INDIVIDUAL DIFFERENCES IN RAPID SPATIAL ORIENTATION ACROSS SPATIAL FRAMES OF REFERENCE

by

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DEDICATION

This dissertation is dedicated to my loving wife Tina, and my parents Edwin and Ingrid.

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I would like to thank the many friends, relatives, and supporters who have made this happen. Although there are too many people I owe some gratitude to, there a few people who are especially deserving of recognition.

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LIST OF ABBREVIATIONS AND SYMBOLS

Sense of Direction Questionnaire .... SDQ
Good Sense of Direction .... GSD
Poor Sense of Direction .... PSD
ROS .... ROS
Mental Rotation Test .... MRT
Head Related Transfer Functions .... HRTF

ABSTRACT

INDIVIDUAL DIFFERENCES IN RAPID SPATIAL ORIENTATION ACROSS SPATIAL FRAMES OF REFERENCE

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A series of studies were conducted with the intent of examining the nature of regions of space (ROS), peripersonal and extrapersonal ROS, and in particular, in the auditory modality. Further, potential individual differences in human interaction within these ROS were examined. Previous research has documented the existence of differences in interacting with visual stimuli presented within versus across ROS. The current investigation sought to examine potential analogous effects for auditory stimuli. Further, research suggests that there are substantial individual differences in spatial abilities and navigation strategies. Specifically, high spatial ability individuals tend to have a good sense of direction (GSD) and tend to use their visual-spatial working memory when performing spatial tasks. Conversely, those with poor spatial abilities tend to have a poor sense of direction (PSD) and generally tend to use a verbal-sequential strategy that relies on verbal working memory when performing spatial tasks. The near and far

representations of space are often separated into functional regions based on proximity to the person. Research using visual stimuli suggests that switching attention from one stimulus to another in distinct regions of space is more difficult than switching attention between two stimuli within the same functional ROS (Di Nocera, Couyoumdjian, & Ferlazzo, 2006). It was predicted that similar performance decrements would be observed when responding to two auditory stimuli presented in different, relative to the same ROS. Additionally, based on previous research investigating individual differences in spatial strategy, it was predicted that individuals with a PSD would experience more difficulty in switching their attention between distinct regions of space whereas those with a GSD would be more fluid in their ability to switch their attention between distinct regions of space. Two experiments were conducted to 1) examine the auditory analog to visual functional ROS, and 2) to examine the potential impact of individual differences in people's spatial strategy and their ability to switch their attention across near and far ROS. In the first experiment, participants had to respond to the location of a series of stimuli played in rapid succession and the stimuli were analyzed in reference to whether the prior stimulus was in the same ROS or in a different ROS. In the second experiment, participants had to selectively attend to either the semantic information of a stimulus or the location of the speaker where the stimulus was played from, in an auditory-spatial Stroop task. Results of Experiment 1 provide preliminary evidence in support of superior performance as a function of ROS in the auditory modality in that participants, in general, responded significantly faster when the stimuli were moving towards them within either ROS, but this effect was not observed when the stimuli crossed ROS. Results also suggest that individuals may differ in their ability to attend to stimuli as a function of direction of travel. Specifically, participants responded significantly faster when responding to stimuli that seemed to be moving towards them, and participants with a PSD responded significantly faster to stimuli coming towards them relative to stimuli going away from them. GSD individuals responded the same regardless of whether stimuli were coming towards them or moving away. Last, participants were more accurate at responding to stimuli on the right side compared to their performance on the left side, consistent with prior research on the Right-Ear Advantage (REA) but also in line with stimulus-response compatibility, since nearly all participants responded with their right hand. Results of Experiment 2 showed inconclusive evidence of individual differences in attending to semantic or spatial information across ROS. However, results provide further evidence that spatial conflict can arise when semantic and location spatial cues are incongruent and further extend these findings to auditory stimuli presented in different ROS. The lack of other significant results are most likely due to a ceiling effect in that all participants performed exceptionally well on all tasks. Follow up studies should include strategic secondary/loading tasks that occupy specific resources. Overall, some individual differences in ability to attend to auditory stimuli that cross regions of space, depending on the direction, were found. This may affect how certain individuals perform using systems with complex auditory displays and may also help with personnel selection for roles that require users to switch their attention between ROS.

INTRODUCTION

Displays and devices that people interact with at work or in everyday life may be designed to present information that appears to come from either near or far locations relative to the person. Research suggests that people may process information differently depending on whether the display is in near or far space. Occasionally, information is presented and people are required to monitor the location of a stimulus as it travels either closer or moves farther away (e.g., listening to an approaching vehicle or object to make a determination regarding whether it is safe for a pedestrian to cross a roadway or to make an accurate determination on when to make contact with a target). Determining whether or not people process information differently if it is in near or far space is important for effective display design. Most previous research on near and far space has been conducted for visual displays. It is not well understood whether differential near and far space effects are also found in the auditory modality. This dissertation examines this issue as well as potential individual differences in the ability to switch their attention between near and far regions of space as a function of spatial strategy. Findings may assist in the design of complex displays, personnel selection, and training.

The way humans interact with both near and far space is often separated into functional regions based on proximity to the person (Previc, 1998). How humans interact with various regions of three dimensional (3-D) space has often been investigated in basic, controlled laboratory studies primarily in the visual channel with the purpose of understanding fundamental cognitive and neurophysiological components as well as perceptual abilities (Couyoumdjian, Di Nocera, & Ferlazzo, 2003; Di Nocera, Couyoumdjian, & Ferlazzo, 2006; Ho, Tan, & Spence, 2006; Ladavas, di Pellegrino, Farne, & Zeloni, 1998; Spence & Santangelo, 2009).

Although differential processing of objects in near or far space appears to be a general characteristic of human performance, the expression of this effect may vary between individuals. Whereas individual differences in spatial strategy have been investigated extensively, few, if any studies have investigated how individuals may differ in how they interact in various functional regions of 3-D space. The study of individual differences in 3-D spatial interaction warrants investigation for several reasons. Research suggests that high spatial ability individuals perform better at tele-operation or remote piloting tasks that require the operator to shift his or her attention from the controls (which are in near space) to the video feed of the equipment being used (which is a representation of far space) (Chen, Haas, & Barnes, 2007; Chen & Joyner, 2009). This type of task can be reasoned to require operators to shift their attention between near and far space. Furthermore, research on regions of space suggests that there is a cost to switching attention across regions compared to within the same region (Couyoumdjian, Di Nocera, & Ferlazzo, 2003; Di Nocera, Couyoumdjian, & Ferlazzo, 2006).

If individual differences in spatial strategy interact with spatial awareness across regions of space, a hypothesis that the studies in this dissertation will test, then the results could have potentially important practical applications. First, personnel selection measures may be warranted to select individuals with a visuospatial strategy who are most likely to perform best for tasks involving interactions with displays in near and far space. Second, specialized training programs could be developed based on variations in spatial strategy. Finally, customizable display designs might be developed that are based on an individual's spatial strategy.

This introductory section will briefly present the general topics of how humans process spatial information and then individual differences in spatial strategy will be discussed, followed by a discussion of regions of space and examples of each. These key constructs form the basic framework and assumptions of this dissertation. Then, entire sections are devoted to theories of spatial abilities and individual differences in spatial strategy, regions of space, and the Stroop paradigm (Stroop, 1935), since these are all essential components of this dissertation. Finally, a series of experiments is presented to investigate the research questions of interest, followed by a detailed discussion of the Methods, Results and a Discussion of the experiments and their implications.

A considerable amount of effort has been spent on investigating how humans process spatial information (Thorndyke & Hayes-Roth, 1982; Sheppard & Metzler, 1972; Loomis, Klatzky, Golledge, & Philbeck, 1998). How people acquire, represent, retain and apply information about where they are in reference to external stimuli in the environment has fascinated psychologists for at least a century (Tolman, 1924, 1927). From this early work forward it was observed that spatial abilities encompass a number of different forms ranging from mental rotation to navigation through large scale environments. Further, considerable variability between individuals has been observed both in terms of ability and strategy.

The two main frames of reference humans use to encode spatial information are egocentric and allocentric (also referred to as geocentric). An egocentric perspective is generally a first person, forward view which on a map representation would indicate a forward up point of view.   Alternatively, an allocentric/geocentric perspective is bird's eye view and on a map would generally be represented by a north up perspective in reference to the world and involves building a visual-cognitive map (Thorndyke & Hayes-Roth, 1982; Gugerty and Brooks, 2004). Thorndyke and Hayes-Roth (1982) found that individuals studying a map layout of an office building had a different understanding (survey knowledge) compared to those who had worked in the office building for several months and had physically walked the environment for months (route knowledge).

It was previously thought that the progression of learning an environment went from landmark to route to survey knowledge. This model has subsequently been called into question since recent evidence suggests that different types of spatial information are utilized depending on the type of spatial information that is provided (Blajenkova, Motes, & Kozhevnikov,2005; Furukawa, Baldwin, & Carpenter, 2004; Reagan & Baldwin, 2006). For example, a visual map usually provides north-up geocentric information whereas auditory route guidance systems usually are egocentric in nature and may not provide any geocentric information. Recently, Blajenkova, Motes, & Kozhevnikov (2005) found that certain high spatial ability individuals were able to draw survey style sketch maps after just one exposure of the environment. These results indicate that the earlier model, progression of learning an environment from landmark to route to survey, may not be absolute. There may be strong individual differences in strategy and existing differences in strategy may be amenable to training.

Individual differences in spatial strategy can impact how effective systems and displays can be. Previous studies have demonstrated superior performance from individuals with high spatial abilities compared to those with lower spatial abilities in a variety of tasks and settings. For example, Chen & Barnes (2011) demonstrated that high spatial ability individuals performed better than lower spatial ability individuals in a variety of robotics operation tasks that required visual scanning. Chen & Joyner (2009) found individual differences in perceived workload in a simulated gunner and robotics operator task – with those with high spatial abilities experiencing lower perceived workload. Chen, Durlach, Sloan, and Bowens (2008) found spatial ability to be a good predictor of target-detection performance in a simulated task where participants controlled semiautonomous unmanned ground vehicles (UGV), unmanned aerial vehicles (UAV), and teleoperated UGVs. Chen and Terrence (2009) even demonstrated a difference in preferred cueing modality in a simulated multitasking environment while operating robotics in which low spatial ability individuals' preferred visual cueing and high spatial ability participants favored tactile cueing. These individual differences can have a profound impact on performance in how people interact with advanced systems and displays, such as remotely piloted robots and advanced display systems such as augmented reality and synthetic displays (Calhoun & Draper, 2006).

Individual differences in spatial strategy have been investigated extensively (Kato & Takeuchi, 2003; Baldwin, 2009; Blajenkova, Motes, Kozhevnikov, 2005; Chen, Barnes, Harper- Sciarini, 2011), but few, if any studies have looked into exactly how individuals may differ in how they interact specifically with three-dimensional space. Recent studies have investigated individual differences in sense-of-direction and spatial strategy (Blajenkova, et al., 2005; Baldwin and Reagan, 2009, Baldwin, 2009). Individuals are often separated by their spatial strategy into either visuo-spatial or verbal-sequential spatial strategy groups or GSD and PSD groups (Kato and Takeuchi, 2003; Hegarty et al., 2002). Fundamentally, individuals may differ in how they approach novel environments or spatial tasks. Baldwin and Reagan (2009) suggest that individuals with a PSD may rely on verbal working memory when learning a route, whereas those with a GSD utilize visuospatial working memory. This topic of individual differences in spatial strategy and a discussion of the differences and similarities between spatial strategy and SOD will be more extensively discussed in a dedicated section on individual differences later on in this dissertation.

Fundamentally, individuals may differ in how they approach novel environments and perform spatial tasks or process spatial information. For example, Garden, Cornoldi, & Logie (2002) found that visuo-spatial strategy individuals experienced more difficulty while navigating while performing a concurrent spatial tapping task, whereas those with a verbal-sequential strategy experienced more difficulty navigating while performing a concurrent articulatory suppression task. The spatial tapping task occupies spatial resources that visuo-spatial strategy individuals would otherwise use for navigation purposes and the concurrent verbal task introduces demand for verbal working memory resources, suggesting that individuals with a visuo-spatial strategy may use spatial working memory resources for navigating whereas verbal-sequential strategy people use verbal working memory and thus a verbal approach to navigating. Baldwin and Reagan (2009) suggest that individuals with a PSD may also rely on verbal working memory when learning a route while navigating whereas those with a GSD utilized visuospatial working memory. They assessed this by having participants learn a route while performing either a concurrent verbal task (articulatory suppression) or a visuospatial tapping task, similar to Garden, et al (2002). They found that those with a PSD had more difficulty while having to perform the concurrent verbal task, suggesting an interference with their verbal working memory. Conversely, those with a GSD experienced more interference while attempting to learn a route while performing a concurrent visuospatial tapping task. This suggests that due to the strategy being used to perform the task, the two tasks (navigation and spatial tapping) were both fighting for visuospatial working memory resources at the same time.

Display designers should be mindful of potential individual differences in how people interact with displays that operate in distinct ROS during the system design process. For example, switching one's attention between navigating and interacting with an instrument within a vehicle while driving may require the user to shift attention back and forth between two distinct functional regions of space. Previous research in the visual domain suggests that there is a significant cost in shifting one's attention between two distinct ROS, above and beyond shifting attention between two stimuli within the same

ROS (Couyoumdjian, Di Nocera, & Ferlazzo, 2003; Di Nocera, Couyoumdjian, & Ferlazzo, 2006). For example, in the driving example mentioned above, the user may be focusing his or her attention within the extrapersonal ROS while navigating, then switching their attention back inside the car to interact with the radio or the air conditioning, which takes place within the peripersonal ROS. This "cost" in switching one's attention between regions of space may be detrimental to response time performance in time critical tasks such as collision warnings. Furthermore, a situation that requires frequent switching of attention between near and far space may be perceived as more difficult or requiring more workload and may result in sub-optimal performance. Some individuals, such as those with a PSD, may have more difficulty switching between ROS than others.

If differential costs or individual differences are observed for switching attention between ROS in the auditory domain, then display designs might be custom tailored to the individual and be optimized to their preferred display or a display that matches the individuals' capabilities. Specifically, if certain individuals do not benefit from the added spatial information of a given display design or if certain individuals experience a greater cost to switching their attention between distinct regions of space, rethinking display design and optimizing interfaces tailored to an individual's strategy may benefit performance and reduce error. Similarly, if certain individuals explicitly benefit from displays designed to exploit the use of ROS, rethinking display design and optimizing interfaces to include the additional information offered by ROS may effectively enhance performance and reduce error. Additionally, training or personnel selection strategies could be incorporated to select only individuals with a GSD to perform tasks or utilize equipment that is better suited for visuo-spatial strategy individuals (Chen & Barnes, 2012).

Each of these theories, paradigms, and concepts will be further discussed within the literature review section. First, a section introducing major theories of spatial behavior and literature on regions of space is provided, followed by a section on applications of regions of space. Next, individual differences in spatial strategy are discussed, followed by a section comparing the various types of spatial strategy and appropriate questionnaires used to identify individuals based on their spatial strategy and SOD. Then, a brief section discussing the Stroop paradigm and Barrow and Baldwin's (in press) auditory-spatial Stroop task as it pertains to this dissertation are presented, followed by a section discussing previous research pertaining to switching ones attention across near and far regions of space. Next, a section merging individual differences and regions of space is provided which presents the general research questions of interest and corresponding hypotheses for this dissertation. That is, do individuals differ in their ability to switch their attention across near and far representations of space? Last, the proposed experiments intended to help address the research question are presented.

Regions of Space

How individuals interact with near and far space has often been organized by distance and function. Previc (1998) identified four distinct regions of space that generally correspond with distance and function. The ROS closest to the individual is the peripersonal system and is the region where visuomotor near-body space interactions take place. This region generally encompasses what can be reached or interacted with within arms-reach. The focal extrapersonal ROS pertains to visual search and object recognition. The action extrapersonal ROS is associated with orientation in topographically defined space, and the ambient extrapersonal ROS pertains to how individuals orient themselves in earth-fixed space. This can be seen in Figure 1.

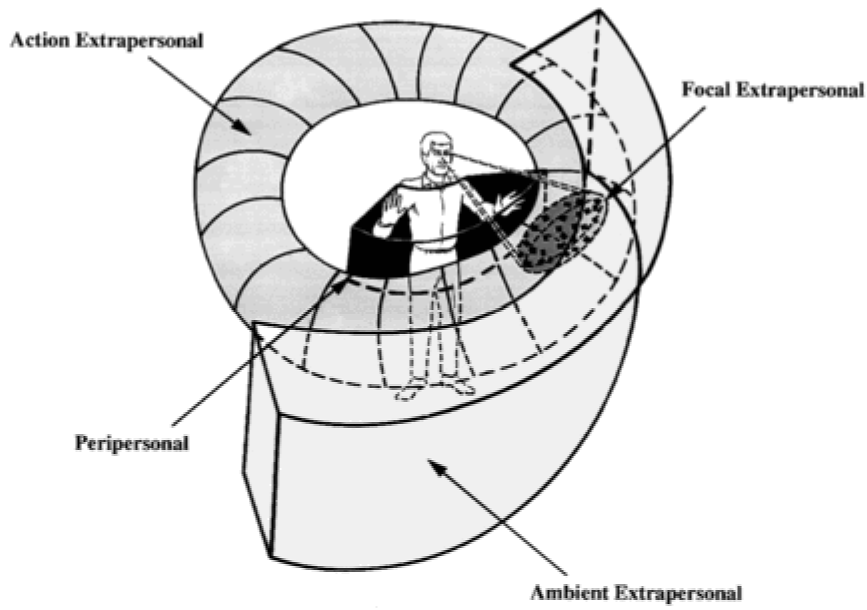

Figure 1- Diagram of Functional Regions of Space. (Previc, 1998)

Other competing models may differ slightly (Previc, 1998; Cutting and Vishton, 1995), but these differences are primarily based on function and not distance. By and large, the vast majority of studies have grouped the regions of space into just two distinct regions, the peripersonal system and the extrapersonal system as a functional representation of near and far space, respectively (Ho, Tan, & Spence, 2006; Ladavas, di Pellegrino, Farne, & Zeloni, 1998; Losier & KIein, 2004; Nicholls, Forte, Loetscher, Orr, Yates, & Bradshaw, 2011; Armbruster, Wolter, Kuhlen, Spijkers, & Fimm, 2007). This grouping is plausible because of both function and space. The focal extrapersonal, action extrapersonal, and ambient extrapersonal regions of space have often times been grouped into a more general extrapersonal system. The peripersonal system remains largely unchanged, resulting in two general distinct regions of space, the peripersonal system, which we will broadly define as the ROS closest to the individual and is generally limited to what can be reached by the person in arms distance, and the extrapersonal system, which we will loosely define as anything outside of the peripersonal system and generally cannot be reached within arms distance. This can be seen in Figure 2.

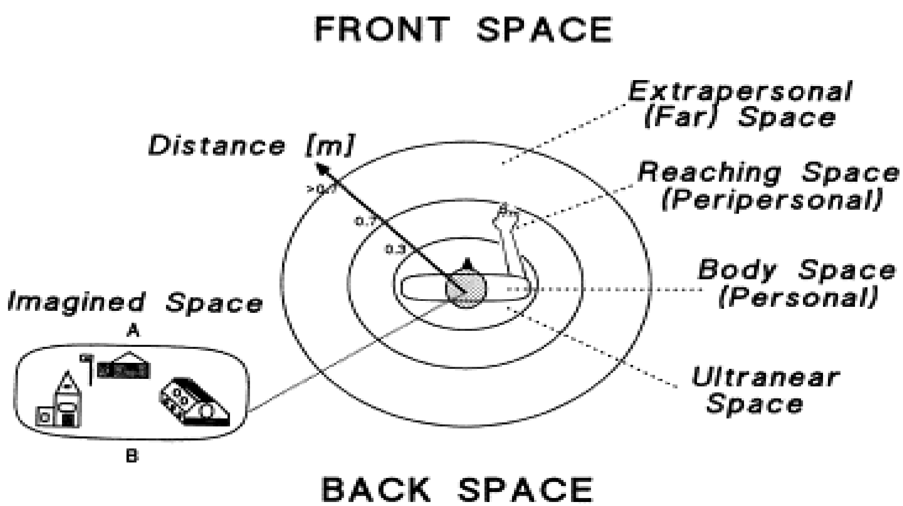

Figure 2- Schematic of near and far space in relation to arm's distance reach.
(From: http://visionhelp.wordpress.com/2012/11/22/emodied-cognition-part-2/neuropsych-regions-of-space/)

There is also neurophysiological evidence that supports the notion that distinct regions of space are associated with differential processing characteristics. The dorsolateral prefrontal cortex is associated with the peripersonal system, the ventrolateral area is associated with the focal-extrapersonal system, the ventromedial region is associated with action-extrapersonal interaction, and the dorsomedial region is associated with the ambient-extrapersonal system (Previc, 1998). Many other studies have investigated neurophysiological differences when interacting with different regions of space pertaining to modality of stimuli (Ladavas, Farne, Zeloni , 1998; Nicholls, Forte, Loetscher, Orr, Yates, & Bradshaw, 2010), neuropsychological disorders (Weiss, Marshall, Wunderlich, Tellmann, Halligan, Freund, Zulles, & Fink, 2000; Ladavas, di Pellegrino, Farne, Zeloni, 1998; Nicholls, Hadgraft, Chapman, Loftus, Robertson, & Bradshaw, 2010), and region expansion (Ladavas, 2002; Maravita & Iriki, 2004). This evidence also appears in primate studies that demonstrate expansion of the peripersonal space when using a tool to reach an object that would otherwise be out of reach (Ladavas, 2002; Maravita & Iriki, 2004). In addition to the neurophysiological evidence suggested above, there is also evidence in the auditory research realm that suggests that humans process near and far space information quite differently, a topic which will now be discussed.

Near- and Far- Field Auditory Localization

In the auditory realm, Brungart and colleagues (Brungart & Rabinowitz, 1999; Brungart, Durlach, & Rabinowitz, 1999; Brungart & Scott, 2001; Brungart, 2002) noticed a difference in near- and far-field auditory localization. They defined near-field as anything within 1 meter of the individual, which is essentially the same boundary proposed by Previc (1998) of arms-distance as a boundary between near and far space. They noticed that head related transfer functions (HRTFs) for near space required far more precision to be accurate compared to auditory localization HRTFs used for distances beyond 1m. Brungart and colleagues also noted that individuals were better able to distinguish between multiple auditory sources when they took place in distinct regions as opposed to coming from the same region. This finding could potentially allude to the existence of distinct pools of cognitive resources as a function of regions of space. These studies further highlight the existence of regions of space, particularly in the auditory domain. A few examples of how regions of space can be taken into account during the system design process will be discussed in a subsequent section. But first, a brief discussion of the impact of presentation laterality will be discussed.

Right Ear Advantage

Researchers have frequently observed laterality differences in auditory and speech perception. Extensive research over the years has demonstrated a Right Ear Advantage (REA) for auditory stimuli, and speech in particular (Hiscock & Kinsbourne, 2011; Saetrevik, 2012; Jerger & Martin, 2004; Mcfadden, 1993; Mcfadden & Mishra, 1993). For example, in dichotic listening tasks, people generally demonstrate greater sensitivity for speech material presented to the right versus the left ear (Mcfadden, 1993; McFadden & Mishra, 1993). The REA is heavily influenced by attention and the localization of the source of the stimulus (Hiscock & Kinsbourne, 2011). This is due to the specialization of the left hemisphere of the brain for speech and language processing, resulting in a REA (Hiscock & Kinsbourne, 2011; Jerger & Martin, 2004). For this reason, a comparison of responses to stimuli presented to the left side and right side is necessary. The REA is specifically applicable to the data analysis performed in Experiment 1 and will be addressed again in that section.

Applications of Regions of Space

The way individuals interact within and between near and far space should be taken into account when designing new systems and interfaces or when selecting personnel who may be better suited to use such complex systems. Many studies have investigated the basic underlying mechanisms and cognitive systems associated with interacting with near and far space, but few studies have taken this approach in applied settings. Of the few applied studies pertaining to how humans interact with regions of space, the transportation industry has garnered the most context specific interest. In a driving setting for example, the driver most likely has to navigate (wayfinding) which is an extrapersonal endeavor (Previc, 1998), but also interact with an abundance of in-vehicle technology, which most likely takes place in peripersonal space. For example, Fagioli and Ferlazzo (2006) conducted a study to assess driving performance while the participants were holding a conversation. The conversations were conducted either through a hand held phone, a wireless earpiece, or the speakers of the car. The authors claim that the fundamental difference between these approaches is that the hand held phone and the earpiece hold the user's attention in peripersonal space whereas the speaker system may better simulate that the conversation is taking place in extrapersonal space. The results show that driver performance was best when drivers held the conversation through the loudspeakers via the car's infotainment system, suggesting that conversing via a hand held phone or an earpiece may require an additional step of switching one's attention between regions of space and maintaining optimal driving performance. A collision warning system may work in a similar fashion in the sense that a driver's attention may be focused on navigating which is an extrapersonal endeavor, while a collision warning system may direct their attention back into the vehicle in peripersonal space to make the appropriate response to the warning.

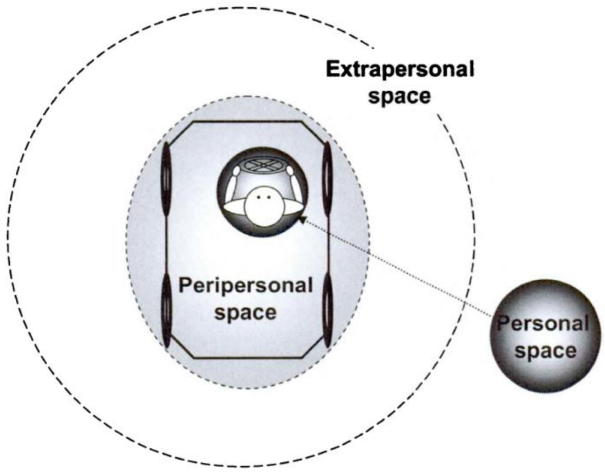

Figure 3- Schematic of peripersonal space and extrapersonal space in -vehicle. Regional expansion may occur with the use of a tool such as a weapon or vehicle (Ho & Spence, 2008).

Ho & Spence (2007) conducted a series of studies investigating whether there is a benefit to spatial cueing in various multimodal collision warning systems. They found that, depending on if your goal was to facilitate attention allocation or to facilitate decision-making, adding spatially informative cues to a collision warning system may be beneficial. The key is to design the multiple modalities to offer the same "congruent" spatial information from all modalities that are included in the given display. In other words, it may not be effective to combine a spatial auditory cue with a non-spatially predictive tactile cue coming from a central/master warning system. This may have the effect of conflicting attention facilitation and response facilitation resulting in inferior performance than a unimodal warning alone (Begault, 1993; Oving, Veltman, & Bronkhorst, 2004). When using an in-vehicle collision warning system, for example, a spatially predictive auditory collision warning may direct the users' attention to where the event may be coming from in extrapersonal space, while the tactile warning cue may be directing the drivers' attention into the vehicle where the tactile stimuli is coming from, in peripersonal space. It may be best to strive for a system that is effective at facilitating the user's attention to where the impending collision may be coming from or to have a system that is effective at facilitating the driver's response to the correct decision (i.e. hitting the brakes) without necessarily needing to know what the impending event is.

Brungart (2002) noted that in many occupational environments, there is a clear difference between peripersonal objects, objects in the immediate vicinity of the operator, and extrapersonal objects and events that occur at a distance from the location of the operator. Brungart (2002) uses an example of an aircraft cockpit and notes that most of the internal systems such as instrument clusters and mechanical warnings occur within the peripersonal ROS because they are stationary in relation to the reference frame of the pilot, whereas, events that occur outside of the cockpit such as missile warnings and communication between nearby friendly aircrafts (wingmen) would be considered an extrapersonal endeavor. For this reason, he advocates for the use of distinct near- and far-space head-related transfer functions as an effective way to direct the pilot's attention to internal and external events (Brungart, 2002).

Increasingly complex systems, particularly in military domains, may require operators with a visuo-spatial strategy to fully utilize their capabilities. Remotely piloted vehicles (Chen, 2010; Chen & Barnes, 2012) and synthetic displays (Draper, Calhoun, & Nelson, 2006), require a high degree of cognitive spatial interaction to operate properly.

Any form of teleoperation (Chen, Haas, & Barnes, 2007), particularly in the medical domain, may also require similar high spatial ability function because the controls of the given system are physically located in peripersonal space and the actions of the system occur in extrapersonal space. Users of such complex systems may be required to concurrently maintain representations of near and far space in working memory, a practice that is similar to how GSD individuals navigate by constantly updating large scale representations of space. Yet most of these studies have investigated performance of these various systems only looking at general spatial ability function. No study, to our knowledge, has explicitly investigated if and how individuals may differ in how they interact with near and far space. These complex systems and tasks may require users to shift their attention between distinct regions of space, particularly when the display is a representation of a distant location (extrapersonal space) and controlled with inputs in near space (peripersonal space). Individual differences in spatial strategy and how it may relate to how individuals interact with near and far space will now be addressed.

Individual Differences

The above mentioned studies incorporated regions of space and spatial cueing into the study of the design of warning systems, or may have investigated individual differences in spatial strategy as it relates to using a variety of complex systems and tasks such as driving while talking on a cell phone. By investigating these issues from an individual differences perspective, greater insight can be gained as to the role of spatial strategy in switching attention between tasks in distinct regions of space. Previous studies have investigated how individuals may differ in their ability to perceive or understand spatial information, based on their individual spatial strategy. Gender differences and sense of direction skills are among the two most important individual differences to consider. Generally speaking, females prefer the egocentric, forward-up perspective (Lawton, 1994), and generally will benefit from the addition of landmarks (Saucier, 2003). Men generally prefer reference oriented allocentric/geocentric perspective and generally perform better than women in navigation tasks. Also, males tend to maintain where they are in reference to cardinal directions. That is not to say women cannot or do not use geocentric perspective information and men do not use egocentric perspective information, these are just generalized findings. As far as sense of direction is concerned, people with a PSD prefer an egocentric perspective. They prefer to be directed from a first-person perspective to navigate from place to place and may not necessarily be interested in learning the environment along the way (Kato and Takeuchi, 2003; Furukawa, Baldwin, & Carpenter, 2004). People with a GSD generally prefer a geocentric perspective, although those with a GSD are generally good at using any method/perspective and can use any information that is available (Kato and Takeuchi, 2003; Furukawa, Baldwin, & Carpenter, 2004). These individual differences in sense of direction will now be discussed in greater detail.

An individual's self-reported sense of direction has generally been shown to predict their navigation strategy. Using their Sense of Direction Questionnaire (SDQ), Kato and Takeuchi (2003) found that individuals with a self-reported GSD tend to maintain their heading in relation to cardinal position whereas PSD individuals were poor at maintaining their cardinal heading. Similarly, Baldwin (2009) found that PSD individuals preferred auditory based ego-centric route guidance systems whereas those with a GSD preferred visual based geocentric route guidance systems. The ego-centric auditory route guidance system was more conducive to the PSD's verbal strategy whereas the visual route guidance system was more conducive to the GSD's visual-spatial method, which will be discussed shortly. Due to the wide range of individual differences in navigation strategy and sense of direction, as well as preferences in navigation display perspective, it is important to balance a user's preferred method of display orientation and design with the type of design that will be the most effective method for navigating route learning. That is, a user may prefer an interface be designed in a particular way, for example, an egocentric route guidance orientation, whereas, based on one's spatial strategy, that user may benefit from a north-up geocentric map based on their sense of direction and spatial strategy, and may also benefit from certain display features that may help facilitate route learning or to allow the option for the user to toggle between multiple display formats. These examples demonstrate how individuals can differ in their approach to certain spatial tasks such as navigating based on spatial strategy, as identified by their sense of direction (SDQ).

Recent research further supports the notion that individual differences in multimodal waypoint navigation may depend on display perspective (egocentric vs. geocentric). Garcia, Finomore, Burnett, Baldwin & Brill (2012) conducted a study to investigate individual differences in waypoint navigation via a visual, auditory, tactile, or multimodal route guidance system. Participants were lead from a variety of uni- or multi-modal route guidance systems from waypoint to waypoint and were instructed to look for certain landmarks throughout the environment. Results indicate that those with a PSD were significantly slower than those with a GSD in traversing the routes, particularly when using a traditional north-up egocentric map. The results of this experiment suggest that there are individual differences in waypoint navigation strategy between those with a GSD and those with a PSD. Overall, the unimodal geocentric visual condition was the slowest and least accurate. Those with a PSD had the most difficulty with this condition and we believe this is partially due to the added workload required to perform mental rotations to align reference frame to the current view (Gugerty & Brooks, 2004), which is a task that those with a PSD may have difficulty with or are incapable of.

Spatial Strategy and Associated Measures

Fundamentally, individuals may differ in how they approach novel environments or spatial tasks. Baldwin and Reagan (2009) suggest that individuals with a PSD may rely on verbal working memory when learning a route while navigating, whereas those with a GSD utilize visuospatial working memory. They assessed this by having participants learn a route while performing either a concurrent verbal task (articulator suppression) or a visuospatial tapping task. They found that those with a PSD had more difficulty while having to perform the concurrent verbal task, suggesting an interference with their verbal working memory. Conversely, those with a GSD experience more interference while attempting to learn a route while performing a concurrent visuospatial tapping task, suggesting that the two tasks were both fighting for visuospatial working memory resources at the same time. Due to their strategy to use spatial information better than verbal-sequential strategy individuals, it is believed that visuo-spatial strategy individuals will perform better at switching their attention between near and far space.

There are several ways to assess individual differences in spatial strategy. One potentially unique way to assess these individual differences in spatial strategy is with an auditory-spatial Stroop task because it is a task in which a prepotent response (semantic processing) conflicts with a newly learned association. Barrow and Baldwin (2009, 2010) used an auditory-spatial Stroop paradigm to assess individual differences in spatial strategy. A spatial version of the Stroop task can be used to assess individual differences in potential response conflict, and, more specifically, may be an effective way to assess an individual's executive function to switch their attention across distinct regions of space, which will now be discussed.

Stroop Paradigm

A Stroop paradigm offers an effective way to assess the degree of conflict exhibited and an individual's executive function control. This is accomplished by providing similar stimuli in a task that varies only in what participants are instructed to do. The original Stroop paradigm (Stroop, 1935) was intended to assess people's ability to handle conflict between perceptual (colors) versus semantic (linguistic) cues. People were asked to attend to either a word or the color of ink the word was written in, while ignoring the other dimension, depending on which task they were instructed to do. The results showed that it was more difficult for participants to pay attention to the ink color (a physical dimension) and ignore the written word (a semantic dimension) than vice versa. This underscores the importance of the semantic information provided by a word and may create a higher order, more automatic process compared to the additional step required to ignore the word and attend to the color of the ink in which the word was written. These results provide support for the role of automaticity in imposing conflict in a Stroop paradigm. Reading a word is a task undertaken on a daily basis whereas, identifying the color of the ink in which a word is printed is usually irrelevant in our day-to-day lives. Therefore, the automaticity of processing semantic content could be reasoned to be stronger than processing the ink color. However, the form of information (semantics versus physical location) may differ as a function of an individual's spatial strategy – a topic that will be examined to a greater extent when assessing proposed individual differences in a spatial Stroop paradigm.

Barrow and Baldwin (2014) created an auditory-spatial Stroop paradigm to assess people's ability to attend to either the spatial location or the semantics of a given stimulus. In the location task, participants were instructed to indicate where a stimulus was coming from (regardless of the word). For the semantic task, participants were instructed to respond to the semantic meaning of the word, while attempting to ignore where it was coming from. In particular, Barrow and Baldwin were interested in determining which type of information would lead to more conflict when incongruent – a physical location or semantic spatial reference. Similar to the results of the original Stroop (1935) findings, Barrow and Baldwin (2014) found that, overall, more conflict was experienced in the location condition – meaning it was more difficult to attend to the spatial location and ignore the semantics of the word, relative to the conflict experienced by an incongruent location when participants were instructed to attend to the semantics while ignoring or inhibiting the spatial location of the word.

However, Barrow and Baldwin (2014) noted strong individual differences based on participants' sense of direction, as based on the sense of direction questionnaire (SDQ; Kato & Takeuchi, 2003). Barrow and Baldwin (2014) found that those with a good sense-of-direction (GSD) experienced the most conflict from incongruent spatial information while performing the semantic version of the task. This resulted in slower responses in the semantic condition. That is, those with a good sense of direction (GSD) experienced difficulty ignoring incongruent spatial information, thus resulting in slower responses when instructed to respond to the semantic information. Conversely, those with a poor sense-of-direction (PSD) experienced more difficulty performing the location version of the task, particularly when the semantic information was incongruent, resulting in slower responses when instructed to respond to the spatial location of the stimuli.

These findings are critical to the design of this proposal. Barrow and Baldwin's results suggest that those with a GSD may rely on more or benefit more from spatial information whereas those with a PSD may rely more on a strategy that emphasizes semantic egocentric spatial cues over location based on allocentric spatially informative cues. These results suggest that individuals with different spatial strategies utilize different spatially informative cues in a differential manor. Concerning automaticity, the results of Barrow and Baldwin (2014), suggest that based on individual differences in spatial strategy, people experience differential patterns of conflict. The manner in which an individual processes spatial information will depend on that person's cognitive spatial processing strategy, i.e., GSD individuals will more efficiently (automatically) process the spatial location of the cue whereas someone with a PSD who tends to process spatial information with a verbal strategy will more efficiently and automatically want to attend to the semantics of the given cue. Thus, when instructed to attend to an aspect of spatial information that is not a native automatic process of that individual based on their sense of direction, conflict arises and more errors and delayed responses occur, as seen in the auditory-spatial Stroop conflict in Barrow and Baldwin's experiments.

A Stroop paradigm is a unique and effective way of assessing a person's executive function ability and the cognitive control required to selectively attend to one type of information over another (e.g., spatial or semantic information in distinct regions of space) (Barrow & Baldwin, 2014). Specifically, it will allow us to assess the cost or conflict experienced (i.e., in terms of speed and accuracy) that individuals may experience as a function of their spatial strategy (Kato and Takeuchi, 2003; Furukawa, Baldwin, & Carpenter, 2004) in each versions of the task. Specifically, we would expect that individuals with a GSD (who rely heavily on spatial location information) would experience more conflict when trying to ignore a spatial cue. Vice versa, we would expect that individuals with PSD (who rely heavily on verbal-sequential information) would experience more conflict when trying to ignore a semantic cue. The Stroop paradigm allows one to present both types of information with the same stimuli while only changing the task instructions. That is, a Stroop paradigm is an ideal experimental paradigm that is sensitive to detecting an individual's ability to selectively attend to certain types of stimuli and the interference that each type of stimuli may produce. As it pertains to the series of experiments proposed in this dissertation, using a Stroop paradigm, participants can be instructed to attend to either the spatial or semantic aspect of a task. Specifically, a Stroop paradigm offers the ability to assess whether an individual automatically processed or attended to the spatial or semantic information of a cue, regardless of what he or she was instructed to attend to. A cue can be given from either ROS in an alternating and random fashion and participants' responses can be assessed to determine which type of cue results in more conflict when incongruent. In other words, it allows assessment of whether they were able to differentially ignore irrelevant semantic or spatial components of the cue and whether this differs systematically based on sense of direction and spatial strategy.

Due to individual differences in sense of direction and the associated evidence previously mentioned of performance differences in tasks within a single ROS, these performance differences may be extended or even magnified when required to perform tasks across near and far regions of space. In the next section, research is presented that has demonstrated costs to switching attention across regions of space. This greater cost required to shifting one's attention across near and far regions of space may have more of a detriment on individuals with a verbal-sequential strategy.

Switching Between Regions of Space

Some tasks, such as monitoring the position of two UAVs, may require an operator to switch spatial attention between two locations. Evidence indicates that the attentional costs of this switch will be higher if the two tasks are located in different regions of space. Di Nocera and Colleagues (Couyoumdjian, Di Nocera, & Ferlazzo, 2003; Di Nocera, Couyoumdjian, & Ferlazzo, 2006) demonstrated a greater cost in switching one's attention between two tasks that take place in distinct regions of space compared to switching between two tasks within the same ROS. That is, it required more attentional resources to switch from a task occurring in peripersonal space to extrapersonal space, or extrapersonal space to peripersonal space, compared to switching between tasks that both occur in peripersonal space or both in extrapersonal space.

In a series of studies, Di Nocera, Couyoumdjian, & Ferlazzo (2006) presented a series of stimuli one right after the other in four conditions, two LED light stimuli occurring in peripersonal space, two LED light stimuli occurring in extrapersonal space, both stimuli crossing from one ROS to another and both stimuli occurring at the exact same location. Participants were instructed to press a button that represented each stimulus on a custom made response box. Participants responded significantly slower and less accurately to the condition that presented the two stimuli in different regions of space. To use an applied example, the results could mean that there may be a cost to directing your attention from navigating (which takes place primarily in extrapersonal space) to a collision warning system (which should direct your attention back into peripersonal space and prime you on the proper action to take related to the warning) while driving. If so, this may warrant designing collision warning systems that prompt a driver to the correct response (response facilitation) instead of a spatially informative collision warning system that may lead the driver to switch their attention across regions of space. Similarly, using synthetic displays with augmented reality capabilities (Draper, Calhoun, & Nelson, 2006) or tele-operations and remotely piloted equipment (Chen, 2010; Chen & Barnes, 2012) may require individuals to shift their attention between near and far spatial representations, near being where the equipment is manually controlled from and far being where the action is taking place. It is predicted that individuals with visuo-spatial strategy may perform better at switching their attention between distinct representations of space which may lead to better performance in tasks similar to those mentioned above.

In controlled laboratory based experiments, often times the experiments are intended to assess an individual's ability to interact with or complete a task with a certain system, such as a route guidance system or collision warning system. Investigating a user's ability to perform while interacting with multiple systems, such as a route guidance system and a collision warning system while driving, may be a more ecologically valid approach compared to traditional controlled sensation and perception lab studies. When testing a collision warning system or a route guidance system in isolation, participants may not have to shift their attention between multiple regions of space because the entire task may occur in only one ROS. Assessing people's ability to interact with multiple systems like a collision warning system and route guidance system while driving may be a more ecologically valid approach because testing each type of system individually does not allow you to investigate the switching of attention between the tasks. Conclusions made from assessing systems individually may be misleading or incomplete because systems are often used in combination with other systems such as a collision warning system and route guidance system, which requires a user to shift their attention between multiple systems and potentially switching their attention across regions of space. Thus, assessing an individual's ability to switch attention across regions of space may be a better predictor of overall performance.

The next section details the plan, motive, and justification for assessing individual differences in ability to switching attention across regions of space as a function of sense of direction and spatial strategy. Then, details of each experiment intended to investigate the existence and extent of individual differences across regions of space are proposed.

Regions of Space, Individual differences, and the Stroop Paradigm

The goal of this dissertation is to better understand how individuals may differ in how they interact with near and far regions of space. Specifically, this dissertation seeks to investigate the cost associated with switching one's attention between near and far spatial representations as a function of spatial strategy. To date, to our knowledge, there has been no explicit investigation addressing individual differences of how people interact with distinct regions of space. This idea is motivated based on experiments on regions of space that demonstrate the cost of switching one's attention between near and far representations of space (Couyoumdjian, Di Nocera, & Ferlazzo, 2003; Di Nocera, Couyoumdjian, & Ferlazzo, 2006) as well as the literature that demonstrates individual differences in spatial strategy (Kato and Takeuchi, 2003; Garcia, et al. 2012, Furukawa, Baldwin, Carpenter, 2004; Hegarty, et al., 2006; Baldwin, 2009) and how individuals may differ in their ability to attend to auditory-spatial information (Barrow & Baldwin, 2009, 2010, in review).

Individual differences can substantially influence the effectiveness of systems with certain displays and interface designs (Chen, 2010; Chen & Barnes, 2012; Draper, Calhoun, & Nelson, 2006). Depending on an individual's spatial strategy, certain groups of individuals may not benefit from the addition of spatially predictive directional cues and may actually perform worse in certain tasks with displays that offer this type of information compared to generic non-spatially predictive cues when having to switch between multiple tasks that take place in distinct regions of space. Specifically, it is predicted that individuals with a PSD will experience a greater "cost" to performing two tasks in different regions of space, and will also experience a greater "cost" in switching between peripersonal and extrapersonal space, above and beyond those with a GSD. The Stroop paradigm offers a unique setting to investigate this hypothesis. A series of experiments will be performed to better understand if and how individuals may differ in their ability to interact with distinct regions of space.

Experiment 1 was designed to further examine the cost to switching one's attention between near and far representations of space above and beyond switching one's attention between two things in the same ROS by examining performance for pairs of stimuli that may originate within the same or different regions of space. Furthermore, Experiment 1 was designed to determine whether this potential cost to switching across rather than within regions of space is greater for individuals with PSD or those with a GSD. Experiment 2 was designed to assess individual differences in one's ability to attend to near and far representations of space. Specifically, using an auditory-spatial Stroop paradigm, Experiment 2 was intended to see if there are individual differences in one's ability to attend to auditory spatial information in both near and far representations of space. The specifics of these proposed experiments will now be presented.

EXPERIMENT ONE

Experiment 1 was designed to investigate whether individuals with a PSD experience a greater cost to switching their attention between distinct regions of space relative to switching their attention between two objects in the same ROS. This experiment extends the results of Di Nocera et al. (2006) by investigating whether there are additional costs to switching one's attention between two stimuli located in distinct regions of space depending on one's spatial strategy, shown before to occur in vision, also occurs in the auditory modality. Di Nocera et al. (2006) found that there was a cost in response time associated with switching attention from one ROS to another. They had participants respond to whether a pair of stimuli either remained in the same ROS, meaning that each stimulus within the pair were both in the peripersonal ROS or both in the extrapersonal ROS, or whether a pair of stimuli switched from one ROS to the other, from either the peripersonal to extrapersonal ROS or from the extrapersonal to peripersonal ROS.

This experiment examined whether individuals differing in spatial strategy show differential costs in switching attention between regions of space. If individuals with a verbal-sequential strategy experienced a substantial cost in switching their attention between two regions of space, they may also experience a greater "cost" to switching between a route guidance system that uses 3D sound and their ability to direct their attention back into the car and respond to a collision warning system, for example. If there are any differences in how well GSD and PSD individuals perform, the results may warrant additional investigation of individual differences in using multiple systems operating in distinct regions of space such as a collision warning system and a route guidance system while driving, or synthetic displays such as augmented reality displays. Such findings would potentially warrant fully customizable in-vehicle technology that can be customized to an individual's capabilities and preferences. To take this example a step further, it is conceivable that an individual with a verbal-sequential strategy who experiences a significant cost to switching their attention from a route guidance system to a collision warning system may perform better with a route guidance system that does not utilize 3D sound in the spatial direction of the next navigation cue and rather emphasizes the semantics of the route guidance system, and may also benefit from a collision warning system that uses one master alarm instead of a CWS that utilizes 3D spatialized sound to allocate the individual's attention to the direction of the potential collision, as is advocated for in Cummings et al. (2007).

The current study used a similar arrangement to Di Nocera et al. (2006) but with speakers instead of lights. Speakers were arranged in a two by four matrix to be able to test whether participants experience a cost to switching their attention across regions of space compared to switching their attention within the same ROS. It was predicted that subjects with a GSD would experience less of a "cost" and would be more accurate and quicker at switching their attention across regions of space. Conversely, participants with a PSD would experience a greater cost to switching their attention between regions of space compared to switching their attention within the same ROS. This hypothesis is based on the vast history of individual differences in spatial strategy previously covered demonstrating PSD individuals' propensity to process spatial information using a verbal strategy and GSD individuals' tendency to use spatial information (Kato and Takeuchi, 2003; Garcia, et al. 2012, Furukawa, Baldwin, & Carpenter, 2004; Hegarty, et al., 2006; Baldwin, 2009; Barrow & Baldwin, 2009, 2010).

Experimental Design

A 2 (sense of direction) X 2 (same region or "Switch" condition) mixed design was used. A more detailed description of these conditions is included in the procedure section.

Methods

Participants

In all, 177 students (130 females, 49 males) were recruited via George Mason University's Sona System participant pool with a mean age of 21 years. Of the 177 participants tested, 44 GSD individuals and 80 PSD individuals (27 male and 17 female GSD, 14 male and 66 female PSD) were identified by scoring one standard deviation above or below the collective mean from the Sense of Direction Questionnaire (*M* = 2.75, *SD* = .75). Individual analyses may differ in the amount of participants included in the analysis by a few participants due to lost data on individual trials, participants not following instructions, or equipment malfunction. No participants over the age of 45 years were retained due to the fact that the tasks required auditory discrimination and hearing ability tends to diminish with aging.

Task

In this experiment, participants had to identify whether each stimuli occurred within the same ROS or in different regions of space. Specifically, participants had to respond to the location of each trial by pressing the button associated to a given speaker that the participant believed the sound came from. The buttons were laid out consistent to the location of each speaker. The buttons on the number pad corresponding with the speakers were 2, 3, 5, 6, 8, 9, /, and *, which corresponded to speakers A, B, C, D, E, F, G, and H, respectively. Speakers were arranged with 20 inches of separation forming a rectangle, as seen in Figure 5, so that the front four speakers were within arms distance (and thus in peripersonal space) and the back four speakers were out of reach (and thus is extrapersonal space). All participants sat in the same chair and were instructed on how far to move the chair in by the experimenter so that all participants sat in almost the exact same position.

A series of auditory stimuli were presented through the eight speakers, as seen in the schematic in Figure 5. The stimulus that was used was an auditory tone approximately 900 milliseconds in duration which contained a variety of frequencies. Eight blocks with 64 trials in each block were presented with a break after each block. The first block was only for training and familiarization purposes and was not included in any data analyses. Participants were instructed to respond immediately to each stimulus and the next stimulus was presented as soon as the participant responded or after 1200 milliseconds (ms) if there was no response within that time. Failure to respond within 1200 milliseconds was scored as an incorrect response. This procedure was mirrored after the procedure used by Di Nocera et al. (2006).

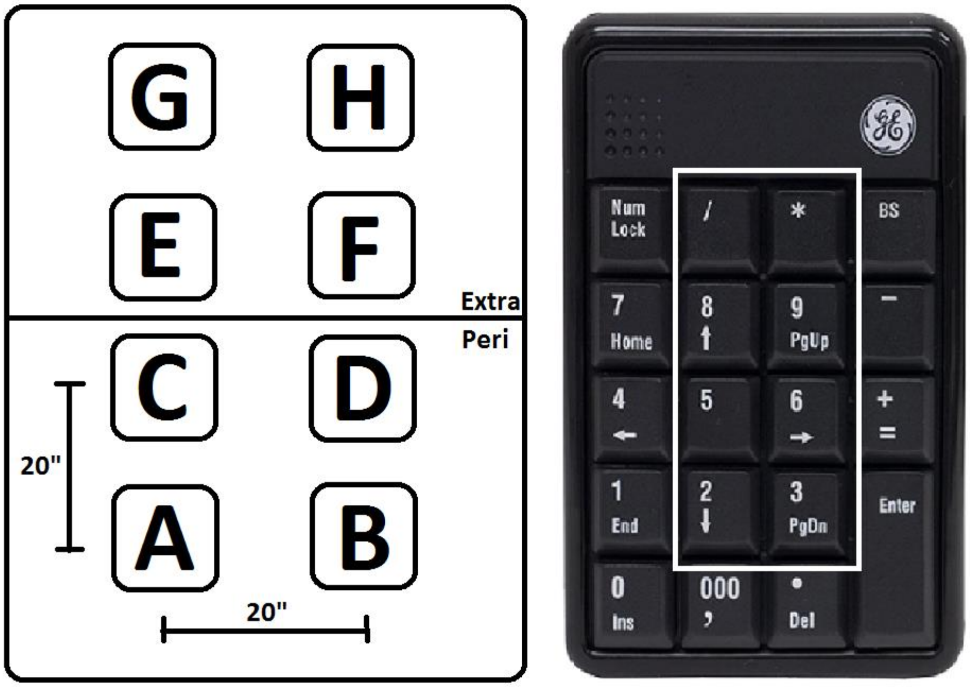

Figure 4- Schematic of speaker and response mechanism layout

Procedure

First, participants were administered an informed consent form and a demographics questionnaire. Next, participants completed the SDQ which was used to assess each person’s sense of direction and spatial strategy. Then, participants were instructed as to how to respond to the stimuli according to the response apparatus mentioned above in the task section. At the end of each block, participants were offered the opportunity to take a break. Once the experiment was completed, participants were debriefed as to the true purpose of the experiment.

Results

Trials with response times below 200 milliseconds and above 1,200 milliseconds were not included in any analyses. Any participant scoring below 50% accuracy was removed from all analyses as well. Failure to meet this level of performance may have been due to a combination of participants not following instructions or computer issues. Each analysis was presented and explained individually and then a logical synthesis of main research questions will be discussed. Specific conditions within an analysis will be referred to by a pair of letters in which the first letter of the pair is the prior stimulus and the 2nd letter of the pair is the subsequent stimulus. For example in the Pair E_C, response times (RTs) are for responding to a sound presented from C when the previous sound had been presented at E. The letter scheme can be seen in Figure 4 above. Table 1 below explains the computed variables used in this section. Note that of the 64 possible trial types, 32 were within the same ROS as the stimulus prior to it and 32 required switching attention across ROS, all of equal probability and completely randomized presentation.

Table 1- 2 (Region of Space or ROS: Across v. Within) by 2 (Side: Left v. Right) by 2 (Direction of Travel: Towards v. Away) by 2 (Sense of Direction or SOD: GSD v PSD)

ROS	Side	Direction	Speakers
Across	Left	Towards	E_C
		Away	C_E
	Right	Towards	F_D
		Away	D_F
Within	Left	Towards	(G_E + C_A)/2
		Away	(A_C + E_G)/2
	Right	Towards	(H_F + D_B)/2
		Away	(B_D + F_H)/2

Switching Between Regions

Of most interest to this dissertation is how participants performed when two consecutive stimuli cross from near to far or far to near space, compared to when consecutive stimuli appeared in the same ROS. This analysis compared stimuli that were moving towards the participant or going away from the participant and stayed within the same region of space or crossed the boundary between ROS. There was a significant multivariate interaction effect for ROS by direction, F (2, 74) = 4.331, $p < .05$, $\eta^2 = .105$. Specifically, the univariate analysis of response time revealed a significant interaction between direction and ROS, F (1, 75) = 7.345, $p < .05$, $\eta^2 = .089$. When two stimuli were presented consecutively within the same ROS, participants responded faster when the stimuli were coming towards them (*M* = .839, *SE* = .013) relative to going away from them (*M* = .872, *SE* = .012). However, when stimuli crossed ROS there was no difference between whether the stimuli seemed to be coming toward or away from the participant (*M* = .859, *SE* = .013) relative to going away from the participant (*M* = .863, *SE* = .013). It should be noted that this pattern of RTs did not come in the form of a trade off in accuracy. Though no significant differences in accuracy was found, [F (1, 75) = .444, ns] the pattern indicated that people did not sacrifice accuracy for speed. They were just as accurate when detecting sounds coming towards them within the same ROS (*M* = .70, *SE* = .017) relative to away within the same ROS (*M* = .557, *SE* = .025) and relative to accuracy for sounds traveling across ROS for towards (*M* = .692, *SE* = .03) and (*M* = .526, *SE* = .031) away. In sum, participants responded significantly faster without a loss of accuracy when responding to stimuli that seemed to be moving towards them compared to moving away from them; but, only when this direction of travel was presented within the same ROS.

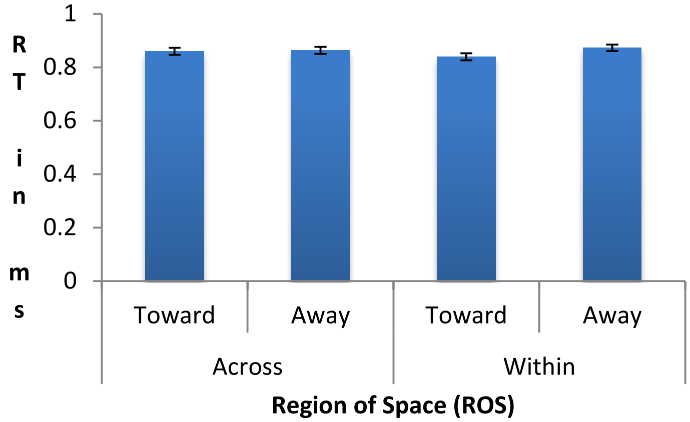

Figure 5- RT for Direction by ROS

Coming Towards versus Moving Away

It is worth pointing out the difference between consecutive stimuli when they were perceived as coming towards or away from the participant. There was a significant multivariate effect for direction, F (2, 74) = 59.422, $p < .05$, $\eta^2 = .616$. Specifically, participants responded faster to stimuli that were coming towards them (M = .849, SE = .012) than stimuli that were going away from them (M = .867, SE = .012), F (1, 75) = 14.195, $p < .05$, $\eta^2 = .159$, as seen in Figure 6 below, as well as more accurately to stimuli that were coming towards them (M = .696, SE = .021) relative to stimuli that were going away from them (M = .541, SE = .025), F (1, 75) = 95.337, $p < .05$, $\eta^2 = .560$, as seen in Figure 7 below. Though note that this main effect is primarily due to the interaction with direction of travel discussed previously.

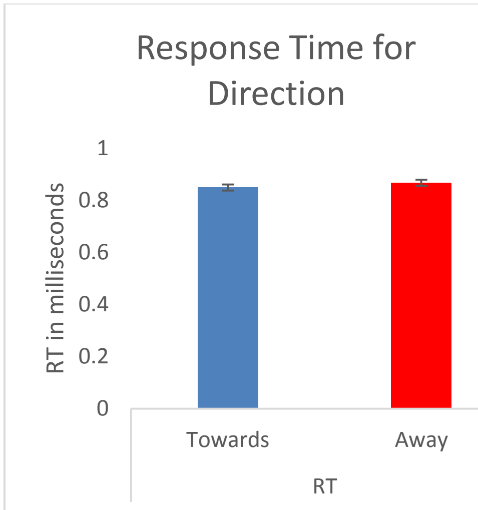

Figure 6- RT in ms for Direction

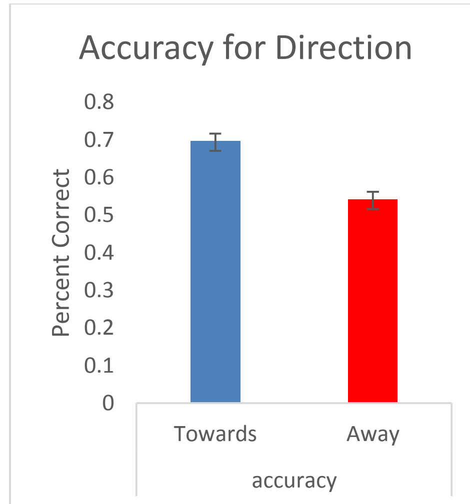

Figure 7- Accuracy for Direction

There was a significant multivariate interaction for Direction by SOD, F (2, 74) = 4.254, $p < .05$, $\eta^2 = .103$. Specifically as illustrated in Figure 8 below, participants with a PSD responded significantly faster to stimuli coming towards them (M = .844, SE = .016) relative to stimuli going away from them (M = .875, SE = .015), F (1, 75) = 6.841, $p < .05$, $\eta^2 = .084$, whereas those with a GSD did not significantly differ in their response time for stimuli that are moving towards (M = .854, SE = .019) them and moving away (M = .859, SE = .019). Although not significant, GSD individuals (M = .844, SE = .016) were nominally faster than PSD individuals (M = .854, SE = .019) when the stimuli were coming towards the participant.

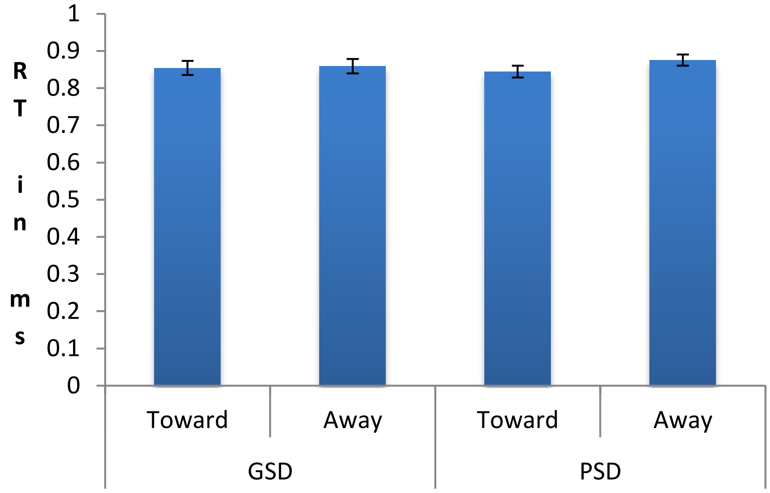

Figure 8- RT for Direction of Stimulus by SOD

Left vs Right Side Speakers

A substantial body of research demonstrating a Right Ear Advantage (REA) for auditory stimuli has been amassed over the last several decades (Hiscock & Kinsbourne, 2011; Saetrevik, 2012; Jerger & Martin, 2004; Mcfadden, 1993; Mcfadden & Mishra, 1993). Using dichotic listening tasks, research suggests a greater sensitivity for auditory speech perception for the right ear (Mcfadden, 1993; McFadden & Mishra, 1993) and is heavily influenced by attention and the localization of the source of the stimulus (Hiscock & Kinsbourne, 2011). This is due to the contralaterality of speech processing with the left hemisphere of the brain (Hiscock & Kinsbourne, 2011; Jerger & Martin, 2004). For this reason, a comparison of left side and right side performance was necessary.

When comparing the left and right side, there was a significant multivariate effect for side, F (2, 74) = 26.054, $p < .05$, $\eta^2 = .413$. Specifically, participants were significantly more accurate at responding to the right side ($M = .68$, $SE = .023$) than the left side (*M* = .558, *SE* = .024), [F (1, 76) = 52.507, $p < .05$, $\eta^2 = .412$]. These results are consistent with previous findings of a REA, as research previously mentioned.

Discussion

Experiment 1 was designed to investigate whether individuals with a PSD experience a greater cost to switching their attention between two stimuli occurring in distinct ROS relative to switching their attention in the same ROS. This experiment extends the results of Di Nocera et al. (2006) by investigating whether differential switching costs occur in the auditory modality and whether they are affected by individual differences in spatial strategy. Di Nocera et al. (2006) found that there was a cost in response time associated with switching attention from one ROS to another. The current study used a similar arrangement to Di Nocera et al. (2006) but used sounds presented from speakers instead of lights. Speakers were arranged in a two by four matrix spatially designed to be able to test whether participants experience a cost to switching their attention across ROS compared to switching their attention within the same ROS.

It was predicted that subjects with a GSD would experience less of a “cost” and would be more accurate and quicker at switching their attention across regions of space. Conversely, participants with a PSD were expected to experience a greater cost to switching their attention between ROS compared to switching their attention within the same ROS. In general, the results provided preliminary evidence in support of greater performance as a function of ROS in the auditory modality, given that participants in general responded significantly faster when the stimuli were moving towards them within a given ROS, but this finding was not prevalent when the stimuli crossed ROS. Results also suggest that individuals may differ in their ability to attend to stimuli as a function of direction of travel. Specifically, participants responded significantly faster when responding to stimuli that seem to be moving towards them, and participants with a PSD responded significantly faster to stimuli coming towards them relative to stimuli going away from them, whereas those with a GSD responded equally well whether the stimuli was coming towards or moving away. Participants were also more accurate at responding to stimuli on the right side compared to their performance on the left side, consistent with prior research on the Right-Ear Advantage (REA). Each of these results will now be covered in greater detail.

There was a significant multivariate effect for ROS by Direction. Specifically, there was a significant interaction between Direction and ROS on response time. Participants responded significantly faster when responding to stimuli that seemed to be moving towards them compared to moving away from them, but only when this direction of travel was presented within the same ROS. In general, participants may respond faster to stimuli that appear to be coming towards them because humans may have an evolved self-defense mechanism that may allow one to respond quicker as a reaction to things coming towards us versus the perception of things going away from us appearing harmless. However, this defense mechanism may be less effective when objects cross ROS.

There was a significant multivariate effect for Direction, in that, overall, participants responded faster to stimuli that were coming towards them relative to stimuli that were going away from the participant. Participants were also more accurate when responding to stimuli that were coming towards them relative to stimuli that were going away from them. Furthermore, there was a significant interaction between Direction and SOD. Specifically, participants with a GSD were less impacted by whether or not the stimuli were traveling toward or away from them, relative to those participants with a PSD. Participants with a PSD responded significantly faster when the stimuli were coming toward them versus away from them. These findings are consistent with literature on looming auditory warnings in that collision warnings that sound like they are coming towards the listener elicited faster response times and more accurate responses to rear-end collision warnings (Gray, 2011; Canzoneri, Magosso, & Serino, 2012).

The interaction between the perceived direction a stimulus is traveling and individual differences in SOD is of great importance. One potential reason for this finding is that PSD individuals may perform better than GSD individuals when the stimulus appears to be coming towards the participant but those with a GSD may respond quicker when unassisted by any self-defense mechanisms, i.e. when stimuli appear to be moving away or sideways. GSD individuals tend to use visuospatial working memory to process spatial information and use a geocentric frame of reference whereas PSD individuals use verbal working memory to process spatial information and use an egocentric frame of reference. For this reason, GSD individuals performed the same regardless of which direction the stimuli was moving whereas PSD individuals, because of their tendency to use an egocentric frame of reference, performed better when the stimuli were moving towards them relative to moving away from them. From a fight-or-flight perspective, sounds that appear to be closing in on a person may elicit an enhanced reaction compared to auditory stimuli that are going away from the participant, all else held constant. For PSD individuals, this fight-or-flight ability may only be prevalent when stimuli are moving towards the individual and not when moving away.

Concerning an effect for right side versus left side, results provide evidence of a right-side advantage in that participants were significantly more accurate at responding to stimuli that came from the right side. This finding is consistent with a body of research consistently finding a phenomenon known as the REA (Hiscock & Kinsbourne, 2011; Saetrevik, 2012; Jerger & Martin, 2004; Mcfadden, 1993; Mcfadden & Mishra, 1993). Previous researchers using dichotic listening tasks have found greater sensitivity for speech stimuli presented to the right ear (Mcfadden, 1993; McFadden & Mishra, 1993) and it is heavily influenced by attention and the localization of the source of the stimulus (Hiscock & Kinsbourne, 2011). This is due to the contralaterality of speech processing dominated by activation of the left hemisphere of the brain and the fact that stimuli presented to the right ear goes directly to the left hemisphere (Hiscock & Kinsbourne, 2011; Jerger & Martin, 2004). The dichotic nature of the task is thought to suppress ipsilateral connections. Although the stimuli in this experiment were not speech based, the attention requirements of this task lend itself to expectations consistent with REA research. It is also possible that the superior performance for the right side versus the left may be due to stimulus response compatibility. An overwhelming majority of participants used their right hand to respond to all stimuli. Stimulus-response compatibility indicates that people are faster to respond to something on the right side with their right hand versus responding to something on their left side or with their right hand. Future studies should potentially counterbalance the hand that is used to respond to stimuli or use a more spatially appropriate response mechanism with buttons on the left and right side to respond to stimuli on the left and right sides, respectively.

The main purpose of this experiment was to examine if in fact individuals differ in their ability to switch their attention between near and far ROS compared to switching attention between two things in the same ROS, as a function of spatial strategy. For the most part, our experiment showed mixed findings in support of this hypothesis. To this end, there are a few potential explanations as to why we were unable to observe individual differences in switching costs. First, contrary to our hypotheses, they may not exist. Alternatively, many previous studies have used a secondary task to place greater demand on processing resources thus making any potential individual differences more likely to be manifest. For example, Baldwin & Reagan (2009) used a concurrent verbal task (articulatory suppression) or a visuospatial tapping task, similar to Garden, et al (2002) while participants were trying to learn routes in a navigation task. They found that those with a PSD experienced more difficulty while having to perform the concurrent verbal task, suggesting an interference with their verbal working memory. Conversely, those with a GSD experienced more interference while attempting to learn a route while performing a concurrent visuospatial tapping task. This suggests that the two tasks, their strategy for navigation as well as the tapping task, were both fighting for visuospatial working memory resources at the same time.

Another perspective in which this paradigm should be investigated is to investigate the modality used to present the stimuli in the experiment. The current experiment used the auditory modality while Di Nocera et al.'s (2006) experiment used the visual modality in which two distinct functional regions of space were shown to exist. Most other studies have used the sense of sight (Ladavas et al., 1998) and touch (Ladavas et l., 1998b). To date, few if any other investigations on regions of space have used the auditory modality. It is possible that the visual modality may operate with two discrete regions of space whereas the auditory modality may use a more linear and continuous way of representing space and encoding attention within three-dimensional space. However, at least partial support was found for the distinction between responding to sounds within and across ROS. Specifically, analysis of RT indicated that participants were less influenced by the direction of travel when stimuli were traveling across relative to within ROS. This finding could not be attributed to a tradeoff in decreased accuracy. Participants were equally accurate, with a slight but not significant trend to also be more accurate when stimuli were traveling towards them within the same ROS. Further research should be performed to better understand whether distinct functional regions of space are a modality specific phenomenon or whether it also exists within the auditory and olfactory modalities and whether there are any multimodal interactions.

An evolutionary explanation of this hypothesis may lend it more credibility. It is possible that humans may have evolved to interact with 3 dimensional space in two general regions for the visual modality, but for the auditory modality humans may have evolved to perceive auditory stimuli in a linear or continuous way. A stimulus moving towards a person may have evolved quicker response for defense purposes as it is likely to elicit a faster motor response in order to avoid any harm. This response has evolved in us as a defense mechanism to threats that may harm us in everyday life.

Another appropriate follow up study to this experiment would be to use a unique auditory tone for each of the 8 speaker locations. Sufficient training would be needed to ensure that participants learn each unique tone associated to each speaker. This would rule out the possibility that an error was due to misunderstanding which speaker a stimulus originated from. Then, once participants have effectively learned the sounds that are uniquely associated to each speaker, if there are any subsequent differences in response time, they should not be at the expense of accuracy or variations in the sound, i.e., the sounds would be unique to each speaker but should not include any features within the sound so as to offer a competitive advantage over another sound.

A potential shortcoming of this study is the type of auditory stimuli that were used. The sound, as previously mentioned, was a generic complex tone and did not include any semantic information. Experiment 2 addressed this issue by looking at individual differences to attend to either location or semantic spatial information in an auditory-spatial Stroop experiment. In the current investigation there was also a substantial imbalance in the amount of males and females per condition. Research shows that males and females may differ in their spatial and navigation abilities (Saucier, et al., 2003). In our groups, there were substantially more males in our GSD group and substantially more females in our PSD group. Future research should investigate gender differences in ability to switch attention across regions of space.

EXPERIMENT TWO

The purpose of this experiment was to examine potential individual differences in how people interact with near and far regions of space as a function of spatial strategy. Barrow and Baldwin (2014) demonstrated individual differences in the ability to attend to the spatial or semantic information of an auditory cue as a function of SOD. For this experiment, an attempt was made to replicate and extend the findings of Barrow and Baldwin (2014) across distinct regions of space to assess whether there are in fact individual differences in near and far spatial interaction as a function of spatial strategy. An experiment utilizing an auditory-spatial Stroop paradigm, similar to Barrow and Baldwin (2014) was created to assess whether individuals differ in their ability to attend to spatial or semantic information in various regions of space based on their spatial strategy.

Methods

Experimental Design

In this experiment, participants performed two tasks in a mixed repeated measures design with task type (semantic or location) and congruency (congruent or incongruent) as within-subjects variables and sense of direction (SOD: GSD and PSD) as a between-subjects grouping variables. Dependent measures were speed (response time) and accuracy.

Participants

181 participants were recruited via George Mason University's Sona-System participant pool. The number of participants needed was determined by a power analysis for an A priori repeated measures mixed within-between design using an effect size f=.15, α=.05, power=.85, groups=2, and number of measurements = 3. Each participant performed the experiment individually. No participant over the age of 45 was retained due to the fact that the incidence of elevated hearing thresholds increases with age.

The Kato and Takeuchi (2003) Sense of Direction Questionnaire (SDQ) is a 17 item questionnaire used to measures one's subjective sense of direction. Groups were created based on their spatial strategy using the same standards used in Experiment 1 to identify GSD and PSD individuals from the SDQ (one standard deviation above or below the mean). The data for 52 PSD and 32 GSD participants was used for the analysis on accuracy and, due to data collection errors, the data for 18 GSD and 26 PSD participants (16 GSD males, 2 GSD females, 4 PSD males, and 22 PSD females) was used for the analysis on response time, with a mean age of 22.71 (34 males and 50 females).

Stimuli

Audacity® sound editing and recording software was used to equate all stimuli for loudness to 70 dB. A sound level meter was used to measure the loudness of the recordings and the gain of each recording will be adjusted so that the recording plays at 70 dB. A recording of the words "near" and "far" were created using these parameters. The stimuli were strategically presented from either of the two speakers depending on the trial and condition. The strategic method of stimulus presentation will now be discussed in the task section.

Tasks

A modified version of the Auditory Spatial Stroop task was used. In this experiment, a speaker was physically placed in extrapersonal space 48 inches in front of the participant, and another speaker was placed in peripersonal space 12 inches in front of the participant. Participants performed both a semantic and location task in a fully counterbalanced design. In the semantic task, participants were instructed to respond to the semantic information of the auditory stimuli, pressing the down arrow when they heard the word “near” and pressing the up arrow on the D-pad of the keyboard when they heard the word “far”, regardless of the location of the stimuli. In the Location task, consistent with Barrow and Baldwin (2013), participants were instructed to respond to the location of the stimuli while attempting to ignore the semantic information of the stimuli. That is, participants were instructed to press the down arrow indicating when the auditory stimuli sounds like it originated in the peripersonal ROS, or pressing the up arrow when the auditory stimuli is presented from the far speaker, regardless of whether the auditory stimuli said “near” or “far”.

Procedure

First, participants were administered an informed consent form and a demographics questionnaire. Next, participants completed the SDQ which was used to assess each person’s sense of direction. Next, each participant was briefed and trained on the first experimental condition. At the end of each block, participants were offered the opportunity to take a break. Next, the participant was briefed and trained for the second experimental condition. There were two blocks of each condition with 54 trials in each block. Participants were able to respond immediately after the stimulus was presented. The next stimulus was played as soon as a response was recorded for the previous stimulus. If a participant did not respond within 5 seconds, an incorrect response was recorded and the next stimulus was presented. Semantic and Location conditions were counterbalanced to account for order effect. Last, participants were debriefed and told the true purpose of the experiment.

Results

Data were analyzed in separate 2 (task-type: Semantic and Location) by 2 (congruency: congruent and incongruent) by 2 (Sense of Direction: GSD and PSD) mixed design repeated measures ANOVAs for the dependent measures response time and accuracy. Results of the ANOVA for accuracy are discussed first.

Accuracy

The dependent measure accuracy, revealed no significant effects. There was no significant main effect for task, no task by SOD interaction, no congruency effect, no congruency by SOD interaction, no task by congruency interaction, and no task by congruency by SOD interaction. Specifically, there was no main effect for congruent versus incongruent trials and no interaction. There was also no effect for SOD. These results are potentially due to a ceiling effect in that all participants performed extremely well in all conditions. Split by SOD, participants performed no worse than 93.6% in any condition. Table 2 below shows the results of accuracy of each task split by sense of direction.

Table 2- Task Accuracy by Sense of Direction

Accuracy of Tasks by SOD

	Awareness of Orientation	Mean	Standard Deviation
Semantic Congruent Accuracy	GSD	0.95	0.041
	PSD	0.93	0.091
Semantic Incongruent Accuracy	GSD	0.96	0.035
	PSD	0.94	0.096
Location Congruent accuracy	GSD	0.94	0.063
	PSD	0.94	0.084
Location Incongruent Accuracy	GSD	0.95	0.047
	PSD	0.93	0.101

<u>Response Time</u>

Regarding response time, there was a significant main effect for congruency, F (1, 44) = 50.382, $p < .05$, in that, participants were about 180 ms faster on congruent trials (M =391.413 ms, SE = 35.351) than incongruent trials (M = 571.389 ms, SE = 32.604). This provides evidence of an intact Stroop effect and a manipulation check. There was no significant main effect for task, no significant interaction for task by awareness of orientation, congruency by awareness of orientation, task by congruency, and task by congruency by awareness of orientation. Participants were marginally faster at semantic trials than location trials, but not to a significant extent. As with the accuracy results above, it is likely that the experiment failed to reveal significant effects due to a ceiling effect, where all participants performed extremely well in all conditions.

Discussion

It was predicted that, consistent with the results of Barrow and Baldwin (2014), participants would generally respond quicker and/or more accurately in the semantic task condition than in the location condition. Of most interest, it was predicted that individuals would differ by SOD in that, those with a GSD would perform better (faster and more accurate) when responding to the location of the stimuli whereas those with a PSD would perform better when responding to the semantic task. If PSD individuals experienced more difficulty attending to the spatial information in distinct ROS, this would have provided further support for previous notions of individual differences in spatial strategy extended specifically to how we interact with near and far space.

The results of Experiment 2 failed to provide any evidence of individual differences in one's ability to attend to semantic or location information across spatial frames of reference based on one's SOD. There are several reasons why this may be. It is possible that individual differences simply do not exist. It is believed that the lack of evidence in support of our hypothesis may be due to a ceiling effect in that all participants performed extremely well on all tasks in Experiment 2, regardless of SOD. In hindsight, a secondary task that occupies specific cognitive resources may have provided additional difficulty to increase sensitivity and observe larger differences between SOD groups. It is predicted that a replication of this experiment with the use of a secondary task (e.g., similar to Barrow and Baldwin, in press) would be more sensitive to identifying individual differences in one’s ability to attend to semantic or location information.

The significant effect of congruency supports an in-tact auditory-spatial Stroop paradigm in that participants performed better on congruent trials than incongruent trials, regardless of task type. A higher fidelity arrangement may also be more sensitive to identifying individual differences in this experiment and the results of a higher fidelity arrangement may have better external validity.

GENERAL DISCUSSION

The purpose of this dissertation was to advance our understanding of how humans switch their attention across regions of space to stimuli in the auditory modality, and specifically how individuals may differ in this respect. Humans generally interact within at least two general regions of 3D space. These are peripersonal (near) space, and extrapersonal (far) space. Two studies were conducted to investigate the potential for individual differences in spatial strategy – notably, sense of direction – to impact human interaction with distinct functional regions of space. Prior research indicates that differences in spatial strategy and navigation strategies impact performance in a wide variety of spatial tasks (Chen, 2010; Chen & Barnes, 2011; Baldwin & Reagan, 2009). Specifically, visuospatial strategy individuals tend to have a GSD and can more efficiently use their visual-spatial working memory (Baldwin & Reagan, 2009) during the performance of spatial tasks. Conversely, those with a verbal-sequential strategy tend to have a PSD and generally utilize verbal working memory to process spatial information. Based on these observations we reasoned that individuals with a GSD versus a PSD might differ in their ability to perform tasks that crossed between peripersonal and extrapersonal regions of space (Baldwin & Reagan, 2009).

More specifically, prior research in the visual domain indicates that switching attention from one stimulus to another in distinct regions of space is more difficult than switching attention between two stimuli within the same functional ROS (Di Nocera, Couyoumdjian, & Ferlazzo, 2006). In the auditory realm, Brungart and colleagues (Brungart & Rabinowitz, 1999; Brungart, Durlach, & Rabinowitz, 1999; Brungart & Scott, 2001; Brungart, 2002) noticed a difference in near- and far-field auditory localization. They defined near-field as anything within 1 meter of the individual, which is essentially the same boundary proposed by Previc (1998) of arms-distance as a boundary between near and far space. They noticed that head related transfer functions (HRTFs) for near space required far more precision to be accurate compared to auditory localization HRTFs used for distances beyond 1m. Brungart and colleagues also noted that individuals were better able to distinguish between multiple auditory sources when they took place in distinct regions as opposed to coming from the same region. This finding could potentially allude to the existence of distinct pools of cognitive resources as a function of regions of space.

Based on the results from previous research investigating individual differences in spatial strategy, it was predicted that those with a PSD would experience more difficulty in switching their attention between distinct regions of space whereas those with GSD would be more fluid in their ability to switch their attention between distinct regions of space. This was examined in the first experiment.

In general, results of this experiment provide preliminary evidence in support of superior performance when processing information within the same ROS, relative to when stimuli cross ROS in the auditory modality. Specifically, participants in general responded significantly faster when the stimulus was moving towards them within a given ROS, but this finding was not present when the stimuli crossed ROS. Results also suggest that individuals may differ in their ability to attend to stimuli as a function of direction of travel. Specifically, participants responded significantly faster when responding to stimuli that seem to be moving towards them, and participants with a PSD responded significantly faster to stimuli coming towards them relative to stimuli going away from them, whereas those with a GSD did not significantly differ in their response time the stimuli was coming towards or moving away. These findings are consistent with literature on looming auditory warnings in that collision warnings that sound like they are coming towards you elicit faster response times and more accurate responses to rear-end collision warnings (Gray, 2011; Canzoneri, Magosso, & Serino, 2012).

For designers of complex and multimodal systems and displays, the findings of this dissertation also suggest that distinct regions of space also exist in the auditory modality. For example, designers of forward-collision warning systems need to carefully design them so as not to hinder performance in perceiving the true meaning of the collision warning. Canzoneri et al. (2012) found an interaction between the tactile modality and auditory stimuli within peripersonal space. Further research is warranted on how multimodal displays may interact between regions as well. Furthermore, concerning our findings on individual differences, the implications are twofold. First, display designers must carefully design their systems so as to take every consumer or user's capabilities into account. In settings where the users can be selected such as military settings, personnel selection practices may be warranted. Selection of individuals with a GSD may be warranted so as to maximize performance potential and reduce accident and error potential on tasks that require interaction across regions of space, particularly with dynamic moving stimuli.

It is possible that humans may have evolved to interact with 3 dimensional space in two general regions for the visual modality, but for the auditory modality humans may have evolved to perceive auditory stimuli in a linear or continuous way. A stimulus moving towards a person may have an evolved quicker response for defense purposes as it is likely to elicit a faster motor response in order to avoid any harm. This response has evolved in us as a defense mechanism to threats that may harm us in everyday life.

Concerning an effect for right side versus left side, results provide evidence of a right-side advantage in that participants were significantly more accurate at responding to stimuli that came from the right side. This finding is consistent with a body of research consistently finding a phenomenon known as the REA (Hiscock & Kinsbourne, 2011; Saetrevik, 2012; Jerger & Martin, 2004; Mcfadden, 1993; Mcfadden & Mishra, 1993). Previous researchers using dichotic listening tasks have found greater sensitivity for speech stimuli presented to the right ear (Mcfadden, 1993; McFadden & Mishra, 1993) and it is heavily influenced by attention and the localization of the source of the stimulus (Hiscock & Kinsbourne, 2011). However, as previously noted the same pattern of results may be explained by stimulus-response compatibility since most participants were responding with their right hand.

In Experiment 2, participants performed an auditory spatial Stroop task across ROS. Barrow and Baldwin (in press) conducted an experiment investigating individual differences in participant's ability to attend to the semantics or location of a particular stimulus. The second experiment here extends Barrow and Baldwin's (in press) experiment across regions of space. The goal of this experiment was to assess whether individuals with a GSD were better at attending to the location of the stimuli whereas those with a PSD were better at attending to the semantics of a given stimuli, a hypothesis consistent with the findings of Barrow and Baldwin (in press). The experiment at hand failed to find a significant difference based on sense of direction. One main difference between our experiment and Barrow and Baldwin's was their use of a secondary task. Participants in the current experiment performed between 93% and 96% in all tasks, regardless of sense of direction or task, and thus may have performed at ceiling. A follow up experiment should utilize a secondary task strategically chosen for the types of resources needed to perform the secondary task and strategically paired with the semantic and location tasks, similar to Reagan and Baldwin (2009). A strategically chosen secondary task may also highlight the requirement of a specific spatial strategy to most effectively switch one's attention across regions of space. Specifically, if spatial-attention cognitive resources are required to effectively allocate one's attention across regions of space, but those resources are occupied with another spatial task, this hypothetical finding could further support the notion of individual differences as a function of spatial strategy and further inform display design practitioners to carefully design systems with minimal spatial-attention interfering stimuli.

Should follow up studies find evidence supporting individual differences in one's ability to switch his or her attention across regions of space, display designers may have to take individual differences into account. For example, there may be a need to allow the capability to customize displays to offer spatial information in systems such as collision warning systems or route guidance systems that can be set based on an individual's spatial strategy. These findings may also help with training or personnel selection in military or medical settings to select individuals with a visuospatial strategy or to be able to customize training for those with a verbal-sequential strategy (Chen, 2010). For example, it may be beneficial to select individuals with a GSD as remotely piloted vehicle operators due to the tasks' requirements to switch ones attention between controls located in near space and the action taking place in far space. A similar recommendation can also be applied to personnel selection for robotic surgery in that visuospatial strategy surgeons can be screened for, and physicians with a verbal-sequential strategy can be informed of their strategy and recommended to perform surgeries in a traditional fashion.

Also, the properties of the stimuli may have an impact on one's ability to switch attention between regions of space, and may affect individuals differently based on their SOD. For example, whether a particular stimulus is moving within the same region or is crossing from near to far or far to near regions of space may have an impact on one's ability to attend to that cue, depending on the location of what they were attending to before. Additional investigation will also be necessary to investigate the effects of cross-modal, cross-regional of spatial interaction. That is, does the modality of the stimuli affect one's ability to attend to it, based on whether the previous stimuli were of the same or a different modality in the same or different ROS? Investigations using a more applied context such as driving, surgery simulation, or UAV training and simulation may also be necessary.

The studies conducted in this dissertation provide a framework for future studies on how individuals switch their attention across ROS in the auditory modality. Although the results of Experiment 2 are inconclusive, the results of Experiment 1 provide preliminary evidence in support of greater performance when two stimuli are presented within the same ROS in the auditory modality. Participants in general responded significantly faster when the stimuli were moving towards them within a given ROS, but this finding was not observed when the stimuli crossed ROS. Results also suggest that individuals may differ in their ability to attend to stimuli as a function of direction of travel. Specifically, participants responded significantly faster when responding to stimuli that seem to be moving towards them, and participants with a PSD responded significantly faster to stimuli coming towards them relative to stimuli going away from them, whereas those with a GSD responded equally well whether the stimuli was coming towards or moving away. Participants were also more accurate at responding to stimuli on the right side compared to their performance on the left side, consistent with prior research on the Right-Ear Advantage (REA). Although the results of this dissertation are mixed, a few of the results of Experiment 1 suggest further studies are warranted to better understand when and how individuals may differ in how they switch their attention between and within ROS.

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APPENDIX

Kato & Takeuchi (2003) Sense of Direction Questionnaire (SDQ)

	St.Diss.	Diss.	Neutr.	Agree	StrAgr.
1. I can make correct choices as to cardinal directions in an unfamiliar place.	1	2	3	4	5
2. I have become confused, as to cardinal directions, when I am in an unfamiliar place.	1	2	3	4	5
3. I have difficulties identifying the moving direction of a train with regard to cardinal direction.	1	2	3	4	5
4. When I get route information, I can make use of ‘‘left or right’’ information, but I can’t use cardinal directions.	1	2	3	4	5
5. I can’t make out which direction my room in a hotel faces.	1	2	3	4	5
6. I can tell where I am on a map.	1	2	3	4	5
7. I can visualize the route as a map-like image.	1	2	3	4	5
8. I feel anxious about my walking direction in an unfamiliar area.	1	2	3	4	5
9. I have poor memory for landmarks.	1	2	3	4	5
10. I cannot remember landmarks found in the area where I have often been.	1	2	3	4	5
11. I can’t use landmarks in wayfinding.	1	2	3	4	5
12. I can’t remember the different aspects of sceneries.	1	2	3	4	5
13. I often can’t find the way even if given detailed verbal information on the route.	1	2	3	4	5
14. I have a lot of difficulties reaching the unknown place even after looking at a map.	1	2	3	4	5
15. I often (or easily) forget which direction I turned.	1	2	3	4	5
16. I become totally confused as to the correct sequence of the return way as a consequence of a number of left-right turns in the route.	1	2	3	4	5
17. I can’t verify landmarks in a turn of the route.	1	2	3	4	5

BIOGRAPHY

Andre Javier Garcia graduated from Miami Palmetto Senior High School in Miami, Florida, in 2004. He received his Bachelor of Arts from the University of Central Florida in 2008 and his Masters of Arts from George Mason University in 2010. He was employed by the US Department of Commerce, the Air Force Research Lab, and the Naval Sea Systems Command. He is now a Human Factors Engineer at the Northrop Grumman Corporation in Melbourne, Florida, upon completion of his doctoral degree. He was born in Mayaguez, Puerto Rico, and grew up in Miami, Florida.