attitude—*occurring one time*.

b. Test: No TSD task and GABOR positioned in the middle of display The GABOR starting in a rolling left attitude and acknowledging when the GABOR changed into a rolling right attitude—*occurring five times*.

5. GABOR Rolling Right

   a. Practice: No TSD task and GABOR positioned in the middle of display The GABOR starting in a rolling right attitude and acknowledging when the GABOR changed into a rolling left attitude—*occurring one time*.

   b. Test: No TSD task and GABOR positioned in the middle of display The GABOR starting in a rolling right attitude and acknowledging when the GABOR changed into a rolling left attitude—*occurring five times*.

The five single tasks were performed at the beginning and at the end of the session while the dual tasks were performance in the middle of the session. Each participant was presented a random order of the single task trials at the beginning of a session and the reverse order of their random set at the end of the session. The order of the four dual tasks across participants was presented in an order determined using a balanced Latin squares (see Appendix E). This design helped minimize immediate carry-over effects by having every condition precede another condition the same number of times. In summary, the dual tasks were:

1.

  a. ***Practice***: The TSD task was performed in the middle of the display. The ASAR starting in a rolling left attitude and acknowledging when the ASAR changed into a rolling right attitude—*occurring one time* in one trial at each hemimeridian locations (randomized).
  b. ***Test***: The TSD task was performed in the middle of the display. The ASAR starting in a rolling left attitude and acknowledging when the ASAR changed into a rolling right attitude—*occurring five times* in one trial at each hemimeridian locations (randomized).

2.

  a. ***Practice***: The TSD task was performed in the middle of the display. The ASAR starting in a rolling right attitude and acknowledging when the ASAR changed into a rolling left attitude—*occurring one time* in one trial at each hemimeridian locations.
  b. ***Test***: The TSD task was performed in the middle of the display. The ASAR starting in a rolling right attitude and acknowledging when the ASAR changed into a rolling left attitude—*occurring five times* in one trial at each hemimeridian locations.

3.

  a. ***Practice***: The TSD task was performed in the middle of the display. The Gabor starting in a rolling left attitude and acknowledging when the Gabor changed into a rolling right attitude—*occurring one time* in one trial at each hemimeridian locations.

b. ***Test***: The TSD task was performed in the middle of the display. The Gabor starting in a rolling left attitude and acknowledging when the Gabor changed into a rolling right attitude—*occurring five times* in one trial at each hemimeridian locations.

4.

a. ***Practice***: The TSD task was performed in the middle of the display. The Gabor starting in a rolling right attitude and acknowledging when the Gabor changed into a rolling left attitude—occurring 5 times in one trial at each hemimeridian locations.

b. ***Test***: The TSD task was performed in the middle of the display. The Gabor starting in a rolling right attitude and acknowledging when the Gabor changed into a rolling left attitude—occurring 5 times in one trial at each hemimeridian locations.

To expound on the tasking ordering, Table 3 shows the task orders for Participant 1 as an example.

The trial associated with each line in Table 3 was initiated by the participant by clicking on the line within an Excel sheet. The participants could see the condition that was to be coming up on this line in the Excel sheet. The Excel sheet launched the Unity task environment. When the participants completed the trial(s) for a line within the spreadsheet, the Unity program exited back out to the Excel sheet and the participants launched the next line to be completed. The participants could see which lines had already been completed by the lines being marked with an “X” next to them. Participants were required to take a break after completing the first set of single task trials and after completing each of the dual tasks.

Table 3. The tasking order for Participant 1.

Line	Trial	Practice or Test	Condition	Single or Dual Task	Number of Flip Events	Location of Attitude Task
1	1	Practice	ASAR Rolling Left initially	ASAR only	1	Center of Display
2	2	Test	ASAR Rolling Left initially	ASAR only	5	Center of Display
3	3	Practice	Gabor Rolling Left initially	Gabor only	1	Center of Display
4	4	Test	Gabor Rolling Left initially	Gabor only	5	Center of Display
5	5	Practice	ASAR Rolling Right initially	ASAR only	1	Center of Display
6	6	Test	ASAR Rolling Right initially	ASAR only	5	Center of Display
7	7	Practice	TSD	TSD only	N/A	N/A
8	8	Test	TSD	TSD only	N/A	N/A
9	9	Practice	Gabor Rolling Right initially	Gabor only	1	Center of Display
10	10	Test	Gabor Rolling Right initially	Gabor only	5	Center of Display
11	11-18	Practice	ASAR Rolling Left initially	ASAR and TSD	1	At each of the 8 peripheral locations
12	19-26	Test	ASAR Rolling Left initially	ASAR and TSD	5	At each of the 8 peripheral locations
13	27-34	Practice	ASAR Rolling Right initially	ASAR and TSD	1	At each of the 8 peripheral locations
14	35-42	Test	ASAR Rolling Right initially	ASAR and TSD	5	At each of the 8 peripheral locations
15	43-50	Practice	Gabor Rolling Left initially	Gabor and TSD	1	At each of the 8 peripheral locations
16	51-58	Test	Gabor Rolling Left initially	Gabor and TSD	5	At each of the 8 peripheral locations
17	59-66	Practice	Gabor Rolling Right initially	Gabor and TSD	1	At each of the 8 peripheral locations
18	67-74	Test	Gabor Rolling Right initially	Gabor and TSD	5	At each of the 8 peripheral locations
19	75	Practice	Gabor Rolling Right initially	Gabor only	1	Center of Display
20	76	Test	Gabor Rolling Right initially	Gabor only	5	Center of Display
21	77	Practice	TSD	TSD only	N/A	N/A
22	78	Test	TSD	TSD only	N/A	N/A
23	79	Practice	ASAR Rolling Right initially	ASAR only	1	Center of Display
24	80	Test	ASAR Rolling Right initially	ASAR only	5	Center of Display
25	81	Practice	Gabor Rolling Left initially	Gabor only	1	Center of Display
26	82	Test	Gabor Rolling Left initially	Gabor only	5	Center of Display
27	83	Practice	ASAR Rolling Left initially	ASAR only	1	Center of Display
28	84	Test	ASAR Rolling Left initially	ASAR only	5	Center of Display

Single Task Lines

When the participants launched a single task, the Unity program displayed one of the following messages: “Maintain Roll Right Attitude, “Maintain Roll Left Attitude,” or “Maintain Track of the Aircraft,” depending if the single task contained and ASAR, Gabor or the TSD. In all cases, the task began with the participants pressing the ‘a” key on the keyboard. After the ‘a’ key was pressed, the stimulus, i.e., ASAR, Gabor, or central task, appeared. Three seconds passed and three sound notifications were given to mark the start of data collection. If the stimulus was an ASAR or Gabor, the stimulus headed toward the opposite roll after some random time between 6 and 14 seconds. As soon as the ASAR or Gabor crossed over level attitude, they pressed the left mouse button. If the trial was practice, then the Unity program exited out to the Excel launcher sheet. If the trial was a test trial, the stimulus snapped to the initial default roll attitude and the procedure was repeated another four times for a total of five events. This procedure is diagramed in Figure 36. In the single tracking task trials, after the 3 beeps were given to notify of the start of trial, the participants tracked the black highlighted aircraft. The trial lasted 10 seconds if it was practice and 60 seconds if it was a test trial. After the 10 or 60 seconds past, the Unity program exited out to the Excel launcher sheet. The procedure for the TSD single task trials is diagrammed in Figure 37.

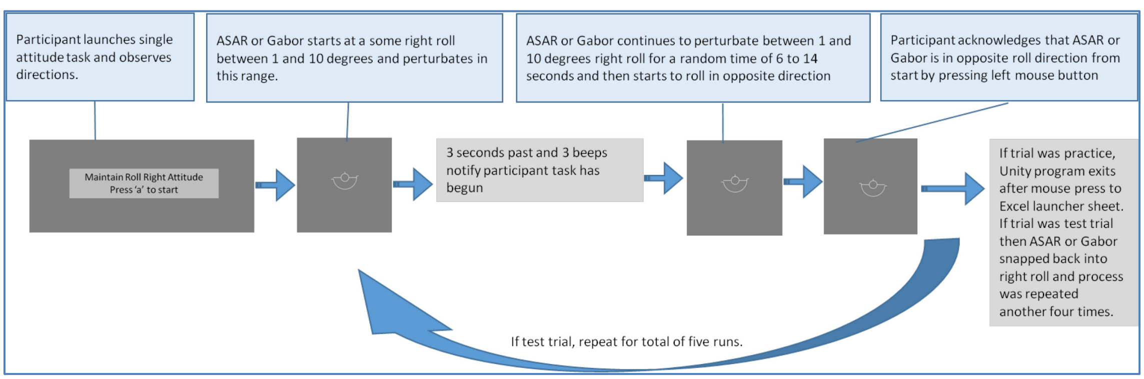


***Figure 36*. Task flow for single task trials containing ASAR or Gabor. Here, the ASAR is shown as the example stimulus.**

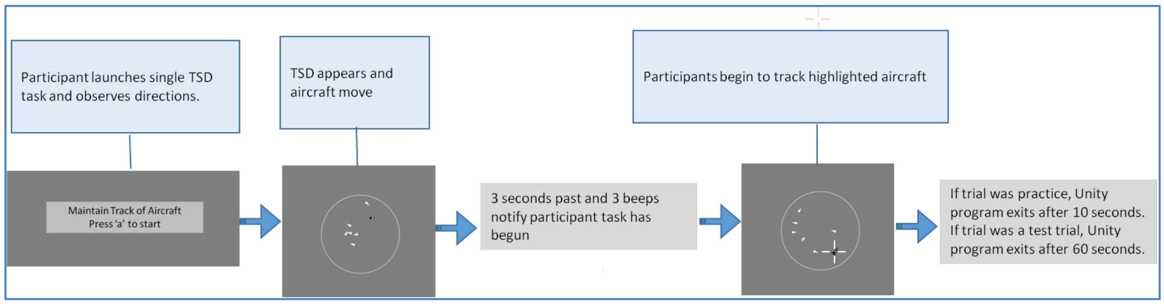


***Figure 37*. Task flow for single task trials containing the TSD.**

Dual Task

The task flow for a dual task was similar to the single task with the ASAR or Gabor stimulus. The procedure is shown in Figure 38. When the task was launched, the participants received instructions on the type of roll attitude they were to maintain. Upon pressing the letter 'a' on the keyboard, the ASAR or Gabor appeared in a random hemimeridian and would be perturbing in the roll direction indicated from the directions. The TSD circle was displayed with no aircraft. This display was shown for three seconds for the participants to understand where the stimulus was in the periphery and to solidify their understanding of the roll attitude that they were to maintain. After the three seconds past, aircraft appeared in the TSD and after another three seconds, three short beeps were used to indicate the start of the trial and data collection. As the participants tracked the highlighted aircraft, they were also instructed to monitor the ASAR or Gabor for flipping in roll direction. As soon as the roll had flipped over level attitude the participants were to acknowledge this event by clicking the left mouse button. After the button press, the ASAR or Gabor snapped back to the initial roll direction at some random angle between 1 and 10 degrees. The process of tracking the aircraft and monitoring the peripheral stimulus began again and this process of acknowledging the stimulus flip was performed five times in total. After the fifth time that the stimulus was acknowledged, the screen froze and a message "click button to continue" was displayed. Once the mouse button was clicked the stimulus appeared in another random hemimeridian location, with the empty circle. The stimulus had the same initial attitude direction as the previous run and followed the same process as the previous run. All hemimeridian locations were tested in the same manner and the random assignment was without replacement so all eight locations were tested once.

While the participants were performing the tasks, their eyes were being tracked by the Tobii Pro/Fusion eye tracker. Four areas on the screen were delineated to help determine where the participants were looking (Figure 39). These four areas were:

(1) *Peripheral:* The region around the ASAR or Gabor-- extended by a radius of 1 visual degree (the green area).

(2) *TSD:* The region around the TSD -- extended by a radius of 1.5 degrees (the light brown area).

(3) *In-Between:* When two tangent line segments are used to connect the two circular regions another region is defined as "in-between." The eyes were either likely traveling from the TSD to the peripheral stimulus or the eyes may have been intentionally gazing in that region.

(4) *NA*: The 4th region is the gray region and if the eyes were measured to be in this area then they were considered to be gazing at nothing applicable (NA).

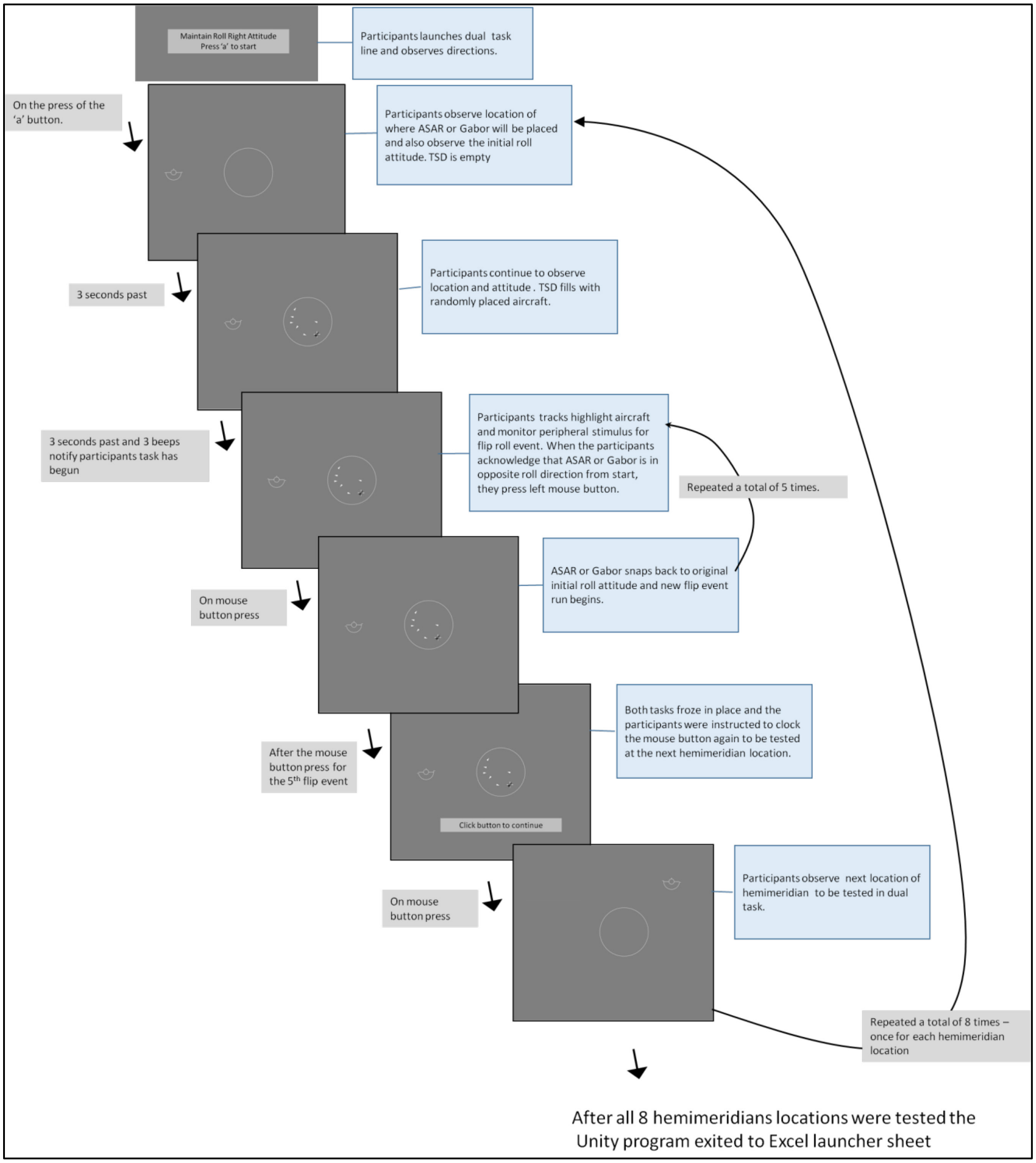


Figure 38. **Task flow for dual task trials containing ASAR or Gabor. Here, the ASAR is shown as the example stimulus.**

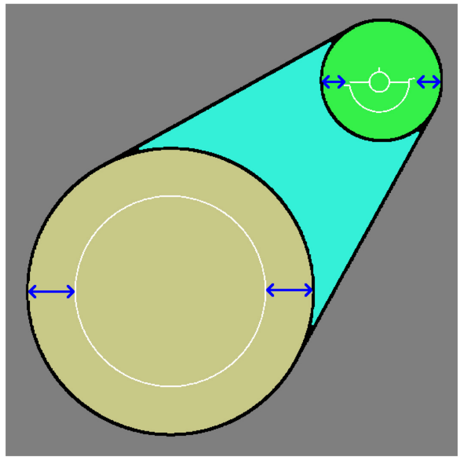


***Figure 39*. The screen was delineated into four regions to help determine where participants were looking during testing.**

Data Analysis

Performance Data Analysis

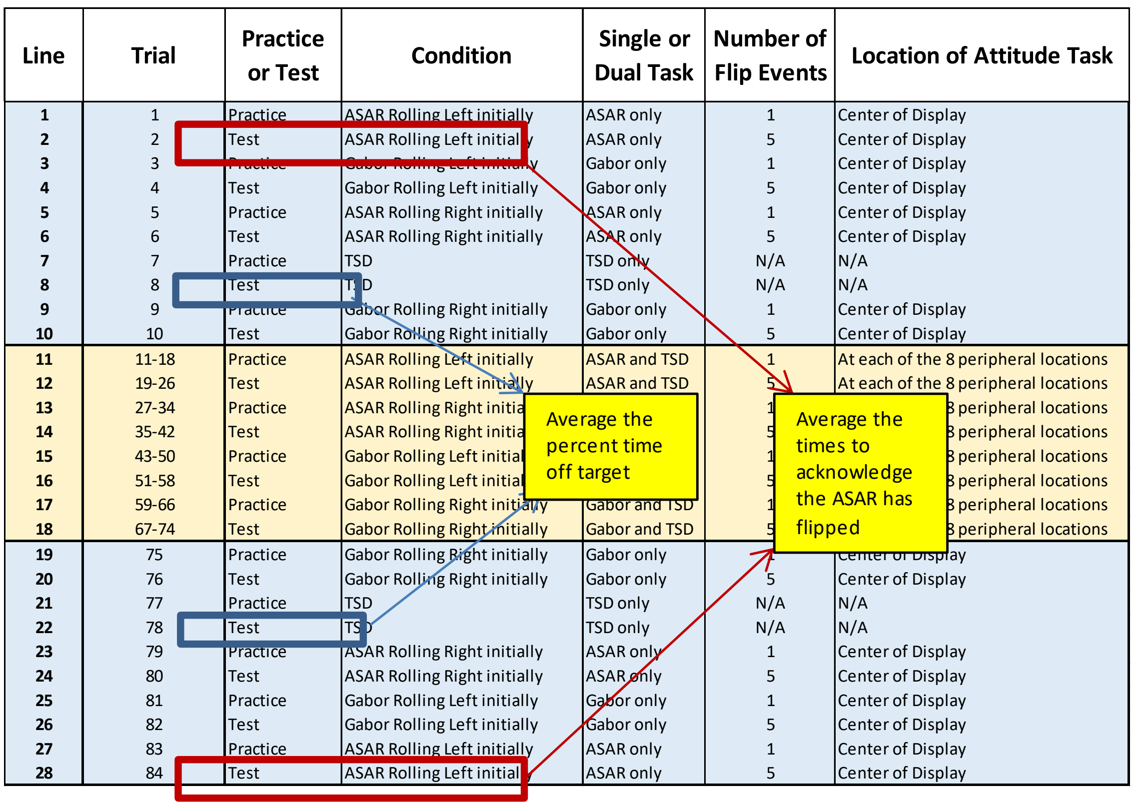
Data were analyzed with IBM SPSS Statistics 22. For each of the four contexts (Gabor rolling left default, Gabor rolling right default, ASAR rolling left default, ASAR rolling right default) a one-way ANOVA was employed. The independent variable was hemimeridian location and the dependent variable was a derived measure called the Total Performance Decrement (TPD).

For each participant, the TPD was calculated by first averaging the front and back end single tasks test trial's dependent measures (Figure 40):

- For the TSD single task trial, the average of the percent of time off target was recorded.
- For the Gabor or ASAR single task trials, the average time to acknowledge the visual stimulus (Gabor/ASAR) having flipped in the

opposite roll was recorded and averaged across the10 flip events (i.e., 5 from the front end trial and 5 from the back end trial).

Next, within each dual task trial, the percent time off target, and separately, the time to acknowledge the flip were averaged across the five runs within each experimental trial, as indicated by Figure 41.



Line	Trial	Practice or Test	Condition	Single or Dual Task	Number of Flip Events	Location of Attitude Task
1	1	Practice	ASAR Rolling Left initially	ASAR only	1	Center of Display
2	2	Test	ASAR Rolling Left initially	ASAR only	5	Center of Display
3	3	Practice	Gabor Rolling Left initially	Gabor only	1	Center of Display
4	4	Test	Gabor Rolling Left initially	Gabor only	5	Center of Display
5	5	Practice	ASAR Rolling Right initially	ASAR only	1	Center of Display
6	6	Test	ASAR Rolling Right initially	ASAR only	5	Center of Display
7	7	Practice	TSD	TSD only	N/A	N/A
8	8	Test	TSD	TSD only	N/A	N/A
9	9	Practice	Gabor Rolling Right initially	Gabor only	1	Center of Display
10	10	Test	Gabor Rolling Right initially	Gabor only	5	Center of Display
11	11-18	Practice	ASAR Rolling Left initially	ASAR and TSD	1	At each of the 8 peripheral locations
12	19-26	Test	ASAR Rolling Left initially	ASAR and TSD	5	At each of the 8 peripheral locations
13	27-34	Practice	ASAR Rolling Right initia		1	8 peripheral locations
14	35-42	Test	ASAR Rolling Right initia		5	8 peripheral locations
15	43-50	Practice	Gabor Rolling Left initial		1	8 peripheral locations
16	51-58	Test	Gabor Rolling Left initial		5	8 peripheral locations
17	59-66	Practice	Gabor Rolling Right initially	Gabor and TSD	1	8 peripheral locations
18	67-74	Test	Gabor Rolling Right initially	Gabor and TSD	5	8 peripheral locations
19	75	Practice	Gabor Rolling Right initially	Gabor only		Center of Display
20	76	Test	Gabor Rolling Right initially	Gabor only	5	Center of Display
21	77	Practice	TSD	TSD only	N/A	N/A
22	78	Test	TSD	TSD only	N/A	N/A
23	79	Practice	ASAR Rolling Right initially	ASAR only	1	Center of Display
24	80	Test	ASAR Rolling Right initially	ASAR only	5	Center of Display
25	81	Practice	Gabor Rolling Left initially	Gabor only	1	Center of Display
26	82	Test	Gabor Rolling Left initially	Gabor only	5	Center of Display
27	83	Practice	ASAR Rolling Left initially	ASAR only	1	Center of Display
28	84	Test	ASAR Rolling Left initially	ASAR only	5	Center of Display

Figure 40. **Example of averaging the single task trials dependent measures. Here, the TSD's percent time off target from the front end trial is average with the back end trial. For the ASAR or Gabor trials, each condition's 5 runs from the front end trial were averaged with the 5 runs from the back end trial—here ASAR rolling left is shown for the front and back end trials.**

Line	Trial	Practice or Test	Condition	Single or Dual Task	Number of Flip Events	Location of Attitude Task
1	1	Practice	ASAR Rolling Left initially	ASAR only	1	Center of Display
2	2	Test	ASAR Rolling Left initially	ASAR only	5	Center of Display
3	3	Practice	Gabor Rolling Left initially	Gabor only	1	Center of Display
4	4	Test	Gabor Rolling Left initially	Gabor only	5	Center of Display
5	5	Practice	ASAR Rolling Right initially	ASAR only	[illegible]	[illegible]
6	6	Test	ASAR Rolling Right initially	ASAR only	[illegible]	[illegible]
7	7	Practice	TSD	TSD only	[illegible]	[illegible]
8	8	Test	TSD	TSD only	[illegible]	[illegible]
9	9	Practice	Gabor Rolling Right initially	Gabor only	1	Center of Display
10	10	Test	Gabor Rolling Right initially	Gabor only	5	Center of Display
11	11-18	Practice	ASAR Rolling Left initially	ASAR and TSD	1	At each of the 8 peripheral locations
12	19-26	Test	ASAR Rolling Left initially	ASAR and TSD	5	At each of the 8 peripheral locations
13	27-34	Practice	ASAR Rolling Right initially	ASAR and TSD	1	At each of the 8 peripheral locations
14	35-42	Test	ASAR Rolling Right initially	ASAR and TSD	5	At each of the 8 peripheral locations
15	43-50	Practice	Gabor Rolling Left initially	Gabor and TSD	1	[illegible]eral locations
16	51-58	Test	Gabor Rolling Left initially	Gabor and TSD	5	[illegible]eral locations
17	59-66	Practice	Gabor Rolling Right initially	Gabor and TSD	1	[illegible]eral locations
18	67-74	Test	Gabor Rolling Right initially	Gabor and TSD	5	[illegible]eral locations
19	75	Practice	Gabor Rolling Right initially	Gabor only	1	[illegible]
20	76	Test	Gabor Rolling Right initially	Gabor only	5	[illegible]
21	77	Practice	TSD	TSD only	N/A	[illegible]
22	78	Test	TSD	TSD only	N/A	N/A
23	79	Practice	ASAR Rolling Right initially	ASAR only	1	Center of Display
24	80	Test	ASAR Rolling Right initially	ASAR only	5	Center of Display
25	81	Practice	Gabor Rolling Left initially	Gabor only	1	Center of Display
26	82	Test	Gabor Rolling Left initially	Gabor only	5	Center of Display
27	83	Practice	ASAR Rolling Left initially	ASAR only	1	Center of Display
28	84	Test	ASAR Rolling Left initially	ASAR only	5	Center of Display

Average the percent time off target across the 5 runs

Average the times to acknowledge the ASAR has flipped across the 5 runs

***Figure 41*. Example showing the averaging of the percent of time off target across 5 fives and the time to acknowledge ASAR had flipped across 5 runs.**

At each hemimeridian location for each dual task condition, a Time Off Target Decrement (Equation 1) and a Time Acknowledged Decrement (Equation 2) was calculated. The term "decrement" refers to the central and peripheral tasks' decline in performance due to them being performance together in a dual task. For the Time Off Target Decrement, the dual task's TSD average time off target measure subtracted the average time off target from the single task trials and this difference quantity was divided by the single task TSD average time off target and then multiplied by 100. For the Time Acknowledged Decrement, the dual task's average Time to Acknowledge subtracted the average time to acknowledge from the respective single task average. The equations toward obtaining the TPD (Equation 3) are shown below.

$$\text{Time Off Target Decrement} = \frac{(\text{Percent Time Off Target}_{Dual\ task} - \text{Percent Time Off Target}_{Single\ Task}) * 100}{\text{Percent Time Off Target}_{Single\ Task}} \tag{1}$$

$$\text{Time to Acknowledge Decrement} = \frac{(\text{Time to Acknowledge Flip}_{Dual\ task} - \text{Time to Acknowledge Flip}_{Single\ Task}) * 100}{\text{Time to Acknowledge Flip}_{Single\ Task}} \tag{2}$$

$$\text{Total Performance Decrement} = \text{Time Off Target Decrement} + \text{Time to Acknowledge Decrement} \tag{3}$$

The Time Off Decrement and Time to Acknowledge Decrement were computed to account for baseline performance differences from single-task performance. This also allows the task decrement (from being in a dual task) to be expressed as a percentage (Abernethy, 1988; McCulloch, 2007; McIsaac, Lamberg, Muratori, 2015). Moreover, by converting these values to percentages, we can now combine the two measures, not only for a simplified metric but more importantly to account for potential performance tradeoffs between the central and peripheral tasks (McIsaac et al, 2007, Wickens, 2002).

Eye Data Analysis

For each of the dual task trials at each of the four contexts, three of the four separate regions of where participants were looking, peripheral, central, and in-between, were analyzed separately, providing 12 separate analyses. The NA region values were not analyzed as these values were for the most part zero or very close to zero across the hemimeridian locations by the four contexts. The analyses in the TSD, peripheral, and in-between areas employed the Friedman non-parametric test due to data normality issues.

The dependent variable was the percentage of time participants gazed in each region. This percentage was normalized to the percentage of time the eye tracking data was valid. Invalid eye tracking data may result due of participants moving their bodies, heads, eyes or eyes during the experiment or equipment artifacts. Only 12 out of 384 dual task trials (participant x context x hemimeridian) had invalid eye tracking data greater than 3 percent of the time. Across the 384 trials, the statistics for invalid eye tracking were: *Mean* = 2.9 percent, *Median*=1.3 percent, *range* = 0 to 89 percent. The majority of the extreme invalid eye tracking data stemmed from one particular participant. However, this invalid eye tracking data of this participant, and, in general, across all the other participants' invalid eye tracking data, appeared somewhat randomly distributed across the four contexts and eight hemimeridian locations.

Results

Across the board, ANOVAs revealed that there was no significant effect of hemimeridian on TPD, as illustrated in Table 4. The data depicted in Figure 42 and Table 5 hint of higher variability in mean TPD values across the experimental conditions when the peripheral stimulus was the Gabor patch, particularly for the roll left condition. However, the variability about each mean was relatively large and thus the differences between means were not statistically significant.

Table 4. Statistics for the four different contexts in Experiment 2. The total performance decrement was not different across Hemimeridian.

	df	*F*	*p*	η_p^2
Gabor Rolling Left	2.34*, 25.76	1.64	.211	.13
Gabor Rolling Right	3.16*, 34.79*	0.58	.639	.05
ASAR Rolling Left	7, 77	1.33	.246	.11
ASAR Rolling Right	7, 77	2.46	.858	.04

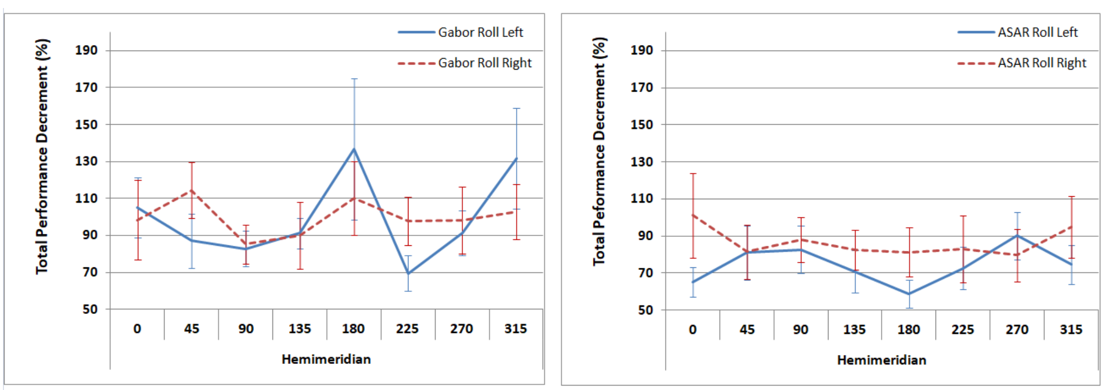


***Figure 42*. The total performance decrement plotted as a function of hemimeridian location (where the stimulus was located). The left graph contains the contexts of Gabor roll left and Gabor roll right; the graph on the right contains the contexts ASAR roll left and ASAR roll right.**

Table 5. The means and standard errors for the total performance decrement across the four different contexts.

	Gabor Roll Left		Gabor Roll Right		ASAR Roll Left		ASAR Roll Left	
Hemimeridian where the stimulus was placed.	Mean TPD	Std. Error	Mean TPD	Std. Error	Mean TPD	Std. Error	Mean TPD	Std. Error
0	105	16	98	21	65	8	101	23
45	87	15	114	15	81	15	81	15
90	83	10	85	10	83	13	88	12
135	91	8	90	18	71	11	83	11
180	137	38	110	20	59	7	81	13
225	69	10	98	13	73	12	83	18
270	91	12	98	18	90	13	80	14
315	132	27	103	15	75	11	95	17

For the eye tracking data, the Friedman one-way analysis of ranks suggested that at most of the contexts, across the various peripheral hemimeridian locations, there were no differences in the percentage of time where participants were looking. The only significant effects of hemimeridian were at the context of the Gabor stimulus rolling left in the peripheral area (p = .027), and for the ASAR rolling left in the in-between area (p = .028), as shown in Table 6. For the context Gabor stimulus rolling left and analyzing the peripheral area, pairwise comparisons revealed that the differences occurred due to the higher percentage gaze times when the Gabor stimulus was positioned in the top hemimeridians over that of the left and right positions; for the context ASAR stimulus rolling left and analyzing the in-between area, shown in Table 7, pairwise comparisons revealed that the differences occurred due to the lower percentage gaze times when the ASAR stimulus was positioned at the 180 degree hemimeridian compared to the 45, 225, and 135 degree positions as shown in Table 8.

Table 6. Statistics for the four different contexts at each of the gaze areas of the TSD, periphery, and in-between. The dependent variable was the percent of time gazing in that area and the independent variable was hemimeridian placement of the peripheral stimulus.

Peripheral Stimulus	Rolling Direction	Gaze Area	degrees of freedom	χ2	*p*-value	Kendall's Coefficent of Concordance, W
Gabor	Left	TSD	7	7.09	.419	.084
Gabor	Left	Peripheral	7	15.84	.027	.189
Gabor	Left	In-between	7	8.57	.285	102
Gabor	Right	TSD	7	3.68	.816	.044
Gabor	Right	Peripheral	7	8.77	.270	.104
Gabor	Right	In-between	7	9.13	.243	.109
ASAR	Left	TSD	7	7.68	.362	.091
ASAR	Left	Peripheral	7	9.74	.204	.116
ASAR	Left	In-between	7	15.69	.028	.187
ASAR	Right	TSD	7	12.17	.095	.145
ASAR	Right	Peripheral	7	12.34	.090	.147
ASAR	Right	In-between	7	6.92	.437	.082

Table 7. Statistically Significant Pairwise Comparisons of Hemimeridians at the Context of Gabor Rolling Left and Assessing the Percentage of Gaze Time in the Peripheral Stimulus Area. Hemimeridian with larger percentage gaze time is shown in the leftward column, unadjusted and adjusted (for family wise error rate) *p*-values are provided for each comparison.

Gabor Rolling Left / Percent of time gazing in the peripheral area			
Hemi. I	- Hemi. J	*p*-value	p-value Bonferroni-Adjusted
90	0	0.007	0.189
90	315	0.007	0.189
45	0	0.022	0.614
135	0	0.022	0.614
45	315	0.022	0.614
135	315	0.022	0.614
90	180	0.041	1

Table 8. Statistically Significant Pairwise Comparisons of Hemimeridians at the Context of ASAR Rolling Left and Assessing the Percentage of Gaze Time in the In-between Area. Hemimeridian with larger percentage gaze time is shown in the leftward column, unadjusted and adjusted (for familywise error rate) *p*-values are provided for each comparison.

ASAR Rolling Left / Percent of time gazing in the in-between area			
Hemi. I	- Hemi. J	*p*-value	p-value Bonferroni-Adjusted
180	45	0.005	0.129
180	225	0.016	0.439
180	135	0.018	0.491

Further inspection of the eye tracking data is carried out in Figure 43, which depicts the Friedman test mean ranks as a function of hemimeridian for the peripheral gaze area, in Figure 44, which depicts the Friedman test mean ranks plotted as a function of hemimeridian for the in-between area, and in Figure 45, which depicts the Friedman test mean ranks plotted as a function of hemimeridian for the TSD gaze area. In Figure 43, the comparison differences highlighted in Table 7 can be seen in the green line where values are relatively high for the 45, 90, and 135 positions while the 0, 180, and 315 positions show lower mean rank values. Although not significant at the other three contexts shown in this graph, the same trend appears across hemimeridian, with higher mean ranks at 45, 90, and135 hemimeridians and lower mean ranks at the 0 and 180 and somewhat at the 315 degree location. In Figure 44, the comparison difference highlighted in Table 8 can be seen in the blue line spiking at the 180 degree hemimeridian, resulting in a higher value than the values at the 45, 225, and 135 hemimeridians. In this graph, although there were no other contexts that had the 180 being higher than other positions, we see the same trend across all the contexts. In addition, we observe a saw-tooth pattern, that is, we observe higher mean ranks at the 0, 90, and 180 locations, and somewhat level at the 270 degree hemimeridian. Results for the conditions in Figure 45 showed no significant differences.

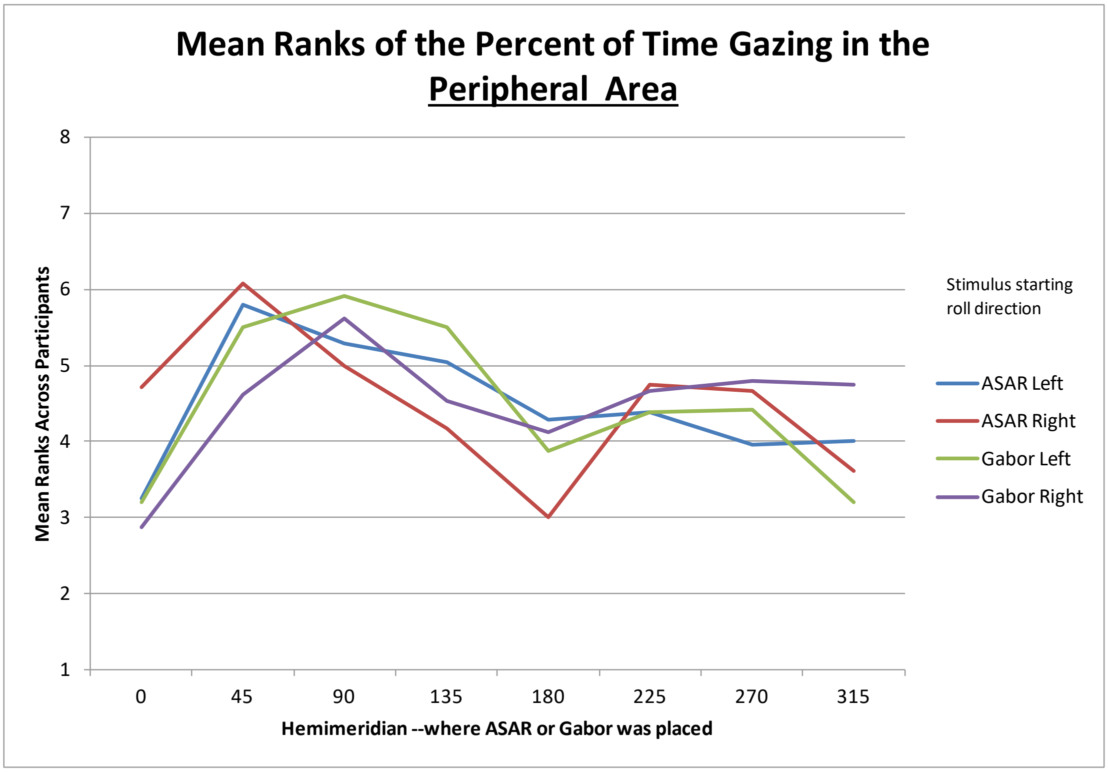


***Figure 43*. Mean ranks of the percent of time gazing in the peripheral area. For the peripheral gaze area, mean ranks are plotted across hemimeridian and data are shown separately for the four different contexts.**

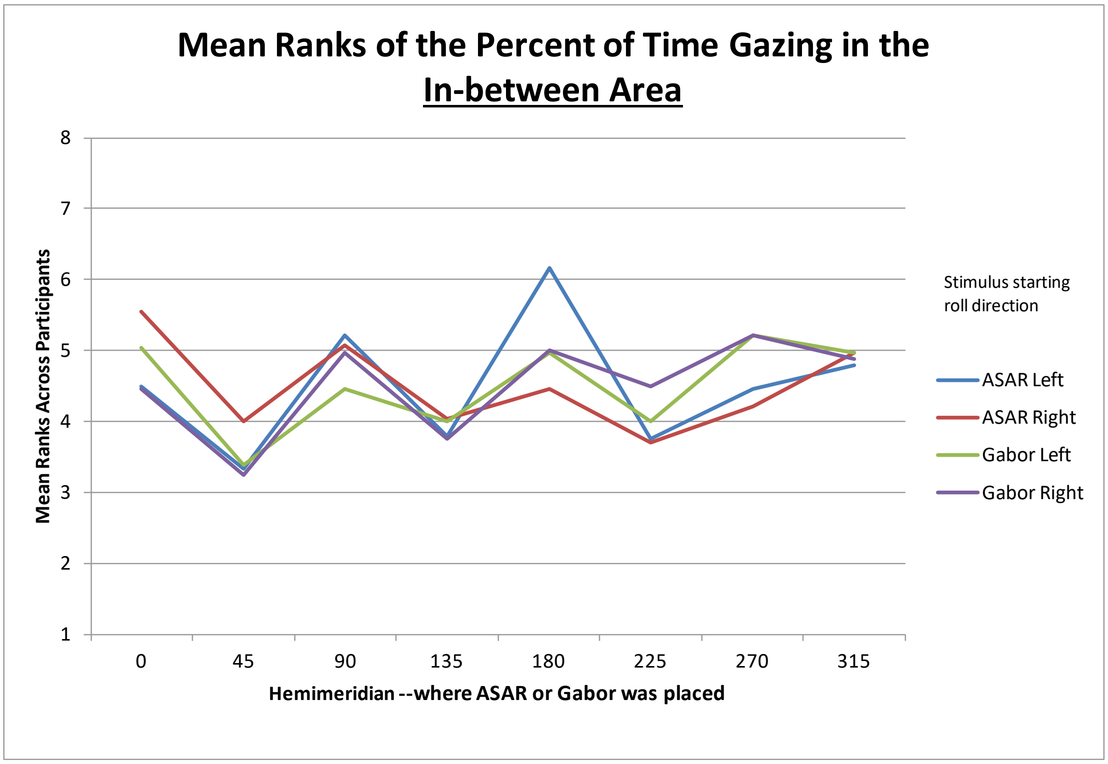


Figure 44. **Mean ranks of the percent of time gazing in the in-between area. For the in-between gaze area, mean ranks are plotted across hemimeridian and data are shown separately for the four different contexts.**

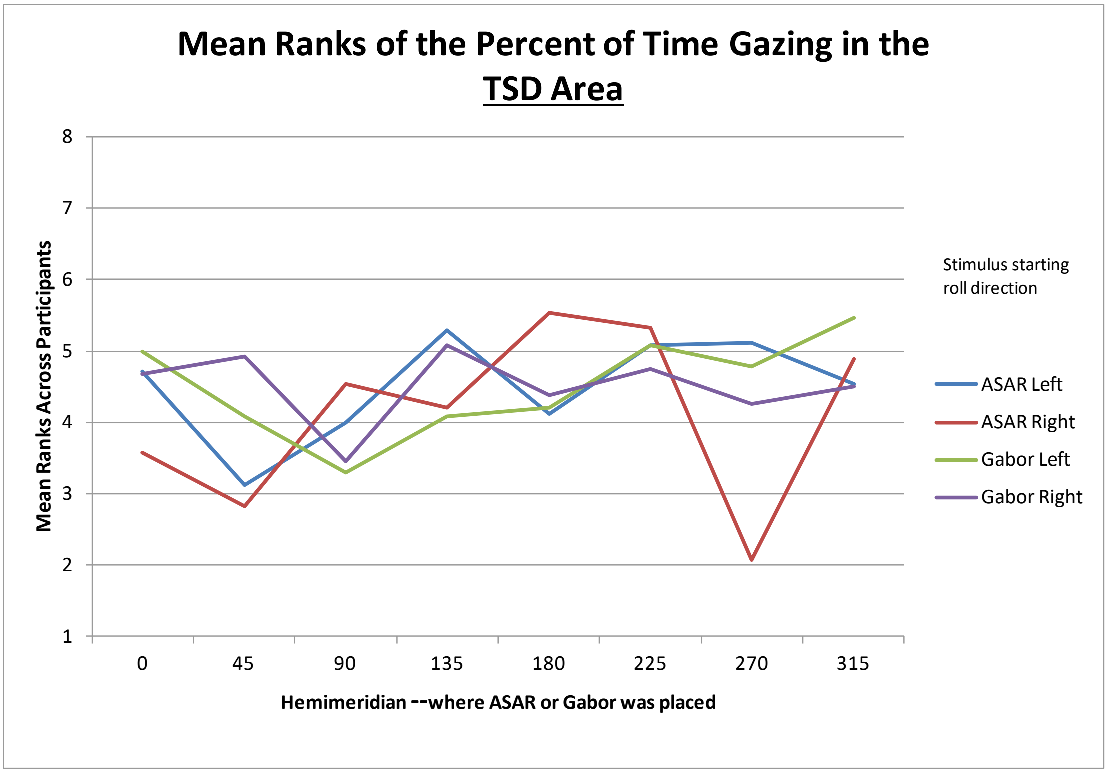


***Figure 45*. Mean ranks of the percent of time gazing in the TSD area. For the TSD gaze area, mean ranks are plotted across hemimeridian and data are shown separately for the four different contexts.**

Discussion

Experiment 2 was designed in a different manner than Experiment 1. Here, a central task was inserted and required a great amount of attentional effort. Although the participants were instructed to maintain equal performance on both tasks, it would appear that the participants learned that they could achieve a desirable level of performance by periodically, quickly glancing over to the ASAR or Gabor stimulus. This is evidenced by the amount of time the participants gazed at the central area versus the peripheral stimulus versus the area in-between; across all participants and contexts, the percentage of gaze time in any particular trial ranged 60%-90% in the central area, 10%-40% in the peripheral stimulus area of the time, and 2% to 35% the in-between area. Participants in Experiment 2 could move their gaze onto the peripheral stimulus if they so chose. This manner of eye movement presented a more realistic operational environment. Here the central task was visually demanding, nevertheless, participants applied overt attention to both tasks (the central and the peripheral task). However, this does not rule out any potential covert attention application to the peripheral task. The application of overt attention seemingly explains the absence of differences in TPD across the hemimeridian. If visual performance field asymmetries would have been apparent they would have potentially been the result of the difference of eye movement from the central area to the various positions in the periphery, in combination with any potential covert attention employment. Considering the difficulty of the central task and the non-significant differences among hemimeridians for the TPD measure (Figure 42), we would expect consistency in the gaze times at each of the areas of the display, across the manipulation of the hemimeridian location. The eye tracking data was looked at to better understand where participants were looking while performing the two tasks and manipulating the position of the peripheral task.

The results stemming from the analysis of the eye tracking data showed for the most part equality among the gaze times across the hemimeridian locations, within each display area (TSD, periphery, in-between). There were a couple of notable exceptions. First, as it was pointed out in the Results section, participants tended to have higher gaze times in the peripheral area when the peripheral stimulus was located in the upper portion of the field as compared to the left and right positions and this trend was supported by the one significant result among the four contexts, namely the Gabor rolling left context. Second, participants tended to gaze more at the in-between region when the peripheral stimulus was at the 180 degree hemimeridian location as compared to the oblique positions (45 deg, 135 deg, 225 deg) and this trend was supported at the ASAR rolling left context. Additionally, although not statistically significant, we can observe an increase in gaze time at the in-between area when the peripheral stimulus was located at the 0 degree hemimeridian. Interestingly, this increase in gaze time at the in-between area when the stimulus is at the 0 and 180 degree peripheral locations mirrors the decrease in gaze time in the peripheral area when the stimulus is in the 0 and 180 degree positions. The participants were instructed to perform both tasks equally well and this would suggest that the participants' eye gazing characteristics would be consistent across conditions, but these differences in gaze location occurred among the different hemimeridian locations. Could the observed differences in the eye movement data suggest an innate, unconscious strategic use of where to gaze to maximize output performance and/or the efficiency of that process? Is it a coincidence that we observe a gaze time tradeoff between the peripheral and in-between areas at the 0 and 180 hemimeridian positions and the fact that we observed better performance at the 0 and 180 degree positions in Experiment 1, the pilot study leading up to Experiment 1, and a great part of the asymmetry literature?

In an attempt to help explain the tradeoff in the gaze time between the peripheral and in-between areas at the 0 and 180 degree positions, we assess some of the literature in attention and multiple object tracking (MOT) (Pylyshyn & Storm, 1988). In MOT, the aim is to track multiple objects, moving randomly within some space in the visual field, among distracters. The study of attention through MOT has tried to elucidate how visual attention is applied to multiple items in the visual field. Various models have been proposed to help explain how attention is applied to the moving objects. These models include grouping, attention switching, multifocal attention, preattentive indexes, and object files (for reviews, see Oksama & Hyo¨na, 2004 and Cavanagh & Alvarez, 2005).

In performing MOT tasks, Fehd and Seiffert, (2008, 2010) suggest that models which include the grouping and multifocal attention best help explain why their participants gazed at the center of the area formed by the items that are tracked. When tracking a group of items connected to form a virtual shape participants' stratigecally gaze at the center of this shape to perform the task. In multifocal attention, the items to be tracked each received some independent share of the attention resource pool and these postions fight for the observer's focal attention. In essense, the multiple tracked items each pull for their share of attention and a balance point evolves from these pulling vectors (Figure 46). Fehd and Seiffert termed this gaze strategy 'center-looking.'

In the research presented in this dissertation, there were no MOT tasks; however, there is similarity in that more than one item requires attention, i.e., maintaining the cursor on target in the TSD task and monitoring the ASAR or Gabor for changing roll direction. From Fehd and Seiffert (2008, 2010), the results indicated that a center-looking strategy trended towards optimizing tracking performance. If we relate this center-looking gaze strategy to the research presented in Experiment 2, we would expect that maybe more time would be spent gazing in the in-between area on the display. It must be noted that the Experiment 2 tasks, together, were quite different individually and different from tracking homgenous appearing and behaving stimuli as in MOT tasks. The

Experiment 2 tasks also differ from the MOT tasks in that the two items are not moving in space across the display and being tracked across this space; however the two tasks in Experiement 2 were tracked in the sense of monitoring their trends, tracking the movement of the arc in the ASAR (and tilt in the Gabor) in the peripheral task and tracking the moving of aircraft and change in which aircraft was highlighted in the TSD task.

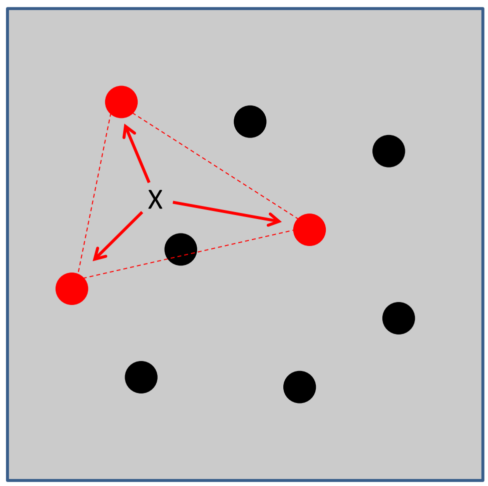


***Figure 46*. Example of a MOT task. The three red items are to be tracked while moving. The participant will gaze roughly, the center of the three red items to optimize performance. The 'X' marks the position of hypothetical gaze.**

The TSD task in Experiment 2 was quite demanding and observing that most of the gaze was put on the TSD task is not surprising. However, why do see trends in more gaze shifting from the peripheral area to the in-between area when the ASAR/Gabor stimulus is presented at the left and right positions (0 and 180 degree hemimerdian postions). If we borrow from the Fehd and Seiffert experiments and suggest that a center-looking strategy helps in optimizing performance then why do we not see better performance differences at the left and right positions? Could it be that although performance levels were the same across hemimerdians, the level of effort spent was less when the ASAR/Gabor was on the left and right positions? If the TSD task was so demanding then the visual system was employing a strategy where it tended to gaze more in the in-between area more—closer to the TSD task or it may have determined that it could use covert attention more efficiently to observe the peripheral area and not needed to overtly attend to the peripheral area as much. Why did this not not occur at the other hemimeridian positions? It might appear that the same neural underpinnings that may have caused better performance in the horizontal meridian in Experiment 1 may also activate a more efficient method to perform the tasks' goals along the same horizontal meridian in Experiment 2. This assertion is supported from the particiapants' feedback at the end of Experiment 2. They were asked to state at which hemimeridian positions were the ASAR and Gabor more difficult monitor. Their responses are listed below:

- 1 of the 12 responded top, bottom, left, right (90, 270, 0, 180) were the most difficult
- 1 of the 12 responded bottom-left, bottom right (225, 315) were the most difficult
- 3 of the 12 participants responded with a neutral rating among the positions
- 7 of the 12 participants responded with the top, bottom, or both top and bottom being the hardest, (90, 270) among the eight conditions.

Although the TPD measure was the same when the ASAR/Gabor was placed across the different hemimeridian locations, the level of effort to achieve that performance level may not have been as great when the ASAR/Gabor is placed at the left and right positions. This claim might better be explored through psychophysiological measures with the current task set-up.

It may be warranted to test the central task at a lower level of demand or instruct participants to apply a different priority to the central task, potentially providing for more opportunity to distribute attention and utilize covert attention of the peripheral task. In support of this statement, we look to the *visual span* research. The visual span (also referred to as ‘functional field of view’ and ‘perceptual scan’) is the area around the visual fixation point where elements can be recognized (Nasanen, Ojanpaa, Kojo, 2000). Various task conditions are associated with the determination of the visual span size (Pomplun, Reingold, Shen 2001) to include foveal load (Ikeda, Taeuchi, 1975; Williams, 1989). In the case of increased foveal load, the visual scan area decreases. The size of visual span has been shown to be associated with a variety of eye movement parameters (Greene, Brown, Paradis, 2013) and thus it may be argued that the eye fixations in the in-between area were accompanied with larger visual span areas on the horizontal meridian to monitor the stimuli from the two tasks.

Summary

This chapter detailed Experiment 2’s design, execution, analysis, and results. The tasks in Experiment 2 provided a more realistic scenario with the use of the ASAR. Here the ASAR was constantly viewable and a central task was incorporated. This experiment was quite different from that of Experiment 1 in that participants could apply either covert or overt attention to either of the two tasks whereas in Experiment 1, the ASAR was only attended to through covert attention. The results revealed that there was no effect on performance due to the placement of the ASAR (or Gabor) across the different hemimeridians. However, some interesting results in the eye tracking data suggest that more efficient eye movements may have been made in performing the task when the peripheral stimuli was placed at the 0 and 180 degree hemimeridians.

V. Conclusions and Recommendations

Chapter Overview

This chapter summarizes the results from Experiments 1 and 2. A discussion examines the relationship between the two experiments' designs and how the two are complementary. The significance of the experiments' results is discussed and how they relate to real operational environments. From the results, recommendations are put forth to interface designers of future HMDs with some precautionary guidelines. Lastly, future research is proposed to include asymmetries in audition.

Conclusions of Research

In this research, it was sought to determine whether the effect of visual perceptual asymmetries on human performance, which have been documented through very controlled laboratory studies, could be demonstrated using real world, meaningful, visual stimuli. To bridge and validate the experimental set-up, a Gabor stimulus was incorporated into the experimentation. Gabor stimuli are often used in visual perceptual asymmetry research due to their properties of matching receptive fields in the visual cortex. In Experiment 1, we observed strong support that the Gabor patch stimulus in this research produced findings similar to those observed in past research, specifically with regards to the horizontal-vertical asymmetry. Visual processing of the Gabor patch was generally better when presented to the left or right of center and worse when presented to the top of bottom of center, following a trend consistent with the HVA.

Experiment 1, with its proceeding pilot study, and Experiment 2, were complementary in that they provided two very different design methodologies to study visual field performance asymmetries. In Experiment 1, participants were constrained to employ only covert attention to observe the peripheral stimuli and no cognitive or perceptual demands were required in a central task. This might be considered the easiest level of engagement in a central task. In Experiment 2, not only was there a central task, but it was very visually demanding, and the peripheral task could be accomplished with the participants gazing directly on it or through peripheral vision should they have chosen to do so and were capable of doing so. However, due to the high visual demands of the central TSD task, it was difficult for the participants to covertly attend to the peripheral task while attending sufficiently to the central task; therefore, they employed a strategy of primarily gazing and attending to the central task, while occasionally glancing at or near the peripheral visual stimulus when performing the peripheral task.

In Experiment 1, we observed visual field asymmetries with the Gabor stimulus which are consistent with experimental results which have been used to support the presence of the HVA. Asymmetries were still evident with the ASAR but were more subdued. In addition, the asymmetries were more clearly apparent in the coordinate data and mixed in the categorical data. In Experiment 2, we did not observe any performance differences due the placement of the ASAR or Gabor among the different hemimeridian locations; although, the eye tracking data suggested that participants may have employed at gaze strategy that allowed them to gaze more in the in-between area when the ASAR or Gabor was placed in the 0 or 180 degree positions than when it was placed at the other locations. This trend towards shifting gaze more into the in-between area may be a result of the visual system seeking to optimize efficiency in the processing of the stimuli. In other words, participants were able to obtain the same level of performance in the tasks but with less effort at the 0 and 180 degree hemimeridian positions. This same efficiency at the 0 and 180 degree positions could also play a role in more covert-attention-employed situations, such as the ones illustrated in Experiment 1. Nevertheless, the findings in the Experiment 2 eye tracking data support the hypothesis that the neural underpinnings for visually processing stimuli at the 0 and 180 degree positions is different than the rest of the visual field. Moreover, although there were no significant effects on behavioral performance across hemimeridian, the results from the eye tracking data might lead one to conclude that over longer periods of time, the visual processing efficiency at the 0 and 180 degree positions may be manifested through behavioral performance data.

The point to be stressed is that the experimental set up used in both Experiments 1 and 2 mimic the scenarios when an operator wears an HMD, that is, the direction of eye gaze is decoupled from head direction. In the experiments presented in this research, the head was held stationary, facing perpendicular to the display. The same effect is obtained with an operator wearing an HMD, regardless of the head turn position, the faces and hence eyes are perpendicular to the display. If the operator were to wear an HMD for a longer period of time and needed to access peripheral information many times over, the behavioral manifestations due to hemimeridian locations may come to a realization.

Summary of results in relation to research hypotheses and investigative questions.

In closing this section of the last chapter, the text and tables below summarize this dissertation's results with the hypothesis outlined in the introductory chapter. Table 9 summarizes the various conditions and performance measures that were investigated in

Experiment 1. The table expresses if statistical significant differences were observed at various combinations of variables that included the stimulus type (ASAR, Gabor), the type of spatial processing employed (Coordinate, Categorical), and Flight Context (Rolling Left/Right, VFP Climb/Dive). The table addresses if statistical significance was present for effects of Angle, Hemimeridian and their interaction. Dependent variables included A-AE, A-RT, and A-PI. The table also provides a general description of the structure of the differences. Cells highlighted in gray containing the mark “x” indicate a statistically significant difference for the effect of Angle, Hemimeridian, or Angle by Hemimeridian interaction. Concerning the analysis of A-PI, cells highlighted in gray containing an “L,” “H,” or both letters indicate a statistical significant difference in the that level of Angle where “L” stands for Low Angle and “H” stands for High Angle. Tables 10, 11, and 12 draw from the research described in Chapters 3, 4 and from Table 9 to assess the hypotheses outlined in Chapter 1.

Table 9. Summary of Statistically Significant Differences for Experiment 1.

				Indication of Statistically Significant Effects			General structure and highlights of differences		
Stimulus	Spatial Processing Employed	Flight Context	Dependent Variable	Angle	Hemimeridian	Interaction	Angle	Hemimeridian	Angle x Hemimeridian Interaction
Gabor	Coordinate	Roll Left	A-AE	x	x	x			While the Low angle condition did not have differences across hemimeridian, the High condition had the top position was worse than left and right.
Gabor	Coordinate	Roll Right	A-AE	x	x	x			While the Low angle condition had the top position being different from left and right, the High condition had the top position being different from almost all of the other positions and the bottom position was worse than other positions.
Gabor	Categorical	Roll Left	A-RT		x			The top and bottom-left positions were worse than many other positions.	
Gabor	Categorical	Roll Right	A-RT	x	x		Low angle level was worse than high angle level.	All the right side positions were better than the rest of the field.	
Gabor	Categorical	Roll Left	A-PI	**L, H**	N/A	N/A	At low and high angle levels the top position was worse than some of the other positions		
Gabor	Categorical	Roll Right	A-PI	**L, H**	N/A	N/A	At the low angle condition, the top and bottom positions were worse than other positions and at the high level, the top was worse than other positions.		
ASAR	Coordinate	Roll Left	A-AE		x	x			While the High angle condition did not show any differences across hemimeridian, the Low angle condition showed the upper positions being worse than the leftward and rightward positions.
ASAR	Coordinate	Roll Right	A-AE			x			While the High angle condition did not show any differences across hemimeridian, the Low angle condition showed the upper positions being worse than other positions.
ASAR	Coordinate	VFP Climb	A-AE		x	x			While the High angle condition shows a variety of positions being worse than the right and bottom-right positions, the Low angle level shows primarily the bottom position being different from other positions.
ASAR	Coordinate	VFR Dive	A-AE	x	x	x			While at the High level of angle, the top position was worse than other positions, the Low level angle showed a variety of positions being worse than the left and right positions.
ASAR	Categorical	Roll Left	A-RT	x		x			While the Low angle level did not show any differences across hemimeridian, the High angle level suggests that the bottom positions are worse than a variety of the other positions.
ASAR	Categorical	Roll Right	A-RT	x	x		Low angle level worse than high angle level.	The right sided positions were better than a variety of the other positions.	
ASAR	Categorical	VFP Climb	A-RT	x		x			While the Low angle condition did not show any differences across hemimeridian positions, the High angle condition showed the right-sided positions being better than the top and left position.
ASAR	Categorical	VFR Dive	A-RT	x		x			While the Low angle condition did not show any differences across hemimeridian positions, the High angle condition showed the top-sided positions being better than a variety of the other positions.
ASAR	Categorical	Roll Left	A-PI	**L**	N/A	N/A	At the Low angle condition, the top-left position was worse than a variety of other positions.		
ASAR	Categorical	Roll Right	A-PI	**L**	N/A	N/A	At the Low angle condition, the top-right position was worse than a variety of angles.		
ASAR	Categorical	VFP Climb	A-PI		N/A	N/A			
ASAR	Categorical	VFR Dive	A-PI		N/A	N/A			

Table 10. Hypotheses for ASAR and Gabor as the Peripheral Stimulus, Processed under Covert Attention.

For ASAR and Gabor as the peripheral stimulus processed under covert attention:	**Conclusion of Testing H_0 --with Gabor.**	**Conclusion of Testing H_0 --with ASAR.**
H_0: There are no differences in visual processing performance due to the interaction effect between hemimeridian (locations of the ASAR or Gabor) and angle (the degree of the roll).	At the Coordinate condition the Null hypothesis is rejected. At the Categorical condition, there is failure to reject the Null.	At the Coordinate condition the Null hypothesis is rejected. At the Categorical condition, in general, the Null hypothesis is rejected.
H_0: There are no differences in visual processing performance due to the main effect of hemimeridian (locations of the ASAR or Gabor).	At the Coordinate condition the Null hypothesis is rejected. At the Categorical condition the Null hypothesis is rejected.	At the Coordinate condition, in general, the Null hypothesis is rejected. At the Categorical condition, in general, there is failure to reject the Null hypothesis.
H_0: There are no differences in visual processing performance due to the main effect of Angle (the degree of the roll).	At the Coordinate condition the Null hypothesis is rejected. At the Categorical condition, in general, the Null hypothesis is rejected.	At the Coordinate condition, there is failure to reject the Null hypothesis. At the Categorical condition, the Null hypothesis is rejected.

Table 11. Hypotheses for ASAR only as the Peripheral Stimulus Processed Under Covert Attention.

For ASAR only as the peripheral stimulus processed under covert attention:	**Conclusion of Testing H_0 --with ASAR**
H_0: There are no differences in visual processing performance due to the interaction effect between hemimeridian (locations of the ASAR) and angle (the climb/dive angle).	At the Coordinate condition the Null hypothesis is rejected. At the Categorical condition, the Null hypothesis is rejected.
H_0: There are no differences in visual processing performance due to the main effect of hemimeridian (locations of the ASAR).	At the Coordinate condition, in general, the Null hypothesis is rejected. At the Categorical condition, in general, there is failure to reject the Null hypothesis.
H_0: There are no differences in visual processing performance due to the main effect of angle (the climb/dive angle).	At the Coordinate condition, in general, the Null hypothesis is rejected. At the Categorical condition, Null hypothesis is rejected.

Table 12. Hypotheses for ASAR and Gabor as the Peripheral Stimulus Processed under Free-viewing (Overt and Covert Attention) and with the Additional Demand of Performing a Central Task.

For ASAR and Gabor as the peripheral stimulus processed under free-viewing (overt and covert attention) and with the additional demand of performing a central task:	**Conclusion of Testing H_0 --with Gabor.**	**Conclusion of Testing H_0 --with ASAR.**
H_0: There are no differences in visual processing performance of the combined central and peripheral tasks the due to the main effect of hemimeridian (locations of the ASAR or Gabor).	There is failure to reject the Null hypothesis.	There is failure to reject the Null hypothesis.
H_0: There are no differences in the gaze time within the **central task region** when the ASAR or GABOR is presented across various peripheral locations, represented through the variable hemimeridian	There is failure to reject the Null hypothesis.	There is failure to reject the Null hypothesis.
H_0: There are no differences in the gaze time within the peripheral region when the ASAR or GABOR is presented across various peripheral locations, represented through the variable hemimeridian.	In general, there is failure to reject the Null hypothesis.	There is failure to reject the Null hypothesis.

(Table continued from previous page)		
H_0: There are no differences in the gaze time within the in-between region when the ASAR or GABOR are presented across various peripheral locations, represented through the variable hemimeridian.	There is failure to reject the Null hypothesis.	In general, there is failure to reject the Null hypothesis.
H_0: There are no differences in the gaze time within the non-applicable region when the ASAR or GABOR is presented across various peripheral locations, represented through the variable hemimeridian.	There is failure to reject the Null hypothesis.	There is failure to reject the Null hypothesis.

Lastly, listed below are the investigative questions outlined in the introductory chapter and a brief succinct answer is given, drawn from the results and discussion sections from the two experiments. For more detail, please see appropriate sections.

(1) Will a Gabor patch stimulus produce similar results as past asymmetry research with the current experimental set-up?

Yes, the Gabor patch produced similar results as past research. We observed trends in performance that followed the horizontal-vertical anisotropy. See Experiment 1.

(2) What are the best positions for processing a Gabor patch with the current experimental set-up?

It appears that positions to the left and right of center are best for processing the Gabor; although other positions, i.e., the adjacent oblique positions may be desirable as well.

(3) What are the best positions for processing an ASAR with the current experiment set-up?

Similar to the Gabor positions in the previous question but the left and right locations may provide advantage over the oblique angles.

(4) Does visual processing performance of an ASAR trend in the same manner as a Gabor patch?

In general, there are elements of the HVA in results for both the Gabor and the ASAR when adhering to the same experimental methodology as past research (Experiment 1). In Experiment 2, both ASAR and Gabor did not produce any salient differences in performance across hemimeridian.

(5) What are the consequences on visual processing performance when engaging with Gabor and ASAR stimuli at various angle representations?

There were interactions between hemimeridian and angle in Experiment 1. Sometimes the low angle and sometimes the high angle level provide the hemimeridian differences. See Experiment 1.

(6) How well does the categorical\coordinate spatial processing dichotomy hold with the ASAR and Gabor under the current experimental conditions?

There were no differences between left and right hemimeridian positions under categorical or coordinate visual processing. This may have been a result of this research study's use of categorical and coordinate tasking being somewhat different from past research. Past research taskings involved predominantly linear relations—the current research relations were angular in nature.

(7) What can we infer between the results from Experiment 1, where the task was designed so covert attention would be employed with no central task and from Experiment 2, where the experiment allowed the participants to use overt attention and contained an extremely attention drawing central task?

The tasks between Experiment 1 and 2 were quite different in how the use of covert and overt attention could be used. Experiment 2 required attentional resources to be directed to the center of the screen and may have prohibited the use of covert attention.

(8) From Experiment 2, what can we infer from where participants were looking?

Although the indication was tenuous, there was some evidence of potential covert attention being applied when the peripheral stimulus was located to the left and right of center. Participants transferred some gaze time from the periphery to the area between the periphery and the central task.

Significance of Research

The research presented here makes the case for understanding visual field performance asymmetries when designing and placing information on HMD systems. As modifications are made to current aircraft and ground-based HMDs (e.g., battlefield airmen, maintenance operators), understanding the optimal placement of information could prove critical. This may be more the case for ground-based systems as they are currently evolving and early in their existence relative to aircraft systems. Granted, the ASAR or any other aircraft attitude symbology may not be placed on a ground-based operator's HMD but other similar symbology such as navigational or alerting information may have an optimal placement due to the considerations of visual field asymmetries. The research presented in the dissertation makes an initial case that visual field asymmetries may affect visual processing performance of the ASAR (and potentially other symbology) and lead to changes in behavioral performance. In the first Experiment, where the central task demands were minute, differences in A-AE reached ~5 deg maximum, a value in climb, dive, or roll that is alarming when translated into other flight dynamics, for example, descending altitude per minute. The Gabor stimulus had differences at ~20 deg maximum. Consider symbology that may entail more resemblance to a Gabor. Here we might expect more error, as shown in the Gabor versus ASAR.

Recommendations for Action

Due to the findings from the current research, further experimentation is warranted in studying visual field performance asymmetries with real operational symbology. Although the effects may not have been substantial, they are at least suggestive for an interface designer. The interface designer should obviously continue to apply the already well established principles of interface design as was explained in the Introduction. However, these principles should be considered alongside potential visual field performance asymmetries. If there is conflict in the placement of certain information on a display due to established principles versus asymmetry effects, it is suggested to default to the established principles as not enough research has been performed to make a strong case for the role of visual asymmetries in design. Nevertheless, if the default design principles do not stipulate a certain placement of certain critical information, then the designer should consider that the left and right positions on a display may be the optimal placement and the top and bottom should be avoided or at least considered last. To remind ourselves, all that was just suggested is in the context that we need to insert information in the periphery of our display so that the central area is free of clutter to permit the user to simultaneously perform time or safety critical tasks using information which appears in the center of the display.

Recommendations for Future Research

It was suggested, at least in Experiment 1, that visual field performance asymmetries can exist with the ASAR, resulting in better performance when the ASAR is placed in certain parts of the visual field. However, these results came from a very simple, controlled laboratory study. The second study provided some support in the way of eye movements which are at most suggestive that advantages may be gained from placing information on the horizontal axis rather than the vertical axis or other of the hemimeridians. More experimentation is needed to fully and clearly understand the level of importance that visual field asymmetries have on visually processing peripheral stimuli. The two experiments presented in this dissertation are in ways two extremes for the assessment of visual asymmetries. The difficultly of attending to a central task and the operational "noise" was nonexistent in Experiment 1 but very present in Experiment

2. Experiments could be designed to be somewhat in the “middle ground,” just as there may be middle ground levels of central task demands in real operations. These manipulations could come in the form of decreasing the attention demands of the middle task, changing characteristics of the peripheral task, such as the size, eccentricity from center, or attention demand imposed by the stimulus.

In designing Experiments 1 and 2, we sought to encompass a variety of operational settings that a pilot might experience. Hence, in Experiment 1, there was an observation of changes in roll and vertical flight path and at both directions for each (left roll / right roll; climb/dive). Understanding if there were changes in left vs right roll had implications for potentially certain operations which require the aircraft to approach a target from the left or right. For the vertical flight path changes, the ASAR changed in the amount of visible pixels on the display and this may affect the asymmetries hence the inclusion of climb and dive conditions. Experiment 2 was controlled in the amount of conditions and as such only rolling left and rolling right in the ASAR was observed. In Experiment 1, we also observed how the ASAR was processed under different directed tasking, categorical versus coordinate. Here, again, varying operational contexts in the way of “how” pilots observed the information may be important. In categorical processing, the observer may make quick assessments for global, general directional evaluation (e.g., scanning a variety of instrument panels or the a variety of symbology on the HMD). In coordinate processing, the pilot needs to maintain a very specific value in the path of the aircraft. Operational contexts should be kept in mind when designing such experiments.

The experimental setup in Experiments 1 and 2 were very controlled, a desktop display, in a quiet room, isolated independent variable, and participants were immobilized with a chin rest. More experimentation in such settings should be executed, however, the next steps should include, replacing the display with a virtual environment with a virtual reality HMD, and then real HMDs. On the desktop display, more of the middle ground experimentation, as mentioned earlier, should be examined. From those experiments, designs should evolve to be implemented in a virtual reality environment and fine-tuned and incorporating what a virtual reality environment can afford such experimentation, such as freedom to move the head around and provide a more immersive environment to mimic the real nuances of the real world. Lastly, the findings stemming from VR experimentation should be confirmed with experimentation with real-world HMDs. These displays may not necessarily be ones used in real operations but can be lower technologically graded but highly calibrated systems, potentially off-the-shelf consumer grade systems which include processing to ameliorate any significant visual artifacts, such as barrel distortions.

The last of the recommendations suggests that audition should also be examined in performance asymmetries. Multimodal sensory integration (see Spence & Driver, 2004 for review) has shown performance benefits (and potential conflicts) but understanding audition, vision, their respective potential perceptual asymmetries (e.g., Brancucci, Lucci, Mazzantenta, & Tommasi, 2009; Robertson, & Ivry, 2000), and any interactions among the aforementioned could prove useful for multimodal displays.

Summary

This chapter examined the results from a pair of experiments. It was determined that the two experiments provided complementary analysis for the level of attention demand that might be required in real operational environments. Visual field performance asymmetries were observed in Experiment 1 but not in Experiment 2. However, the eye tracking data in Experiment 2 supported to some degree that the neural underpinnings that guide these visual perceptual asymmetries were at play. Although the results from the two experiments are not overly conclusive that asymmetries influence human performance when dealing with real world stimuli, there were statistically significant differences under certain conditions and thusly these results should be considered when designing the placement of symbology in future HMDs barring any potential conflict with established design principles. The research presented in this dissertation has recognized that visual field performance asymmetries need further examination with real-world symbology and information. Lastly, future research could include other modalities, especially that of audition.

Appendix A: Participants' Demographics

From Experiment 1

Participant	Gender	Age	FLANDERS Handedness (-10 Left-handed to 10 right-handed)	Eye Dominance	Peg Board Left Hand	Peg Board Right Hand	Right over Left	Piloting Experience	Gaming Experience	Language Experience
1	Male	53	10	Right	14	17	3	Gaming simulation	few hours a week	7th grade Spanish
2	Male	49	10	Left	16	16	0	Gaming Simulation	few hours a week	none
3	Male	53	10	Left	15	16	1	Experience Pilot	none	none
4	Male	26	-1	Right	15	16	1	none	Extensive gaming	Intermediate Spanish
5	Female	39	10	Left	15	16	1	none	none	3rd grade level Tagalog
6	Male	40	10	Right	14	18	4	none	none	none
7	Female	22	9	Right	17	19	2	none	little gaming	some Greek, Spanish
8	Female	39	10	Right	16	18	2	none	none	none
9	Female	32	10	Right	15	17	2	none	none a little gaming	high school French
10	Female	25	-5	Left	15	15	0	none	couple of hours a week	none
11	Female	35	10	Right	17	18	1	50 hours	none	Diploma French
12	Male	51	10	Right	14	15	1	none	couple of hours a week	High School French

From Experiment 2

Participant	Gender	Age	FLANDERS Handedness (-10 Left-handed to 10 right-handed)	Eye Dominance	Peg Board Left Hand	Peg Board Right Hand	Right over Left	Piloting Experience	Gaming Experience	Language Experience
1	Male	52	-10	Right	15	14	-1	Gaming simulation	a long time ago	Greek
2	Male	50	10	Left	16	16	0	Gaming Simulation	few hours a week	none
3	Male	54	10	Right	14	17	3	Gaming simulation	few hours a week	7th grade Spanish
4	Male	55	10	Left	15	16	1	Experience Pilot	none	none
5	Male	29	10	Right	14	15	1	none	~10 hours/week	none
6	Male	22	10	Right	13	16	3	none	15/week	none
7	Male	32	9	Right	13	17	4	none	~10 /week	none
8	Female	31	10	Right	14	13	-1	none	~7 /week	none
9	Male	26	10	Right	15	16	1	none	2/day	none
10	Male	25	10	Right	16	16	0	Gaming simulation	30+	none
11	Male	30	10	Left	15	18	3	none	none	none
12	Male	39	10	Right	16	15	-1	none	1/week	none

Appendix B: Coordinate Data, Pairwise Comparisons for Hemimeridian Locations.

(Note: comparisons stem from main effects from omnibus F tests or simple effects analysis. Tables show from left to right, hemimeridians with higher A-AE, hemimeridians with lower A-AE, *p*-value from LSD test, and *p*-values adjusted by Holm's-Bonferroni method. Only comparisons which showed significant LSD p-values were included and shaded rows indicate significant p-values if observing the Holm's-Bonferroni method.

Coordinate Gabor Roll Left

Hemimeridan at Low Angles

N/A

Hemimeridan at High Angles

Hemi. I	- Hemi. J	*p*-value LSD	p-value Holm's-Bonferroni
90	0	.000	0.007
90	180	.001	0.028
90	135	.001	0.038
225	315	.007	0.176
90	45	.010	0.240
90	315	.010	0.240
45	0	.023	0.514
270	315	.025	0.520

Coordinate Gabor Roll Right

Hemimeridan at Low Angles

Hemi. I	- Hemi. J	*p*-value LSD	p-value Holm's-Bonferroni
90	180	.009	0.242
90	0	.011	0.305
135	180	.019	0.494
315	180	.021	0.514
90	270	.024	0.581
135	0	.039	0.891
45	180	.047	1

Hemimeridan at High Angles

Hemi. I	- Hemi. J	*p*-value LSD	p-value Holm's-Bonferroni
90	45	.000	0.001
90	180	.000	0.002
90	0	.000	0.003
90	225	.000	0.012
90	135	.002	0.039
90	315	.002	0.046
135	45	.006	0.122
270	225	.006	0.125
135	180	.013	0.250
270	315	.017	0.330
270	180	.019	0.344
135	0	.032	0.541
270	45	.037	0.597
270	0	.042	0.629

Coordinate ASAR Roll Left

Hemimeridan at Low Angles

Hemi. I	- Hemi. J	*p*-value LSD	p-value Holm's-Bonferroni
90	0	.003	0.072
90	180	.006	0.150
90	225	.008	0.217
45	0	.011	0.285
45	180	.017	0.397
135	180	.017	0.397
90	270	.023	0.502
315	0	.028	0.596
225	0	.030	0.609
135	0	.032	0.609
90	45	.033	0.587

Hemimeridan at High Angles

N/A

Coordinate ASAR Roll Right

Hemimeridan at Low Angles

Hemi. I	- Hemi. J	*p*-value LSD	p-value Holm's-Bonferroni
45	180	.004	0.112
90	180	.010	0.271
90	0	.018	0.468
90	315	.019	0.482
90	270	.020	0.485
135	180	.028	0.652
45	0	.031	0.688
90	225	.033	0.691
45	225	.040	0.796
45	315	.044	0.829

Hemimeridan at High Angles

N/A

Coordinate ASAR VFP Climb

Hemimeridan at Low Angles

Hemi. I	- Hemi. J	*p*-value LSD	p-value Holm's-Bonferroni
270	180	.002	0.061
270	135	.003	0.085
270	225	.004	0.102
270	0	.016	0.392
270	45	.018	0.423
90	180	.033	0.755
315	180	.036	0.785
270	315	.039	0.826
225	180	.048	0.962
45	225	.040	0.796
45	315	.044	0.829

Hemimeridan at High Angles

Hemi. I	- Hemi. J	*p*-value LSD	p-value Holm's-Bonferroni
180	0	.004	0.123
90	315	.017	0.449
270	315	.036	0.939
135	315	.039	0.980
180	315	.046	1.000
90	0	.048	1.000

Coordinate ASAR VFP Dive

Hemimeridan at Low Angles

Hemi. I	- Hemi. J	*p*-value LSD	p-value Holm's-Bonferroni
270	180	.001	0.036
315	0	.002	0.041
270	0	.002	0.058
225	0	.025	0.632
90	0	.027	0.649
135	0	.030	0.687

Hemimeridan at High Angles

Hemi. I	- Hemi. J	*p*-value LSD	p-value Holm's-Bonferroni
90	135	.000	0.001
90	45	.000	0.005
90	180	.000	0.010
90	0	.000	0.011
90	270	.002	0.045
225	180	.031	0.722

Appendix C: Categorical Data, Pairwise Comparisons for Hemimeridian Locations.

(Note: comparisons stem from main effects from omnibus F tests, simple effects analysis, or Friedman tests. Tables show from left to right, hemimeridians with higher A-RT or A-PI, hemimeridians with lower A-RT or A-PI, *p*-values from LSD tests, and *p*-values adjusted by Holm's-Bonferroni or Bonferroni method. Only comparisons which showed significant LSD *p*-values were included and shaded rows indicate significant *p*-values if observing the adjusted *p*-values.

Categorical Gabor Roll Left

Dependent Varaible A-RT

Hemimeridan at All Angles

Hemi. I	- Hemi. J	*p*-value LSD	p-value Holm's-Bonferroni
225	315	.000	0.008
90	135	.002	0.055
225	0	.005	0.131
90	45	.010	0.244
90	315	.012	0.294
225	135	.013	0.307
90	0	.020	0.434
225	180	.049	1

Dependent Varaible A-PI

Hemimerdian at Low Angles

Hemi I	Hemi J	p value	Bon Adj
90	0	0.030	0.847
90	180	0.030	0.847
90	135	0.050	1

Hemimerdian at High Angles

Hemi I	Hemi J	p value	Bon Adj
90	270	0.005	0.129
90	0	0.007	0.189
90	45	0.007	0.189
90	315	0.01	0.274
90	135	0.046	1

Categorical Gabor Roll Right

Dependent Varaible A-RT

Hemimeridan at All Angles

Hemi. I	- Hemi. J	*p*-value LSD	p-value Holm's-Bonferroni
270	0	.004	0.105
270	315	.007	0.197
180	315	.007	0.197
225	315	.014	0.348
90	45	.017	0.396
180	0	.022	0.504
180	45	.025	0.557
90	0	.027	0.574
90	315	.028	0.574
180	135	.033	0.636
225	0	.038	0.680
270	45	.038	0.680
135	0	.044	0.701
135	315	.047	0.702

Dependent Varaible A-PI

Hemimerdian at Low Angles

Hemi I	Hemi J	p value	Bon Adj
90	180	0.002	0.057
90	0	0.003	0.076
90	315	0.01	0.274
90	45	0.014	0.391
270	180	0.024	0.685
270	0	0.03	0.847
90	225	0.034	0.94

Hemimerdian at High Angles

Hemi I	Hemi J	p value	Bon Adj
90	180	0.006	0.167
90	0	0.024	0.685
90	45	0.027	0.762
90	225	0.037	1

Categorical ASAR Roll Left

Dependent Varaible A-RT

Hemimeridan at High Angles

Hemi. I	- Hemi. J	*p*-value LSD	p-value Holm's-Bonferroni
315	135	.007	0.184
270	180	.008	0.210
270	135	.009	0.231
270	90	.019	0.473
225	135	.022	0.528
270	45	.022	0.528
0	135	.023	0.528
270	225	.033	0.690
0	45	.039	0.775

Dependent Varaible A-PI

Hemimerdian at Low Angles

Hemi I	Hemi J	p value	Bon Adj
135	45	<.001	0.008
135	225	0.007	0.189
135	270	0.008	0.215
135	90	0.011	0.309
45	180	0.02	0.55

Categorical ASAR Roll Right

Dependent Varaible A-RT

Hemimeridan at All Angles

Hemi. I	- Hemi. J	*p*-value LSD	p-value Holm's-Bonferroni
270	0	.004	0.105
270	315	.007	0.197
180	315	.007	0.197
225	315	.014	0.348
90	45	.017	0.396
180	0	.022	0.504
180	45	.025	0.557
90	0	.027	0.574
90	315	.028	0.574
180	135	.033	0.636
225	0	.038	0.680
270	45	.038	0.680
135	0	.044	0.701
135	315	.047	0.702

Dependent Varaible A-PI

Hemimerdian at Low Angles

Hemi I	Hemi J	p value	Bon Adj
45	315	0.005	0.129
45	135	0.008	0.215
45	225	0.018	0.491
45	90	0.024	0.685
45	180	0.046	1

Categorical ASAR VFP Climb

Dependent Varaible A-RT

Hemimeridan at High Angles

Hemi. I	- Hemi. J	*p*-value LSD	p-value Holm's-Bonferroni
90	315	.010	0.278
90	45	.028	0.746
180	0	.036	0.947
180	315	.039	0.980

Dependent Varaible A-PI

N/A

Categorical ASAR VFP Dive

Dependent Varaible A-RT

Hemimeridan at High Angles

Hemi. I	- Hemi. J	*p*-value LSD	p-value Holm's-Bonferroni
225	45	.000	0.011
315	45	.003	0.077
270	45	.003	0.081
135	45	.008	0.200
225	135	.016	0.374
225	90	.017	0.394
0	45	.017	0.394
180	45	.024	0.502
315	90	.024	0.502
315	180	.026	0.502
315	135	.032	0.581
270	90	.036	0.607
90	45	.038	0.607
225	180	.042	0.636

Dependent Varaible A-PI

N/A

Appendix D: Example Calculation of the Mean Ranks in the Freidman Test.

The data shown here are those of the A-PI in Categorical Gabor Rolling Right at the Low Angle level. The A-PI scores are rank ordered from lowest to highest (1 to 8), where ties are accounted for by averaging the sum of the ranks associated with the tied scores.

Participant	Hemimeridian_0	Rank 1	Hemimeridian_45	Rank 2	Hemimeridian_90	Rank 3	Hemimeridian_135	Rank 4	Hemimeridian_180	Rank 5	Hemimeridian_225	Rank 6	Hemimeridian_270	Rank 7	Hemimeridian_315	Rank 8
1	0	3.5	0	3.5	0.125	7	0.625	8	0	3.5	0	3.5	0	3.5	0	3.5
2	0	4	0	4	0.125	8	0	4	0	4	0	4	0	4	0	4
3	0	3	0.125	6	0.25	7.5	0.25	7.5	0	3	0	3	0	3	0	3
4	0	3	0	3	0.125	6.5	0.125	6.5	0	3	0	3	0.25	8	0	3
5	0	4	0	4	0	4	0	4	0	4	0	4	0.125	8	0	4
6	0.25	5	0	2	0	2	0	2	0.125	4	0.625	7.5	0.5	6	0.625	7.5
7	0	3.5	0	3.5	0	3.5	0.125	7	0	3.5	0	3.5	0.25	8	0	3.5
8	0	3.5	0.125	7.5	0.125	7.5	0	3.5	0	3.5	0	3.5	0	3.5	0	3.5
9	0	4	0	4	0.25	8	0	4	0	4	0	4	0	4	0	4
10	0	3.5	0	3.5	0.5	8	0	3.5	0	3.5	0	3.5	0.125	7	0	3.5
11	0	2	0.125	4.5	0.375	8	0	2	0	2	0.25	6.5	0.25	6.5	0.125	4.5
12	0	3	0	3	0.25	8	0	3	0	3	0.125	6.5	0.125	6.5	0	3
Sum		42		48.5		78		55		41		52.5		68		47
Mean Ranks		3.50		4.04		6.50		4.58		3.42		4.38		5.67		3.92

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14. ABSTRACT
Two experiments were conducted to examine visual performance asymmetries when perceiving complex, meaningful visual stimuli, such as the Arc Segment Attitude Reference (ASAR). The ASAR symbology represents an aircraft's attitude. Experiment 1 examined participants' performance while recalling and reporting various attitudes of ASAR symbology and a Gabor patch, which were briefly presented in the peripheral visual field. Performance was assessed for coordinate and categorical judgments at various display locations. The results were consistent with the horizontal-vertical anisotropy literature, which implies that performance would be better for stimuli placed on the horizontal meridian as compared to stimuli placed on the vertical meridian. Experiment 2 assessed asymmetries for continuously presented stimuli. Participants performed a visual psychomotor task using stimuli in the center of a display while monitoring peripherally located ASAR or Gabor patches. The visual stimulus in the periphery was displayed constantly and observers could move their gaze on such stimuli. This experiment sought to understand if eye movement is paired better between a center task and the various peripheral locations. No performance differences were found among the different peripherally located stimulus placements, but eye tracking data suggested efficient visual processing for the horizontal meridian.

15. SUBJECT TERMS
visual asymmetries; attitude symbology; Arc Segment Attitude Reference; ASAR; augmented reality

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