BEHAVIORAL AND NEUROLOGICAL STUDIES IN TACTILE MAP USE AND TRAINING BY PERSONS WHO ARE BLIND OR VISUALLY IMPAIRED

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This research investigates the relationship between map use tasks, spatial abilities and training-based effects in persons who are blind or visually impaired. A mixed-method approach using theories and methods in behavioral geography, tactile cartography and functional magnetic resonance imaging have produced finds that identify both behaviorally-based as well as biologically-based impacts resulting from systematic tactile map use and spatial thinking training. The neurological results indicate that prior to training a dominant egocentric/route strategy is used to answer all experimental map tasks, while after training an allocentric/survey strategy is used. The current study demonstrates that the adoption of an allocentric perspective is coupled with improved behavioral performance. The findings provide supporting evidence that people who are blind are capable of learning and applying sophisticated spatial strategies. The systematic progression from egocentric/route processing to allocentric/survey processing in the participant population follows traditional developmental models of spatial knowledge.

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This dissertation is dedicated to my loving parents Doug and Mary Lawrence.

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CHAPTER I

INTRODUCTION

People who are blind and visually impaired are faced with unique challenges surrounding independent travel and mobility. The lack of sight, a highly efficient and effective channel for inputting environmental spatial data, makes travel by people who are blind or visually impaired more difficult. Tactile maps have the ability to significantly aid travel through the real-world environment by presenting an abundance of environmental information in one setting. Reading a tactile map by a person who is blind requires the use of the haptic modality (or dynamic touch) and can be more time consuming and is sometimes more complicated than reading a map with the use of vision (Spencer, Morsley, Ungar, Pike & Blades, 1992; Ungar, Blades & Spencer, 1997a). Fortunately, tactile map use is a research area that is rapidly advancing, producing research regarding tactile map design and empirical research results addressing the perceptual and cognitive processes used during map reading (Ungar, 2000; Golledge, 1992; Kitchin, Blades & Golledge, 1997). This dissertation continues the advancement of tactile map research, but focuses on a new area, training effects and its neurological/behavioral impacts and influences.

Nearly everyone is impacted in a very direct way by access to effective education, educational materials, and access to the built environment. While researchers are beginning to understand spatial tasks, map tasks, and spatial thinking (Lobben 2007, 2004; Golledge, March & Battersby, 2006; National Research Council, 2006), gaps persist. Most significantly, researchers have not successfully identified how different populations engage in map use, spatial ability, and spatial thinking. Moreover, we know little about the extent to which pedagogic tools designed to enhance these skills actually impact post-training/educational performance, nor about the cognitive process that are instrumental in spatial thinking by people who are blind and visually impaired engaging in environmental-map interactions (Lawrence & Lobben, 2006).

Past research has focused on tactile map use from a psychophysical-based (Heath 1958; Jehoel, McCallum, Rowell & Ungar, 2006; Lawrence & Lobben, in review), a cognition and performance-based (Ungar, Blades & Spencer. 1995a; Kitchin & Jacobson 1997; Espinosa, Ungar, Orchaita & Blades, 1998; Golledge, Klatzky & Loomis 1996), and a training-based approach (Ungar, Blades & Spencer 1995b; Thinus-Blanc & Gaunet 1997; Ungar, Blades & Spencer 1997b). But, these methods have not yet been integrated. It is the assertion here that a mixed methodological approach will provide a more holistic measure not only of spatial and map use tasks, but also on the effects of training. This dissertation brings together concepts, theories, and experimental design approaches of behavioral geography, tactile cartography, and functional Magnetic Resonance Imaging. The experimental design will illustrate how the methods from these fields can be integrated to provide a cross-disciplinary methodological approach.

Studying spatial cognition and learning has been a notoriously difficult process given that our behavioral methods have been limited to reaction times, performance, and talk aloud protocols. But with modern brain imaging techniques such as functional magnetic resonance imaging (fMRI) we have the ability to uncover the neural underpinnings for complex cognitive map reading tasks. Functional MRI may reveal strategies employed while engaged in map reading activities, and differences in neurological activity after training occurs. Traditional behavioral measures can be used in conjunction with neuroimaging results to provide evidence for how strategy use affects performance. The following research questions are proposed.

> **#1**. Are there significant brain activation *differences/similarities* between two survey and two route style tactile map task questions?
>
> **#2**. What is the extent to which training protocol affects neurological activity during performance on the same survey/route style tactile map use tasks in research question #1?
>
> **#3**. What is the extent to which a training protocol improves behavioral performance on tactile reading tasks from question #1 and two geographic spatial abilities tasks?
>
> **#4**. Can valid and reliable tactile versions of previous vision-based geographic spatial abilities and map use tasks be developed?

The first section in Chapter Two outlines the current literature in tactile map reading and identifies one of the largest barriers to quality tactile map reading as the lack of appropriate strategy choice and use. Often people who are blind or visually impaired will employ a dominant internal or egocentric strategy, even when it is less efficient, and may fail to use of an external or allocentric strategy. But as Golledge (1993) suggests, it is not the lack of ability to use spatial cognitive processes and strategies but rather a lack of training that produces map reading discrepancies between a sighted and blind population.

The second section in Chapter Two identifies egocentric and allocentric frames of reference in the literature and suggests that they make up two separate but equal cognitive processing streams. Frames of reference influence and support spatial abilities, spatial mental transformation models, and route and survey knowledge. To accurately solve route and survey map reading tasks a person must be able to employ both egocentric and allocentric strategies. The two streams of cognitive processing may be used as the two spatial problem-solving strategies and can subsequently be strengthened or taught by using the fundamental spatial abilities visualization and orientation.

Knowing when, and how, to use cognitive strategies to solve map reading problems is a complicated behavior and involves robust spatial thinking. Spatial thinking is a problem-solving process that brings together and uses a broad set of interconnected spatial skills that can be taught and learned. Section three in Chapter Two provides a theoretical basis for including spatial thinking training in the tactile training protocol.

Chapter Three provides the methodology developed for this dissertation. The dissertation experiment took place in a series of stages including two pre-training testing sessions, the training and two post-training testing sessions. Tactile tasks and training materials have been designed for each stage of the experiment and are reviewed in detail. To ensure that the tactile materials are valid and reliable, this research developed the materials based on the cognitive tactualization approach and previous research that has been conducted in the Spatial and Map Cognition Research Lab at the University of Oregon. The testing procedures for all experimental sessions are outlined.

The experimental results are presented in Chapter Four and reviews how functional magnetic resonance imaging works and data analysis procedures. The analysis for the neuroimaging data is conducted according to robust standards in the field. Both the behavioral and the neurological data are presented in categories based on pre- and post- training, not individual tasks.

The discussion, Chapter Five, is split into two sections. The first section demonstrates that the neuroimaging results do not show a route-survey task dichotomy but rather present findings that suggest a dominant egocentric/route strategy for all task pre-training and a dominant allocentric/survey strategy for all tasks after training. This dissertation uses previous literature in the neuroimaging field to identify the brain areas associated with egocentric/route versus allocentric/survey processing and provide support for the above claim. The second section discusses the learning effect. Previous studies have identified one difficulty in studying large-scale learning is the identification of strategies and how the adoption of those strategies leads to successful performance (Denis, Pazzagalia, Cornoldi & Bertolo, 1999). The mixed-method approach used in this study has identified strategy use through neurological data and performance through behavioral data to provide evidence that using an allocentric perspective to answer tactile map reading questions is coupled with improved performance.

Chapter Six, presents concluding remarks. This dissertation found that the tactile training protocol did produce a learning effect and provides neurological data to suggest that there are two cognitive streams of processing based on frames of reference. Egocentric/route and allocentric/survey cognitive processes appear to function like strategies. This research finds supporting evidence that traditional spatial knowledge developmental models hold true for people who are blind or visually impaired. All of the participants passed first through a phase of egocentric strategy use followed by allocentric strategy use, but failed to choose strategies based on task demands. Further conclusions suggest that perhaps the map reading tasks did not adequately test for route versus survey knowledge and/or well accepted theories of spatial knowledge structures require future research.

CHAPTER II

LITERATURE REVIEW & BACKGROUND

The following chapter will review current literature in tactile mapping, frames of reference, and spatial thinking. The goal of this literature review is to identify the gap that persists between inadequate strategy use by those who are blind engaging in tactile map reading, and a theoretical approach concerning methods of training to enhance map use. This project proposes that tactile map training should both include the enhancement of spatial thinking, and involve appropriate adoption of both internal (egocentric) and external (allocentric) coding strategies, entailing efficient use of frames of reference.

Blind Tactile Map Use

Compared to the empirical studies produced using a sighted population, blind map use is a relatively small and new field. Early studies in tactile map use focus on the effectiveness of different types of tactile maps (Leonard & Newman, 1970), and investigations of the best behavioral techniques for scanning and gathering tactile map information (Berla, Butterfield & Murr, 1976). For example, Nolan & Morris (1971) suggest that tactile map reading should start with a gross scan of the map (perhaps like a sighted person would do with a visual scan) and then proceed to detailed study using both hands to trace the map features; other studies suggest the opposite, and recommend using just one of the index fingers (Berla et al., 1976). Additional studies suggest free exploration of map details (Bentzen, 1980), while still others encourage systematic investigation (Kikuza, 1989). These papers reflect a discontinuity in the literature on tactile map use, producing contradictory statements about best practices. However, what these studies have in common is that they were not backed up by empirical evidence, often used pseudo-maps or simple outlines, and did not include a conversation about the larger concept of map comprehension. Landau (1986), while criticized for her in-depth studies using only one participant, did bring forth the idea that tactile map use is a direct and natural function of the spatial knowledge system required to support all kinds of other spatial inferences seen in the development of blind children. Ungar and Blades (1994) further support the above-mentioned idea by showing that untrained blind children can accurately estimate the direction of objects from a map with no training. Empirical evidence demonstrates that people who are blind and visually impaired have the innate ability to understand and use cartographic representations in a number of contexts, performing a variety of tasks.

While people who are blind have the ability to use maps, researchers concur that tactile map reading is less precise than sighted map reading (Perkins & Gardiner, 2003). Tactile map reading is a serial process, in which the fingers gather the information and gradually build an overview of the spatial relationships between the raised map symbols (Tatham, 1991). In tactile map investigation, the parts (tactile symbols) slowly become a whole map, rather than the map being broken down into identifiable chunks by the sighted map reader (Perkins & Gardiner, 2003). There are some similarities between sighted and tactile map investigation, such as edge processing, which plays an important cognitive role in both tactile and sighted map reading (MacEachren, 1995). But previous studies demonstrate that the way in which a person who is blind utilizes a map are often different than that of a sighted person. For example, the results of Edwards, Ungar and Blades (1998) demonstrate qualitative differences in route descriptions between sighted and blind children. Blind students made reference to hazards, included alternative routes (that they believed to be safer), and talked about following edges that provided tactile information (not shown on the map) they would use when traveling. These findings are consistent with Passini and Proulx (1988) who demonstrate that blind adults rely on different types of environmental information than sighted adults. In a map recreation tasks both blind and sighted participants were asked to draw a sketch map from memory after exploring a tactile map (Jacobson, 1992). The sketch maps drawn by blind participants show a greater level of detail integration. The maps have a higher level of *utility* and include information needed to safely navigate an area. Qualitatively, the types of information gathered from a map (or included when a blind participant is producing one) are different between people who are sighted and blind or visually impaired.

While the above literature shows that people who are blind interact with maps differently than people who are sighted, they also demonstrate that people who are blind or visually impaired (VI) are able to effectively encode, retain and recall map elements. But there is evidence to the contrary that suggests that tactile map displays (in some cases) make it more difficult to gather geographical display information. For example, some blind participants encode and remember less spatial information when using a map than when given simple geographical descriptions (Blades, Ungar & Spencer, 1999). The potential reasons for this difference may be due to the difficulty in the perceptual modality used for coding the spatial information (Espinosa et al., 1998), difficulty in creating a complete mental map due to the sequential acquisition of tactile map information (Heller, 1991; Warren, 1984), poor tactile map design (Gardiner & Perkins, 2005; Jehoel et al., 2006), a dominant reliance on internal, egocentric spatial information coding strategy (Klatzky, Loomis, Golledge, Cicinelli & Pellegrino, 1995), and the use of inadequate strategies for tactile map reading (Blades et al., 1999; Ungar et al., 1997a; Ungar et al., 1997b).

Therefore, people who are blind or visually impaired should receive training on how to acquire the spatial information contained in tactile maps and the use of effective strategies for solving map reading tasks (Ungar et al., 1993; Ungar, Blades & Spencer, 1996; Ungar et al., 1997a). Ungar et al. (1997b) demonstrate that very young, congenitally blind children can be trained to use map reading strategies with tactile maps. When children with visual impairments were asked to make distance judgments from a tactile map, most of them did not employ a direct strategy to aid in their decision-making process. But when the same group of blind children was trained with a ratio calculation strategy, they made significant improvements and brought their performance to that of (untrained) sighted children. Ungar and Blades (1994) showed that when children were given no strategies (in this case on a self-location task) good performers spontaneously adopted strategies. Two distinct strategies were noted: a ‘look-ahead’, and an ‘open-mind’. The ‘look-ahead’ strategy resulted in the children scanning the map from their current location into the direction they thought they were headed (either correct or incorrect). The ‘open-mind’ strategy showed children exploring all possible options near their current location and determining all possible moves until further evidence provided other options. Both strategies create a plan of attack, and while they produced better results than having no strategy at all, they were not always the best procedure for solving the self-location task.

Ungar et al. (1995a) provide further evidence of spontaneous strategy adoption in a study that asked children to learn the layout of one, three, and five raised shapes, and to reproduce the layouts after they were confident that they had memorized the positions. The researchers noted that the *good* performers focused their efforts on learning both the relative positions of the shapes (in relation to one another), and the absolute position (their location in relation to the edge of the display). The research reviewed above provides evidence that people will naturally organize their efforts in meaningful ways and adopt problem-solving techniques to aid in decision-making. It also suggests that people who are blind or visually impaired can be taught to use effective tactile map reading strategies. What is lacking in the literature is the identification of a systematic approach to studying tactile map reading strategies and how teaching a strategic map reading approach affects the cognitive processes associated with strategies.

The term “strategy” is frequently used in the tactile map literature (as demonstrated in the literature reviewed above), but surprisingly few studies focus on the larger underpinnings of cognitive processes that define those strategies. Perhaps part of the reason for this hole in the literature is the lack of a widely accepted definition of what a cognitive strategy is. Lobben (2004) defines a map reading strategy as a specific method or tactic employed by a map-reader to complete a task. But more importantly, Lobben discusses the differences between a process, which everyone possesses, and a strategy, defined as the ability to choose a specific cognitive process. The identification of tactile map reading strategies and the cognitive processes that accompany them is an area of research that requires further investigation.

One way to begin investigating tactile map reading strategies is to identify what blind map readers already do. Blades et al. (1999) conclude that a *good* map reader will focus on the spatial relationships between items on the map and look for patterns that are formed by map elements and locations of places in relation to the external framework of the map. Ungar, Blades & Spencer (1995c) mimic this basic finding in a tactile mental rotation experiment with children and found that those who explored both the internal and external relationships of the layout performed better than the children who ignored these relationships. The results suggest that sophisticated spatial strategies that incorporate the ability to adopt external coding strategies (allocentric space) and internal coding strategies (egocentric space) lead to better performance. Coding processes are procedures for maintaining information in working memory, as well as procedures for structuring and organizing that information into long term memory (Thorndyke & Stasz, 1980). Klatzky et al. (1995) argue that a lack of visual experience will lead to a body-centered, internal (egocentric) dominant coding strategy for people who are blind, and an egocentric coding strategy leads to less effective performance on mental rotation or mental reorganization tasks.

If it is true that people who are blind or visually impaired maintain a dominant egocentric coding strategy, then there should be an emphasis on training toward strategies that make use of cues that are external to their body space and use external frames of reference. Providing training on an allocentric coding strategy using maps that promote a top-down perspective may: 1) introduce an allocentric frame of reference with which a blind map reader is unfamiliar, and 2) teach methods to use allocentric perspectives when appropriate. Tactile map training should provide instruction in understanding the differences between egocentric and allocentric perspectives and strengthen these two cogntive processing systems.

People who are sighted adopt different strategies for map reading based on appropriate conditions and experience, but is the same true for people who are blind or visually impaired? Millar (1981, 1982, 1988) put forward the idea that the performance differences between people who are sighted and blind on spatial tasks are due to different strategies for coding spatial information, not different basic spatial abilities. While sighted people use vision to influence their use of external frames of reference (and therefore use of allocentric strategies), the lack of vision promotes egocentric or internal coding strategies. Millar (1988) stresses that the differences in strategy use are optional, and that people who are blind and visually impaired have the ability to adopt different coding strategies based on task demands.

Golledge (1992) suggests that, rather than a lack of basic human spatial abilities to use efficient strategies, the real issue is insufficient training to teach people who are blind or visually impaired to choose and effectively use efficient spatial strategies during tactile map use. Ungar and Blades (1994) argue that the spatial developmental lag seen in blind children could be significantly minimized with the inclusion of tactile map training. Maps provide critical environmental information at a large enough scale to explore with the haptic sense (Ungar et al., 1997b) and can be used extensively by children and adults who are blind or visually impaired. If blind people who are blind can use egocentric and allocentric encoding strategies to acquire both route and survey knowledge, and integrate this knowledge into a complete view of their environment (a cognitive map), then training could, “broaden the horizons, both figuratively and literally, of people who are visually impaired (Millar, 1988, pg.77).”

When tactile maps are used for mobility training, they provide a source of spatial information that preserves the interrelationships between objects in space (Ungar, 2000), and offer an externally based code framework for structuring spatial representations (such as cognitive maps), making the spatial relations between location more accessible (Millar, 1994; 1995). Ungar (2000) suggests that spatial decision making, both from direct experience and inferential, is more efficient and reliable when those decisions are based on an external coding system that produces a 'map-like' representation of a spatial layout (in a person's mind). Therefore, cognitive maps may be influenced by using tactile maps, and this use produces a greater potential for more accurate mental map construction, which in turn leads to better spatial decision-making.

The cognitive map is the basic building-block model of the world that we live in (Golledge & Stimpson, 1997), and is at the intersection of spatial cognition and environmental perception. While cognitive mapping is a process that incorporates the perception, storage, and recall of information about the world we live in, it is also incorporates the way we think and feel in the geographic environment (Jacobson, 1998). We know that people who are blind and visually impaired use maps in different ways when compared to sighted people, and pay attention to different environmental cues to aid navigation. One difference in spatial competency (such as cognitive maps) between the sighted and blind can be explained by an intervening variable such as access and use of maps (Passini & Proulx, 1988). Tactile maps are able to extend the conception of a person's environment beyond direct experience (Jacobson, 1998). Jacobson (1992) discovered that participants produced more accurate sketch maps when using tactile maps with direct experience than through direct experience alone. Therefore, tactile map use and training may improve a person's ability to construct a more accurate mental map.

Frames of Reference (Internal and External Frameworks and Strategies)

The previous section argues that accurate tactile map reading requires both internal and external coding strategies. An internal coding strategy incorporates spatial information into memory using an egocentric perspective and an external coding strategy using an allocentric perspective. The two perspectives are defined in the literature as frames of reference. This dissertation argues that frames of reference are fundamental to spatial strategy adoption that are subsequently used to answer route and survey knowledge task questions.

Identifying what cognitive processes control strategies, like frames of reference, provides a framework for geographic research (Lobben, 2004), including the research presented in this dissertation. Given that we know that a combination of external and internal strategies lead to better tactile map reading in blind and visually impaired people, it follows that: 1) a scientific exploration of the cognitive components that make-up and support these external and internal frames of reference will provide a more complete explanation of the cognitive processes that control strategy use, and 2) will provide a theoretical basis for developing education and training.

The literature defines and discusses frames of reference (and their supporting role) in a variety of contexts. For example, as a function of the scales of psychological space (Ittelson, 1973; Garling & Golledge, 1987; Montello, 1993), as a basis for psychometric mental transformation models (Bryant & Tversky, 1999; Zacks, Ollinger, Sheridan & Tversky, 2002; Zacks & Michelon, 2006), in spatial abilities (Koshevnikov &

Hegarty, 2001; Golledge & Stimson, 1997; Albert & Golledge, 1999) and for its role in spatial knowledge acquisition and spatial knowledge structures (Golledge, 1992; Golledge, Dougherty & Bell, 1995; Ishikawa & Montello, 2006). But the topics outlined above rarely discuss how these topics may fit together to form two streams of cognitive processing that are used to solve spatial problems and guide spatial behavior. I argue that ego/allocentric frames of references are the base building blocks that influence and support increasingly complex cognitive tasks, such as those for identifying route and survey knowledge structures.

Egocentric and allocentric frames of reference are perspectives. They are a framework for viewing the environment and I hypothesize they support spatial abilities, mental transformation models, and route and survey knowledge structures that maintain distinctive streams (that can more broadly be couched in terms of internal and external strategy frameworks). For example, the internal egocentric stream consists of an egocentric perspective frame of reference, orientation spatial ability, egocentric transformation model, and route style knowledge acquisition. The external stream consists of allocentric perspective frame of reference, visualization spatial ability, object transformation model and survey knowledge acquisition and knowledge.

We know that frames of reference allow us to update our relative positions and perspectives as new information comes in. Burgess (2006) suggests that egocentric and allocentric perspectives exist as parallel modes, which combine to support behavior. Burgess (2006) also suggests that people frequently switch between these two perspectives, with little to no external signals, or perhaps without being aware of it themselves. Egocentric and allocentric perspectives may be the two main cognitive strategies to solve complex route and survey tasks (Igloi, Zaoui, Berthoz, & Rondi-Reig, 2009). Igloi et al. (2009) trained participants to use both allocentric and egocentric strategies, and demonstrated that both types of strategies can be adopted spontaneously, and that all participants shifted between the two strategies with ease. This dissertation suggests that people will use an egocentric strategy to solve a route knowledge tasks and an allocentric strategy to solve a survey knowledge tasks.

Like with many complicated behaviors such as map reading, there may be a variety of possible solutions to solve a map task, and those strategies may be highly individualistic. Even the development of spatial knowledge over time is highly individualistic, and may be difficult to explain with a simple model (Ishikawa & Montello, 2006). The variability of performance in a blind population can be great and, as suggested above, part of this variability may be explained by strategy use (or lack thereof). If internal and external frameworks are independent streams, training people to strengthen the sub-components within those streams provides a training protocol that plans for this individualistic strategy use (within a larger known strategy plan that works).

In the following sections, this paper will review the pertinent literature that defines and provides support for frames of reference use in mental spatial transformation models, visualization and orientation spatial abilities, and route and survey knowledge. A large section of this project is based on training people who are blind to use both an egocentric and allocentric frame of reference strategy. This dissertation suggests that frames of reference and spatial strategies can be taught through spatial abilities tasks, and those tasks will in turn aid in spatial knowledge manipulation. Using the spatial abilities tasks is appropriate as mental spatial models and route and survey knowledge have previously been defined by task differences, including tasks that are fundamentally similar to the spatial abilities tasks used this project.

Mental spatial transformation models. A mental model incorporates information about temporal, spatial, causal, person, and object-related features of a particular event (Noordzij, Zuidhoek & Postma, 2006). The spatial aspects of mental models have been studied at length, and show that people can build spatial mental models containing information about spatial relationships and distances even when they may be missing pieces of directly experienced information (Rinck, Williams, Bower & Becker, 1996; Bestgen & Dupont, 2003). Mental model construction requires an ongoing integration and transformation of several pieces of information (Cornoldi & Vecchi, 2000).

In the psychometric literature, the concept of mental transformation models has produced an object-based spatial transformation and an egocentric perspective transformation. The object-based model suggests that imagined rotations or translations of objects are made in the reference frame of the environment (outside of the body). In contrast, the egocentric transformations are imagined rotations or translations based on the reference of one’s point-of-view (Zacks et al., 2002). While both object-based transformations and egocentric perspective transformations involve updating of the relationship between the environment, objects in that environment, and the position of the observer, the difference lies in a dominant fixed reference point. For example, in the case of object-based transformation, the environmental and egocentric frames remain fixed, while the object’s intrinsic coordinate frame is updated. In egocentric transformations, the environmental and object frames remain fixed, while each of their relationships with the observer’s egocentric coordinate frame are updated (Zacks, Mires, Tversky, & Hazeltine, 2000; Zacks et al., 2002; Zacks & Tversky, 2005).

The two mental transformations are most likely controlled and implemented by different cognitive processing systems. In behavioral studies, mental rotation is a prototypical example of an object-based transformation. A rotation task, in which one mentally rotates an object (or other stimuli, like maps or even drawings of human bodies), can be performed by examining the scene from a position that is seemingly outside of the stimuli, or looking down onto the stimuli. While the objects’ frame of reference change, according to this literature, the observer’s perspective stays constant, and most likely occurs as a top down view (much like the allocentric frame of reference defined above). While the previous sentiment is not explicitly argued in the papers reviewed here, an allocentric viewer perspective can be inferred. The studies discussed above demonstrate that there are different chronometric profiles for different planes of rotation, therefore suggesting a strong relationship between rotation and reaction time. But when participants are asked to imagine themselves in the orientation as the rotated object, the reaction time does not maintain the same relationship with degree of rotation. Instead, results are similar to those of a left-right task that tests egocentric perspective transformations (Zacks et al., 2002; Zacks & Michelon, 2005).

A series of experiments (Zacks & Tversky, 2005; Zacks, Vettel & Michelon, 2003) further demonstrate that these two transformations are dissociable by manipulating the instructions, but keeping the stimuli constant. For example, based on an experiment originally developed and tested by Presson (1982), participants were asked to either imagine an array of objects rotating, or to imagine themselves rotating around the array.

That study provides evidence for both behavioral and neurological differences between these two types of mental manipulations. The evidence suggests that these two types of transformations are indeed separate, and that individuals can flip between them with ease. People may use one or (more likely) both of these spatial mental transformations when confronted with complex spatial problem-solving like map reading. The spatial abilities literature suggests that these two types of mental transformations may be supported by, or share fundamental similarities with, spatial abilities.

Spatial abilities (visualization vs. orientation). Spatial abilities have traditionally been defined as the ability to generate, retain, retrieve, and transform images (Lohman, 1979). In general, spatial abilities refer to the mental processes we use in perceiving the world around us, the spatial perception that determines spatial relationships, and how we manipulate that information. Perhaps most importantly, spatial abilities support high-order thinking, creativity, and are a unique aspect of human intelligence (Shepard, 1978; McGee, 1979). The amount of literature that has been produced on spatial abilities from a psychometric point of view shows the clear importance of this area of study for understanding human abilities (Lobben, 2007). But it is the way in which spatial abilities are applied, and their relationship to environmental tasks such as map reading and navigation, which provides the geographic perspective that leads to better understanding of geographic spatial behavior and the cognitive aspects that drive it. In the literature there are more geographic spatial abilities identified than those compiled and tested by psychology. Geographic spatial abilities include additional spatial skills necessary for real-world spatial decision-making common in navigation and map reading (for a review of geographic spatial abilities see Golledge & Stimson, 1997).

Within both geography and psychology, spatial abilities are commonly divided into two distinct and separate factors: spatial orientation and spatial visualization (Lohman, 1979; McGee, 1979; Golledge & Stimson, 1997; Montello, Lovelace, Golledge & Self, 1999; Albert & Golledge, 1999). Spatial orientation is the ability to imagine how objects will appear from a different orientation or perspective (McGee, 1979). Many tests have been developed to record and measure this spatial ability, such as the Guilford-Zimmerman Spatial Orientation test (Guildford & Zimmerman, 1948), and the map perspective and object perspective tests developed by Koshevnikov & Hegarty (2001). The objectives of all of these tasks are to have the participant imagine his/her body orientation or perspective change. Spatial orientation ability involves movement of the egocentric frame of reference, which encodes objects with respect to the observer's body (Bryant & Tversky, 1999; Wraga, Creem & Profitt, 2000). Spatial orientation has been shown to play a role in a variety of geographic tasks, such as the acquisition of route knowledge during navigation (Person & Ialongo, 1986), during simulated navigation (Albert, 1997), and map reading comprehension.

Spatial visualization involves the ability to imagine the movement of objects and environments (McGee, 1979; Albert & Golledge, 1999). Spatial visualization requires imagination of a complex sequence of mental manipulations, and allows a person to see with their mind's eye how objects/environments would appear after a series of transformations (Lobben, 2004). For example, to visualize an area (in regards to map reading) one must mentally transform the two dimensional map into a three dimensional world in order to see environmental objects such as streets and buildings (Crampton, 1992). The most commonly used test for this ability is mental rotation of 2D and 3D images (for example, the classic Shepard and Metzler blocks), but other exams like the paper folding test (Carrol, 1993) and the mental rotation of maps have been used (Lloyd & Steinke, 1984; MacEachren, 1992). In contrast to spatial orientation, spatial visualization requires the imagined movement of the location of objects or environments with respect to other objects, while the perspective of the observer's body stays constant from a top down perspective (or an allocentric perspective) (Koshevnikov & Hegarty, 2001). Visualization has been shown to be a cognitive process used in map reading (Aretz & Wickens, 1992; Lloyd & Steinke, 1984), in mental map development and recall (Crampton, 1992), and in gathering survey knowledge obtained from a map (Lobben, 2004).

Spatial knowledge structures (route vs. survey). Researches who work on spatial knowledge acquisition have suggested that people pass through stages of egocentric to allocentric knowledge (Piaget & Inhelder, 1967; Siegel & White, 1975). Golledge (1978) put forward the idea that our knowledge structures are dominated by landmarks first, connected into routes next, and followed by a full survey understanding of an environment. But the theory of spatial knowledge acquisition that follows this traditional developmental path has been challenged. Liben (1981) argues that developmental stages only partially account for changes in spatial knowledge. Instead, one may go through all stages from egocentric to allocentric as part of a local learning process (Golledge, 1977). Further, Kuipers (1977) suggests that people acquire spatial knowledge in a more piecemeal "bottom-up" process. We gather bits of knowledge and integrate them into a way of solving problems of spatial movement (Golledge, Gale, Pellegrino & Doherty, 1992) and it is the access to frames of reference that is the initial step in the processes of reasoning about space, understanding spatial relationships and in developing route and survey spatial knowledge structures.

Route-level knowledge is the acquisition of environmental features collected from the orientation of a user's viewpoint, or first person out perspective (Bowman, Davis, Hedges & Badre, 1999). Route knowledge is composed of landmarks, choice points, and the sequencing and arrangement of environmental components that form procedural knowledge from an egocentric frame of reference (Golldge, 1992). Golledge (1989) shows that when a participant is restricted to a forward-looking view only, they are able provide fewer details of routes and scenes. Instead it is the ability to imagine different orientations in 360 degrees within an egocentric perspective that leads to more complete reassembly of environments. Therefore, route knowledge is supported by the orientation spatial ability. Often the pieces of information that are encoded and recalled in route knowledge are developed parsimoniously, and are composed of critical bits of information that an individual finds important (Golledge et al., 1992). But a complete environmental knowledge structure does not consist of objects, features, and facts (and the connections between them) only. Environmental knowledge requires the understanding of spatial associations, relationships, and patterns. The assimilation of environmental information is supported by the internal integration and manipulation processes known as spatial abilities that lead to the development of strategies for learning spatial layouts (Golledge, 1993). By definition, when a person grasps the layout of a large environment, this is survey knowledge, and does not come from a single egocentric viewpoint, but rather from when routes are scaled and integrated into a global allocentric reference system (Ishikawa & Montello, 2006).

Survey-level knowledge can be described as the ability to discern elements in the environment from a bird’s-eye-view (Golledge et al., 1995). This type of knowledge incorporates understandings of a range of visual, geometric, perceptive, and descriptive information into a configurational whole, and applies that whole to a bounding frame of allocentric reference. Survey knowledge is composed of and possesses the essence of one of the three most commonly accepted dimensions of spatial ability, visualization (Golledge et al., 1995). People deconstruct environments into landmarks, nodes, districts, paths, and boundaries and then tie them together topologically and geometrically to construct knowledge structures, often in the form most commonly referred to as cognitive maps. The way in which people manipulate these bits of spatial information to solve everyday problems can be tied back to using spatial abilities, in particular visualization and orientation (Golledge, 1993).

Although it seems as if adults should possess both route- and survey-type knowledge structures, Golledge et al. (1995) argues that many who should have the ability to perform a variety of spatial tasks seemly are unable to do so at a level of competency. This discrepancy begs the question, how can these types of spatial skills be taught? In a longitudinal study, Ishikawa & Montello (2006) discovered surprisingly little behavioral improvement in performance after multiple sessions without instruction. Therefore, to affect learning, instruction is critical. In the case of map reading and spatial knowledge development, training may require more than teaching frames of reference and spatial knowledge manipulation, training should provide an infrastructure for organization and processing spatial information.

Spatial Thinking

Spatial thinking, as outlined by the National Research Council, is composed of three elements: concepts of space, tools of representation, and the processes of reasoning. Understanding the meaning of space and using the properties of space allows spatial thinking to structure problem-solving. Often it is visualizing the relationships within a spatial structure that aids us to perceive, remember, and analyze everyday problems, such as map reading and navigation. But there is no single recipe for how to think spatially. Instead, the process may be comprised of a broad set of interconnected competencies that can be taught or learned (National Research Council, 2006).

Therefore, spatial thought is a broad topic area and is not used exclusively by any one discipline. The constructs of spatial thinking do not share a common set of components or a universally shared formalism (Liben, 2006). But as Liben (2006) suggests, there are three components of spatial thinking that are well suited to topics in geography, education, and training. First, to define spatial thinking principles through a geographic lens, a person must understand some organizational basics of space, including units of measurement, the basis of a coordinate system, and geometric relationships (concepts of space). Second, spatial thinking involves understanding environmental representations (maps), the relationships among map views, and how they translate into internal representations of space (cognitive maps and frames of reference/ tools of representation). Third, the ability to extrapolate, interpolate and use spatial strategies to make decision (process of reasoning) is a key component of spatial thinking. To put it more simply, people need be able to organize space in meaningful ways, understand how the physical environment relates to both maps and mental representations of the environment, and to use organization and representation to form strategies in order to solve geographic problems.

Golledge, Marsh and Battersby (2006) define spatial thinking as a process of first transforming *data* into *information,* and then taking that information and making it into *knowledge* that we use to solve problems. A series of geocognitive processes take place and may be explained as a series of actions that include perception, encoding, storing, and recalling spatial data that can be used in a variety of ways among diverse spatial problems. When defining spatial thinking as an internal cognitive process it is critical to examine the external sources that shape it, such as the language we use to define and discuss it.

Golledge et al. (2006) suggest that poor understanding of the spatial concepts that affect spatial thinking may be due to the lack of technical language and/or training to express and internalize a person's understanding of spatial associations, relations, connections, and hierarchies that are basic to the world of geography. He argues that geography has a substantial but largely unorganized technical language base for discussing spatial concepts. But the lack of an organized, official set of terms should not stop researchers and educators from using language as a spatial thinking tool. In fact, learning the language associated with spatial thinking may provide the essential tools needed for comprehending environmental knowledge that people gain through personal experience (Golledge et al., 2006).

Golledge (1993) believes that a lack of spatial language training is particularly problematic with people who are blind and visually impaired populations. He argues that people with vision loss do not lack the ability to think geographically, or spatially.

Rather, they may not possess the vocabulary through which to express themselves and to make the connections between what they know and how that translates into geographic or spatial concepts. Vocabulary training, then, becomes a necessity to link persons with blindness and visual impairment with the abilities they possess, the geographic concepts that exist, and how to express them into useful spatial thinking and decision-making skills. Vocabulary training may include teaching higher-level concepts, such as region, to seemingly simple concepts, such as how the environment is made up of geometric shapes.

Even though people may not be acutely aware of it, we perceive and organize our environment into relationships that follow geometric principles (Montello, 1993). Geometry literally means earth-measuring, and is way of understanding and organizing the shape, size, the relative position of environmental features into the properties of space. The environment is made up of geometric properties that people use frequently, such as distances traveled and angles of turns. But people rarely use strict geometric relationships (like metric distance) to guide spatial behavior. Instead, we organize the environment into shapes (paths) and attach attributes to them (landmarks) (Clemets, 1998).

Organizing and using these geometric relationships requires human information processing. Cognitive maps tend to be distorted and only after repeated, prolonged environmental exposure does a more formal geometric understand of spatial information take place (Golledge, 1993). Furthermore, no single standard of a geometrical reference system exists, as precision of information about spatial situations and relationships vary too greatly (Montello, 1992). Using geometry and geometric language to describe the environment may strengthen the relationship between the physical environment and the mental representation of it through visualization. Visualizing the world through geometric relationships (shapes and connections) may be a component of spatial thinking that provides better mental representations of real-world spatial components.

Creating a spatial, geometric ontology, or knowledge built on spatial language, may be critical to spatial thinking training because the objects within space are not just located in space but are intrinsically tied to it and carry its structural qualities (Smith & Mark, 1998). Therefore, spatial thinking should include vocabulary and geometry training to link the concepts of space with representations of space.

From a human cognition standpoint, we all operate within a range of spatial thinking capabilities that can be influenced by education and training. An established relationship between performance on spatial tests and success in universal components of education is not currently available (Liben, 2006), unlike correlations seen with verbal skills. But Einstein claimed he rarely thought in words at all. Instead, spatial skills are likely to create representations that organize relevant information more effectively. Research does suggest that training on mental rotation tasks with engineering students increased performance on later standardized tests and improved student retention (Sorby & Baartmans, 1996; 2000). Pallrand and Seeber (1984) asked college students in a physics course to practice drawing outdoor scenes and geometric transformations. The training sessions led to higher grades in the course. That study provided evidence that improving spatial thinking aids in routine education in math and science. But perhaps even more interesting is research that suggests that enhancing spatial skills may offer motivational benefits. Casey, Nuttall and Pezaris (1997) found that training on mental rotation with 10th grade girls improved their attitudes towards math. Teaching spatial skills may have a positive impact on confidence.

Using the spatial thinking elements including concepts of space, tools of representation, and processes of reasoning to teach tactile map reading may seem redundant, since maps are arguably the most important tool for teaching spatial thinking (Liben, 2006). Geographic education and training can be approached holistically with an emphasis on spatial thinking. Spatial thinking is a vehicle for structuring problems, finding answers and communicating solutions (National Research Council, 2006). Spatial thinking can assist map reading by strengthening a person’s ability to perceive, remember, and analyze static map representations via mental transformations of the dynamic properties of objects, the relationships between those objects, and the map viewer. Spatial thinking will strengthen a person’s ability to use maps by giving them the vocabulary to define space, the ability to manipulate the physical and mental properties of space, and the faculty to formulate a spatial strategy to employ during different types of map tasks.

CHAPTER III

EXPERIMENTAL METHODS

The following chapter discusses the tasks that have been designed, the experimental procedures for the pre-training, training, and post-training testing stages, and the spatial thinking based tactile map training protocol. Three sets of tactile instruments have been designed for this dissertation. First, a set of tactile maps have been made for use in the MR scanner to test route and survey knowledge behaviorally and neurologically. Second, two sets of tactile spatial abilities tasks, rotation and orientation, have been designed for use in a laboratory setting to collect behavioral measures. Third, a set of tactile graphics have been produced to aid in the spatial thinking tactile map training. The research reported here has been approved by the human subjects committee at the University of Oregon, and has been carried out in accordance with those procedures. All participants met the safety requirements for qualification of a functional MRI in a research setting.

Instrument Development

Design of the tactile graphics developed for this project was based on the principles of cognitive tactualization (Jehoel et al., 2006). Cognitive tactualization is a construct that comes out of the tactile mapping literature but can also be applied to the design of any tactile graphic. The construct suggests that tactile information input and encoding includes two processes, perceptual and cognitive. The first process is the perception of the tactile stimuli and the receptors on the fingertips that allow the information to be comprehended. The second process includes the cognitive processes that transform the response to the tactile stimuli into information that a user can interpret.

Based on the psychophysical properties (that guide cognitive tactualization) of tactile discrimination and legibility all of the symbols placed on the experimental graphics are separated by a minimum distance of ¼ inch. Empirical testing in the Spatial and Map Cognition Research Lab identified the most discriminable and interpretable tactile symbols, and they were used to reflect a conceptual tactile hierarchy. All the graphics also follow a 3/3/3 rule, or they include no more than three different types of line symbols, three polygon symbols, and/or three fill symbols. The 3/3/3 rule is used so that the graphics do not overload a participant's working memory.

All of the tactile tasks have been designed and formatted in Adobe Illustrator and/or Photoshop. The tactile materials have been produced on microcapsule paper with a Tactile Image Enhancer. The tactile materials for the fMRI testing have been mounted on heavy card stock to make them rigid and durable for multiple usages in a MR scanner environment.

fMRI experimental tasks. The first research question and first neurological research goal of this dissertation was to identify the brain activation patterns associated with four map reading questions. These questions are asked in conjunction with a tactile map. The test questions isolate the behavioral and neurological correlates of route and survey knowledge. Questions one and two are hypothesized to test for route knowledge and questions three and four for survey knowledge. The task questions are as follows:

1. From the store to the park do you turn right at the school?
2. From the park do you cross railroad tracks before the school?
3. On the map is the park north of the school?
4. From the park is the store twice as far as the school?

Spatial knowledge is a complicated construct; therefore two different types of route or survey questions have been developed to more accurately examine spatial knowledge structures. Asking multiple questions to isolate the cognitive processes of a single type of behavior is a common technique in behavioral geography. This research project follows traditional behavioral geographic methods by examining spatial knowledge from multiple angles with multiple task questions.

This project uses one tactile map stimulus to present a single environment for both route and survey questions. The task instructions do not stipulate which perspective to use, either egocentric or allocentric, but instead rely on the hypotheses of previous works stating that, 1) humans possess both route and survey knowledge, which are distinct, and are applied independently of one another based on task demands (Montello & Freundschuh, 1995; Golledge, 1993), 2) different neurological activations are associated with using route and survey perspectives, and a person can move between these perspective transformations using the same graphic (Zacks, Mires, Tversky & Hazeltine, 2000; Zacks & Tversky, 2005), and 3) tactile map graphics, as an instrument medium, are accessible and interpretable by people who are blind and visually impaired when they are appropriately designed (Rowell & Ungar, 2003; Lobben & Lawrence, in press).

Each tactile map is comprised of six map symbols: school, park, store, railroad tracks, streets, and north arrow (see Figure 3.1). The symbols are as follows: the store is the un-filled square, the school is the filled circle, the park a textured polygon, the streets are straight lines with a line weight of three, the railroad track is a pair of parallel lines with hatch marks all set at line weight of three, and the direction of north is marked by an arrow. A set of twenty maps have been designed in which all six of the tactile symbols are present but have been placed in different locations and/or positions, resulting in unique but equivalent stimuli for each trial.

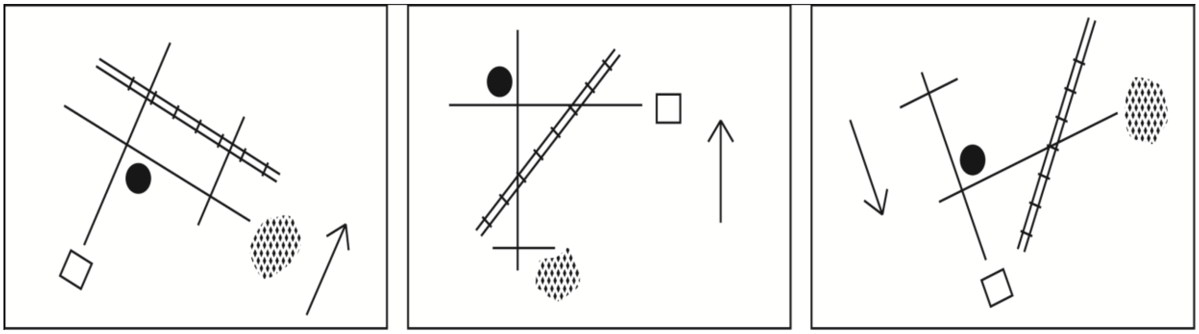


Figure 3.1. fMRI experimental tasks

fMRI control task. A control task in fMRI experimentation is a way to isolate the cognitive brain activity associated with the experimental tasks from perception of the stimuli, instructions, or physical action of answering the task question. In this experiment, a control is used to eliminate brain activity resulting from listening to the task questions being read and the action of pushing the answer box. Any brain activation that remains constant in both the experimental condition and the control condition will be removed from the set of observed activations associated with the experiment task. The remaining observed activations represent the isolated cognitive brain function associated with performing the spatial reasoning aspects of the experimental condition. The procedure described is known as the subtractive method (Posner, 2005). The subtractive method is applied for each subject across each of the four experimental task conditions. The control task instruction is: “Did you answer ‘x’ questions?” where ‘x’ is either two or four.

Behavioral experimental tasks. The second research question of this dissertation asks whether map training will improve participants' performance on two geographic spatial tasks. Therefore, the first behavioral goal is to determine a baseline for the two spatial abilities: visualization and orientation. Traditional tasks designed to test for these spatial abilities were developed for a sighted population using print graphics. While most visuo-spatial tasks require prominent visual demands, the tactile modality can be used to adapt vision-based tasks (Beauvais, Woods, Delaney & Fein, 2004). It is not possible to follow exact protocols of previous vision-based tasks in tactile versions, so the original spatial abilities tasks have been changed to create versions that maintain valid and reliable tactile test development.

The first task, a mental map rotation task, is a tactile version of a map rotation task frequently used in a print format (see Figure 3.2) (Lloyd & Steinke 1984; Levine, Marchon & Hanley, 1984; Shepard & Hurwitz, 1984; Aretz & Wickens, 1992), and has been tested and used successfully in SMCRL in a tactile format. Following current tactile graphic guidelines, the maps designed for the tactile mental map rotation task reduced both the number of map features included and the complexity of map layout. The map rotation test instrument is composed of two tactile maps, separated by a dotted line. The map on the left side of the graphic is constant, while the map on the right side of the test instrument is manipulated by being either rotated from the original map position (as indicated by the map on the left of Figure 3.2), or rotated and flipped. The rotating map

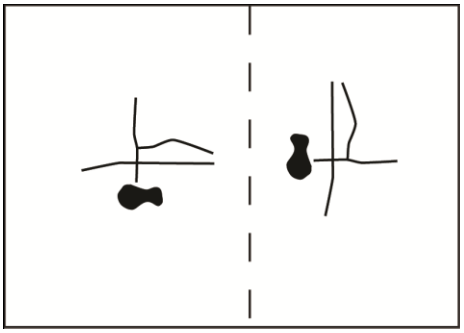


Figure 3.2. Rotation task

graphic is shown in an equal number of rotations between 0-180 and 180-360 degrees. The task instruction is: “Is the map on the right rotated, or rotated and flipped?”

The second task, a tactile orientation task (see Figure 3.3), has been designed specifically for this project and piloted with a blind population in two testing sessions. An orientation task is designed to require a participant to imagine where an object will be located after taking a different perspective in space (Kozhevnikov & Heagary, 2001). To test for the orientation spatial ability, Kozhevnikov & Heagary (2001) developed a task in which a person is shown an array of two-dimensional objects, imagines their perspective within the array, and indicates the direction toward a target object from that perspective. The task designed for this project is similar, but again simplified for a tactile version. Instead of multiple objects in an array, the tactile task has one target object. The task is comprised of a tactile arrow representing the participant’s body orientation and a tactile box located somewhere within the 360 degrees around the arrow. The graphics are designed so that the arrow and box were rotated equally often between 0-180 and 180-360 degrees. The target box appears equally as many times in front and behind the orientation of the imagined body rotation. The task instruction is: “Imagine you are facing in the direction of the arrow; is the box to your left or your right?”

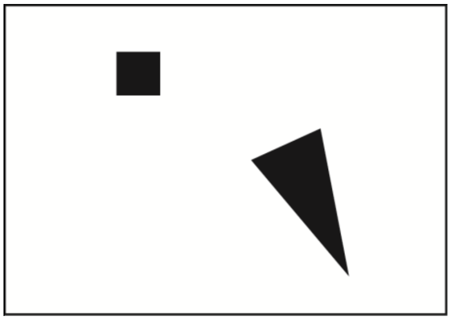


Figure 3.3. Orientation task

Training

Research questions two and three investigate whether tactile map training will affect the behavioral and neurological measures associated with spatial abilities and route and survey style questions. A primary goal of this dissertation is to create a training protocol that will produce a learning effect. The tactile map training protocol is composed of two modules. The first module teaches spatial vocabulary and environmental geometry. The second module teaches the building blocks of frames of reference. The training protocol is based on the principles of spatial thinking and is not designed as a simple ‘see and repeat’ process. Rather than repeatedly performing the experimental tasks until their performance improves (or training to the task), this tactile map training protocol uses a series of spatial abilities and perspective-taking exercises that increase in complexity and difficulty to help strengthen the cognitive processes needed to form efficient strategies to employ during map reading.

The protocol presents a series of activities that are outlined in the Spatial Thinking Tactile Map Training Protocol below. For the first module, the instruments include two tactile maps and tactile geometric shapes (see Figure 3.4). The triangle map is used in the vocabulary lesson to demonstrate simple travel patterns and concepts associated with known travel decisions, such as short cuts. The tactile geometric shapes

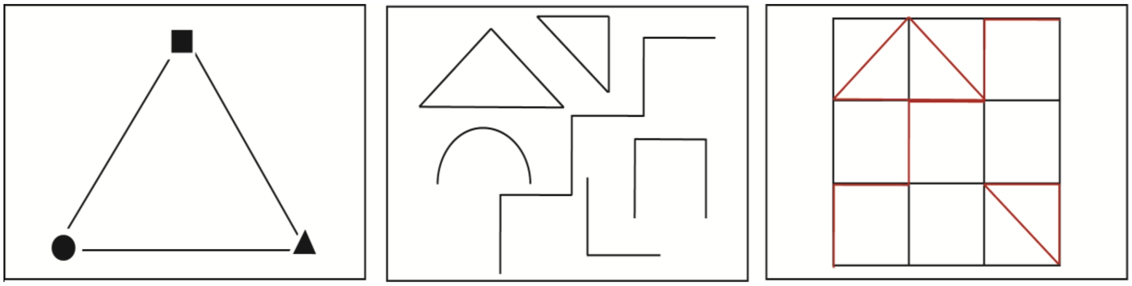


Figure 3.4. Module one training materials introduce environmental geometry by having the participant place cut outs of geometric shapes on top of the map to mimic real travel patterns.

The second module includes three sets of graphics (see Figure 3.5). The first set of graphics teach the principles of visualization and allocentric perspective taking in three steps. The participant engages in making judgments about the spatial relationships of the map features from a top down perspective as the map is rotated. Each step in the lesson includes six graphics, in which difficulty increases by manipulating the angle of rotation and increasing complexity by adding graphical features, such as a north arrow (a map specific feature). The second set of graphics teaches orientation skills and egocentric body manipulations in three steps. The participant engages in imagined perspective-taking from multiple locations. Similar to the set of graphics for teaching allocentric perspective, six graphics in each step become more complex by adding map features. Changing the anchor point from which the perspective is taken further increases the complexity. Initially, the graphic uses an arrow that points in the direction the participant is to imagine their body orientation. The arrow is then taken away, and the participant has to imagine perspectives from different environmental objects with no explicit indication of body direction. The third sets of graphics are tactile maps of a wooden maze constructed for the outdoor portion of the training. The navigational map reading lesson increases in difficulty in three steps (similar to the laboratory activities) and includes three trials. First, a tactile map with a pre-described route is used for navigation. Second, a tactile map without a pre-described route aids navigation. Finally, a third map presents symbols representing “road-blocks.”

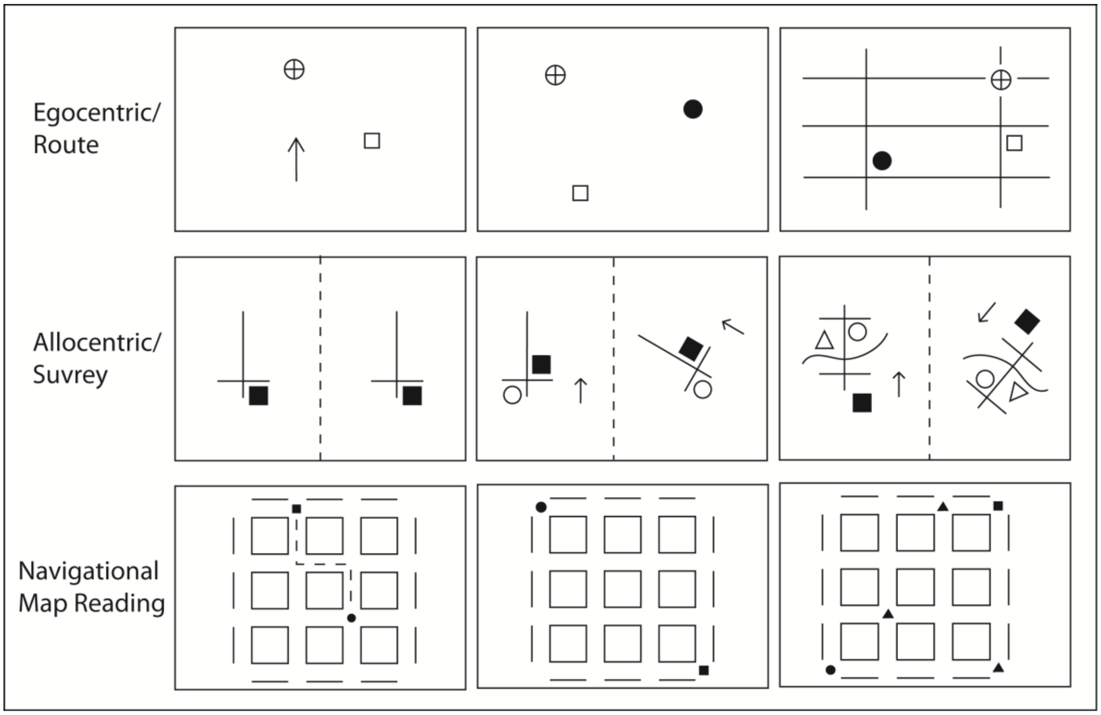


Figure 3.5. Module two training materials

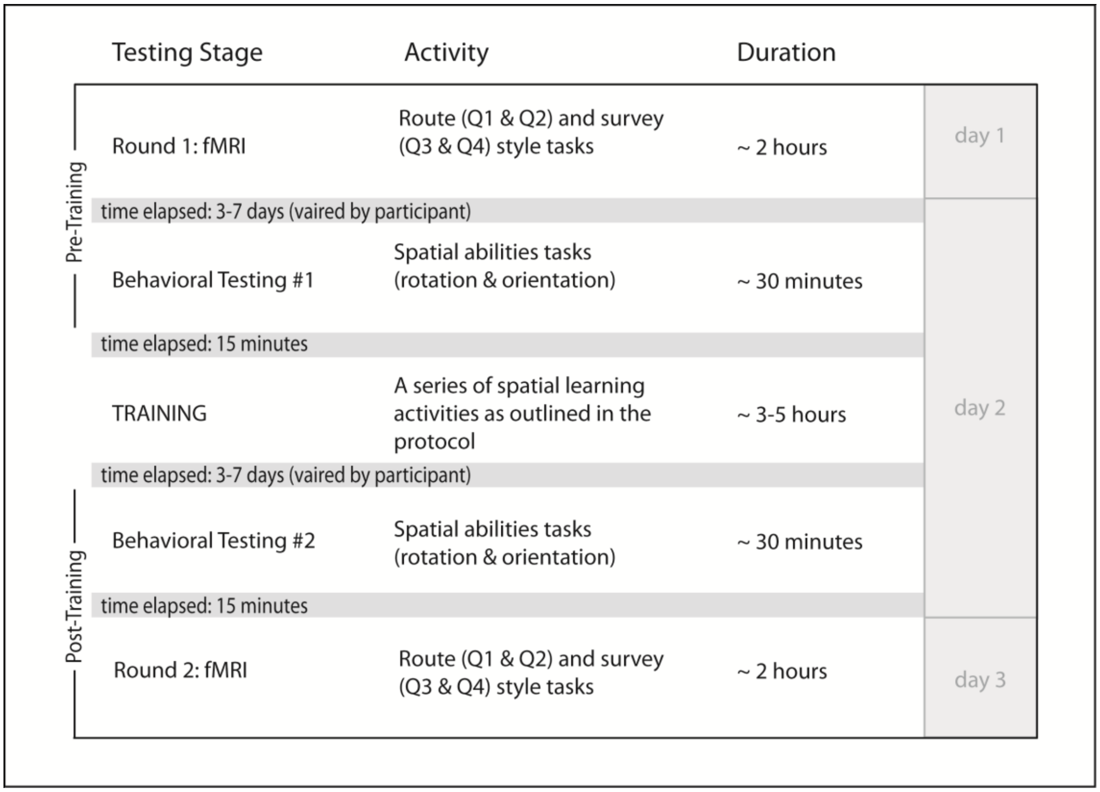
The maze is a physical wooden structure that was constructed and set-up on the lawn behind Johnson Hall, across from Johnson Lane, on the University of Oregon campus. Navigational map reading is a complex task and can be confounded by unpredictable events and distracters in the real-world (i.e. urban) environment. Therefore, the maze is used instead of actual city-blocks in order to establish some control over the testing environment. The experiment is designed to provide the same experience to each participant but still mimic the real-world as much as possible. The maze measures 40 x 40 feet and is constructed of wooden boards with paths that are large enough for the participant to walk through with a dog guide, but small enough that a single cane swath will detect the sides. A guide cane requires a physical tactile boundary (or lack thereof) for feedback to guide a straight walking path. The maze boards are 1.5 feet high so that a cane can easily detect the sides of the paths. The road blocks consist of large orange cones that are visible to dogs and detectable by cane.

Procedures

Participants. Five research participants were recruited for this study. All participants were female with a range of ages from 18-62. One participant was significantly visually impaired, requiring the use of a dog guide for travel. The other four participants were totally blind. Two of the totally blind participants were congenitally blind (or blind from birth) and the other two have been blind for over twenty-five years. Four of the five participants were dog guide users and one was a cane user.

This dissertation required a significant time commitment on the part of each participant. Each participant spent multiple hours on multiple days involved in research activities. The MR scanning took place at the Lewis Center for Neuroimaging and behavioral testing and training occurred in the Spatial and Map Cognition Research Lab, both located on the University of Oregon campus in Eugene, Oregon. Such a time commitment required that all participants were Eugene, OR residents. While the number of participants for this study may seem low, it is not uncommon for research conducted with a blind population to include between three and ten participants (Jacobson, 1992; Blades, Lippa, Golledge, Jacobson & Kitchin, 2002; Jansson, Juhasz & Cammilton, 2006).

Participant activity schedule. Activities were organized into three stages (see Figure 3.6). First, a pre-training testing phase gathered behavioral and neurological data. The second phase included development and administration of the training protocol. Third, a post-training testing phases gathered data to be compared with pre-training data. All participants followed the same activity phase order.



	Testing Stage	Activity	Duration	
Pre-Training	Round 1: fMRI	Route (Q1 & Q2) and survey (Q3 & Q4) style tasks	~ 2 hours	day 1
	time elapsed: 3-7 days (vaired by participant)			
	Behavioral Testing #1	Spatial abilities tasks (rotation & orientation)	~ 30 minutes	day 2
	time elapsed: 15 minutes			
	TRAINING	A series of spatial learning activities as outlined in the protocol	~ 3-5 hours	
	time elapsed: 3-7 days (vaired by participant)			
Post-Training	Behavioral Testing #2	Spatial abilities tasks (rotation & orientation)	~ 30 minutes	
	time elapsed: 15 minutes			
	Round 2: fMRI	Route (Q1 & Q2) and survey (Q3 & Q4) style tasks	~ 2 hours	day 3

Figure 3.6. Experimental timeline

fMRI testing: pre-scanning. Before the participants entered the scanner, the experiment was explained in full and each person had the opportunity to practice all the tasks they would be required to perform in the MR scanner. An example test graphic was presented to the subject and all of the map symbols explained. The subject was given as much time as needed to become familiar with the entire set of map symbols, as they will encounter those same symbols on every map stimulus. Next, the four experimental tasks and the control task were reviewed while the participant had the tactile map graphic in front of them. The participants were allowed to take as much time as needed to fully understand every question, and the participants were quizzed before the scanning commenced. Following the initial practice trial, a new test graphic was presented and the participants completed a small portion of the experiments with appropriate timing, mimicking the experience of performing the experiment in the scanner.

fMRI testing: MR scanning. The tactile stimuli, reinforced with a card stock backing, were presented in the scanner by placing them on a wooden board that sat on the participant's lap. The board was specifically designed to hold the experimental tactile graphics, ensuring that the participant could read the graphic with both hands and all fingers comfortably while in the MR scanner. A pair of specially designed shoes (flip flops) with a response button embedded in the toe recorded responses. The participant pushed the button corresponding to their answer (right/left) with their right or left big toe. The answers to the questions were designed for a binary response, either yes or no. A "yes" response corresponded with a right toe press and "no" response with a left toe press.

All of the instructions during the scanning were delivered auditorily. The auditory instructions were created using a text-to-speech synthesizer, Naturally Speaking. The order in which a participant experienced one block within a run (ten blocks) is as follows. The subject initially heard "begin map study" and a tactile map was simultaneously placed on the wooden board. The study period lasted for twenty seconds at which time the subject heard "stop." The tactile map was removed from the board and one of the four questions was read. The subject was given eight seconds to answer the question by pressing the left or right toe button. The same process was repeated for the three remaining questions. The subject was asked the control questions after all the experimental tasks were read. A ten second rest period was included at the end of each block. After the rest period, a new map was presented and the participant heard "begin map study," indicating the beginning of a new block. Each block lasted 74 seconds and each run lasted 12 minutes 33 seconds. A single experiment was composed of four runs. The experimental condition lasted 49 minutes and 32 seconds and the anatomical scan lasted eight minutes. The experiment was organized, coded and delivered using Presentation software. Presentation also gathered all of the response data, logging both actions and temporal sequence.

Behavioral testing. The behavioral testing, both pre- and post- sessions, took place on the same day as the training. The participants performed ten mental map rotation tasks, followed by the ten orientation tasks. The graphics were placed in front of the participant on a table consecutively. The reaction times were recorded using a stop-watch and the participants gave verbal answers to each task trial. No time limit was placed on any of the spatial abilities tasks.

Training. Each subject participated individually in the training over one day. The actual time spent on the training varied depending on the speed at which each participant learned the concepts and the lengths of appropriate breaks. The training protocol advanced depending on the needs of the participant and ran like a workshop, spending as much time as needed on each exercise until the participant had mastered it. The training protocol is presented on the next page and outlines in detail how the training was conducted.

The training protocol is presented in a lesson plan format. The lesson plan format provided step-by-step instructions that were repeated identically with each participant for experimental control. Secondarily, the lesson plan approach will allow the protocol to be disseminated to Orientation and Mobility teachers to use the training with their students who are blind or visually impaired. Each of the two modules begins with a brief discussion of why the underling concepts introduced through the activities are important and useful, followed by step by step instructions for each of the activities, and prompts to relate the activities to real-world.

Spatial Thinking Tactile Map Training Protocol

Module one: spatial vocabulary training. Spatial language allows people to express spatial experiences, talk about where things are, and how to get to them. Spatial language training may teach a person how to successfully acquire, organize, use, revise, and reuse knowledge of their environment through a natural language structure (Golledge et al., 2006). By creating a systematic interface that links what a person already knows how to do in space with the natural language they would use to describe it, a strong interconnected spatial problem-solving ‘network’ may be built. A spatial language network becomes the correspondence between environmental spaces and the cognitive framework of spatial knowledge and spatial decision-making. Spatial representations may require different modalities, but they are translated into a common format that is neither visual nor tactile but spatial. Language is the primary mechanisms for people who are blind to describe spatial experiences and it can be viewed as the linguistic image of external and internal representations of these experiences (Werner et al., 1997).

Module one: geometry training. Using a map to aid navigation, or planning navigational behaviors when the entire space cannot be seen or understood from a single point of view, may lead people to use a Euclidian type of geometric spatial reasoning with a Cartesian coordinate system, incorporating metric relations (Frank, 1996). While humans do use quantitative spatial information to aid in spatial decision making, our descriptions of space are without much reference to a formal coordinate system (Golledge, 1992). Instead, people store and recall spatial information in more simplistic manner that is a mix of quantitative and qualitative reasoning. For example, “my favorite coffee shop is close; just head up two blocks and turn right,” is a demonstration of concepts such as proximity and connectivity. Teaching people to define their navigational movements in terms of geometric shapes may reinforce concepts like connectivity. In addition, geometric and vocabulary training provide a guideline for solving spatial problems built on the spatial language structures described above. Explaining to a blind traveler that their environment and navigational movements can be described by shapes can perhaps enhance the spatial thinking processes.

Module one: activities.

Purpose of the lesson:

The purpose of this module is to give examples of what spatial skills blind or visual impaired people already possess, and begin to assign names and words to them. The lesson allows for a vocabulary to be built around spatial abilities, skills, and activities.

The lesson location: The classroom

Activity content of the lesson:

1. To pair common spatial terms with their “correct” counterparts of geographical concepts.
2. To demonstrate that the physical world is made up of geometric shapes and relationships.

Materials to be used:

1. Three objects: cup, stapler, eraser (or any set of identifiably different objects).
2. Cut out tactile geometric shapes.
3. Tactile map #1, triangle graphic.
4. Tactile map #2, map of city-like blocks.

There are six activities in this module denoted by a capital *A* and a number following it, example *A1*. After the activity is finished, it is followed by a discussion of how the lesson impacts what the student knows, what they have learned, or how it relates to tactile map reading. The discussion prompts are in the italic sections starting with *EXPLAIN*.

Lab Training

There will be four activities in this section.

A1) Place three objects on a table top arranged in a triangle. Take the hand of the student and guide it to complete the triangle of the object position starting with object A (lower right corner), up to B (top), down to C (lower right corner), and back to A. Do this a few times, then ask the student to go from object A to C. They will most likely move from A to C without going through B.

EXPLAIN: This is an example of how the person knows and possesses the following:

- *how to take shortcuts,*
- *has a sense of direction,*
- *geometry and geometric relationships,*

A2) Ask the person to explain why they do not run into their coffee table at home (or any other object in an individual's personal space).

EXPLAIN: This is an example of their

- *mental map*

- *distance estimation*
- *direction estimation*

FURTHER EXPLANATION: When spaces are large, it can be difficult to accurately form a mental map, maintain correct orientation, and make correct directional decisions. Maps can aid in this process.

A4) Place the triangle map in front of the student. Show how the locations of the small, filled in triangle, square and circle can represent the three objects on the table.

FURTHER EXPLANATION: Maps are representations of the location of objects in the world around us. Maps may not tell us where all environmental objects are located because they are simplifications. But they do lay out the organization of world, like city blocks, and we can learn the general shapes of the environment.

A5) Place the cut out geometric shapes in front of the student for them to explore. Ask them to identify the shapes by name. Use geometric tactile shapes to give examples of what kinds of shapes the environment can be made up of. Ask them for an example of something in the real environment that is that shape; or a route that they take frequently that is a shape of one of the geometric objects.

EXPLAIN: Example: 'L' shaped route are half of a city block, 'U' shaped routes can take them around a series of blocks, zig-zag of series of blocks

A6) Give them tactile map #2 to study. Show how the geometric shapes fit into the map and make up the environment.

EXPLAIN: The environment can be described by geometric shapes, as well as the patterns we make when we navigate.

Module two: allocentric frame of reference. A rotation task may be used to teach an allocentric perspective and strategy because it allows the participant to practice perceiving and manipulating spatial information from an external, top-down point of view. A blind navigator may not be well versed in taking a top-down perspective (or imagining the environment from allocentric map-like view) as a lack of vision may impede perception of the real-world in this way (Klatzky et al., 1995). Much of the navigation training that currently takes place with people who are blind is from an egocentric centered model, by memorizing routes or knowing a list of navigational directions (like those given by a GPS). Having a person who is blind or visually impaired practice mental manipulations of environmental objects from an allocentric perspective may lead to the strengthening of, and adoption of, allocentric encoding and strategy use after training.

Module two: egocentric frame of reference. An orientation task may be used to teach and strengthen an egocentric frame of reference because it instructs people how to manipulate their imagined body orientation and subsequently imagine how the environment will look afterwards. A blind navigator may use an egocentric strategy predominantly, but they may not have a well defined connection between body rotations and environmental updating. As noted above, current navigational training often results in a play by play list of directions that are memorized and followed. Having a person who is blind or visually impaired practice body and environment orientations may strengthen egocentric encoding and strategy use, but it may also help a blind person relate the environment to their personal body space in a more sophisticated way.

Module two: activities.

Purpose of the lesson:

To train people how to better use frames of reference (egocentric and allocentric perspective taking).

The lesson location: In the classroom and outdoors.

Activity content of the lesson:

1. To practice mental map rotation and indication of the cardinal direction of objects on the map as it rotates.
2. To practice body rotations and environmental updating.
3. To use tactile maps to navigate in a real-world setting.

Materials to be used:

1. Allocentric training material set.
2. Egocentric training material set.
3. Navigational map set.

Lab Training

There are six activities in this section.

A1) Use the first set of maps in the allocentric materials packet (6 maps) and ask the student to practice mental map rotation. Instructions: Is the map on the right flipped? Do the task a few times. Ask them how they did the task. What was their strategy?

A2) Use the second set of maps and ask the student to identify if the circle is north or south of the square in the rotated map on the right. If they have trouble, refer the student to the map on the left which is oriented north up. Proceed through the 6 maps. The activity becomes more difficult as the angle of rotation increases through the set of maps.

A3) Use the third set of maps to engage in the same activity but change the question by asking about the cardinal directional relationship between different features on the map. For example, is the filled in circle north or south of the square, is the square north or south of the triangle, etc. Again, if the student has trouble, have them refer to the north up map on the left.

EXPLAIN: Understanding the directional relationship of objects in the environment is needed when you have to make a return trip, and all of the environmental objects are now on your opposite side. People who are blind/VI need environmental objects to help them navigate (especially if lost or disoriented), so understanding and being able to rotate the map in relation to the environment is critical.

A4) Use the first set of maps in the egocentric materials (6 maps) and ask the student to practice body orientation. Instructions: Imagine you are standing at the triangle facing in the direction of the tip. Is the direction of the square on your right or left? Ask them how they did the task. What was their strategy?

A5) Use the second set of maps but change the instructions slightly. Ask the student to imagine standing at a map feature (square) facing in the direction of a second map feature (circle), ask if the third map feature is to their left or to their right. Ask the same orientation question as above multiple times by changing the map feature you ask them to imagine standing at, facing, and indicating direction. The task becomes more difficult as they have to imagine different body orientations with no directional arrow help.

A6) Use the third set of maps and explain to the students that the map features are real landmarks. The circle with the cross in it is an intersection, the circle a school, the square a park. Ask the student to imagine standing at the intersection; and ask them if the school on their left or right? The task potentially becomes more difficult to correctly answer with additional features that are not necessary to correctly answer the task. The task also becomes a real-world map reading exercise with the inclusion of definitions of the map graphic features as landmarks.

EXPLAIN: Part of using a map as a tool is understanding how your egocentric space and the map are related. The ability to manipulate your viewer perspective (either egocentric (first-person) or allocentric (top down-birds eye view)) can be taught. We have the ability to go from one perspective to another. The orientation task is an example of an egocentric perspective and the mental rotation task requires you to take an allocentric perspective. Next explain how each task is useful in map reading.

Outdoor Training

Build the outdoor maze. The maze will be 40 x 40 feet. During the outside map reading, use a clipboard to provide a hard surface so the student can read the tactile map. The student will not carry the map as they navigate but they should always have access it.

There are three activities in this section.

A1) Use the set of maps (3 maps) with routes shown on them. Ask the student to find and follow the route displayed on the map in the maze environment.

A2) Use the second set of maps without the routes to have the student find their own routes between the two indicated map features. Indicate to the student the start point and have them navigate to the end point.

A3) Place the road block cones in the maze where they are indicated on the maps. Change the location of the road blocks between each navigational trial. Indicate the start point to the student and have them navigate to the end point without going through any of the road blocks.

EXPLAIN: Is the alternative path the 'shortest' path? If they do not make the shortest path show what that path would be. What type of geometric shape do they make? This is another way of showing how we can think of our environment as consisting of geometric objects and this can help us organize the world to navigate efficiently within it. When navigating with maps, we engage in both allocentric and egocentric perspective taking. To read tactile maps well for navigational purposes we must turn top-down map information into first person movement.

CHAPTER IV

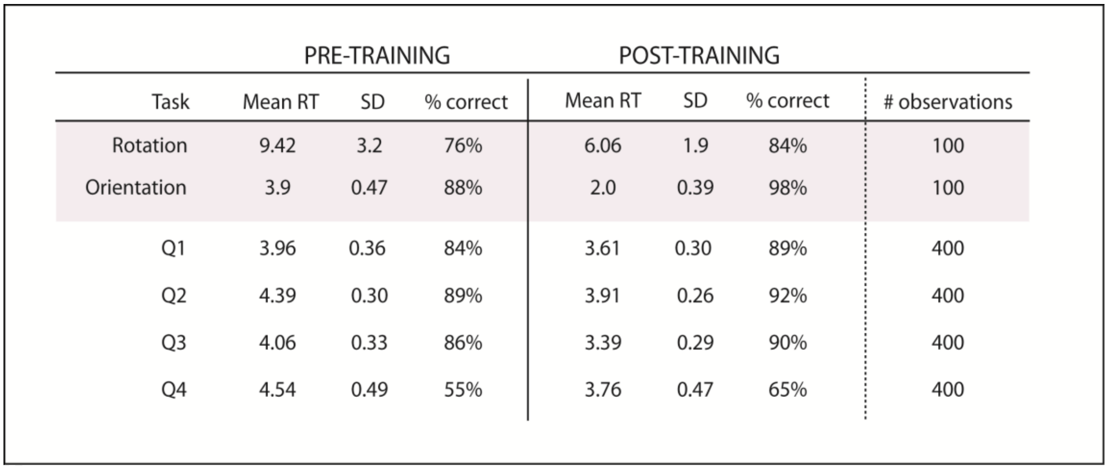
RESULTS

Results for the experiments are reported in two sections. The first section reports the behavioral results for all of the experimental tasks, pre- and post- training. The second section describes how functional MRI works, the fMRI data analysis procedures and outlines the basic anatomy of the brain and vocabulary used to describe locations in the human brain in reference to functional activation. In addition, the neurological results for the round one, pre-training fMRI experiment and the round two, post-training fMRI testing are included in the second section. Experimental results will be interpreted in Chapter Five, Discussion.

Behavioral Data Analysis

The behavioral data collected in the Spatial and Map Cognition Research Lab (SMCRL) and the Lewis Center for Neuroimaging (LCNI) have been analyzed to identify reaction times, standard deviations, and percent correct for each task. A small sample population, coupled with a relatively small number of observations, precludes the use of traditional statistical analysis to investigate post-training learning effect. With a small data set, this project cannot make many of assumptions of classical statistics, such as a normal distribution. The data are therefore, reported by descriptive statistics in pre- and post- training categories to highlight the observed differences after training (see Table 4.1).

Table 4.1: Behavioral data



	PRE-TRAINING			POST-TRAINING			
Task	Mean RT	SD	% correct	Mean RT	SD	% correct	# observations
Rotation	9.42	3.2	76%	6.06	1.9	84%	100
Orientation	3.9	0.47	88%	2.0	0.39	98%	100
Q1	3.96	0.36	84%	3.61	0.30	89%	400
Q2	4.39	0.30	89%	3.91	0.26	92%	400
Q3	4.06	0.33	86%	3.39	0.29	90%	400
Q4	4.54	0.49	55%	3.76	0.47	65%	400

Note. The mean reaction times are in seconds. Questions 1-4 are the tasks delivered in the scanner and rotation and orientation are tasks delivered in a laboratory setting.

The rotation task has the longest mean reaction time both pre- and post- training, 9.42 and 6.06, seconds respectively. The mean reaction time for the orientation task is 3.9 seconds, which is similar to the mean reaction time of the other pre-training tasks, (ranging from 3.96 - 4.54 seconds), but the mean reaction time for the orientation task demonstrates the greatest post-training decrease (down to 2.0 seconds). The range of values for the rotation task is larger than that of all of the other tasks, which can be seen in both the standard deviation and in the observed range of values. As evidence by the changes in pre-and post-training statistics, and in data visualization (Figure 4.1), the range in response for all experimental tasks both narrows and shifts to smaller values. All of the fMRI tasks share similar mean reaction times in pre-training with a range between 3.96 and 4.54 seconds, and post-training with a range between 3.30 and 3.91. The reaction times for the fMRI tasks become shorter in post-training, but these reductions are smaller than those observed for the SMCRL lab tasks. Overall, the range of reaction time values for the fMRI tasks is smaller than the range for the lab tasks. This difference is most likely due to the fact that participants were given a maximum of 8 seconds to complete the tasks, whereas the SMCRL lab testing allowed participants unlimited completion time.

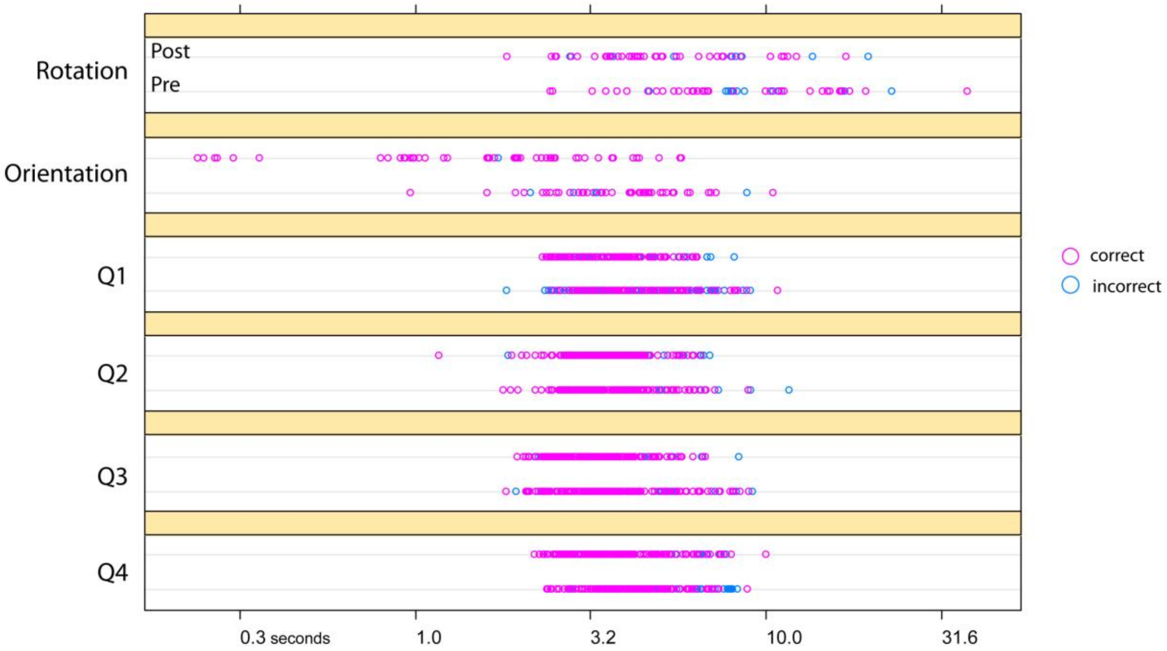


Figure 4.1. The lattice plot displays the logged reaction times.

The percentage of all tasks answered correctly, except fMRI question four, demonstrate that the participants did much better than chance with a range of 84-89% correct in pre-training testing and improved by four percentage points or more after training to a range of 89-92% correct. The fourth fMRI task stands out from this trend. Before training, participants answered question four correctly only 55% of time. While correctness did increase ten percentage points after training, maintaining the trend of improvement, the range of values remains different from the rest of the experimental tasks. The participants demonstrated a larger improvement in the SMCRL administered tasks than the fMRI tasks 1-3. The pre- and post- training percentage range of correct responses for the rotation task is 76% to 84% and orientation is 88% to 98%.

fMRI Data Analysis

The development of the fMRI data acquisition technique, using the blood oxygen level-dependant (BOLD) method, has provided researchers with the ability to localize brain activity and subsequently link that activation to specific known cognitive processes defined by previous research. In this project fMRI is used to identify patterns of brain activation during map reading and then make comparisons of those patterns of activations within and between tasks and subjects.

The goal of fMRI, also referred to as functional neuroimaging, is to map the activity of the living brain. Functional MRI measures vascular parameters such as cerebral blood oxygenation. The physiological basis of this method is the fact that brain cell activity is associated with changes in glucose and oxygen consumption through what is known as neurovascular coupling in cerebral blood flow (CBF) (Kim & Ugurbil, 1997). When a subject conducts a task, the result is an increase in neural activity within a particular area of the brain, which corresponds to an increase in the cells' metabolic rate and an increase in the amount of cerebral blood flow. If blood flow surpasses the oxygen metabolism, less oxygen is removed from the blood and blood oxygenation increases. The magnetic resonance (MR) signal is sensitive to this change due to the paramagnetic properties of deoxyhemoglobin. The BOLD method identifies areas of the brain that show changes in deoxyhemoglobin levels. Regions with greater oxygenated blood proportional to deoxygenated blood appear brighter in an MR image (Buxton, 2002).

The MR and fMRI scanning for this project was performed on a three Tesla (3T) scanner with a head only, fast switching gradient coil. An initial high resolution anatomical MR scan was taken to determine the structural configuration of each subject's brain, followed by a set of functional scans. The functional scans consisted of a series of thirty-two four millimeter thick, horizontal functional brain scans, also known as slices or volumes, which were taken every 2.1 seconds. The scan was taken while the subject performed experimental tasks, controls, and rests. Each slice consisted of 3.125 x 3.125mm volume elements known as voxels (with 64 x 64 voxels in each slice). Each voxel contains data in the form of a series of intensity values (sampled once every 2.1 seconds) which reflect the brain's activation over time. This series of activations for a single voxel, or region of voxels, is known as a time course.

The fMRI data underwent a series of preprocessing analysis steps. One series was performed using FSL (a library of processing tools for fMRI data). Preprocessing within FSL first corrected the data for three-dimensional head motion. Next, the data were subjected to temporal filtering to eliminate non-brain activity related changes or drifts. Spatial smoothing was done with an 8mm isotropic Gaussian kernel (consistent with preprocessing standards in the field).

Preprocessing outside of FSL required three steps, which included spike check, spike patch and the utilization of Artfind. These three preprocessing analysis steps are data cleaning measures. Spike check inspected and identified volumes with spikes (when more than 150 voxels within a volume were found to be activated at a confidence level of 0.03 difference away from the mean). Spike patch removed the spiked volumes and replaced them with an interpolation of the volumes directly above and below. Artfind identified artifacts in the data due to motion and identified the time of the event, creating an explanatory variable (EV) file or a time course of the event. The event variables where then added to the general linear model (GLM) as a confound explanatory variable. Motion in fMRI is often mistaken for activation associated with a task. Therefore, it is important to remove activation that is caused by movement, as opposed to an experimental task, by identifying these artifacts in time.

fMRI Data analysis procedures. The project used a GLM hypothesis-driven analysis to identify activated voxels (Fristion, Holmes, Worsely, Frith & Frackowiak, 1995). A statistical neural model is built for each subject and condition based on the events. The reaction time for each event (e.g. each trial) is first modeled with a square wave whose width is equal to the reaction time. During this period of time, the subject is engaged in cognitive processing specific to the task at hand and one should therefore observe task-specific neural processing during this period. However, since the BOLD response is delayed by an average of six seconds relative to the neural events giving rise to it, the initial reaction-time-defined neural response is convolved with a model of the hemodynamic response (defined as the response to a briefly presented external stimulus). This operation results in a slightly delayed neural model for each event.

The hypothesis was tested by contrasting the experimental condition activation verses the control condition activation for each of the four task questions. For each voxel, if the activation for the experimental condition is greater than that of the control condition for a given statistical threshold it appears as a colored voxel. The collection of all colored voxels in all brain slices are known as a statistical brain map. The statistical brain maps illustrate which voxels have the highest likelihood of being activated by the tasks, based on the observations of this experiment. The statistical brain maps shown in this dissertation are averaged across all subjects for each task pre- and post- training. The individual subject data was reviewed and no one subject's neurological activation skewed the averaged data (see Appendix A). The threshold probability for this experiment is $p < 0.05$. The pre-training data has a z-score threshold of 5 and the post-training data is set to 3.5 (further explanation for differing thresholds pre/post training below).

The final step of data analysis was to register each participant's anatomical image and functional data to the standard space of the MNI (Montreal Neurological Institute) brain. The MNI brain is an average of 250 brain scans processed to identify known brain landmarks, resulting in a robust coordinate system. The coordinate system is composed of x,y and z values for each hemisphere independently. Registering each brain to a standard space and using the coordinate values for functional identification minimizes the difficulty in identifying and defining brain regions across subjects and increases the accuracy of multi-subject averaging. The brain regions reported here have been identified and cross referenced with MNI coordinates, the Harvard-Oxford probabilistic atlas (Desikan, Segonne, Fischl, Quinn, Dickerson, Blacker, Buckner, Dale, Maguire, Hyman, Albert, & Killiany, 2006) and the *Atlas of the Human Brain* (Mai, Assheuer, Pazinos, 2004).

Brain Regions. The human brain is divided into large regions called lobes, or well-defined portions of the brain. The major lobes are the occipital, parietal, temporal, and frontal. The frontal and parietal lobes are split by the motor and sensory motor strips (see Figure 4.2). The brain can further be discussed in terms of its two hemispheres, right and left. The term bilateral refers to activation being in both the right and left hemispheres.

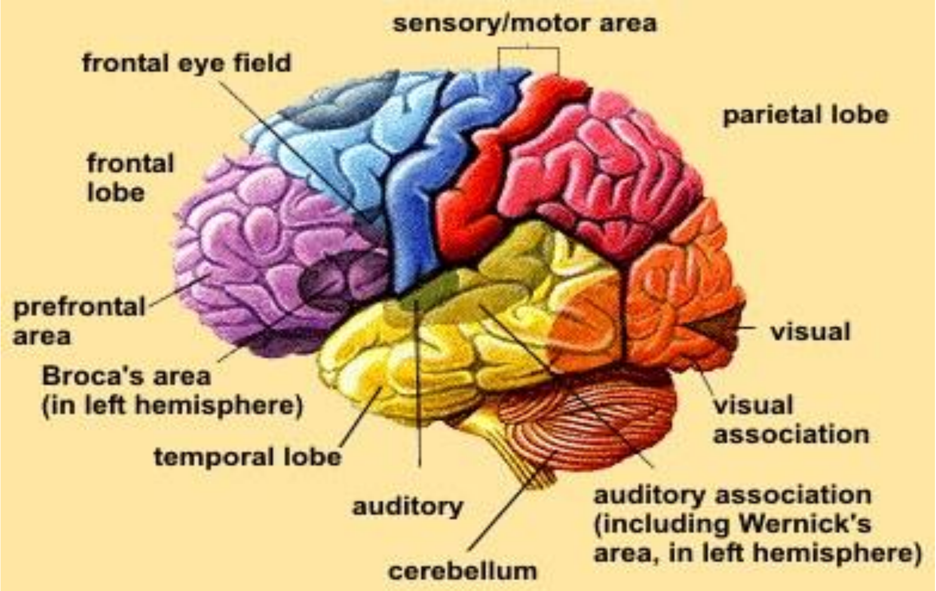


Figure 4.2: Brain Regions from the *Psychology Careers and Educational Resource Center*.

The brain is subsequently sub-divided with use of anatomical terms of location. Anterior is a term that means toward the front of the body, while posterior describes anatomy that is toward the back. Dorsal means toward the top of the head and ventral (or inferior) means towards the bottom of the body, or in this case towards the shoulders. Medial describes anatomy that is towards the inside of the brain and lateral means towards the outside of the brain. Brain regions run through relatively long portions within a single lobe and the Montreal Neurological Institute x, y and z coordinates provide more precise locational identification of neurological activations.

The human brain has recognizable physical features, much like the physical formations of the earth, and these features are often used to describe which portion of the identified brain region is active. A sulcus is a depression in the surface of the brain and is found in conjunction with the gyrus that is the convolution of the surface caused by the folding of the cortex (see Figure 4.3). The gyri are bound by the sulci and vice versa. Large sulci that divide the brain into lobes are called fissures. A lobule is a smaller portion of a lobe and it can be difficult to precisely distinguish this feature without dissection (yet this term is used frequently).

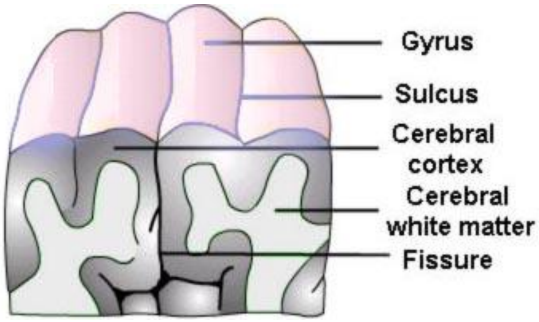
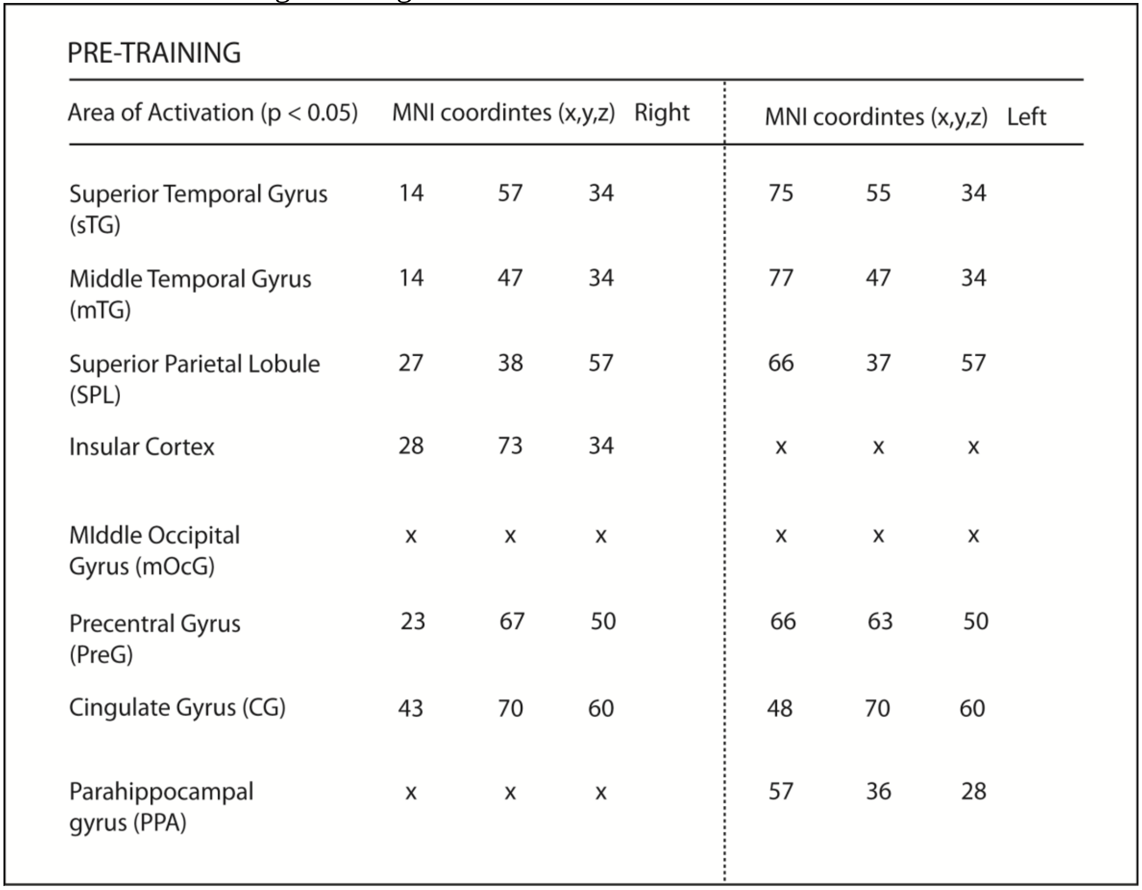


Figure 4.3: Brain Formations from *St. Petersburg Center for Interdisciplinary Neuroscience*.

Pre-training activations. The neurological results (see Figure 4.4) are reported by indicating the Montreal Neurological Institute coordinates of the significant areas of brain activations for the pre-training fMRI testing session (see Table 4.2). The reported locations of activation are based on the activated brain region that are present for all tasks in round one scanning. The z-score reports the highest intensity value for the voxel cluster of activation. The right and left labels indicate the MNI coordinates for the right and left hemisphere. The statistical brain maps (see Figure 4.5) present the activations for each task by area of activations as indicated by the crosshairs. xThe highest z-score in the cluster for each task's activation is noted at the bottom of each image. Due to the human brain not being symmetrical (and the functional areas covering a number of voxels), the corresponding functional brain areas in the left and right hemisphere may not share exact x, y, z locations.

Table 4.2: Pre-training neurological activations



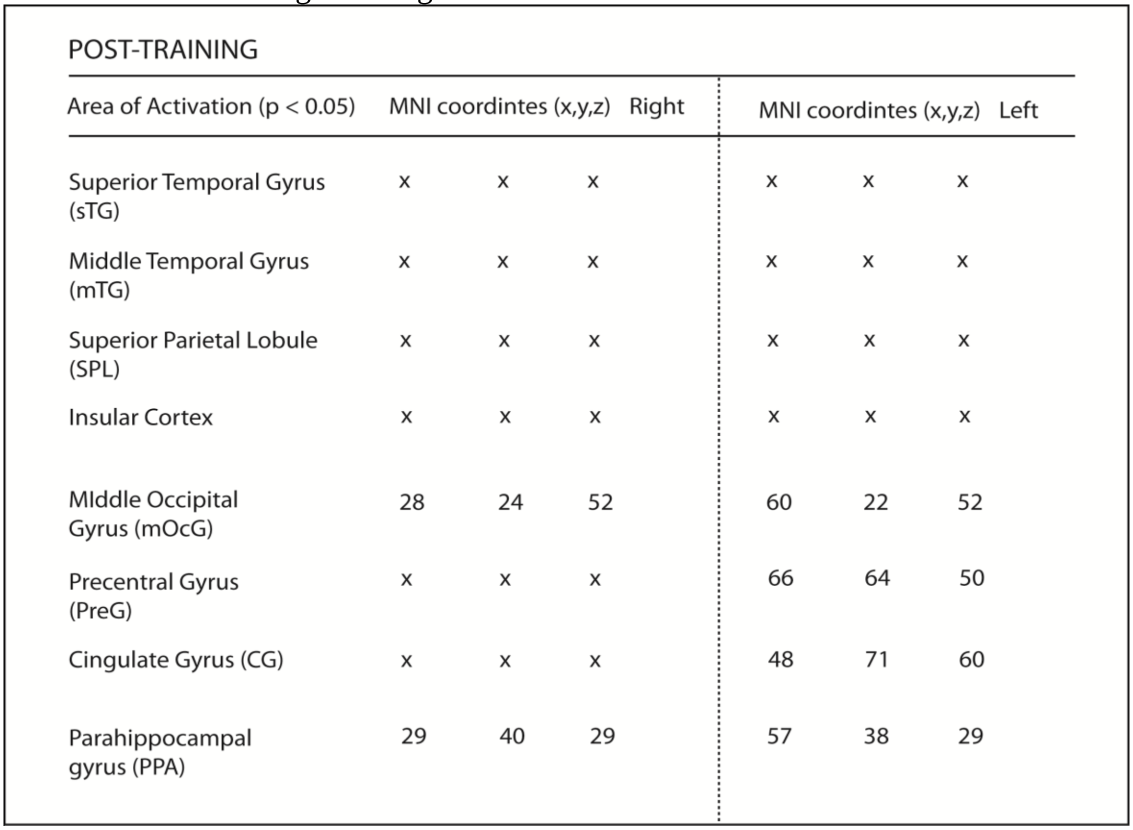
PRE-TRAINING

Area of Activation ($p < 0.05$)	MNI coordintes (x,y,z) Right			MNI coordintes (x,y,z) Left		
Superior Temporal Gyrus (sTG)	14	57	34	75	55	34
Middle Temporal Gyrus (mTG)	14	47	34	77	47	34
Superior Parietal Lobule (SPL)	27	38	57	66	37	57
Insular Cortex	28	73	34	x	x	x
MIddle Occipital Gyrus (mOcG)	x	x	x	x	x	x
Precentral Gyrus (PreG)	23	67	50	66	63	50
Cingulate Gyrus (CG)	43	70	60	48	70	60
Parahippocampal gyrus (PPA)	x	x	x	57	36	28

The results for the pre-training fMRI scanning session include robust activation running from the superior temporal gyrus (sTG) into the middle temporal gyrus (mTG) bilaterally. The superior parietal lobule (SPL) activation is also bilateral, while the insular cortex activation is found unilaterally on the right side. Activation in the precentral gyrus (PreG), also known as the primary motor cortex, is bilateral for all tasks in the pre-training scanning session. Activation in the cingulate gyrus (CG) is located near the front of the brain and is functionally identified as an area that is located along the hemispheric division, although in the literature it is not common to speak of it in terms of hemispheric specificity. The parahippocampal gyrus (PPA) activation is small and located unilaterally in the left hemisphere

Post-training activations. The post-training activations are reported in the same way as the pre-training by providing the Montreal Neurological Institute coordinate for areas of activations that are shared by all the tasks in round two verses the control condition (see Table 4.3). The threshold for the round two testing session is set to 3.5, which is lower than for round one which is set to five. Decreases in activation intensities are noted when mental skills become more efficient in route and survey processing due to strategy choice (Shelton & Gabrieli, 2004). In order to identify the brain areas that are active during round two (post-training) a lower threshold is required. The statistical brain maps indicate which tasks are associated with specific functional areas and their resulting z-scores (see Figure 4.6).

Table 4.3: Post-training neurological activations



POST-TRAINING

Area of Activation ($p < 0.05$)	MNI coordintes (x,y,z) Right			MNI coordintes (x,y,z) Left		
Superior Temporal Gyrus (sTG)	x	x	x	x	x	x
Middle Temporal Gyrus (mTG)	x	x	x	x	x	x
Superior Parietal Lobule (SPL)	x	x	x	x	x	x
Insular Cortex	x	x	x	x	x	x
MIddle Occipital Gyrus (mOcG)	28	24	52	60	22	52
Precentral Gyrus (PreG)	x	x	x	66	64	50
Cingulate Gyrus (CG)	x	x	x	48	71	60
Parahippocampal gyrus (PPA)	29	40	29	57	38	29

Neurological activation for the post-training scanning session includes robust activation in the middle occipital gyrus (mOcG) bilaterally. Activation in the precentral gyrus (PreG) and cingulate gyrus are unilateral in the left hemisphere. Parahippocampal gyrus activation is bilateral for all tasks in the post-training fMRI testing session.

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Figure 4.4. Statistical brain maps of neurological activations by task for pre-training and post-training fMRI.

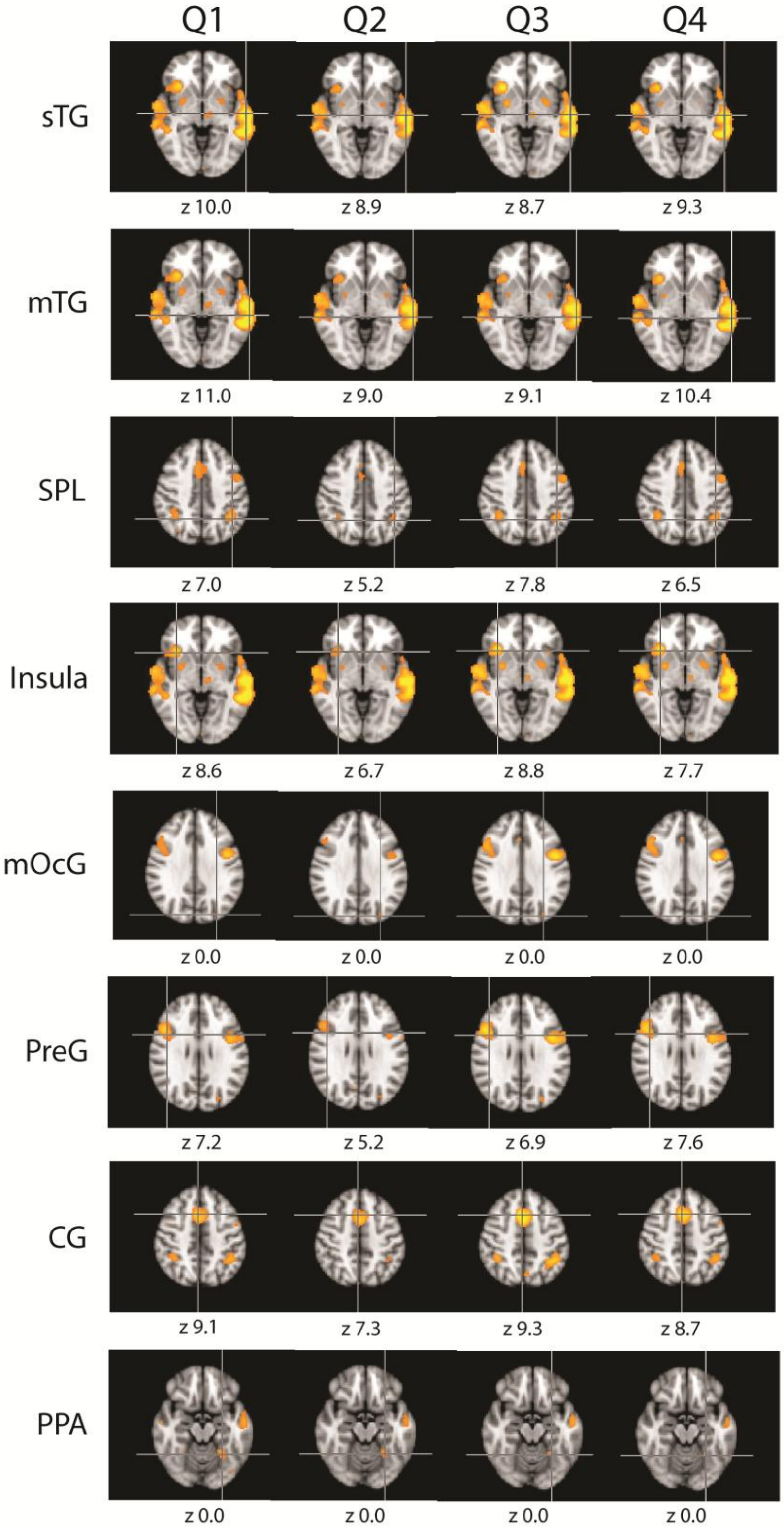


Figure 4.5. Statistical brain maps of neurological activations by task for the pre-training fMRI.

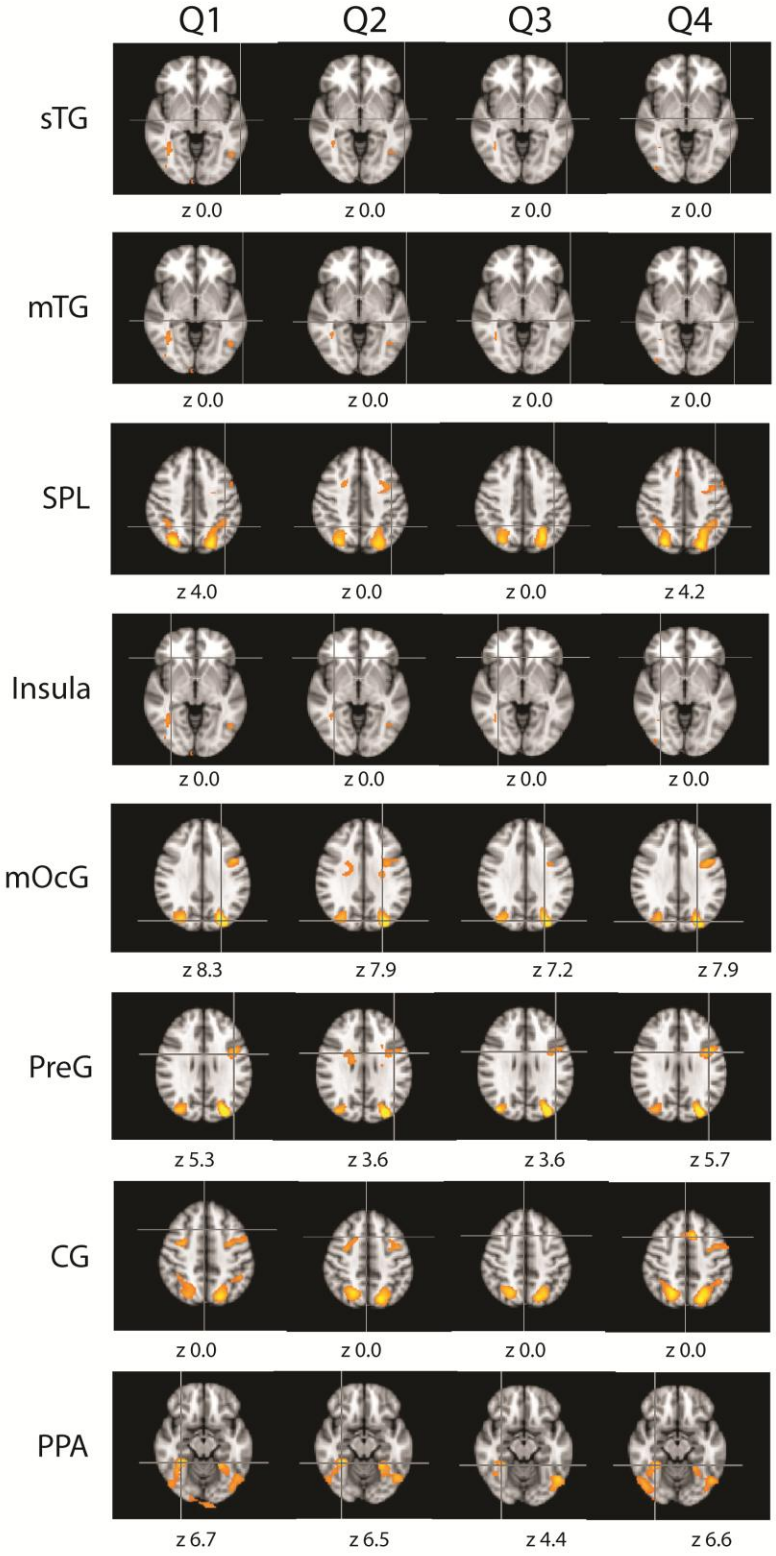


Figure 4.6. Statistical brain maps of neurological activation by task for the post-training fMRI.

CHAPTER V

DISCUSSION

The discussion of experimental results is organized into two sections. The first section provides an overview of the primary findings from the fMRI testing sessions, followed by a discussion of the neurological results for both the pre-training scanning and the post-training scanning. The first section concludes by discussing the neurological brain activations that the pre- and post- training scanning sessions share. Next, the second section provides remarks about the learning effects produced by the administration of the spatial thinking tactile map training protocol and how these learning effects relate to a blind population.

fMRI Testing

To isolate the differences in brain activity associated with route/survey knowledge processing, previous studies have used an instructed or forced perspective technique, isolating the neurological differences in ego/allocentric networks. This technique is useful as it highlights the neurological differences in the two processing systems. This dissertation draws from previous research that has isolated the neurological networks used in egocentric/route and allocentric/survey processing to define the cognitive processes used to solve the task questions administered in this project. But telling a person to take a route or survey perspective negates the discovery of differences in skills and strategies that people naturally adopt (Waller, 2000; Ishikawa & Montello, 2006). By not indicating or forcing a perspective, this dissertation will demonstrate the cognitive processes that participants spontaneously adopted to answer the task questions before and after training, and therefore suggest the strategies that are being used and how they differ.

The neurological data in the pre-training fMRI testing result in remarkably similar activations across all four of the task questions (see Figure 4.4). The post-training neurological task results are strikingly similar between tasks as well, but the neurological patterns of activation are different for pre- and post- training scanning results (see Figure 4.4). Based on the differences in neurological processing between pre- and post- training scanning sessions, this research demonstrates that all participants used a single dominant egocentric/route strategy to answer all of the task questions presented to them in round one fMRI testing, and a dominant allocentric/survey strategy to answer both route and survey questions in round two (as discussed in detail below).

The route-survey dichotomy appears to be strong, but this discovery does not reflect route-survey knowledge occurring along task lines (as seen in previous studies). Nor does the route-survey task dichotomy appear as a function of training (i.e. once a participant learns how to use ego/allocentric perspectives, they will appropriately choose them to solve route versus. survey knowledge task questions). Instead, the route-survey dichotomy is revealed between pre- and post- training fMRI results. Neurological evidence supports a hypothesis that people have the ability to use different spatial strategies to answer a variety of map reading tasks. This evidence also demonstrates that spatial knowledge is not a rigid structure in which spatial information is encoded and recalled. But instead strategies and spatial knowledge are flexible problem-solving systems.

Neurological findings for pre-training scanning. The pre-training, round one fMRI results strongly indicate a route strategy adoption for all tasks based on the neural networks present based on knowledge of neural activation associated with these processes. Activation in the parahippocampal gyrus (PPA), cingulate cortex (CG), insular cortex, superior parietal lobule (SPL), precentral gyrus (PreG), superior temporal gyrus (sTG) and middle temporal gyrus (mTG) are known for their role in supporting an Egocentric/route perspective. While each of the areas noted above play a significant role in supporting egocentric behavioral strategies, the combined recruitment of these areas tells a larger, perhaps more significant story about egocentric encoding and strategy use (Shelton & Gabrieli, 2002). The following section discusses the neurological activations found for round one fMRI testing by looking at previous studies that have found similar activations (or combinations of activations), the behaviors those neurological activations are known to support, and suggests why these activations may be present in this study for an egocentric/route strategy.

The results from pre-training neurological testing demonstrate small, left hemisphere PPA activation. The parahippocampal cortex (PPA) is well known for its role in scene recognition, such as cityscapes, landscapes, rooms, and even artificially constructed scenes with Legos® (Epstein, Graham & Downing, 2003; Epstein, Parker, & Feiler, 2007). The PPA is also integral for mental imagery of place (O’Craven & Kanwisher, 2000), and shapes imagined mental navigation (Rosenbaum, Ziegler, Winocur, Grady & Moscovitch, 2004). Activation in the PPA for this study is found as a mechanism for recalling the encoded map environment. But the small, unilateral activation suggests that participants were not dominantly relying on or using a well-formed cognitive map of the map environment as a whole before training occurred. Instead, the map environment may be recalled in route segments from an egocentric point-of-view, as supported by the strong activation in the cingulate cortex.

Previous studies have found activation in the cingulate cortex in conjunction with the parahippocampal cortex for processing the mental imagination of navigation from a route perspective (Hartley, Maguire, Spiers & Burgess, 2003; Wolbers, Weiller, & Buchel, 2004; Ghaem, Emmanuel, Fabrice, Tzourio, Bernard, Alain & Michel, 1997). The cingulate cortex is noted for its involvement when a person takes an egocentric vantage point to determine the appropriate direction of travel (Epstein, 2008). Head direction cells located in the cingulate gyrus are used for controlling egocentric planned movement. The cingulate gyrus was recruited for this study to support encoding of routes and translating that information to allow a person to imagine body orientations for intended travel. The combination of parahippocampal gyrus and cingulate gyrus for this research suggests that participants took the cognitive map information and transformed it into egocentric/route segment information (Iaria, Chen, Guariglia, Ptito & Petrides, 2007).

The right hemisphere activation in the insula may play a connective role between an egocentric navigational perspective (primarily controlled by the cingulate gyrus) and planning spatial, goal-directed movement controlled by the superior parietal lobule. The insular cortex has been cited in previous studies as a mechanism controlling egocentric frames of reference and self-awareness (Bottini, Kamath, Valler, Sterzi, Frith, Frackowiak & Paulesu, 2001). The insula is part of the vestibular system (a sensory system that leads to contributions about movement and sense of balance) and is involved in the internal representation of space from a sensory or bodily awareness point of view.

Activation in the precentral gyrus is bilateral for all tasks in round one, pre-training scanning. The precentral gyrus is more commonly known as the primary motor cortex. The motor cortex is an area of the brain that is involved in the planning, control, and execution of voluntary motor functions. Studies have demonstrated that most of the regions that are active during overt movement, such as the motor and parietal cortices, are active during mental simulation of the same movement (Grafton, Fagg, Woods & Arbib, 1996). Interestingly, the motor and somatosensory cortices are not active during standing, either real or imagined. These areas only become active during imagined locomotion (Jahn, Deutschalander, Stephan, Strupp, Wiesmann & Brandt, 2004). The significant precentral gyrus activation demonstrates that participants imagine themselves walking. The inclusion of parietal lobe activation found in this study, in conjunction with the primary motor cortex, may be due to participants planning and executing imagined navigational movement.

The integration of motor areas and parietal cortices are further implemented in first-person perspective imagined actions (Marzoli, Mitaritonna, Maretto, Carluccio & Tommasi, 2011). In particular, first-person movement perspectives show increased activations in the left parietal lobule and the precentral gyrus (Grezes & Decety, 2001). Jeannerod (1994) suggests that motor imagery refers to first-person processes involving both kinesthetic (motor simulation of one’s own body) and visual representations; whereas, visual imagery from a third-person perspective involves processes noted for visual representation only (controlled by the occipital cortex). The parietal activation reflects the important role of this region in programming a person’s intended movements, which can be translated into actual movements when necessary (Ruby & Decety, 2001).

The largest and most noteworthy activation for pre-training scanning results occurred in the superior and middle temporal gyri bilaterally. Shelton & Gabrieli (2002) found robust activation bilaterally in the medial areas of the temporal lobe during route encoding. Similar activation is reported by Mellet, Bricogne, Tzourio-Mazoyer, Ghaem, Petit, Zago, Etard, Berthoz, Mazoyer & Denis (2000) during retrieval of route information. The combination of middle temporal activation with left hemispheric parahippocampal gyrus is reported for spatial episodic memory or retrieval of spatial information in non-topographical manor (Speirs, Burgess, Hartley, Vargha-Khadem & O'Keefe, 2001; Burgess, Maguire, Speirs & O'Keefe, 2001). Route strategies require participants to link a sequence of movements through an environment (beginning, middle, and end). The entire layout of space may be extracted like successive steps bound together (Shelton & Gabrieli, 2002). Previous findings of robust superior and middle temporal activation for route tasks may reflect this area's role in supporting the ability to update one's local environment as he or she moves (or imagines moving) through space (Shelton & Gabrieli, 2002). For this study, the superior temporal gyrus and middle temporal gyrus activation suggests that after planning and imagining navigational movement the participants are updating the imagined environment based on the routes and landmarks they memorized from the stimuli.

Middle temporal activation has also been shown to be involved in semantic processing of pictures (Vandenberghe, Gillis, Van Leemputte, VanHecke, Vanstapel & Hespel, 1996). Mellet et al. (2000) found middle temporal gyrus (mTG) activation during the mental scanning of internal representations built from language, but not when images were learned exclusively from maps. The mTG activation in this study may result from participants making lists of map features and/or lists of the relationships between the map features. Participants may use the list of the landmarks (or map symbols) to determine how they would follow a route between the landmarks. Creating a list of navigational instructions would be a logical strategy for the participants in this study because making or asking for specific navigational instructions is a technique that they would have been taught to do in Orientation and Mobility training (Ungar, Blades & Spencer, 2001).

To summarize, when using an egocentric/route strategy to answer a map reading question, the combination of the above mentioned brain activations support the following story: first, the encoded map environment is recalled as a series of routes (controlled by parahippocampal gyrus) and a person orients themselves within the imagined environment in an egocentric perspective (controlled by cingulate gyrus), next a person plans how they would travel between landmarks (controlled by superior parietal lobule) based on a set of navigational instruction (controlled by middle temporal gyrus) and subsequently imagines themselves walking through the environment (controlled by precentral gyrus), as a person imagines herself/himself walking they update the imagined scene (controlled by superior temporal gyrus and middle temporal gyrus).

The use of a dominant route strategy for pre-training suggest that using a map, which is encountered from a survey perspective and has the potential of forcing participants to encode the environment from a survey perspective, does not always led to allocentric spatial encoding. Interacting with the physical stimuli is separated from the mental processes of spatial problem-solving. It would appear that the process of encoding and recalling spatial information is influenced by pre-established egocentric problem-solving techniques. Often, virtual environments are used for creating stimuli to test for the difference between route and survey perspectives. For example, the virtual environment creates two scenes from either a top-down perspective or a first person out, and mimics the changes a person would experience from viewing an environment from those different perspectives. This dissertation demonstrates that route and survey strategy choice can be tested from a single map environment without a forced perspective or perspective specific instructions.

Neurological findings for post-training scanning. The significant activations for all tasks in the second round of neurological testing strongly suggest a change from an egocentric/route strategy to a dominant allocentric/route strategy. The neural networks of parahippocampal gyrus (PPA) and occipital gyrus are known to support a survey perspective, while the precentral gyrus is known to be involved with mental rotation activities. While the first round of testing also shares PPA and precentral gyrus activations, the specific combination of these three brain regions tell a story of allocentric-route processing. The following section discusses previous studies that have found activations (or combinations of activations) similar to post-training testing, the behaviors those neurological activations are known to support, and suggests why these behaviors are present in this study.

The second round of testing demonstrates bilateral activation in the parahippocampal gyrus that is larger and recruits more voxels in the defined functional brain region. Bilateral PPA activity is shown during environmental retrieval tasks (Iaria et al., 2007), or when a person is using a mental map and remembering specific information about routes and landmarks. The PPA seems to be activated for information processing from both a route and survey perspective (although more active when participants imagine a cognitive map-like view). The PPA encodes every aspect of a scene into one, large fixed object (a mental map), in contrast to other areas in the hippocampus that appear to encode specific objects (Lee, Buckley, Pegman, Spiers, Scahill, Gaffan, Bussey,Davies, Kapur, Hodges & Graham, 2005). Bilateral activation in the PPA for the second round of testing demonstrates that participants are recalling the map environment in a well formed cognitive map format from a top-down, allocentric perspective. The tactile map training appears to have influenced the participants' ability to encode and recall the map information from a top-down, whole map view.

The dominant activation for round two is bilateral middle occipital gyrus (mOcG). The middle occipital gyrus is implicated in tasks that require spatial mental imagery (Mellet et al., 2000) and is hypothesized to be crucial for retrieval of visual images (Aguirre & D'Esposito, 1999). The combination of parahippocampal gyrus and occipital gyrus are noted for their importance in perception of visual scenes (Epstien & Kanwisher, 1998) and when scenes are brought to mind (Epstein & Ward, 2010), strongly suggesting that these areas create a processing stream for visuospatial memory retrieval and imagery (Shelton & Gabrieli, 2002; Burgess et al., 2001; Epstein et al., 2007). In this dissertation, the combination of bilateral PPA and bilateral mOcG strongly suggests that the participants constructed a mental map and imagined the spatial layout in their minds. These results suggest that people who are blind have the ability to form mental spatial images, imagine the spatial layout in a pictorial way, and retrieve information from that image.

The inclusion of precentral gyrus (PreG) activation in the post-training scanning results suggests that participants imagine movement. In the previous section, the precentral gyrus was noted for imagined locomotion or walking. It is the combination of the superior parietal lobule with the precentral gyrus that provides critical evidence for imagined walking navigational movement. The post-training fMRI results indicate that the precentral gyrus may be activated as imagined movement of the environment and not the body. The PreG is also known to be recruited for mental rotation tasks (Rinck et al., 2000) and motor processes are an inherent part of the mental rotation of a number of different objects, such as imagined scenes (Vingerhoets, Santens, Van Laere, Lahorte, Dierckx & De Reuck, 2001; Gauthier, Hayward, Tarr, Anderson, Skudlarski & Gore, 2002). A mental rotation task was used in the training protocol to aid participants in developing allocentric perspective skills and the manipulation of environmental objects from a top-down view. These results indicate that the participants not only learned how to take an allocentric perspective but also how to mentally manipulate an external environment.

When a survey strategy is used, a person encodes the environment as one large, global structure rather than updating the environment relative to one’s bodily orientation in space (Shelton & Gabrieli, 2002). A survey perspective and strategy may be limited to extrapersonal space and may induce participants to treat the environment more like a map rather than a local, navigable environment. Therefore, they may pay greater attention to global properties and the use of those properties in the processes of building a complete representation of the stimuli into a mental map (controlled by the PPA). The mental map is then recalled as an image in the participant’s mind’s eye (controlled by the mOcG) and mental manipulations of the environmental features follow to aid in making spatial judgments (controlled by the PreG)

Neurological findings shared by pre- and post- training scanning. The cingulate cortex (CG) activation is dominant in round one, and is also active in round two for question four. The CG is known for its function when a person is converting back and forth between ego and allocentric representation (Maguire, 2001; Iaria et al., 2007). The CG may make it possible for us to relate local scenes to an allocentric spatial representation such as a cognitive map. This network is well-positioned to translate between egocentric and allocentric spatial codes. The combination of the CG with other functional neuroanatomy may be the complementary components of the spatial processing system, providing allocentric heading direction and egocentric imagery information (Rosenbaum et al., 2004). Different dominant strategies may be used before and after training, but as noted in the literature review people have the ability to use route and survey knowledge interchangeably. Not only can people use both perspectives as strategies, but may combine the two types of spatial knowledge unknowingly to aid in best answering the question at hand. The presence of CG activation provides evidence that map reading is a complex behavior, and that people will use all of their cognitive resources.

The superior parietal lobule (SPL) is activated bilaterally for all questions in the pre-training scanning results, and is noted for controlling the planning of navigational body movements and spatial orientation (Marzoli et al., 2011). Activation in the SPL is also present bilaterally for questions one and four in the post-training fMRI scanning session. Shelton and Gabrieli (2002) suggest that survey encoding recurites a subset of brain areas that support and control route encoding, including the parietal cortex. The act of encoding and using route and survey information are both inherriently spatial processes that may require brain areas known to control larger, more general spatial functionality. The SPL is a functional brain region that is part of an executive system that controls spatial working memory (D'Esposito, Detre, Alsop, Shin, Atlas, & Grossman). The SPL may be present for both route and survey processing because of the demands these cognitive processes place on spatial memory. It is the differences in brain activation between the two rounds of testing that hightlight two different types of spatial information systems.

Both pre- and post-training rounds share precentral gyrus activation, though bilateral in pre-training and unilateral in the left hemisphere in post-training. The primary motor area is noted previously in the discussion for its involvement in imagined first-person, egocentric perspective imagined movement. Lorey, Bischoff, Pilgramm, Stark, Munzert & Zentgra (2009) report that an egocentric, first-person perspective results in stronger activation in the motor cortex (and motor related areas such as the parietal). But Lorey et al. (2009) do show small amounts of activation in motor areas for allocentric perspective tasks. The motor cortex, besides imagined body movement, is also noted for its recruitment during mental rotation tasks (Richter, Somorjai, Summers, Menon, Gati, Georgopoulos, Tegeler, Ugurbil, & Kim, 2000). A mental rotation task, or a visual-mental rotation exercise, engages a participant in imagining objects being rotated in their mind's eye. Internal manipulations of map elements may be necessary for both an egocentric and an allocentric perspective. The activation in the precentral gyrus may be active in round one for a different reason than round two. Many functional areas of the brain are used for multiple types of cognitive processing.

In both rounds, the parahippocampal gyrus (PPA) activation is present, but it is not as large or strong as other areas of activation. The PPA's important role in spatial processing warrants its lengthy discussion, even though the activations in this project are not as large as in other similar projects that investigate route-survey knowledge. Perhaps activation in the PPA is small due to its dominant role in the representation of local scenes (Epstein & Kanwisher, 1998), and in the evidence that this area responds strongly only after participants have learned a larger spatial framework (Wolbers & Buchel, 2005). In this study, each map is viewed for only twenty seconds, leading to smaller activations due to less time spent learning the environment. Another possibility is that previous studies investigating the PPA have used pictures, videos, and virtual environments. This study uses maps as representation of place, instead of pictures of a place itself. One other known study that uses a geographic-style map is Blanch, Brennan, Condon, Santosh & Hadley (2004); they used a pictorial map of Maestricht, the Netherlands, of unknown date or origin. While it seems like common knowledge to geographers that maps would be recognized as places, maps are much less studied in the neuroimaging literature. The neurological evidence in this study suggests that maps and mental maps are processed in similar ways to pictures.

Learning

This dissertation adds to the current literature providing evidence that without training people who are blind will use an egocentric strategy to answer a variety of map reading questions, even if the strategy is less efficient or effective. These findings are replicated in the tactile mapping literature reviewed in Chapter Two and further supported by studies investigating strategies for recognizing and navigating new environments (Fletcher, 1980), coding environmental information (Millar 1981, 1982, 1988), and memory of spatial locations (Gaunet, Marinez & Thinus-Blanc, 1997). A dominant egocentric strategy in all of the above mentioned contexts may be due to the sequential characteristics of the haptic modality, which leads people who are blind to encode an environment in successive reference to their own body before executing spatial inference between objects (Simonnet, Guinard & Tisseau, 2006). Or perhaps an egocentric strategy dominates because Orientation and Mobility training focuses mainly on route learning (Ungar et al., 2001), providing people who are blind or visually impaired with egocentric learned behavior.

The spatial knowledge development literature argue that an egocentric frame of reference is recruited first, followed by an allocentric frame of reference. This dissertation is consistant with traditional spatial knowledge developmental models that suggest egocentric/route processes are developed before allocentric/route processes. Previous studies contend that a lack of vision may prohibit the complete development of an allocentric frame of reference and could be to blame for the difficulty that people who are blind have progressing past egocentric world views (Klatzky et al., 1995). However, the findings from this study provide strong evidence that vision is not essential for building allocentric spatial representations. Rather, a lack of education and training seems to be preventing people who are blind from readily using allocentric strategies.

The former statement provides additional evidence for and is supported by the Difference theory. The difference theory states that blind and visually impaired persons have the same spatial abilities as persons with sight. The differences, both qualitatively and quantitatively, are due to lack of access to information and experience (Passini & Proulx, 1988; Golledge, 1993). Ontogenetic spatial development is slowed down but it is not prohibited. The Difference theory has been supported by a number of studies including those that discuss performance on spatial tasks including distance estimation and rotation (Klatzky & Golledge, 1995), the ability to effectively learn novel routes and perform map recreation tasks (Blades, Lippa, Golledge, Jacobson & Kitchin, 2002), and the ability of children to make distance estimates on tactile maps (Ungar & Blades, 1994). This dissertation adds to existing Difference theory literature by demonstrating improvement in leaning sophisticated spatial strategies after access to instruction. This study also provides functional neural data associated with learning. This research is a good example of how fMRI can highlight the effects of learning new strategies and their employment on previously performed tasks.

One difficulty in studying large-scale spatial learning is the identification of different strategies and how the adoption of those strategies leads to successful performance (Denis et al., 1999). For example, Shelton and Gabrieli (2004) demonstrate that a less effective strategy (demonstrated through increased cortical activity) was not accompanided by large behavioral differences once other (perhaps better) strategies were adopted. Relying on behavioral data alone may not reveal how training affects a participant’s ability to learn new strategies or when they will use them. But the mixed method approach used in this research examines the complex behaviors of learning by effectively asking two different research questions, one specifically addressing strategy use and another about performance. The collection of neurological data allows this study to pinpoint strategy qualitatively and is not bound by constraints of behavioral data. A combination of the neurological data that demonstrates participants’ strategies changed after training, coupled with improved behavioral performance, provides evidence that strategy choice does influence successful performance. The two data sets complement one another and are more meaningful together than alone.

The behavioral data alone cannot deliver strong evidence that strategy adoption led to improved performance. But the training did appear to influence performance on spatial abilities tasks. The spatial thinking training protocol used the spatial abilities as a mechanism to train the participants in perspective taking and environmental manipulations. It is therefore not surprising that the participants' performance on the spatial abilities tasks improved as they had extensive exposure to the task types. Overall, the spatial thinking tactile map reading protocol positively affected the cognitive processes used to answer all experimental tasks that resulted in improved behavioral performance on all tasks in the behavioral and neurological testing (as demonstrated in Figure 5.3).

Figure 5.1. A mosaic plot showing the proportions of correct versus incorrect answers for all experimental tasks pre- and post- training.

But do the results show the brain of a "better performer" after training? In adherence with developmental models, a more advanced level of geographic knowledge is shown in the neurological data after training. But this finding may also suggest that survey knowledge is always better to use than route knowledge; that assumption may not be true. Instead, the best approach lies in knowing when to use a particular strategy to best answer a given question. The results presented in this dissertation do not reflect that training aids a participant in choosing different strategies (that may be most helpful) for different map reading tasks. If it did, the results would have reflected one dominant statistical brain map for the pre-training fMRI results and then differing neurological results for different task questions in round two.

The above results beg the question of why the participants do not choose different spatial strategies based on task demands. Or, why is there no task route-survey dichotomy after training as performance increases? Etchamendy and Bohbot (2007) show that good navigators are participants who choose ego/allocentric strategies based on the demands of the task. One explanation is that the participants in this research could be classified as successful learners, but still do not possess the cognitive flexibility to efficiently shift from between the egocentric/route and allocentric/survey processing systems. Perhaps this fluid shift requires practice and experience. A further explanation is in the adoption of spontaneous strategies, which implies that people do not specifically choose a strategy out of the whole range of possibilities, but rather strategy choice is more automated and potentially influenced by recent experience. These explanations strengthen the argument that training and education are essential to aiding people who are blind in spatial performance.

Training

The training protocol consisted of a series of activities as outlined in Chapter Three. While no data was collected on any of the training actives, the participants did not demonstrate particular difficulty performing the tasks. That is not to say that every participant correctly answered every training task question the first time, but there were no obvious outliers as far as a participant that had difficulty performing the activities or a particular task that a majority of participants had difficulty completing. The time it took for each participant to go through the training did vary, but the differences were mainly due to the individual differences in pacing going through the training and number of breaks taken.

Anecdotally, the training did not appear to be overly challenging for the participants. A number of the participants commented that the training would be useful for children, or people who are newly blind, leaning to read tactile maps and navigate. Although the activities did not prove difficult to do as evident by ability to finish the activities, the training did have an effect on the participants' ability to use an allocentric/route spatial strategy. The results from this dissertation suggest that allocentric/survey spatial strategies are not difficult for adults who are blind to learn and maters. But rather that the participants had not encountered instruction on how to process map information in an allocentric/survey way.

Perhaps a more sophisticated training protocol would help adults that may have some prior map reading experience and good navigational abilities understand and use spatial strategies to an even greater extent. As noted above, the training did not result in the participants varying the spatial strategy used after training. The cognitive flexibility required to effortlessly switch between the two spatial strategies may be taught with a more difficult training regime.

CHAPTER VI

CONCLUSIONS

This dissertation draws a series of conclusions under three main topics. The first set of conclusions address the effects of the spatial thinking tactile map training protocol. The second set applies to the theoretical model presented in Chapter Two addressing the two streams of cognitive processing based on frames of reference and route and survey knowledge. The third provides concluding remarks about spatial knowledge structures and spatial problem-solving strategies. First, recall the research questions.

> **#1**. Are there significant brain activation *differences/similarities* between two survey and two route style tactile map task questions?
>
> **#2**. What is the extent to which training protocol affects neurological activity during performance on the same survey/ route style tactile map use tasks in research question #1?
>
> **#3**. What is the extent to which a training protocol improves behavioral performance on tactile reading tasks from question #1 and two geographic spatial abilities tasks?
>
> **#4**. Can valid and reliable tactile versions of pervious vision-based geographic spatial abilities and map use tasks be designed and developed?

The first primary conclusion is that the spatial thinking tactile map reading protocol did indeed influence the neurological activity observed for the map reading task questions (research question two), and led to improved behavioral performance both in the MR scanner and the laboratory on spatial abilities tasks (research question three). These results provide evidence that people who are blind and visually impaired have the ability to learn sophisticated spatial strategies. The participants were all capable of learning to use external coding strategies, which require an allocentric frame of reference to guide behavior when answering tactile map reading questions. In conjunction with this adoption of allocentric/survey strategies, improved performance is observed, and this study has provided evidence in regards to a notoriously difficult research questions addressing whether strategy choice influences successful performance.

What this dissertation has been unable to tease out is which part of the training (vocabulary, geometry, or frames of reference) is responsible for the observed learning effects. The thrust of the project was to investigate whether training would improve performance and affect neurological activity, which it did. But the capability of direct correlation to specific sections within the training protocol cannot be made. As the field of spatial thinking continues to mature, this dissertation provides evidence that teaching the processes of thinking spatially has an observed effect on a number of different spatial problem-solving behaviors. Further research is needed not only to systematically test each section of the training protocol, but also to identify individual spatial thinking skills and their relationship to map use in both sighted and blind populations.

The second primary conclusion is that there are two streams of cognitive processing that are supported and influenced by frames of reference. The two streams, an egocentric/route processing network and an allocentric/survey-processing network, have both been identified through observed neurological differences and verified by previous literature. These two cognitive processing systems have been identified, in this study, as a function of training, not as a function of a route-survey task dichotomy. Chapter Two presents a model that suggests the two streams of cognitive processing are fundamentally supported by frames of reference and include spatial abilities, mental transformation models, and spatial knowledge structures. This argument produced a hypothesis of a parallel model, wherein people have the ability to switch between the two cognitive processing streams with ease. But without a task dichotomy, this dissertation cannot suggest that spatial abilities, mental models, and spatial knowledge exist within the steams of processing, because the three areas noted above have all been identified and defined based on task difference.

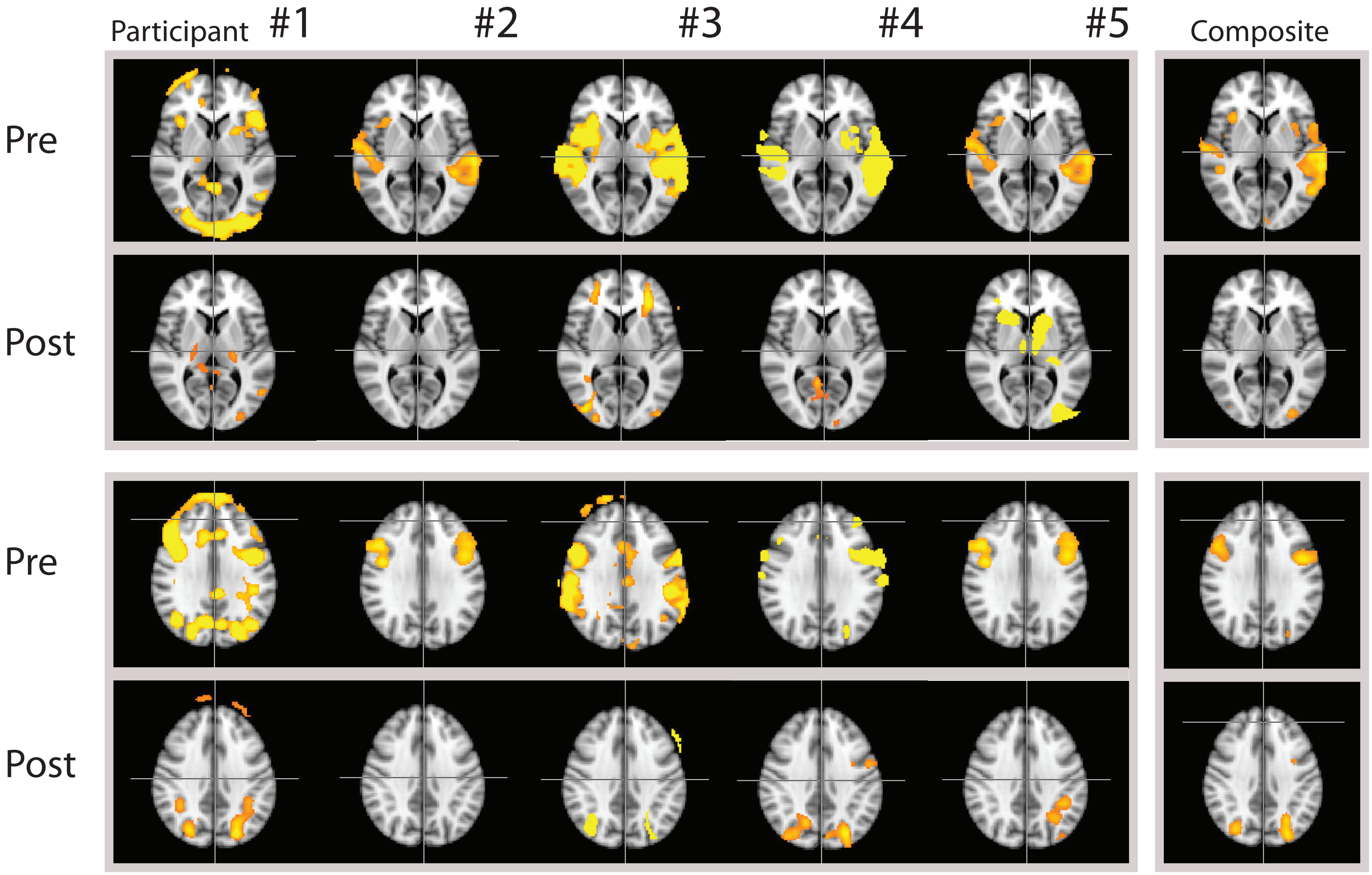
All of the tactile stimuli developed for this dissertation are discriminable and legible (research question four), a contention supported by the evidence that the participants could perform tasks adequately, as demonstrated by the behavioral statistics. This lack of a task dichotomy is not due to modality issues of interacting with the physical tactile graphics. It is, however, possible that the map task questions used in the MR scanning portions of the experiment did not test what they were designed for. This project is guided by the current theoretical standards, which hold that route and survey knowledge are distinct and can be tested for with appropriate tasks. Due to the unobserved task differences, this dissertation cannot suggest that the map reading task questions are truly valid and reliable. These nuances speak to the overwhelming importance of extensive testing for both validity and environmental reliability when developing tasks to test human behavior.

In addition to task development issues, this dissertation concludes that the traditional models of spatial knowledge development are particularly strong for a blind and visually impaired population. The results indicate that the participants may have had underdeveloped egocentric/route strategy use before training. After training, they were capable of using and or choosing an allocentric/survey strategy. As addressed in the discussion section, it is puzzling why the participants were unable to use both egocentric/route and allocentric/survey knowledge interchangeably after training, as it is clear they could use both processing systems.

Therefore, the third (and potentially contentious) conclusion of this dissertation is that traditional theories of route and survey knowledge may require second thought. Perhaps spatial knowledge does not function as an overarching structure, which can be tapped into with appropriate task questions. Instead, perhaps route and survey knowledge function more like strategies. People apply knowledge about the environment and their bodies based on experience and practice. But, the extent to which knowledge structures differ from strategies is difficult to define. The dissertation results speak most strongly to the use of cognitive strategies on map reading questions, suggesting knowledge does not develop until a person has practiced using both cognitive systems outlined above. But additional research addressing route and survey knowledge structures and strategies are open for future inquiry.

APPENDIX

INDIVIDUAL SUBJECT DATA



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