In-Car Navigation Systems: The Effects of Landmark Specificity and Map Rotation on Spatial Knowledge and Route Acquisition

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IN-CAR NAVIGATION SYSTEMS: THE EFFECTS OF LANDMARK SPECIFICITY
AND MAP ROTATION ON SPATIAL KNOWLEDGE AND ROUTE ACQUISITION

A thesis submitted in partial fulfillment
of the requirements for the degree of
Master of Science

By

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B. S., Denison University, 2004

2008
Wright State University
Wright State University

SCHOOL OF GRADUATE STUDIES

13 DECEMBER, 2007

I HEREBY RECOMMEND THAT THE THESIS PREPARED UNDER MY SUPERVISION BY Tiffany Saffell ENTITLED In-Car Navigation Systems: The Effects of Landmark Specificity and Map Rotation on Spatial Knowledge Acquisition BE ACCEPTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF Master of Science.

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ABSTRACT

Saffell, Tiffany N., M.S., Human Factors and Industrial/Organizational Psychology Program, Department of Psychology, Wright State University, 2008.

In-Car Navigation Systems: The Effects of Landmark Specificity and Map Rotation on Spatial Knowledge and Route Acquisition.

Current in-car navigation systems do not refer to environmental landmarks when providing directions to drivers. Instead, they provide guidance by presenting drivers with distance-to-turn information. Default displays use track-up map orientations. These display conditions do not facilitate the acquisition of spatial knowledge. As a consequence, drivers using these systems are unlikely to acquire spatial knowledge needed to judge the reasonableness of the directions they are receiving, leaving them susceptible to accepting directions that are grossly incorrect and dangerous (Forbes & Burnett, 2007). Landmarks have been shown to be critical sources of information when people acquire both route and configural spatial knowledge. By providing landmark information, route and configural knowledge acquisition could potentially be enhanced.

Two experiments compared the use of specific landmarks versus generic landmarks. Measures of both configural and route knowledge were obtained. Landmarks were presented either generically or specifically in voice directions or as visual icons on the display. Both Hunt’s distinctiveness theory (1993, 2003) and Paivio’s dual-coding theory (1973, 2006) indicate that participants hearing specific voice directions while simultaneously viewing specific visual icons would perform better than those experiencing the other combinations. The two experiments produced conflicting results. Experiment 1 found large effects of both landmark specificity and map orientation.
Participants acquired better configural spatial knowledge with specific than generic visual icons. Also, north-up maps led to better configural spatial knowledge than track-up maps. Experiment 2, which modified the procedure somewhat, found no reliable differences.
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I. INTRODUCTION

*GPS and In-Vehicle Navigation Systems*

In-vehicle navigation systems are increasingly being used to provide navigation information to drivers. These microprocessor systems use electronic street and road maps together with satellite global positioning information to locate a driver’s current position on the map and to guide him or her to a specified location. These systems appear to help drivers navigate in unfamiliar places. However, current systems also fail in ways that create serious problems. For example, Forbes and Burnett (2007) surveyed drivers who used in-vehicle navigation systems. They found that 82% of the drivers reported that their system gave them incorrect or inefficient directions. Forty-three percent had received dangerous or illegal route guidance instructions. Twenty-three percent of these drivers followed those directions. Forbes and Burnett could not attribute these errors to any demographics variable they measured, although older drivers were more susceptible to follow the dangerous or illegal instructions than younger drivers.

These mistakes appear to arise from drivers depending too much on the route guidance directions, which only give localized very specific spatial information at the time of required maneuvers, limiting the extent to which drivers obtain general spatial knowledge of the environment. Because these systems deliver just in time information, giving drivers directions just prior to when the directions should be executed, drivers do not have much time to analyze the impact of executing a system-proposed maneuver. There is not enough time for drivers’ “common sense” to override. Sometimes, there is
also not enough time for drivers to find and read signs. In a recent review of the Magellan750M system the driver commented that “There were moments during my trip, especially when driving small roads late at night, when I didn't really have a sense of where I was. I followed the prompts much as a pilot might follow instruments when flying through a fog bank. It got me where I wanted to go, but I worry that future generations of drivers may lose all sense of where they are and may not notice that the lake has no bridge” (Magid, 2007, ¶10). The commenter had been directed by the Magellan system to drive through the middle of a lake that had no bridge. Loss of knowing where you are may lead to dangerous driving errors such as trying to drive over a non-existent bridge or errors such as those reported by Forbes and Burnett (2007).

Driving errors in their study included, but were not limited to, driving onto roads with vehicle restrictions, driving onto pedestrian walkways, tramways, fjords, rivers, or woodland areas, or performing other prohibited maneuvers.

In our research, we asked participants about their experience with in-vehicle navigation systems. A sample of comments appears in Table 1. We classified these comments into two broad classes of problems. First, there are local view problems. Comments 1, 2, 3, 4, and 5 are examples. The complete set of comments can be seen in Appendix A. There are also attention and mental workload problems. The local view problems are examples of poor directions given to the driver by the in-vehicle navigation system. The in-vehicle navigation system misdirected the drivers or sent them on an inefficient path and they realized it too late. Thus, the local view problem does not allow drivers to make informed decisions about whether the navigation system is being
inefficient or wrong. It also does not provide the driver with information needed to navigate without minute by minute directions from the system.

Comments 6, 7, 8, and 9 in Table 1 are examples of potential attention and mental workload problems. Sometimes, drivers report having difficulty using the system while driving. Others cannot drive at all while using the system. This may occur because in order to use the navigation system information drivers must pay attention to it at critical times. For example, the information is provided just before a turn with little or no

Table 1
*Subjective User Complaints about In-Vehicle Navigation Systems*

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<tr>
<th>Comment Number/ Comment</th>
<th>Local View Problems</th>
<th>Mental Workload Problems</th>
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<td>1</td>
<td>It took us the longest route possible to get there. When I realized where we were, I could have gotten there a lot faster with my own directions</td>
<td>Sometimes I get confused if the automated system fails to talk to me. But while looking at the screen, I get confused most of the time.</td>
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<td>2</td>
<td>Didn't always choose the best path.</td>
<td>Sometimes the GPS system got a little confusing and didn't have any alternative routes I could not navigate with it unless my passenger was the one operating it.</td>
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<td>3</td>
<td>Sometimes it takes you the long way around for getting to a destination</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>It sometime required unnecesary &quot;U&quot; turns</td>
<td>It's hard to read and drive at the same time and I had to pull over and take it out of my car so it could find a satellite</td>
</tr>
<tr>
<td>5</td>
<td>Told different way to go even though I knew a shorter way</td>
<td></td>
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preview. Thus, drivers are faced with taking in new information at the same time that they are maneuvering the vehicle, avoiding cross traffic and pedestrians. These local view and mental workload problems could be ameliorated by providing information that allows drivers to learn more about the spatial environment and by providing it in a manner that reduced mental workload at critical periods.

One way to address local view and mental workload problems is to provide the information people need to acquire configural spatial knowledge, as well as route guidance information. Configural knowledge is one of the three types of spatial knowledge described by Siegel and White (1975). The other two types are landmark knowledge and route knowledge. The next section reviews the theoretical and empirical literature on spatial knowledge and the importance of landmarks in all three types of spatial knowledge. The second section discusses why in-vehicle navigation systems make certain errors and how the acquisition of configural knowledge could aid in overcoming in-vehicle navigation system direction errors. The third section discusses driver attention on in-vehicle navigation systems while driving and how acquisition of configural knowledge could decrease the attention on in-vehicle navigation systems. The fourth section reviews distinctiveness and how it potentially relates to landmark usage. The fifth section is a more comprehensive review of current in-vehicle navigation systems. It describes the current state of the systems and describes potential evolutionary paths for future development. Finally, in the last section the theoretical issues identified are related to potential future in-vehicle navigational system designs.
Spatial Knowledge Types

Landmark spatial knowledge is the knowledge about important or distinguishable objects or features of an environment. Landmark knowledge merely refers to the ability to use uniquely identified items in the environment as points of reference. Besides providing a type of spatial knowledge by itself, landmarks are important components of both route and configural spatial knowledge.

Route spatial knowledge is knowledge about the actions that must be performed to get from one location to another, the route. Thus, the point to point steps are known, but the overall layout is not. People merely know what actions to take at the locations of critical points. Landmarks are used as the critical points in the makeup of a mental representation of a route (Hirtle & Heidorn, 1993; Siegel & White, 1975; Tversky, 1993). A person can acquire route knowledge on their own or they can acquire route knowledge through verbal or written instructions from another person. Therefore, a person could acquire route knowledge by driving a route or can acquire route information via other forms of media.

Finally, configural spatial knowledge, which also has been called survey spatial knowledge, is knowledge of the spatial layout of objects and their locations in an environment so that directions and straightline distances are embedded in these spatial representations. These are mental representations of the configuration of objects in an environment. The objects in these representations typically are important ones—landmarks (Evans, Skorpanich, Garlin, Bryan, & Bresolin, 1984; Hirtle & Hudson, 1991; Hirtle & Jonides, 1985; May, Ross, & Bayer, 2005). If a person has configural knowledge, they can place themselves in the environment in relation to other objects.
They may know that there is an unseen lake close to the road they are driving on and it is to the right of the road they are driving on. A driver can acquire configural knowledge from personal experience or from studying a map. When configural knowledge is learned via a map or another second hand experience, it is more likely to be called survey knowledge, although the terms survey and configural are not used consistently in the literature. Only the term configural knowledge is used in this thesis because the two terms have not been used consistently. Siegel and White (1975) originally theorized that a person who is directly experiencing an environment must first pass through landmark knowledge acquisition and route knowledge acquisition before obtaining configural spatial knowledge. However, more recent research has indicated that a person need not necessarily pass through the three stages of knowledge in sequence (e.g. Colle & Reid, 1998; Gillner & Mallot, 1998; Maguire et al., 1998; Wolbers, Weiller, & Buchel, 2004).

Drivers can navigate using either route knowledge or survey knowledge and landmarks are important components of both (Siegel & White, 1975). When a driver navigates using only route knowledge, a person will know, for example, the exact steps to get from their home to work. The driver will know to turn right at McDonald’s® before turning left at BP®. Both McDonald’s® and BP® are landmarks. Using only route knowledge, however, a person easily becomes lost when forced to take an unexpected detour.

If a driver navigates using survey knowledge, the person can drive from point A to point B using many different, sometimes novel routes. If an unexpected detour develops, the person should be able to make it to their destination. This occurs because the driver understands the layout of the environment and the relationship between its
landmarks. The relationships between objects in the environment are known, enabling
the person to mentally map new paths to travel.

Landmarks are important components of both navigating using route knowledge
and navigating using configural knowledge. However, in-vehicle navigation systems do
not present landmark information. Instead, as previously described, they use distance-to-
turn directions. Landmark information has been shown to be more useful for navigation
in general. A later section examines the role of landmarks in current in-vehicle
navigation systems and potential modifications.

Depending on the information provided by an in-vehicle navigation system,
drivers could be transformed from being ignorant of their environment to having
configural spatial knowledge, so that they are not exclusively dependent upon in-vehicle
navigation system directions. In effect, a driver would become their own knowledgeable
passenger and could direct themselves. However, as previously mentioned, current in-
vehicle navigation systems do not provide the necessary information for a driver to learn
their environment. As shown below, drivers are susceptible to erroneous decisions when
they depend on in-vehicle navigation systems for guidance.

*Coping with In-Vehicle Navigation System Errors*

In-vehicle navigation systems typically are rule-based, using a set of algorithms
for determining the best route from the current location to a destination. In contrast, a
person familiar with the environment usually has detailed familiarity with the layout of
an entire region. A knowledgeable person can plan optimal routes based on
considerations not taken into consideration by in-vehicle navigation systems such as
taking only two lane roads and avoiding a particular road.
Typically a route planned by an in-vehicle navigation system sufficiently guides a driver to a destination, but the route may have major limitations. For example, many in-vehicle navigation systems cannot be given specific requests such as “drive as much as possible on Elm Street” or “avoid Main Street if possible, there is a street fair today.” If a person has sufficient knowledge of their environment, he or she can make such adjustments. Not only can people create novel routes, they also know when a route does not “make sense.” It is not likely that a person who has developed knowledge of his or her environment will drive into a lake or down a dead end street, or to turn onto railroad tracks. Such incidents have occurred with drivers using in-vehicle navigation systems (Forbes & Burnett, 2007; Magid, 2007, ¶10). The rule-based in-vehicle navigation systems can make such catastrophic errors. Unless a driver has a sense of the environment, he or she is unlikely to recognize the errors or question them. With sufficient information, human drivers appear to be able to use heuristics to plan better routes than in-vehicle navigation systems.

In-vehicle navigation systems do not take advantage of human spatial knowledge capabilities. In-vehicle navigation systems could be used to help drivers acquire spatial knowledge by taking advantage of their natural capabilities. Environmental landmarks are important for configural knowledge acquisition (Foo, Warren, Duchon, & Tarr, 2005; Vinson, 1999; Sorrows & Hirtle, 1999). Environmental landmarks are also important for human spatial navigation (Allen, 1999; Burnett, 2000a; Burnett, 1998). Landmarks are used to identify locations where important actions such as turns should be executed (Cohen & Schuepfer, 1980; Denis, Pazzaglia, Cornoldi, & Bertolo, 1999; Hirtle & Heidorn, 1993; Janzen & Turenout, 2004; Lee, Tappe, & Klippel, 2002; May, Ross,
Bayer, 2003, 2005; Siegel & White, 1975; Tversky, 1993). The lack of landmarks and distinguishing features appears to make maze navigation difficult (Arthur & Passini, 1992). People tend to provide navigational instructions by directing a driver’s attention to prominent landmarks in the environment such as “turn right at the Burger King” (Denis, Pazzaglia, Cornoldi, & Bertolo, 1999; Weissensteiner & Winter, 2004). In Japan, China, Korea, and other Asian countries, people use landmarks in conjunction with street names instead of addresses in conjunction with street names (Green, Levison, Paelke, & Serafin, 1993). The landmarks also can be spatially related to each other, especially when an integrated set of directions are provided. In-vehicle navigational systems, however, typically do not refer to landmarks either visually or auditorily. Instead, in-vehicle navigational systems provide “distance-to-turn” information such as “turn left in 200 feet.” Typically, these systems also display a very limited field-of-view map along with auditory directions. If a driver can acquire configural knowledge about their environment using their in-vehicle navigation system, then the driver can focus more on the driving task. There is evidence that in-vehicle navigation systems require attention resources and can therefore distract from the driving task.

Attention, Driving and In-Vehicle Navigation Systems

In-vehicle navigation systems are designed to be a tool to increase the safety and efficiency of drivers, yet in-vehicle navigation systems can sometimes present information that actually competes with the visual demands of driving (Seppelt & Wickens, 2003) or with the driving task in general (Lansdown, Brook-Carter, & Kersloot, 2002). Lamble, Laasko, and Summala (1999) demonstrated that performing a visual attention task while driving decreased time-to-collision with another vehicle. Time-to-
collision depends on the relative velocity of the vehicle ahead, the distance to the vehicle ahead, and the deceleration of the vehicle ahead. An in-vehicle navigation system also has been shown to compete for the visual attention of the driver. Liu (2001) found that more complex visual displays led to more frequent major lane deviations than the same information presented in an auditory only mode or in both an auditory and visual mode. Information complexity on the visual display included factors such as the number of place names, road types, positions, or instructions that were represented on the display. Wierwille, Antin, Dingus, and Hulse (1988) also showed that driving an unknown route while using an in-vehicle navigation system demanded more visual attention than driving a memorized route. In their study, participants either had to drive an unknown route, relying exclusively on the in-vehicle navigation system, or had to drive a memorized route. Participants using the in-vehicle navigation system to drive an unknown route spent less time looking at the road and more time looking at their navigation aids than those driving the memorized route. The attention demands of an in-vehicle navigation system will depend on both the system’s displays and on the navigation strategy that was designed to be used with it.

Driving is primarily a visual activity. According to Rockwell (1972), at least ninety percent of the information used to drive is visual. Most in-vehicle navigation systems also require a heavy use of visual displays. That does not mean, however, that visual displays should be excluded from in-vehicle navigation systems. Although drivers use auditory turn commands, they prefer to have some information displayed visually, such as the current position of the vehicle and where the vehicle is going to go (Streeter, Vitello, & Wonsiewicz, 1985). Liu (2001) also pointed out that visual information is
presented continuously so it can be used at a pace determined by the driver. The driver is most likely to seek out visual information when driving demands are low. Auditory information, however, is presented at a pace and time as determined by the in-vehicle navigation system. The system does not consider the driving demands of the current situation. Therefore, auditory information may have to be kept in working memory. The visual information, however, remains on the screen and can easily be rechecked if forgotten. If the visual information is designed appropriately, it could foster the acquisition of configural knowledge of an environment.

In-vehicle navigation systems should be designed to be compatible with driver’s spatial knowledge capabilities. As previously mentioned, drivers can navigate using either route knowledge or survey knowledge (Allen, 1999). In-vehicle navigation systems could be designed to foster the acquisition of this spatial knowledge in order to take optimal advantage of natural human abilities. In-vehicle navigation systems should foster configural knowledge acquisition, the most flexible spatial knowledge type. Configural knowledge would be better to develop than route knowledge because drivers could develop alternate routes when their desired route is obstructed. Developing a sense of configural knowledge about the environment would make the driver less dependant upon the in-vehicle navigation systems and would enable the driver to focus more on the driving task. It would also be advantageous to design systems so that drivers could focus on driving at critical times instead of on the in-vehicle navigation system.

**Distinctiveness**

Although in-vehicle navigation systems direct drivers using distance to turn information, people give directions by referring to landmarks. The nature of this
communication is an important distinction. Using landmarks as part of the directions may be more natural to drivers, enhancing safety and efficiency by facilitating processing. This suggests that landmarks should be used as reference points when giving directions. However, current in-vehicle navigation system do not use them. These systems give directions such as “turn right in 200 feet onto Maple Street.” Maple Street could be two or five streets ahead. People are not good a judging environmental distances (e.g., McNamara, Ratcliff, & McKoon, 1984; Radvansky, Carlson-Radvansky, & Irwin, 1995; Thorndyke, 1981; Thorndyke & Hayes-Roth, 1982). Therefore, they would need to check each street sign while simultaneously driving. In contrast, if a passenger was providing directions he or she is likely to tell the driver to turn right at a landmark near the critical turning point. For example, a passenger might say “turn right up ahead by McDonald’s®” (Denis, Pazzaglia, Cornoldi, & Bertolo, 1999; Green, Levison, Paelke, & Serafin, 1993; Weissensteiner & Winter, 2004). The street name may not even be given or vital. It is important to note, however, that a passenger is likely to identify the restaurant specifically by name. Giving a driver the direction to turn right at ‘the restaurant’ would be uninformative. There may be several restaurants in view on upcoming blocks along the road and the driver would be uncertain about where to turn. Therefore, landmarks used for directions should probably be distinctive.

Distinctiveness is also important for memory (Hunt & McDaniel, 1993). Hunt and McDaniel argued that distinct items improve memory because distinct items are encoded with unique characteristics, which as a consequence have greater discriminability during retrieval. They described distinctive processing as occurring when a person processes differences among items that are in some way similar. It is most
helpful to memory if two objects are different from each other yet still related on a dimension. The combined processing of both the similarities and differences make the items easier to remember (Hunt, 2003).

In order to be identifiable and memorable, navigational directions should consider how landmarks are specified. In a later section, the nature of landmarks and landmark icons is described. However, as previously mentioned, in-vehicle navigation systems use distance to turn information, not landmarks, to give directions. Before describing the nature of possibly effective navigation directions, the current state of in-vehicle navigation systems will be described.

**In-Vehicle Navigation Systems**

A Global Position System, also known as GPS, is a satellite navigation system accessible to anyone using a GPS receiver. Satellites orbit the earth sending radio signals from orbit to GPS receivers so the receivers can calculate the receiver’s current position. Using several changes in position, a GPS receiver can also calculate speed and direction of travel. GPS systems are becoming more common in vehicles such as vehicles and trucks. In-vehicle navigation systems consist of GPS receivers combined with databases of roads and addresses, which are used to provide both visual and verbal directions to a specified goal location.

In-vehicle navigation systems can come in one of two forms, permanently-mounted or portable. Permanent in-vehicle navigation systems are built into a vehicle’s dashboard or control consol. This is an option available from many vehicle manufacturers such as Pontiac, Honda, and General Motors. The interior of the Honda Ridgeline with optional in-vehicle navigation system shown below in Figure 1. If a
vehicle does not come with an in-vehicle navigation system preinstalled, one can be installed into the dashboard or control consol. Such a system is shown in Figure 2.

A portable in-vehicle navigation system can be removed from a vehicle or transferred from vehicle to vehicle. Portable navigation systems are made to attach to either the windshield or dashboard of the vehicle. Two such systems, the Siemens MS2100 and the Garmin Street Pilot C330, are shown in Figures 3 and 4.

Features of Current In-Vehicle Navigation Systems

While in-vehicle navigation systems vary in their features, all current systems have similar basic features. First, you enter a destination address. If you have entered that particular address previously, you may have the option of selecting it from a menu of stored addresses. The system will consider your current position as your starting address.
It provides guidance sequentially as you move from your current position to the destination address. If you travel off the directed path, the in-vehicle navigation system will automatically recalculate your route.

*Arrow Icons for Current Position*

An arrow near the center of the screen indicates a vehicle’s current position and it indicates the direction of travel. Figure 5 below shows several personal navigation systems. The arrows vary slightly among the three displays, yet all share a similar shape. Each arrow is an isosceles triangle with the two equivalent sides forming the angle indicating the current direction of travel. The Garmin Street Pilot and the Tom Tom Navigator arrows have a slightly 3-dimensional appearance while the eXplorist arrow is flat and 2-dimensional.
Figure 5. Screens for a variety of Global Positioning Systems. The Garmin Street Pilot 2730 (A), Magellan eXplorist 200 (B) and Tom Tom Navigator PDA (C) are examples of screen characteristics of Global Positioning Systems. Note differences in perspective, street representations, and current position arrow indicators.

Map Displays

Figure 5 shows examples of maps available on current in-vehicle navigations systems. Some systems, such as the eXplorist 200 from Magellan, employ a simple monochromatic screen. In contrast, the Garmin Street Pilot 2730 and the TomTom Navigator PDA both have color screens. The three navigation displays also differ in map perspective. Both the Garmin Street Pilot and the Tom Tom Navigator employ an aerial view as defined by Green, Levison, Paelke, and Serafin (1993). These displays simulate the angled view one would experience from the viewpoint of a low flying helicopter. This has been called a tethered view in aviation research (Wickens & Prevett, 1995). The eXplorist employs a plan view as defined by Green, Levison, Paelke, and Serafin (1993).
A plan view is comparable to a view one would experience while looking straight down at a standard paper map. Finally, the systems depict different types of roads using different colors or textures on chromatic displays and different textures on monochromatic displays. Some streets, especially the streets of relevance to the navigation task, are labeled. Note that the Tom Tom navigator indicates the planned route using a long extended green arrow on its display, but the eXplorist and Garmin do not indicate the planned route.

Map Rotation

Although most in-vehicle navigation systems give you a choice of a track-up map or a north-up map, in-vehicle navigation systems are set by default to one map type, most often the track-up map. A track-up map is oriented such that the direction you are heading is always at the top of a display. A north-up map is oriented such that north is always at the top of the display. An arrow indicates your current location and points in the direction you are heading. Therefore for track-up maps, the arrow will always be pointing up. The map rotates and translates under the arrow to accurately show the vehicle’s current position. For north-up maps, the arrow rotates to indicate the vehicle’s current direction. The map still translates under the arrow to accurately indicate the vehicle’s current position.

Points of Interest Icons

Both the Tom Tom and Garmin navigation systems present points of interest on their displays. Points of interest are locations, such as restaurants, gas stations, and hotels, which may be of interest to drivers. Points of interest are indicated on the screen
Figure 6. Points of interest icons. Here are examples of icons representing various Points of Interest for In-Vehicle Navigation Systems.

using icon representations. See Figure 6 to view examples of icons on in-vehicle navigation systems. Points of interest typically are represented using generic icons for broad categories (i.e., eating establishments, gas stations, or hotels) on both the Tom Tom and Garmin, as well as on other manufacturers’ displays. These generic icons make it difficult to identify one specific restaurant from another specific restaurant or one specific hotel from another specific hotel.

Recently, several manufacturers have started using more specific icons for known landmarks. For example, Lexus cars come equipped with a Kenwood Generation 5 in-vehicle navigation system which presents specific icons for points of interest. Add-ins can also be purchased from non-manufacturer companies that will present specific icons for identifiable landmarks. The McDonald’s® icon for the Tom Tom system shown in Figure 7 is an example.
Figure 7. Specific Points of Interest icons. These specific icons are post-purchase add-ons that can replace the generic Points of Interest icons used for In-Vehicle Navigation Systems.

Icon locations are displayed at their correct position on navigation maps, but many generic icons create screen clutter. As Figure 8 shows, it can be difficult to discriminate one icon from another and to discriminate their locations accurately. Consequently, it would be difficult to find them in the environment. Finally, when I tested the Garmin Street Pilot, icons would appear and disappear for no apparent reason.

Auditory Navigation Directions

In-vehicle navigation systems often present auditory information about upcoming turns, typically voiced as commands. The commands are short and are spoken just before a turn begins. In all systems, the spoken commands include the direction of turn and the distance to the turn in feet on American systems. These auditory commands have been called “distance to turn” commands (May & Ross, 2006; May, Ross, & Bayer, 2005). An example of a distance to turn command is “Veer left in 200 feet onto Main Street.” The
Figure 8. Various views of generic Points of Interest icons. Generic icons representing Points of Interest can be seen on both an aerial view map (A) and a plan view map (B).

directions and information presented by the in-vehicle navigation system are different than what the knowledgeable passenger would present. The next section will examine this and other current problems with in-vehicle navigation systems.

Implications for In-Vehicle Navigation Systems

There are several features of in-vehicle navigation systems which could be redesigned to improve their effectiveness. The next section describes the use of distance to turn directions. The second section describes the potential use of landmark information. The final section describes the use of track-up versus north up map rotation techniques and their relationship to the acquisition of configural and route spatial knowledge. The use of track-up maps and distance to turn directions makes it difficult for a driver to learn their environment and thus they are more likely to be completely dependant upon the in-vehicle navigation system.
Distance to Turn Directions

Human informants do not typically use distance to turn directions when giving directions. As previously mentioned, a passenger will direct a driver by making statements such “turn left up ahead at the Wendy’s” (Denis, Pazzaglia, Cornoldi, & Bertolo, 1999; Green, Leison, Paelke, & Serafin, 1993; Weissensteiner & Winter, 2004). Current in-vehicle navigation systems, however, direct drivers by saying “turn left in 200 feet.” May, Ross and Bayer (2003) have shown that people prefer landmark information instead of distance to turn information. Preferring landmark navigation over the standard street and distance to turn navigation is also true when the directions are only heard or when the directions are only seen (Green, Hoekstra, Williams, Wen, & George, 1993). In-vehicle navigation systems do not refer to landmarks, which appear to be important for human spatial knowledge.

Current in-vehicle navigational systems already have databases of information about landmarks. This information could be utilized to allow the vocal directions to more closely mirror that of an informed passenger and aid in the development of autonomous driver knowledge. More specifically, in-vehicle navigation systems have the capability of presenting points of interest such as restaurants, hotels and gas stations. When identifiable objects or locations such as these are used in navigation, they have been called landmarks (e.g., Burnett, 1998; May, Ross, & Bayer, 2005). Therefore, a select set of points-of-interest could be used as referent landmarks. They could be displayed visually as landmark icons. Currently, there is no vocal presentation of the landmark information. Landmarks could also be referred to auditorily in turn directions. In this thesis, landmarks shown on the screen will be referred to as visual landmarks.
Landmarks heard in auditory direction will be referred to as auditory landmarks.

Landmarks that are in the environment will be referred to as environmental landmarks.

Distance to turn directions provide information that aids navigation to a destination, however, visual and auditory landmark directions in an in-vehicle navigation system may improve driving and navigational performance. Instead of just distance to turn directions, landmark at turn directions could be presented. The visual and auditory presentation of landmarks could also foster the acquisition of landmark, route, and configurational spatial knowledge. Participants considered distance information as the least important piece of information in a study by May, Ross, and Bayer, (2003). Participants listed the three most common pieces of primary information as environmental landmarks, junction descriptions, and then lane changes. In this study, however, environmental landmark categories were very broad. Environmental landmarks could include items such as bridges, mailboxes, phone booths, gas stations, and bridges. People prefer landmark navigation over the standard street and distance to turn navigation when the directions are only heard or when the directions are only seen (Green, Hoekstra, Williams, Wen, & George, 1993).

Landmarks

Current in-vehicle navigation systems do not use visual displays or auditory directions to refer to environmental landmarks. Landmarks could be included in in-vehicle navigation systems and might aid in spatial knowledge acquisition. As previously mentioned, landmarks are important components of memory representations of landmark, route, and configurational spatial knowledge. Drivers may have difficulty acquiring spatial knowledge from current in-vehicle navigation displays because of a lack
of distinguishable visual and auditory landmarks. The visual landmarks on the display can show the exact configuration of the environmental landmarks. The auditory landmarks, while aiding in route guidance, will also serve to draw attention to important environmental landmarks.

Previous research has suggested that environmental landmarks are recommended to acquire configural knowledge while driving. Vinson (1999) recommended that landmarks be included in virtual environments because they are necessary to form accurate configural knowledge. Sorrows and Hirtle (1999) also claimed that intersections must be visually distinguishable from one another if a person is to form accurate configural knowledge. Landmark directions also appear to improve performance. Burnett (1998) showed the usefulness of landmarks in a series of experiments. Bengler, Haller, & Zimmer (1994) found that using road signs as landmarks significantly reduced turn signal errors and had a non-significant tendency to reduce driving errors. People have been found to make fewer wrong turns when landmarks were used compared to left/right/straight ahead directives (Alm, Nilson, Jarmark, Savelid, & Hennings, 1992) and when landmarks were used compared with distance information (May, Ross, & Bayer, 2005). May and Ross (2006) found that using good landmarks as opposed to poor landmarks or distance to turn information lead to improvements in navigation, driving, and driver confidence immediately before a turn while using an in-vehicle navigation system.

**Evidence for Landmark Use**

Subjectively, people appear to value landmarks when getting or receiving directions. Britain's rated environmental landmarks as primary pieces of information for
driving at a greater frequency than direction signs, distance, junction names, lane changes, node geometry, path geometry, road markings, road types, time, and even street names/numbers and junction descriptions (May, Ross, & Bayer, 2003).

A number of investigators have recommended that landmark icons be used on in-vehicle navigation systems (Burnett, 2000a; Burnett, 2000b; May, Ross, & Bayer, 2005; Pauzie, Daimon, & Bruyas, 1997; Ross, May, & Grimsley, 2004). There have been several studies presenting experimental evidence that in-vehicle navigation systems incorporating landmarks are an improvement over standard in-vehicle navigation systems using distance-to-turn information. May, Ross, and Bayer (2005) showed that participants had lower glance time and made fewer driving errors and navigation errors using an in-vehicle navigation system presenting auditory directions referencing good environmental landmarks compared to distance to turn information. May, Ross, and Osman (2005) incorporated references to environmental landmarks in the auditory directions of an in-vehicle navigation system. Such systems led to reduced time looking at the visual display, fewer navigation errors, and fewer driving errors compared to standard distance to turn auditory directions. Burnett (1998) showed that drivers were more efficient when using a landmark-based voice and visual navigation system compared with a distance to turn and street information system. Participants receiving this landmark information glanced at the in-vehicle navigation display less frequently and reported lower ratings of mental workload. People were also subjectively more content when landmarks were included with in-vehicle navigation systems, with visual landmarks being preferred slightly more than auditory landmarks. Alm, Nilsson, Jarmark, Savelid, & Hennings (1992) showed that drivers made fewer driving errors in general, such as
incorrectly using turn signals, when landmarks were included with in-vehicle navigation systems. Drivers reported being more confident about where to turn when using an auditory landmark based navigation system versus a left/right/straight ahead navigation system.

Map Rotation

The default way to display a map with most in-vehicle navigation systems is to use a track-up map. As previously described, a track-up map rotates as the driver turns such that the direction the driver is heading is always “up” on the display. The alternate and less commonly used map type is a north-up map, which is oriented such that north is always upward. Each of the map types has its own advantages and disadvantages.

The two map display options used by in-vehicle navigation systems are consistent with two of the three reference frames described by Shepard and Hurwitz (1984). One is an egocentric-oriented frame of reference and the other is an allocentric-oriented frame of reference. In the egocentric-oriented frame of reference, planes are defined with reference to a person, the main actor. Two planes are defined by the current location of the body. The midsagittal plane through the body specifies straight ahead or behind in the environment. The second plane is specified by the midcoronal plane of the body so that left and right sides refer to the left and right hand sides of the body, respectively. In driving navigation, all movement is in the horizontal plane corresponding to the road. The allocentric-oriented frame of reference is defined with respect to the cardinal directions north/south and east/west. These two frames of reference appear to be used in track-up and north-up map displays, respectively. Like a track-up map, an egocentric reference frame changes according to the direction a person is facing. Like the north-up
map, an allocentric environmental frame is constant. Shepard and Hurwitz also defined a third reference frame, which has not been used in navigation systems, but has potential applications. This object centered reference frame specifies directions with respect to an outside person or object in the environment. In navigation systems, this could correspond to a destination-up map. The map in an in-vehicle navigation system would always be oriented so that the destination object such as a building would be at the top of the map. So regardless of whether a driver was headed north or west or had just turned, the destination would always be at the top of the map.

The best type of reference frame to use for a situation appears to depend on the tasks one wants to accomplish. Similarly, the best map to use for an in-vehicle navigation system depends on the task. Often, when a person needs to navigate, a track-up map is the better choice. This has to do with orientation specificity. Orientation specificity occurs when the map of the environment was remembered in the orientation in which it was viewed (Presson & Hazelrigg, 1984; Richardson, Montello, & Heggarty, 1999; Rossano, Warren, & Kenan, 1995).

One of the results of orientation specificity is that making turn decisions is easier. Numerous studies have shown the advantages of track-up maps for making turn decisions. That is because a location to the right on the map is also a right turn in the environment and a location to the left on the map is also a left turn in the environment. While navigating, a person needs to make many left and right turn decisions. People tend to report that making left or right turn judgments is easier when the road they are heading forward on is also heading upward on the map (Levine, 1982). Kim, Han, Nam, Park, and Han (1997) commented that it is easy to select a direction to turn when the view out
your car window matches the view on an electronic map display. Richter and Klippel (2002) in their research on You-Are-Here maps also recommend that a map should be aligned with the environment in order to ease left and right turn decisions. You-Are-Here maps are static maps such as those found on kiosks which show buildings on campus or mall stores. They show the current location on the map.

There is also considerable experimental evidence indicating it is more difficult to make turn decisions when the map is not aligned with the environment. Levine (1982) conducted studies of aligned and contraligned You-Are-Here maps. Aligned You-Are-Here maps are oriented such that the destination location is above the current location so that it is forward from a first person point of view. Contraligned maps are oriented such that the destination object is below the current location so that it is behind the person from a first person point of view. When people were asked to decide which direction to head to get to a destination they made more errors and took longer to decide with contraligned maps than with aligned maps. The contraligned map lent itself to longer discovery times than the aligned map when people were looking for the location of another object. One third of the time, participants viewing the contraligned map walked in the wrong direction away from their target (Levine, 1982). Similar performance decrements have been found by other investigators (Gugerty & Brooks, 2001, 2004; Shepard & Hurwitz, 1984). Presson & Hazelrigg (1984) found similar results for memorized maps. Other studies have turned from paper maps to dynamic map displays on a screen. Aretz (1991) and Aretz and Wickens (1992) studied the dynamic displays used by pilots and flight navigators. They also recommended that track-up maps be used when left and right turns decisions need to be made. Kim, Han, Nam, Park, and Han
(1997) studied in-vehicle navigation systems specifically. They found that those who saw a north-up map took longer to make it to their destination. Aretz (1991) and Aretz and Wickens (1992) found evidence that mental rotation is used when two reference frames (e.g., the outside world and your map) are not aligned.

It appears that track-up maps are naturally better for use with in-vehicle navigation systems because of orientation specificity. However, while the effects of orientation specificity are very robust, numerous studies have indicated limitations in orientation specificity. Lloyd and Cammack (1996) showed that it is the limited number of initial viewing orientations that cause the orientation specificity effects with memorized maps. However, orientation specificity does not occur when a person learns an environment through firsthand experience (Evans and Pezdek, 1980). Orientation specificity does not seem to occur in the natural environment (e.g., Ruddle, Payne, & Jones 1997). Prabhu, Shalin, Drury, and Helander (1996) examined the possibility of a heading-separated display. A heading-separated map was a color-coded map with the north half of the map being colored differently than the south half of the map. For all headings from northeast to northwest, north would be oriented to the top of the map. For all headings southeast to southwest, south would be oriented to the top of the map. Prabhu et. al found that the heading separated map was at least as good as track-up maps for task completion time, and dwell time and possibly better than track-up maps for missed external information. Recently Viita and Werner (2006) showed that even when headings were misaligned by $\pm 50^\circ$ there was no significant difference in either error rates or reaction times when compared to headings that were perfectly aligned. They speculated that a semi-fixed display centered around perfect alignment would improve
configural knowledge. They further argued there is little cognitive cost with turn
decisions for a wide range around perfect alignment.

Given the unclear indications from previous research, versions of both track-up
maps and north-up maps should be considered for in-vehicle navigation system displays.
This thesis examines these map orientation displays and landmark characteristics as
potential design features for improving in-vehicle navigation systems.

Suggestions for Improved In-Vehicle Navigation Systems

Proposed Auditory Directions and Evidence for Landmark Inclusion

Landmark Definition

In order to add landmarks to auditory directions, criteria for good environmental
landmarks are needed. Currently there is no single definition of landmarks. Lynch
(1960) defined landmarks as “external reference points that are easily observable from a
distance.” Kaplan (1976) defined landmarks as a “known place, a place for which the
individual has a well-formed representation.” Kaplan went further and listed some
specific characteristics of environmental landmarks. He listed distinctiveness, location,
and frequency of contact with a landmark as being important considerations when
choosing an environmental landmark. Other researchers tend to note characteristics that
comprise good environmental landmarks. Akamatsu, Yoshioka, Imacho, Daimon, and
Kawashima (1997) saw that popularly chosen environmental landmarks in their study
were “visible from a distance, unique in appearance, and close to or part of the road
infrastructures.” Green, Levison, Paelke, and Serafin (1995) similarly listed good
environmental landmarks as being visible from a distance and located near junctions.
They also defined good environmental landmarks as being close to the road and
permanent. Burnett, Smith, and May (2001) listed five attributes of good environmental landmarks for driving navigation in particular. Four had previously been listed as attributes that make a “good” environmental landmark: permanence, location, visibility, and uniqueness (incorporating distinctiveness). They also added “ability to be described with brevity.” In 2006, May and Ross listed good environmental landmarks as being visible, familiar, unique, and useful. May and Ross also showed that poor environmental landmarks could lead to more navigational difficulty than good landmarks and standard distance to turn information. Note that distinctiveness/uniqueness was listed as an important characteristic in all of the studies examining good environmental landmarks.

**Auditory Directions**

Effective directions should include an identifying landmark, a street, and a turn direction. Landmarks can actually serve several functions. Their ideal location depends on what purpose the landmark is serving. May, Ross, and Bayer (2005) defined landmarks as being preview, identify, or confirm. Alm, Nilsson, Jarmark, Savelid, and Hennings (1992) also defined three landmark categories: where to turn, if the driver is on the right track, and where to stop. Preview landmarks (May, Ross, & Bayer, 2005) indicate that a turn, key maneuver, or decision is upcoming. Identify landmarks (May et al.) or where to turn landmarks (Alm, Nilsson, Jarmark, Savelid, & Hennings, 1992) pinpoint the actual locations of a turn, maneuver, or decision. Confirm landmarks (May, Ross, & Bayer, 2005) or “if the driver is on the right track” landmarks (Alm, Nilsson, Jarmark, Savelid, & Hennings, 1992) indicate that you are on the correct path and usually occur after a decision point. Where-to-stop landmarks (Alm, Nilsson, Jarmark, Savelid,
& Hennings, 1992) indicate where to stop. In my pilot research I also found that people indicated “went too far” landmarks to provide a warning in case a person missed a turn.

Identify landmarks are located at decision points, which have also been called critical points. Decision points were defined by May, Ross, and Bayer (2003) as points where a driver has to make a navigation decision. These locations were termed critical points by Denis, Pazzaglia, Cornoldi, and Bertolo (1999). Critical points were defined by Denis, Pazzaglia, Cornoldi, and Bertolo (1999) as locations where orientation problems have to be solved. Denis, Pazzaglia, Cornoldi, and Bertolo (1999) used the term critical points to define locations in the city of Venice, an environmental reference frame. May, Ross, and Bayer (2003) used the term decision points to refer to environmental locations that in-vehicle navigation systems should incorporate. The term “critical point landmark” will be used in this thesis to refer to landmarks located at critical points in both the environment and the in-vehicle navigation system. It is important to note that not all critical points may have a landmark. Similarly and as previously discussed, not all landmarks will be located at critical points.

Not every landmark in the environment should be presented on a map or in auditory directions. Primarily, map icons and auditory directions should use environmental landmarks that are located at critical points. Locating the icons at turn locations will minimize the amount of visual clutter (Green, Levison, Paelke, & Serafin, 1993) while still providing highly useful turn information (Janzen & Turenout, 2004; Michono & Denis, 2001; Pazzaglia, Cornoldi, & Bertolo, 1999).

People often use environmental landmarks at critical points. Denis, Pazzaglia, Cornoldi, and Bertolo (1999) found that when giving directions, people tended to include
landmarks concentrated at critical points where a turn decision was to be made. Experimental evidence also has indicated that critical point landmarks are important. Cohen and Schuepfer (1980) found that children had poor memory for environmental landmarks that were not at critical points. Adults were also better able to recall environmental landmarks at critical points than at points where turns were not possible. They also had better recall of landmarks located at critical points where turns were made compared to critical points where no turns were made. Lee, Tappe, and Klippel (2002) found similar results. Adults recalled more critical point landmarks when turns were made compared to critical point landmarks where no turns were made. There is also biological evidence indicating the importance of critical point landmarks. Janzen and Turenout (2004) found that the parahippocampal gyrus was more active for objects located at potential critical points than for objects that were located at non-potential critical points, even when the objects were at intersections at which turn decisions did not have to be made. This was true for objects that were later remembered as well as objects that were later not remembered.

By identifying critical point landmarks in both the auditory directions and visual map icons of an in-vehicle navigation system, the system can capitalize on the natural tendency of people to remember environmental landmarks located at critical points, especially where turns are made. Enhancing memory for landmarks should also help drivers acquire better spatial memory of an environment. Therefore, in-vehicle navigation systems should provide information about environmental landmarks, however, the manner in which these landmarks should be referred to still needs to be examined.
Landmark Depictions

Environmental landmarks may be distinctive, but their depictions in map displays may or may not be distinctive. Displayed landmarks should be more likely to be remembered if they belong to a category or a limited number of categories and they are distinctive. As previously discussed, Hunt (1993; 2003) argued that distinctive items of a same category were more memorable than non-distinctive items of the same category or non-distinctive items of different categories. Therefore, Hunt’s research suggests that visual landmarks used for in-vehicle navigation systems should be distinctive icons from the same category.

Paivio’s (1971; 2007) dual-coding theory also suggests that specific landmark depictions should be better than generic depictions. According to dual-coding theory, people are capable of storing two different types of memory representations, verbal and nonverbal. When they see a picture, they can store a nonverbal representation of it, a visual image of it. If the picture is easily nameable, then they also are very likely to store a verbal representation of it. Memory for printed or spoken words is stored using verbal representations. However, a person may also store a nonverbal code spontaneously if the word easily elicits an image of the word. This recoding tends to occur more readily for concrete than for abstract words, but it is less likely to occur than the implicit verbal naming of a picture. Dually coded items are assumed to be more accessible than singly coded items. A primary empirical consequence of these assumptions was summarized by Paivio (2007). The research showed that recall of pictures was better than concrete words, which was better than abstract words. A picture of an object is very likely to be dually encoded. Concrete words may or may not be dually encoded. A word, such as
bird, could arouse an image, but it is not necessary for an image to be created in order to verbally remember the word. Abstract words are likely to only be encoded verbally. Words such as truth, justice, and freedom, are not likely to arouse mental images. Therefore, given a series of pictures, concrete words, and abstract words, a person is likely to recall fewer concrete words than pictures and fewer abstract words than concrete words. Paivio has also argued that concreteness is more important for words or pictures when they are used as retrieval cues than when they are recallable items. Although Paivio did not discuss the use of landmarks in spatial learning, it could be argued that landmarks serve as retrieval cues for spatial locations.

Landmark depictions could be presented to foster dual coding, in order to make them more memorable. In-vehicle navigation systems can depict landmarks as pictures, concrete words or abstract words. Dual coding theory would predict that recall would decrease for depictions of pictures, concrete words, and abstract words, respectively. A landmark could be presented as a specific icon such as the golden arches of McDonald’s®. This picture would likely elicit both nonverbal and verbal encoding. In addition, most restaurant icons that could be used as display icons not only have pictorial logos, but they include the restaurant name as a part of the logo. Therefore, displayed distinctive restaurant logos should produce dual codes in memory. In contrast, if all visual landmarks are the same generic fork and knife icon, then the fork and knife would be remembered as having occurred. Although these generic icons should be dually encoded with an image of the knife and fork and verbally coded as “restaurant,” this dual coding should not be as effective as the specific visual icons because Paivio (2007) has
argued that dual coding is effective both because images improve recall by enhancing distinctiveness as well as by enhancing interitem associations.

The design of auditory landmark information must also be considered. If the specific name of a restaurant such as Subway® is named at a critical point, it would be coded verbally. It is unlikely to generate an auditory image because most restaurant names are not related to acoustic events such as an associated tune or melody. Specific names could generate a visual image of the restaurant or its logo. This name to visual image transformation is more likely for specific names, which are more concrete nouns than the more abstract generic word “restaurant.”

Landmark directions could consist of specific or generic visual icons and specific or generic auditory directions. Paivio’s dual coding theory predicts that specific visual icons should be remembered better than generic visual icons. It also predicts that specific auditory directions should be remembered better than generic auditory directions. The relative performance of the three combinations of visual icons and auditory directions depends on the likelihood of unique dual coding. Specific visual icons by themselves should generate unique visual image and verbal name. Therefore, the addition of a specific or generic auditory direction should be redundant and store little additional information in memory. Specific auditory directions could add some verbal coding only if the visual icon does not generate the verbal code. In contrast, when a generic visual icon is presented, it does not produce a unique visual image code. It should produce a verbal code, which is a relatively abstract name. Therefore, specific auditory directions should enhance verbal coding by producing a more unique verbal code and by making it more likely that this code would generate a visual image. However, the combination of
Table 2

*Implications of Paivio’s Theory on the Current Study*

<table>
<thead>
<tr>
<th>Display Condition</th>
<th>Coding of Visual/Auditory</th>
</tr>
</thead>
<tbody>
<tr>
<td>SS</td>
<td>specific visual/specific auditory</td>
</tr>
<tr>
<td>SG</td>
<td>specific visual/generic auditory</td>
</tr>
<tr>
<td>GS</td>
<td>generic visual/specific auditory</td>
</tr>
</tbody>
</table>

generic visual icon and specific auditory directions (GS) should not be coded as effectively as presentations with specific visual icons because pictures have been found to be more memorable than concrete words (Paivio, 1971, 2007). Therefore, dual coding theory implies that SS = SG > GS, as summarized in Table 2, where SG stands for specific visual/generic auditory and SS stands for specific visual/specific auditory.

According to Hunt’s (1993) research, specific representations would be better than generic representations. Hunt (1993) and Hunt and McDaniel (1993) have argued that when an item is processed with distinctive characteristics, then it has greater discriminability during retrieval. Therefore, a specific restaurant representation would likely be easier to recall than a generic restaurant representation. Hunt’s theory of distinctiveness implies that the specific visual/specific auditory group with two sources of distinctive information would be better than either the specific visual/generic voice or the generic visual/specific voice groups, which only have one source of distinctive information. Unlike Paivio’s dual coding theory, however, Hunt’s theory of distinctiveness would dictate that the specific visual/generic voice and the generic visual/specific voice are not inherently different. There is no a Hunts relatedness-distinctiveness theory implies that SS > SG = GS, as summarized in
Table 3

*Implications of Hunt's Distinctiveness Theory on the Current Study*

<table>
<thead>
<tr>
<th>Display Condition</th>
<th>Modality</th>
</tr>
</thead>
<tbody>
<tr>
<td>SS specific visual/specific voice</td>
<td>Both visual and auditory codes are distinctive</td>
</tr>
<tr>
<td>SG specific visual/generic voice</td>
<td>Visual code is distinctive/auditory code is not</td>
</tr>
<tr>
<td>GS generic visual/specific voice</td>
<td>Visual code is not distinctive/auditory code is</td>
</tr>
</tbody>
</table>

Table 3. The set of contrasts used to evaluate the current study were generated to examine the Hunt distinctiveness predictions. Therefore, the specific visual/specific voice condition will be priori reason that one source would be more effective than the other. Therefore, compared against specific visual/generic voice and generic visual/specific voice condition. In addition, the specific visual/generic voice condition will be compared against the generic visual/specific voice condition.

*North Up Map*

In order to enable person to create mental maps of their environment, and therefore become less dependent on in-vehicle navigation systems, north up maps should be used on the display. However, this may make turn judgments while using contra-aligned north up-maps may be more difficult and take more time than aligned track-up maps for In-Vehicle Navigation Systems. Recently, however, Viita and Werner (2006) showed that even when headings were misaligned by ± 50° there was no significant difference in either error rates or reaction times when compared to headings that were perfectly aligned. They argued there is little cognitive cost with turn decisions for a wide range around perfect alignment. They further speculated that a semi-fixed display centered around perfect alignment would improve configural knowledge.
Proposed Research

Previous research indicates that the best type of map to use depends upon the task to be completed. The general purpose of in-vehicle navigation systems is to provide on-line guidance directions to get a person from one location to another. In-vehicle navigation systems should also provide users with information to use at a later time. As previously discussed, people have their attention focused on observing and following the in-vehicle navigation system. Therefore, they may not be paying attention to their environment appropriately, checking to see if the maneuver dictated by the in-vehicle navigation system is both legal and safe. This leads to drivers making errors such as turning down one-way streets and trying to drive on railroad tracks or pedestrian walkways. If a driver is confident and accurate about where they are driving to, then they can pay less attention to the in-vehicle navigation system and more attention to the road and environment. In addition, if the navigation system is removed, the user should have learned enough to move from one location to the next. However, this is unlikely with current in-vehicle navigation systems because while they provide good route directions as the person is driving, they provide poor configural knowledge and little preview of upcoming maneuvers.

This study proposes to investigate ways to make information presented by in-vehicle navigation systems easier to remember. In particular the use of specific landmarks, which are currently in place as points of interest for in-vehicle navigation system, could aid in configural knowledge acquisition and make the driving task easier to focus on. The generic icons currently used are there merely to present information and are not being utilized to aid in spatial knowledge acquisition or on-line driving directions.
Gaining configural knowledge could potentially decrease a person’s dependence on the display. The configural knowledge gained using specific landmarks will be compared to the configural knowledge gained using generic landmarks. More specifically, this study is going to examine the use of specific or generic landmarks.

Also, in-vehicle navigation systems currently provide direction using a track-up map, the worst map to use for spatial learning. This study will also examine the effects of north-up maps and track-up maps on configural knowledge. Both maps will be tested utilizing generic or specific icons. The in-vehicle navigation system is a tool that should present information in the best manner possible so that drivers do not have to constantly check back to figure out where to go next.
II. METHOD

Participants

Participants were students \((N = 144)\) from Wright State University. Participants were recruited from introductory psychology courses and received course credit for their participation. Forty-seven males and ninety-seven females participated in this study. Forty-three men were currently licensed to drive a vehicle while four were not. Ninety-one of the women currently licensed to drive a vehicle while six were not. Mean age of participants was 20.32 years \((SD = 4.58)\). Thirty-five participants indicated previous use of GPS.

The experiment was a 3 x 2 between-subjects factorial design. One factor was type of information presented (specific visual/specific voice, generic visual/specific voice, specific visual/generic voice). The other factor was map rotation (track up, north up). Twenty-four participants were randomly assigned to each of the six experimental conditions.

Materials

Street Maps.

Static overhead street map images of Denver, Colorado were downloaded from Google Maps (http://maps.google.com, March 2006). The separate images were recombined using Photoshop to make a large view seamless map. Further modifications were made to the map so that no distinguishing landmarks were visible (e.g., public park identifications were removed). Distinguishing street patterns such as a large roundabout
Figure 9. Street layout map. The map above shows the street layout of the environment in which the participants traveled. Roads are shown in white or yellow on a light grey background.

were also removed. The remaining streets were arranged in two distinct grid patterns. The first grid pattern was oriented so that the streets run north to south and east to west. The second set of grid patterns was offset by about 45° and oriented so the streets run approximately southwest to northeast and northwest to southeast. Figure 9 shows the street layout. All roads are shown in bright yellow or white on a light gray background. Color coding was standard coding used by Google Maps.

Restaurant Icons.

Restaurants were represented on the map using icons. Six icons were located in positions critical for correct navigation (critical point icons). Two additional icons were located along the route but not located at turn locations or street corners. These two other icons were passed but not critical for correct navigation. Three additional icons were visible to
participants but did not fall along the route. Four of the critical point icons were located at turn locations. One critical point icon was located at the start position and one critical point icon was located at the end position. The icons were either generic or specific. Generic icons were small red squares with a white fork and knife in the middle. In the generic icon condition, the same icon was used for each of the six restaurants. Specific icons were reflective of the restaurants they were representing. For example, McDonald’s® was represented with its famous “M” golden arches symbol. Therefore, in the specific icon condition eight separate icons were used (6 critical point icons and 2 non-critical point icons). See Table 4 below for a complete listing of all restaurants, symbols, and functions of the symbols.

*Simulated In-Vehicle Navigation System.*

The simulated in-vehicle navigation system slide show was presented using Microsoft PowerPoint® (http://office.microsoft.com) with icons inserted using Adobe Photoshop® (http://www.adobe.com/products/photoshop/family/). The critical point icons were placed onto street corners of the large street map. The two additional icons were placed along the path participants would take. Then the map was focused so that approximately five full blocks were visible at all times. The “current position” was placed in the center of the screen and a screen shot was taken. When screen shots were being taken for the generic map condition, the generic symbols were visible. When screen shots were being taken for the specific map condition, the specific symbols were visible. The screen shots were then pasted into Microsoft Power Point®. A blue arrow was placed in the center of the image to indicate current position. Using Adobe Photoshop®, the map image was moved slightly opposite the direction of travel.
<table>
<thead>
<tr>
<th>Symbol (Icon)</th>
<th>Restaurant</th>
<th>Role</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image" alt="Arbys" /></td>
<td>Arbys®</td>
<td>Critical Point Icon: Ending Location</td>
</tr>
<tr>
<td><img src="image" alt="Bob Evans" /></td>
<td>Bob Evans®</td>
<td>Critical Point Icon: Turn</td>
</tr>
<tr>
<td><img src="image" alt="Burger King" /></td>
<td>Burger King®</td>
<td>Critical Point Icon: Turn</td>
</tr>
<tr>
<td><img src="image" alt="Chick-Fil-A" /></td>
<td>Chick-Fil-A®</td>
<td>Visible icon, not passed</td>
</tr>
<tr>
<td><img src="image" alt="Kentucky Fried Chicken (KFC)" /></td>
<td>Kentucky Fried Chicken (KFC)®</td>
<td>Critical Point Icon: Turn</td>
</tr>
<tr>
<td><img src="image" alt="McDonald's" /></td>
<td>McDonald’s®</td>
<td>Visible icon, not passed</td>
</tr>
<tr>
<td><img src="image" alt="Panera Bread" /></td>
<td>Panera Bread®</td>
<td>Passed Icon</td>
</tr>
<tr>
<td><img src="image" alt="Pizza Hut" /></td>
<td>Pizza Hut®</td>
<td>Visible icon, not passed</td>
</tr>
<tr>
<td><img src="image" alt="Starbucks Coffee" /></td>
<td>Starbucks Coffee®</td>
<td>Critical Point Icon: Starting Location</td>
</tr>
<tr>
<td><img src="image" alt="Subway" /></td>
<td>Subway®</td>
<td>Passed Icon</td>
</tr>
<tr>
<td><img src="image" alt="Taco Bell" /></td>
<td>Taco Bell®</td>
<td>Critical Point Icon: Turn</td>
</tr>
<tr>
<td><img src="image" alt="Generic Symbol" /></td>
<td>Generic Symbol</td>
<td>Function Varied</td>
</tr>
</tbody>
</table>
Another screen shot was taken and pasted onto the next slide of Microsoft Power Point®. The arrow was once again placed in the center to indicate the current location. This process was repeated to create an entire “trip” where the participant encountered the eight icons. By pasting slightly different screen shots onto consecutive power point slides, a presentation was created that simulated an in-vehicle navigation system that was tracking a vehicle’s current travel. See Figures 10, 11, and 12 below to see two consecutive slides. Figure 10 shows two consecutive slides in the north up, specific icon condition. A participant would first see frame A and then one second later see frame B. As you can see, the map in frame B is shifted slightly to the right compared to the map in frame A. The participant sees this slight shift as a change in position as the “vehicle” (indicated by the arrow) moves from right to left. Figure 11 shows two consecutive slides in the track-up, generic icon condition.

![Figure 10. Two consecutive specific landmark slides. Above are two consecutive slides from the specific landmarks In-Vehicle Navigation System simulation. The map in (B) is shifted slightly to the left compared to the map in (A). The blue arrow remained in the middle of the map.](image-url)
Figure 12 shows two consecutive slides in the north up, generic icon condition. The different conditions are more thoroughly described in the next section.

Each slide show contained 75 slides. Four of the slides were introductory and instruction slides. The other 71 slides comprised the in-vehicle navigation simulation and were presented at 1 slide per second. The participant visibly traveled 1 cm in monitor distance from one slide to the next. The scale was 1cm on the map corresponded to 30m of physical driving distance. The slide change corresponded to a physical distance of 30m. Each city block was approximately 8.83cm tall by 4.30cm wide. In physical distance, each block was approximately 212m tall by 103m across. Due to the inexact nature of block sizes, these numbers only represent an average block size. The presentation was 22.5cm wide by 22cm tall. In physical distance, approximately .445km$^2$ (445500m$^2$) were visible on the screen at any time. The total physical distance traveled by the participant was 2.10km.

*Track up and North Up*

In the track-up presentation, the map was always oriented such that “up” was the person’s current direction of travel. Therefore, the map would rotate as the person would make a turn. When a person was making a turn, the map would rotate in 18 degree increments in accordance with the turn. The icons would also rotate individually in 18 degree increments in their respective map locations such that they were always oriented up. The indicator arrow always remained stationary and oriented to point “up.” See Figure 11 below to see two consecutive slides for a turn in the track-up condition.
Figure 11. Two consecutive generic landmark slides. Above are two consecutive slides from the Generic Track Up In-Vehicle Navigation System simulation. The map in (B) has been rotated 18 degrees counter-clockwise from the map in (A) indicating that the vehicle is turning right. The arrow has not moved.

In the north-up presentation, the map was always oriented such that “north” was always up. North in this experiment was arbitrary. The direction which the participants originally started moving was considered the arbitrary north. Therefore the map was always oriented such that this direction was up. When a turn occurred, the arrow rotated in 18° increments to indicate the change in direction. See Figure 12 to see two consecutive slides for the same turn in the North-Up condition.

Verbal Directions

The simulated in-vehicle navigation system also gave verbal directions. The directions always preceded an upcoming turn and were presented in a male voice. Those in the specific voice condition would hear the restaurant referenced by its specific name. For a turn near Burger King®, a male voice announced “At the restaurant, turn right onto east 17th avenue.” Note that participants could tell which landmark was being referenced
because the generic voice condition was only used when specific icons were also being used. For each turn, the landmark at the turn location, the street names at the turn location, and the direction (right/left) a participant was turning was mentioned. The directions were always started several slides before the actual turn. Because of the varying length of the verbal instructions, the directions were not started a fixed number of slides before the turn. Instead, the instructions were timed to end one to two slides before the start of the turn. The verbal instructions also served to identify the generic icons.

The verbal instructions follow:

1. Start out at Starbucks® on the corner of east Colfax Avenue and Grant Street. Proceed straight ahead on Grant Street.
2. At Burger King®, turn right onto east 17th Avenue.
3. At Bob Evans®, turn left onto Pennsylvania Street.
4. At Taco Bell®, turn left onto East 18th Avenue.
5. At Kentucky Fried Chicken®, turn right onto Broadway.
6. End at Arby’s® at the corner of East 19th Avenue and Glen Arm.
Participant Recall Maps

Each participant received a blank 8.5 by 8.5 inch square sheet of paper on which to draw a freehand map of the environment. The map had an inch by ½ inch arrow in the upper left hand corner indicating the direction of travel at the start of their in-vehicle navigation simulation. Appendix B shows an example of a freehand map drawn by one on the participants on the blank paper.

Each participant also received an 8.5 by 8.5 inch square sheet of paper with a street map of the environment. The street names were blurred and unreadable and the icons were not present on the map. The street map included the entire area presented in the slide show plus areas not included in the slideshow. One-half of the street map contained an area which the participants experienced in the slide show while the other half of the map contained an area which the participants did not experience in the slide show. See Appendix C for a copy of this map.

Free Recall of Restaurant Names

Participants were asked to recall the names of the restaurants in any order. They were provided paper with 21 one and a half inch lines to write the names for the free recall task. A copy of these pages and the free recall instructions are in Appendix D.

Route Description Sheets

Participants were asked to describe the route that they traversed describing all turns, restaurants passed and number of blocks between turns. They were given two sheets of lined paper for this route description task. The first sheet contained instructions in addition to the blank description lines. The second sheet was titled “Route Description Sheet Two.” There was sufficient space between the blank description lines in which
participants could later insert information. A copy of the lined paper and the route
description instructions are in Appendix E.

Demographics Questionnaire

A demographics questionnaire assessed each participant’s previous driving
experience. The questionnaire also assessed each participant’s previous experience with
GPS navigation systems and in-vehicle navigation systems. Finally, participants were
asked open ended questions about what they liked or did not like about the systems. See
Appendix F for a copy of the Demographics Questionnaire.

Procedure

In-Vehicle Navigation Simulation

Participants were instructed to watch the slide show as if they were interacting
with an in-vehicle navigation system display while receiving directions from the in-
vehicle navigation system. They were also warned that their knowledge of the
environment would be tested. See Appendix G for verbal instructions. Once the slide
show ended, participants were asked to freely recall all the landmarks they remembered
encountering in the environment.

Freehand Sketch Map

Upon completing their free recall, participants drew a free-hand sketch map on a
square blank sheet of paper. See Appendix H for the blank map. Participants were
shown an example of a map with the desired format. See Appendix I for the sample map
and Appendix J for the instructions. The instructions directed participants to indicate
streets with a double line so that blocks were clearly demarcated. Participants were also
asked to include any street names if they were remembered. Participants were instructed
to represented landmarks using squares and to clearly label each landmark with a restaurant name. A checklist of all critical point landmarks (the restaurant names) in the environment was given to each participant so that all restaurant names included in the slide show were placed onto the map. Participants were instructed to include all landmarks on the list and to check off each landmark as it was added. See Appendix K for the checklist of landmarks on the freehand map. Experimenters confirmed that each landmark was included on the freehand map and that each landmark was clearly labeled. Once participants completed the freehand map, it was removed.

Street Map

Participants were then given the street map of the environment. They were instructed to complete the same drawing task as before, but this time they only had to draw the landmarks. See Appendix L for a copy of the street map and Appendix M for the instructions. They were also given another checklist of all critical point landmarks (the restaurant names) included in the slide show. Once again the experimenters confirmed that each landmark was included. Once participants completed the street map, it was removed.

Route Lines

Participants were then asked to draw route lines on each of the maps they had previously drawn. Participants were not permitted to modify their original map however they were able to modify their route line as they saw fit. Participant’s route lines had to pass beside each landmark. Participants also clearly labeled the landmarks with a unique number from 1 to 6 to indicate the order in which the landmarks were passed. The starting and ending landmarks were also considered a passed landmark. The route line
was completed first for the freehand map, then the freehand map was removed and the route line was completed for the street map. See Appendix N for route line instructions.

Route Recall Paragraph

Finally, participants were asked to describe the route they took through the environment in a route description. They were instructed to include all the landmarks they encountered on their route, the number of blocks they passed between turn locations or landmarks, and the direction they turned at each landmark. They were allowed to go back and modify any previous portions of the text as they wrote. Participants were also given a list of all critical point landmarks and asked to include each landmark in their route description. The experimenter confirmed that all landmark, block, and turn direction information was included in the route description. The instructions have been attached in Appendix O. The example given to participants can be found in Appendix P. The route description checksheet is included in Appendix Q. Participants then completed the demographics questionnaire (Appendix F).

Scoring

Restaurant Name Recall

The number of restaurants free recalled correctly was counted for each participant. The maximum number correctly recalled was 6 passed landmarks.

Freehand Sketch Map, Street Map, and Route Lines

The maps were individually scored. Appendix R describes how maps were scored. Angles were calculated between each of the landmarks. The dependent variable is absolute angular error, the absolute value of the difference between the participants’ angle and the correct angle for each landmark pair. See Appendix R for the inter-
landmark error calculation procedure. The mean absolute angular error was calculated for each participant’s map by computing the mean angular error amongst all possible landmark pairs.

*Identity Map Scoring*

The scoring procedure was completed using the landmarks as they were identified by participants on the map for both the freehand map and the sketch map. The landmarks were scored regardless of what order they were numbered by participants during the route line task.

*Ordered Map Scoring*

The maps were also scored using ordered landmarks from the route lines task. Participants numbered the landmarks in the order which they were passed. In the simulated environment, Starbucks was the starting landmark and Burger King was the first landmark passed. Some participants, however, may have put Taco Bell® as the starting landmark and Bob Evans® as the first landmark passed. Therefore the angular error was computed by comparing the landmarks in numbered order, regardless of the landmark identity. Therefore, in the above example, the correct angle was computed between landmark 1 (Starbucks®) and landmark 2 (Burger King®) in the simulated environment. The angle was also computed between participant’s landmark 1 (in this example, Taco Bell®) and participant’s landmark 2 (in this example, Bob Evans®). The angular error was then computed between landmarks 1 and 2 using the same procedure previously discussed. One participant did not complete the ordering task and was therefore excluded from the appropriate analyses.
Paragraph Route Recall

The route descriptions were individually scored. Turn directions and number of blocks passed were recorded in the order written in the route description (i.e., one, left, two, right, three, right...). The turn directions and number of blocks passed were compared with the correct turn directions (i.e., two, right, three, right, two, right...). The number of correct turns and number of blocks passed were counted for each participant, scoring in order from the beginning of the route. If the number of turns reported by the participant was greater than the number of turns they actually encountered, then only the number of turns encountered was examined from the beginning. In other words, if the participant reported “left, right, right, left, right, right, left” and the correct answer is “right, left, left, right” then only the first five responses of “left, right, right, left, right” was considered. If the participant reported fewer turns than the number of turns they actually encountered, then the omitted turns were counted as errors.
III. RESULTS

*Configural Spatial Knowledge*

*Free and Street Maps*

*Contrasts*

This experiment was a 3 x 2 x 2 mixed factorial design with the between subjects factors of icon type (generic visual/specific voice, specific visual/generic voice, and specific visual/specific voice) and map rotation (north up, track up) and a repeated measures factor of map type (freehand map, street map). However, this experimental design was analyzed using orthogonal contrasts. Table 5 shows the entire set of orthogonal contrasts.

All of the contrasts, except contrasts 2, 3, 4, 5, 8, and 9 are standard factorial Analysis of Variance (ANOVA) contrasts. The factor of icon type was divided into two contrasts. One contrast, shown in row 2, compared the effect of specific information on both modalities versus the mean of the two single modality conditions (specific visual/specific voice versus mean of specific visual/generic voice & generic visual/specific voice). The other contrast, shown in row 3, compares generic visual/specific voice versus specific visual/generic voice. The interactions of these two contrasts with map rotation are shown in rows 4 and 5, respectively. The interactions of these two contrasts with map type are shown in rows 8 and 9, respectively.
Two separate ANOVAs were computed using these contrasts. One ANOVA used angles based on name identities as a dependent variable, as described in the method section. The other ANOVA used angles based on the order of visitation.

**Name Identity Analysis**

The mean absolute angular error was computed for each participant when treating the names of landmarks as identities as defined in the methods section. As Figure 13
Figure 13. Angular error results for the name identity analysis (full thesis data). Mean absolute angular error as a function of icon type and map rotation for the name identity analysis. The data for the freehand map can be seen on the left and the data for the street map can be seen on the right. SS = specific visual, generic voice. GS = generic visual, specific voice. SG = specific visual, generic. All conditions appear to be equivalent.

shows, the six experimental conditions were very similar for both free and street maps. None of the contrasts were statistically significant. The overall mean absolute angular error was 44.18°. Importantly, specific information on both the visual map and voice directions was not statistically different from the mean of the two single sources of specific information, $F(1, 138) = 2.65, MSE = 1032.76, p = 0.106$. There also was not a statistically significant difference between generic visual/specific voice versus specific visual/generic voice, $F(1, 138) = 2.73, MSE = 1032.76, p = 0.101$. The main effect of map rotation also was not statistically significant, $F(1, 138) = 1.16, MSE = 1032.76, p = 0.284$. There was no difference between free and street maps, $F(1, 138) = 0.08,$
\[ \text{MSE} = 117.75, \ p = 0.78. \] None of the interactions were statistically significant. The complete ANOVA table is in Appendix S.

**Visitation Order Identity Analysis**

Mean absolute angular error when treating visitation order as location identities, as described in the Method section, for both the Freehand Map and the Street Map were also analyzed using the contrasts in Table 5. Figure 14 shows the results of visitation order identity scoring for both freehand and street sketch map. Unlike the name identity scoring, there was a significant interaction between generic visual/specific voice versus 

\[ \text{Figure 14. Angular error results for the ordered identity analysis (full thesis data).} \]

Mean absolute angular error as a function of icon type and map rotation for the ordered identity analysis. The data for the freehand map can be seen on the left and the data for the street map can be seen on the right. SS = specific visual, generic voice. GS = generic visual, specific voice. SG = specific visual, generic. The GS participants had greater error in the north up condition than in the track up condition while those in the SG condition had greater error in the track up condition than in the north up condition.
specific visual/generic voice and map rotation, $F(1, 137) = 4.463, \text{MSE} = 746.19, p = 0.036$. As you can see in Figure 14, for the generic visual/specific voice condition participants had greater mean angular error in the north up condition ($M = 31.71^\circ$) than in the track up condition ($M = 27.26.68^\circ$). In contrast, those in the specific visual/generic voice condition had greater angular error in the track up condition ($M = 337.22^\circ$) than in the north up condition ($M = 27.01^\circ$). There was no overall difference between the generic visual/specific voice condition versus specific visual/generic voice condition, $F(1, 137) = 0.832, \text{MSE} = 746.19, p = 0.363$. Also, there was no main effect for map rotation. North up maps yielded similar results as track up maps, $F(1, 137) = 2.88, \text{MSE} = 746.19, p = 0.09$. Finally, specific information on both the visual map and voice directions was not statistically different from the mean of the two single sources of specific information, $F(1, 137) = 1.74, \text{MSE} = 746.19, p = 0.183$, and its interaction with map rotation also was not statistically significant, $F(1, 137) = 1.88 \text{MSE} = 746.19, p = 0.172$. All other effects also were not statistically significant. See Appendix T for the full ANOVA table.

**Route Knowledge**

The number of correct turn directions and number of correct blocks also were analyzed using contrasts. As there was no within-subjects variable of “Map Type”, only contrasts 1-5 were used without the within-subjects analysis. A simplified version of the original contrast without the within-subjects effects are shown in Table 6.
Number of Turn Directions

Figure 15 shows the mean number of correct turns serially identified. As you can see, generic visual/specific voice icons produced better performance than specific visual/generic voice directions, $F(1, 138) = 4.37, \text{MSE} = 1.3744, p = 0.039$. The mean number of correct turns recalled correctly was 3.33 versus 2.83, respectively. There was no significant difference between the presentation of specific information in both the visual map and voice directions compared to specific information in only one of the two modalities, $F(1, 138) = 1.01, \text{MSE} = 1.374, p = 0.317$. There was also no significant effect for map rotation, $F(1, 138) = 0.020, \text{MSE} = 1.374, p = 0.887$. There were no
Figure 15. Mean number of turns correctly recalled (full thesis data). Mean number of turn directions serially correctly recalled as a function of icon type and map rotation. Those in the GS condition had better recall than those in the SG condition.

statistically significant interaction effects. The overall mean number of turns reported correctly was 3.013. The maximum possible was 4. The complete ANOVA table can be found in Appendix U.

Number of Correct Blocks

As Figure 16 suggests, neither specificity of the directions nor map rotation affected the number of correct blocks that were described in the protocols. There was no significant difference in the correct number of blocks recalled between the specific visual/specific voice condition when compared to the specific visual conditions or the specific voice conditions, $F(1, 138) = 1.53, MSE = 1.1002, p = 0.219$. There was also no difference between presenting specific visual only or specific voice only, $F(1, 138) = 0.038, MSE = 1.100, p = 0.846$. There was also no difference between track up maps or
Mean number of blocks correctly recalled (full thesis data). Mean number of blocks serially correctly recalled as a function of icon type and map rotation. Those in the GS condition had better recall than those in the SG condition.

north up maps, \( F(1, 138) = 0.227, \text{MSE} = 1.1002, p = 0.634 \). No interactions were significant. The overall mean number of blocks reported correctly was 1.514. The maximum possible was 5. See Appendix V for the complete ANOVA table.

**Free Recall**

Free recall of restaurants (out of 6) was examined using the contrasts in Table 6. As Figure 17 shows, there was a large effect of the modality of the specific directions, \( F(1, 138) = 12.5, \text{MSE} = 0.905, p = 0.0005 \). Fewer restaurant names were recalled for specific visual icons (\( M = 4.33 \)) than for specific voice directions (\( M = 4.67 \)). There was no statistically significant difference in the free recall of those who saw specific visual icons on the map and heard specific voice compared with those who only saw specific
Figure 17. Mean number of restaurants for free recall. Mean number of restaurants correctly recalled as a function of icon type and map rotation. Those in the GS condition had better recall than those in the SG condition.

visual icons or only heard specific voice directions, $F(1, 138) = 0.004, MSE = 0.905, p = 0.951$. There was no significant difference in number of items freely recalled between those who saw a north up map and those who saw a track up map $F(1, 138) = 0.928, MSE = 0.905, p = 0.337$. There were no statistically significant interactions. The complete ANOVA table can be found in Appendix W.

Pilot Study

The results of the thesis were surprising because I had previously conducted an experiment which used very similar methods. The primary difference between this previous pilot experiment and this experiment was the manipulation of icon type. All subjects in the pilot study heard specific icon names while they saw either generic or specific icons. In contrast, for the thesis study, participants heard either specific or generic icon names while they saw either generic or specific icons. The map type
manipulation was constant across the two studies. Therefore, the pilot study was a 2 (map rotation) x 2 (visual icon) x 2 (map type) mixed subjects design. The two between-subjects factors were map rotation (north up vs. track up) and visual icon (generic vs. specific). The within-subjects factor was map type (freehand map vs. street map).

Materials and Material Differences

All of the materials and instructions were the same with a few exceptions. In the thesis, the arrow on both the street map and the freehand map sheets was located in the upper left hand corner, but it had been located in the lower right hand corner in the pilot study. Appendices X and Y show where the arrow was located on the pilot study’s freehand and street maps, respectively. The comparable maps for the thesis experiment are in Appendices I and K. Note that there is very little room at the top of the arrow on the thesis maps. However, in the pilot study, the arrow was placed in lower right hand corner, leaving much room directly above it for participants to draw. Some subjects in the pilot study drew their map starting at the arrow location, regardless of instructions that the arrow did not indicate the starting location but merely the direction of travel. The arrow was moved to the upper right hand corner in the thesis in order to avoid this potential source of confusion.

Dependant Variables

The same dependant variable measures used for the thesis were also used for the pilot. Mean angular error was computed between the landmarks for each participant for the both the freehand map and the street map. This was done using both named identity analysis and visitation order identity analysis as described in the methods section. Participants’ free recall for the restaurants was also analyzed. Those in the pilot,
however, did not complete the route description. Therefore the dependant variables of blocks and turns were not collected or analyzed.

Participants

Forty-eight undergraduates at Wright State University participated in the pilot study. They were randomly assigned to the four between-subject conditions to create a balanced design. Five of the undergraduates were male and forty-three were female. Of the men, all five were drivers. Of the women, thirty-eight were drivers while only five were non-drivers. Four participants indicated prior use of GPS navigation systems. Mean age of participants was 18.67 (SD = 1.05).

Results

The pilot data were examined using 2 x 2 x 2 mixed ANOVAs with the between subjects factors of map rotation and visual icon type and the within subjects factor of map type.

Name Identity Analysis

As Figure 18 shows, maps with generic visual icons led to greater angular error than maps with specific visual icons. The main effect of landmark representation was statistically significant, \( F(1, 44) = 9.01, \text{MSE} = 1145.126, p = .004 \). Mean absolute angular error was 57.01° for maps with generic visual icons, but was only 41.39° for maps with specific visual icons. As Figure 18 shows, track up maps led to greater angular error than north up maps. This main effect was statistically significant, \( F(1, 44) = 4.75, \text{MSE} = 1145.126, p = .035 \). Mean absolute angular error was 59.28° for the track up maps compared with 44.22° for the north up maps. Thus, both north up maps and maps
Figure 18. Angular error results for the name identity analysis (pilot data). Mean absolute angular error as a function of icon type and map rotation for the name identity analysis for the pilot experiment. The data for the freehand map can be seen on the left and the data for the street map can be seen on the right. Unlike the thesis experiment, the pilot experiment only had specific voice references. Therefore, only the visual icon was manipulated. Those who saw generic icons performed worse than those who saw specific icons. Also, those who used a track up map performed worse than those who used a north up map.

with specific visual icons led to better configural knowledge. The interaction of map rotation and landmark representation was not statistically significant, $F(1, 44)= 0.013$, $MSE = 1145.126$, $p = .910$.

The difference between the freehand sketch maps and street map sketch maps was not statistically significant, $F(1, 44) = 0.720$, $MSE = 134.466$, $p = .40$. Importantly, there also were no statistically significant interactions of sketch map drawing with any of the other factors. The full ANOVA table can be found in Appendix Z.
Order Identity Analysis

As you can see in Figure 19, the visitation order identity analysis yielded results similar to the name identity analysis. As Figure 19 shows, maps with generic visual icons did not lead to greater absolute angular error than maps with specific icons. The main effect of landmark representation was only marginally statistically significant, $F(1, 44) = 3.95, MSE = 735.545, p = .053$. Mean absolute angular error was $38.67^\circ$ for maps with generic icons, but was only $32.6^\circ$ for maps with specific icons. As Figure 19 shows, track up maps led to greater absolute angular error than north up maps. The main effect of map rotation was again statistically significant, $F(1, 44) = 10.208, MSE = 735.545, p = 0.003$. Mean absolute angular error was $46.9^\circ$ for the track up maps compared with

![Figure 19](image.png)

*Figure 19.* Angular error results for the ordered identity analysis (pilot data). Mean absolute angular error as a function of icon type and map rotation for the visitation order identity analysis for the pilot experiment. The data for the freehand map can be seen on the left and the data for the street map can be seen on the right. The pattern of results is similar to the pattern of results for the name identity analysis shown in Figure 18.
29.29° for the north up maps. The interaction of map rotation and landmark representation was not statistically significant, $F(1, 44) = 2.09$, $MSE = 735.545$, $p = .156$. Thus, north up maps led to better configural knowledge while there was some indication that specific visual icons may have led to better configural knowledge.

The difference between the freehand sketch maps and street map sketch maps was not statistically significant, $F(1, 44) = 0.01$, $MSE = 205.145$, $p = .933$. Importantly, there also were no statistically significant interactions of sketch map drawing with any of the other factors. The full ANOVA table can be found in Appendix AA.

Overall, the results indicated that specific visual icons led to better spatial knowledge acquisition than generic visual icons. The results also indicated that north up maps led to better configural spatial knowledge acquisition than track up maps.

*Free Recall*

As you can see in Figure 20, those in the generic visual icon condition recalled a greater number of restaurants than those in the generic visual icon condition, $F(1, 44) = 4.981$, $MSE = 0.602$, $p = 0.031$. Those who in the generic visual icon condition recalled 4.71 restaurants as compared to 4.21 restaurants for those in the specific visual icon condition. There was no main effect for map rotation, $F(1, 44) = 0.138$, $MSE = 0.602$, $p = 0.712$. There was also no significant interaction between map rotation and icon type, $F(1, 44) = 0.553$, $MSE = 0.602$, $p = 0.461$. The complete ANOVA table can be found in Appendix AB.
**Figure 20.** Mean number of restaurant for free recall (pilot data). Free recall of restaurant names in the pilot experiment. Those who saw generic icons and heard specific restaurant names recalled a greater number of restaurants than those who saw specific icons and heard specific restaurant names.

**Pilot Experiment versus Thesis Experiment**

As the pilot experiment produced several statistically significant effects and the thesis produced few significant effects, the data from the pilot experiment and the thesis experiment were examined together using a new set of contrasts. This set of contrasts differed from the original contrasts in order to directly compare the two experiments. First, the pilot experiment did not contain the icon voice manipulation. It did not have the SG condition. It only had the GS and SS conditions. Therefore, the pilot study could not be compared with the current study on the dimension of icon type as it was previously defined. Icon type in the thesis experiment had all three icon conditions, SG as well as GS and SS. Therefore all participants in the thesis experiment who received the specific visual, generic voice condition were excluded from the analysis.
The second difference between the pilot experiment and the thesis experiment was the number of participants per condition. The pilot experiment had only 12 participants per between-subjects condition, but the thesis experiment had 24 participants per condition. Therefore, a balanced design was created to perform a methodological check on the thesis experiment as well as comparing the thesis and pilot experiments. The thesis experiment was split into two halves based on order of testing. This led to a balanced design because participants had been randomly assigned to conditions using block randomization. The two halves were labeled as experiment half A, for the first 48 participants and experiment half B for the second 48 participants. Therefore, experiment halves A and B each had 12 subjects per group. Combining these data with the pilot experiment data created a 3 (halfA, halfB, pilot) x 2 (icon) x 2 (map rotation) x 2 (map type) mixed factorial design. Experiment (halfA, halfB, pilot study), icon (generic, specific), and map rotation (north, track) were the between subjects factors. Map type (freehand, street) was the within subjects factor.

**Pilot versus Thesis: Contrasts**

The experimental design was analyzed with a set of contrasts to answer the methodological comparison of the halves of the thesis experiment and the comparison of the two halves with the pilot experiment. These comparisons were accomplished by dividing the factor of experiment into two contrasts. The first contrast, H, shown in line 1 of Appendix AC compared half A with half B of the thesis experiment. The second contrast, called Exp and shown in line 2 of Appendix AC, compared half A and half B combined against the pilot experiment. Appendix AC shows the entire set of contrasts, including main effects of icon type and map rotation, and all interactions.
Pilot versus Thesis: Results

Pilot versus Thesis: Name Identity Analysis

The comparison between the thesis experiment and the pilot experiment was statistically significant, $F(1, 132) = 5.92, MSE = 1030.228, p = 0.016$. Overall, mean absolute angular error was smaller for the thesis experiment ($M = 41.99^\circ$) than for the pilot experiment ($M = 51.75^\circ$). There was also a significant effect for icon type, $F(1, 132) = 5.306, MSE = 1030.23, p = 0.023$. Those who saw generic visual icons had a mean angular error of 49.60°, which was greater error than the mean angular error of 40.64° for those who saw specific visual icons. More importantly there was a significant interaction of experiment (thesis vs. pilot) and icon type, $F(1, 132) = 5.048, MSE = 1030.228, p = 0.026$. As can be seen in Figure 21, there was a greater difference in the effects of icon type for the pilot experiment than for the thesis experiment. Those who saw specific visual icons performed better than those who saw the generic visual icons by 20.7° for the pilot experiment compared to only 2.7° for the thesis experiment. These differences were found for both freehand and street maps, and both north up and track up maps.

The main effect of map rotation was not statistically significant, $F(1, 132) = 2.00, MSE = 1030.228, p = 0.159$. As Figure 21 shows, mean absolute angular error was similar for north up and track up maps. The interaction of Experiment and map rotation also was not statistically significant, although it was close, $F(1, 132) = 3.29, MSE = 1030.228, p = 0.072$.

Methodologically, the thesis experiment appeared to be internally consistent. There appeared to be no difference between the first half and the second half of the thesis.
Figure 21. Angular error results for the name identity analysis (pilot versus thesis). Mean absolute angular error as a function of map rotation and visual icon type for name identity icons. For all three graphs, the freehand map is on the left and the street map is on the right. The first graph shows the first half of the thesis (Thesis A). The second graph shows the second half of the thesis (Thesis B). The third graph shows the pilot. There are no differences between Thesis A and Thesis B, indicating internal thesis consistency. However, the Pilot differs from Thesis A and Thesis B.
(halves contrast), $F(1, 132) = 0.996$, $MSE = 1030.228$, $p = 0.320$. More importantly, there were no statistically significant interactions of halves with any other factor. See Appendix AD for the ANOVA table of all contrasts.

**Pilot versus Thesis: Ordered Configural Knowledge Measures**

The comparison between the thesis experiment and the pilot experiment was again statistically significant, $F(1, 132) = 7.45$, $MSE = 856.711$, $p < 0.01$. Overall, mean absolute angular error was smaller for the thesis experiment ($M = 28.15^\circ$) than for the pilot experiment ($M = 38.13^\circ$). The main effect of map rotation was also statistically significant, $F(1, 138) = 4.03$, $MSE = 856.711$, $p = 0.047$. Those in the north-up condition (28.34) had smaller absolute angular error than those in the track-up condition (37.95). There was also significant interaction of experiment (thesis vs. pilot) and map rotation, $F(1, 132) = 4.87$, $MSE = 856.711$, $p = 0.029$. As can be seen in Figure 22, there was a greater difference in the effects of map rotation for the pilot experiment than for the thesis experiment. The difference between north up and track up for the pilot experiment was $17.68^\circ$ compared to the difference of only $1.54^\circ$ for the thesis experiment. Both the freehand map and the street map and both the generic and specific icons yielded these differences. There was also a three-way interaction between experiment, map rotation, and icon type, $F(1, 132) = 4.46$, $MSE = 856.71$, $p = 0.037$ See Figure 22 for the interaction. There was no significant interaction between experiment and icon type, $F(1, 132) = 1.76$, $MSE = 856.71$, $p = .187$. There was also no significant effect for icon type, $F(1, 132) = 1.72$, $MSE = 856.71$, $p = 0.192$. 
Figure 22. Angular error results for the ordered identity analysis (pilot versus thesis). Mean absolute angular error as a function of map rotation and visual icon type for ordered identity icons. For all three graphs, the freehand map is on the left and the street map is on the right. The first graph shows the first half of the thesis (Thesis A). The second graph shows the second half of the thesis (Thesis B). The third graph shows the pilot experiment.
Again, methodologically the thesis experiment appeared to be internally consistent. There appeared to be no difference between the first half of the thesis experiment and the second half of the thesis experiment (halves contrast), $F(1, 132) = 1.73, MSE = 856.711, p = 0.191$. More importantly, there were no statistically significant interactions of halves with and other factor. See Appendix AE for the full contrast and ANOVA table.

**Pilot versus Thesis: Free Recall**

Analysis on the recall data indicated that the effect of icon type was statistically significant, $F(1, 132) = 7.29, MSE = 0.801, p = 0.008$. The presentation of generic icons

![Figure 23](image)

*Figure 23. Mean number of restaurant for free recall (pilot versus thesis). Mean number of restaurants serially correctly recalled as a function of map rotation and visual icon type. Thesis A can be seen in the left panel. Thesis B is in the middle panel. Pilot is in the right panel. Note that those who saw specific icons had greater recall than those seeing generic icons.*
produced greater recall than specific icons, means of 4.81 versus 4.40 items, respectively. The interaction of icon type with experiment was not statistically significant, $F(1, 132) = 0.212, MSE = 0.801, p = 0.646$, which is not surprising because the significant effects of icon types was found in both the experiment and the pilot study. Figure 23 shows the results. Map rotation and the interaction of map rotation with experiment were not statistically significant, $F(1, 132) = 0.217, MSE = 0.801, p = 0.642$ and $F(1, 132) = 0.524, MSE = 0.801, p = 0.470$, respectively. There were no other significant effects.

Methodologically, the thesis appeared to be internally consistent with no significant effects for the halves contrast or interactions with the halves contrast with any other factor. See Appendix AF for the full contrast and ANOVA table.

**GPS Non-Users Analysis**

In reviewing the thesis and pilot experiments, I noticed a difference between the participants in the two experiments. The thesis experiment appeared to have more participants who had previously used a GPS in-vehicle navigation system than the pilot experiment, 27.7% users in the thesis experiment versus only 8.3% users in the pilot experiment. Frequencies are shown in Table 7. This difference was found to be statistically significant using a Chi-Square Test of Independence, $\chi^2(1, N = 192) = 7.71, p = 0.006$. Data was obtained from the yes/no responses to the demographics question “Have you ever navigated using a GPS system” which was used in both the pilot and the thesis experiments.

**GPS Non-Users Analysis: ANOVA and Contrasts**

In order to determine if the results of the thesis study were skewed by previous experience with GPS systems, the analyses on configural knowledge (both name identity
Table 7.

Frequencies of GPS Non-Users and GPS Users

<table>
<thead>
<tr>
<th></th>
<th>GPS Non-Users</th>
<th>GPS Users</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Thesis Experiment</strong></td>
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<tr>
<td><strong>Pilot Experiment</strong></td>
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<td>4</td>
</tr>
<tr>
<td>Both</td>
<td>44</td>
<td>4</td>
</tr>
</tbody>
</table>

and visitation order identity) and free recall were repeated on the thesis data excluding those subjects who had previously used a GPS system. The original analyses can be found in sections A, and C, respectively. This left an unequal number of participants per group. The group sizes can be found in Table 8.

The name identity contrast and the ordered identity contrast were computing using the contrast found in Table 5. The recall contrast was computing using the contrast found in found Table 6.

**GPS Non-Users: Configural Knowledge Acquisition**

**Name Identity Analysis**

The mean absolute angular error was computed for each participant when treating the names of landmarks as identities as defined in the methods section. There were no

Table 8.

Number of Participants per Group: GPS Non-Users Only

<table>
<thead>
<tr>
<th></th>
<th>Specific, Specific</th>
<th>Generic, Specific</th>
<th>Specific, Generic</th>
</tr>
</thead>
<tbody>
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<td>North</td>
<td>18</td>
<td>14</td>
<td>18</td>
</tr>
<tr>
<td>Track</td>
<td>16</td>
<td>18</td>
<td>20</td>
</tr>
</tbody>
</table>
significant effects found for the original set of data. There were also no significant
effects found for those who had not used a GPS system. Figure 24 shows the data for the
participants who had not previously used a GPS system. As Figure 24 shows, there were
no differences between the six groups. There was no difference between the presentation
of two specific types of information (specific visual/ specific voice) versus the
presentation of a single piece of specific information (specific visual/ generic voice and
generic visual/specific voice), $F(1, 98) = 1.91, MSE = 1092.907, p = .17$. There also was
not a statistically significant difference between generic visual/specific voice versus

![Figure 24](image_url)

**Figure 24.** Angular error results for the name identity analysis (GPS Non-Users). Mean absolute angular error as a function of icon type and map rotation for the name identity analysis for Non-GPS participants. The data for the freehand map can be seen on the left and the data for the street map can be seen on the right. SS = specific visual, generic voice. GS = generic visual, specific voice. SG = specific visual, generic. Once again, all conditions appear to be equivalent.
specific visual/generic voice. \( F(1, 98) = 3.23, MSE = 1092.907, p = 0.075 \). The main
effect of map rotation also was not statistically significant, \( F(1, 98) = 0.42, MSE = \\
1092.907, p = 0.518 \). No differences appeared between the conditions due to either free
effect of map rotation also was not statistically significant, \( F(1, 98) = 0.42, MSE = \\
1092.907, p = 0.518 \). No differences appeared between the conditions due to either free
or street map mean angular error. None of the interactions were significant. The
complete ANOVA table is in Appendix AG

 Ordered Identity Analysis

The original analyses found a statistically significant interaction between generic
visual/specific voice versus specific visual/generic voice and map rotation, \( F(1, 138) = \\
4.46, MSE = 746.190, p = 0.036 \). The generic visual/specific voice condition participants
had greater mean angular error in the north up condition (\( M = 31.71^\circ \)) than in the track up
condition (\( M= 26.68^\circ \)). In contrast, those in the specific visual/generic voice condition
had greater angular error in the track up condition (\( M = 37.22^\circ \)) than in the north up
condition (\( M = 27.01^\circ \)). However, this effect was not statistically significant for the Non
GPS participants, \( F(1, 97) = 1.564, MSE = 741.831, p = 0.214 \), although the pattern of
results was similar. Generic visual/specific voice condition participants had nominally
greater mean angular error in the north up condition (\( M = 28.90 \)) than in the track up
condition (\( M = 26.96 \)). Those in the specific visual/generic voice condition had
nominally greater angular error in the track-up condition (\( M = 39.08 \)) that in the north-up
condition (\( M = 29.40 \)). Figure 25 shows the data for the non-users for both freehand and
street sketch maps. None of the other contrasts were statistically significant. Specific
Figure 25. Angular error results for the ordered identity analysis (GPS Non-Users). Mean absolute angular error as a function of icon type and map rotation for the ordered identity analysis for Non-GPS participants. The data for the freehand map can be seen on the left and the data for the street map can be seen on the right. SS = specific visual, generic voice. GS = generic visual, specific voice. SG = specific visual, generic. There were no significant effects, although the pattern of results was similar to the pattern found when examining all participants.

Information on both the visual map and voice directions was not statistically different from the mean of the two single sources of specific information, $F(1, 97) = 1.78, MSE = 741.831, p = 0.185$. There also was not a statistically significant difference between generic visual/specific voice versus specific visual/generic voice. $F(1, 97) = 1.846, MSE = 741.831, p = 0.177$. The main effect of map rotation also was not statistically significant, $F(1, 97) = 3.01, MSE = 741.831, p = 0.081$. No differences appeared between the conditions due to either free or street map mean angular error. None of the interactions were significant. The complete ANOVA table is in Appendix AH.
**GPS Non-Users: Route Knowledge Acquisition**

The number of correct turn directions and number of correct blocks were analyzed using the contrasts found in Table 6.

*Number of Turn Directions*

The contrasts for the original data found a statistically significant effect of modality. Generic visual icons with specific voice directions produced better performance than specific visual icons with generic voice directions (3.33 versus 2.83, respectively).

![Graph showing mean number of turns correctly recalled for GPS Non-Users.](image)

*Figure 26.* Mean number of turns correctly recalled (GPS Non-Users). Mean number of turns directions serially correctly recalled as a function of icon type and map rotation for Non-GPS participants. Similarly to data for all participants, those in the GS condition had better recall than those in the SG condition.
For the Non GPS data, this contrast was also significant, $F(1, 98) = 4.71, MSE = 1.29, p = 0.032$. A similar difference was found (3.46 versus 2.87 respectively). You can see the effect in Figure 26. The other contrast for icon type was not statistically significant, $F(1, 98) = 1.47, MSE = 1.29, p = 0.229$. The effect of map rotation was not significant, $F(1, 98) = 0.452, MSE = 1.29, p = 0.503$. The two interactions between icon type and map rotation were also not significant. You can see ANOVA table with all contrasts in Appendix AI.

**Number of Correct Blocks**

There were no statistically significant effects in the original analysis of all participants. For those participants who had no previous GPS experience, there were no differences in the number of blocks recalled between the six groups. Neither contrast for icon type was significant, $F(1, 98) = 0.077, MSE = 1.103, p = 0.78$ for modality and $F(1, 98) = 0.391, MSE = 1.10, p = 0.533$ for number of specific presentations. The effect of map rotation was also not statistically significant, $F(1, 98) = 0.735, MSE = 1.103, p = 0.393$. The two interactions between icon type and map rotation were also insignificant. The full contrast and ANOVA table can be found in Appendix AJ.

**GPS Non-Users: Free Recall**

In the analysis of all participants, more restaurant names were recalled when specific information was presented as voice directions ($M = 4.85$) than as visual icons ($M = 4.17$), $F(1, 138) = 0.227, MSE = 1.100, p = 0.634$. Similar results were found when only participants who had not previously used a GPS system were analyzed, $F(1, 98) = 7.36, MSE = 0.941, p = 0.008$. As Figure 27 suggests, more restaurant names were
Figure 27. Mean number of blocks correctly recalled (GPS Non-Users). Mean number of blocks serially correctly recalled as a function of icon type and map rotation for Non-GPS participants only. There were no significant effects.

recalled when specific information was presented as voice directions \((M = 4.83)\) than when it was presented as visual icons \((M = 4.20)\). The other contrast for icon type (specific visual and voice versus specific visual alone and specific voice alone) was not statistically significant, \(F(1, 98) = .001, MSE = .941, p = 0.976\). The main effect for map rotation was also not significant, \(F(1, 98) = 2.29, MSE = .941, p = 0.133\). The interactions between Icon and Map Rotation were also not significant. You can see the full ANOVA table in Appendix A.

Excluding participants with previous GPS experience did not produce the results of the pilot study. Therefore, the differences between results of the Thesis and pilot
Figure 28. Mean number of restaurant for free recall (GPS Non-Users). Mean number of restaurants correctly recalled as a function of icon type and map rotation for Non-GPS participants only. Those in the GS condition had better recall than those in the SG condition. More restaurant names were recalled when specific information was presented as voice directions than when it was presented as visual icons.

experiments were unlikely to be attributed to differences in participants’ previous use of in-vehicle navigation systems.

Women Only Analysis

The two experiments also differed in the number of women participating. The pilot experiment appeared to have more women participants than the thesis experiment, 89.6% of users in the pilot experiment were women versus only 67.4% of users in the thesis experiment. Frequencies are shown in Table 8. This difference was found to be statistically significant using a Chi-Square Test of Independence, \( \chi^2(1, N = 192) = 9.00, \)
$p = 0.003$. The gender data was obtained by asking participants to indicate whether they
were male or females on the demographics questionnaire.

**Women Only Analysis: ANOVA and Contrasts**

In order to determine if the results of the thesis study differed from the results of
the pilot study because of the disproportionate number of women in the pilot study, the
analyses on configural knowledge (both name identity and visitation order identity) and
free recall were repeated on only the data from women participants. The original
analyses can be found in sections A, and C, respectively. This left an unequal number of
participants per group. The group sizes can be found in Table 9.

The name identity contrast and the ordered identity contrast were computing
using the contrast found in Table 4. The recall and route contrasts were computing using
the contrast also found in Table 4.

**Women Only: Configural Knowledge Acquisition**

**Name Identity Analysis**

Again, the mean absolute angular error was computed for each participant when
treating the names of landmarks as identities as defined in the methods section. As
previously mentioned, there were no significant effects found for the original set of data.
There were also no significant effects found for women only. Figure 29 shows the data

<table>
<thead>
<tr>
<th>Table 9.</th>
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<tbody>
<tr>
<td><strong>Number of Participants per Group: GPS Women Only</strong></td>
</tr>
<tr>
<td><strong>(Visual, Voice)</strong></td>
</tr>
<tr>
<td>North</td>
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<tr>
<td>Track</td>
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for women only. As Figure 29 shows, there were no differences between the six groups. There was no difference between the presentation of two specific types of information (specific visual/ specific voice) versus the presentation of a single piece of specific information (specific visual/ generic voice and generic visual/specific voice), $F(1, 91) = 0.778, MSE = 967.417, p = .380$. There also was not a statistically significant difference between generic visual/specific voice versus specific visual/generic voice. $F(1, 91) = 0.944, MSE = 967.417, p = 0.334$. The main effect of map rotation also was not

![Figure 29. Angular error results for the name identity analysis (Women Only). Mean absolute angular error as a function of icon type and map rotation for the name identity analysis for only women participants. The data for the freehand map can bee seen on the left and the data for the street map can be seen on the right. SS = specific visual, generic voice. GS = generic visual, specific voice. SG = specific visual, generic. Once again, all conditions appear to be equivalent.](image-url)
statistically significant, \( F(1, 91) = 2.114, \) \( \text{MSE} = 967.417, p = 0.149. \) No differences appeared between the conditions due to either free or street map mean angular error. None of the interactions were significant. The complete ANOVA table is in Appendix AL

*Ordered Identity Analysis*

The original analyses found a statistically significant interaction between generic visual/specific voice versus specific visual/generic voice and map rotation, \( F(1, 138) = 4.46, \) \( \text{MSE} = 746.190, p = 0.036. \) The generic visual/specific voice condition participants had greater mean angular error in the north up condition (\( M = 31.71^\circ \)) than in the track up condition (\( M = 26.68^\circ \)). In contrast, those in the specific visual/generic voice condition had greater angular error in the track up condition (\( M = 37.22^\circ \)) than in the north up condition (\( M = 27.01^\circ \)). This effect was not statistically significant for the women participants, \( F(1, 90) = 2.036, \) \( \text{MSE} = 825.575, p = 0.157, \)

None of the other contrasts were statistically significant. Specific information on both the visual map and voice directions was not statistically different from the mean of the two single sources of specific information, \( F(1, 90) = 0.385, \) \( \text{MSE} = 825.575, p = 0.537. \) There also was not a statistically significant difference between generic visual/specific voice versus specific visual/generic voice. \( F(1, 90) = 1.047, \) \( \text{MSE} = 825.575, p = 0.309. \) The main effect of map rotation also was not statistically significant, \( F(1, 90) = 2.667, \) \( \text{MSE} = 825.575, p = 0.106. \) No differences appeared between the
Figure 30. Angular error results for the ordered identity analysis (Women Only). Mean absolute angular error as a function of icon type and map rotation for the ordered identity analysis for women only. The data for the freehand map can be seen on the left and the data for the street map can be seen on the right. SS = specific visual, generic voice. GS = generic visual, specific voice. SG = specific visual, generic. There were no significant effects, although the pattern of results was similar to the pattern found when examining all participants.

conditions due to either free or street map mean angular error. None of the interactions were significant. The complete ANOVA table is in Appendix AM and the means can be seen in Figure 30.

Women Only: Route Knowledge

The number of correct turn directions and number of correct blocks were analyzed using the contrasts found in Table 6.
Figure 31. Mean number of turns correctly recalled (Women Only). Mean number of turn directions serially correctly recalled as a function of icon type and map rotation for women. Similarly to data for all participants, those in the GS condition had better recall than those in the SG condition.

Number of Turn Directions

The contrasts for the original data found a statistically significant effect of modality. Generic visual icons with specific voice directions produced better performance than specific visual icons with generic voice directions (3.33 versus 2.83, respectively). For the women, this contrast was also significant, $F(1, 91) = 4.630, MSE = 1.433, p = 0.034$. A similar difference was found (3.27 versus 2.66 respectively). You can see the effect in Figure 31. The other contrast for icon type was not statistically significant, $F(1, 91) = 1.158, MSE = 1.433, p = 0.285$. The effect of map rotation was not significant, $F(1, 91) = 0.777, MSE = 1.433, p = 0.380$. The two interactions between icon
type and map rotation were also not significant. You can see ANOVA table with all contrasts in Appendix AN

*Number of Correct Blocks*

There were no statistically significant effects in the original analysis of all participants. Analysis of GPS non-users produced similar results. As Figure 32 suggests for those participants who had no previous GPS experience, there were no differences in the number of blocks recalled between the six groups. Neither contrast for icon type was significant, $F(1, 91) = 0.086$, $MSE = 1.20$, $p = 0.770$ for modality and $F(1, 91) = 0.1364$, $MSE = 1.20$, $p = 0.713$ for number of specific presentations. The effect of map

![Figure 32. Mean number of blocks correctly recalled (Women Only). Mean number of blocks serially correctly recalled as a function of icon type and map rotation for women. There were no significant effects.](image-url)
rotation was also not statistically significant, $F(1, 91) = 0.359, MSE = 1.203, p = 0.550$. The two interactions between icon type and map rotation were also insignificant. The full contrast and ANOVA table can be found in Appendix AO.

**Women Only: Free Recall**

As you can see in Figure 33 more restaurant names were recalled when specific information was presented as voice directions ($M = 4.79$) than as visual icons ($M = 4.19$) in the analysis of all participants. As can be seen in Figure 33, similar results were found in the analysis of all participants. As can be seen in Figure 33, similar results were found.

*Figure 33. Mean number of restaurants correctly recalled as a function of icon type and map rotation for Non-GPS participants only. Those in the GS condition had better recall than those in the SG condition. More restaurant names were recalled when specific information was presented as voice directions than when it was presented as visual icons.*
when only women were analyzed, $F(1, 91) = 6.533, MSE = 0.961, p = 0.012$. More
restaurant names were recalled when specific information was presented as voice
directions ($M = 4.79$) than when it was presented as visual icons ($M = 4.19$). The other
contrast for icon type (specific visual and voice versus specific visual alone and specific
voice alone) was not statistically significant, $F(1, 91) = 0.387, MSE = 0.961, p = 0.528$.
The main effect for map rotation was also not significant, $F(1, 91) = 0.755, MSE = 0.961,
p = 0.387$. The interactions between Icon and Map Rotation were also not significant.
You can see the full ANOVA table in Appendix A.

Looking only at female participants did not produce the results of the pilot study,
as seen in section D. Therefore, the differences between results of the Thesis and Pilot
experiments were unlikely to be attributed to differences in gender.
IV. DISCUSSION

The results are difficult to interpret because two very similar experiments produced very different results. The pilot experiment was a well-controlled completely balanced experiment with random assignment to each of the conditions. It found strong effects of both icon type and map rotation on configural spatial memory. Specific icons and specific auditory directions (SS) produced less absolute angular error than the generic knife and fork icons with specific auditory directions (GS). North up maps also produced less absolute angular error than track up maps. The primary thesis experiment did not find any consistent effects of icon type or map rotation. Yet, it had a similar experimental design with twice as many participants per group as the pilot experiment.

Several possible reasons for the discrepancy between these two experiments were explored. The two experiments were completed about six months apart, the pilot experiment in the Fall Quarter and the primary thesis experiment in the Spring Quarter of the same academic year. The thesis experiment had lower absolute angular error than the pilot experiment. Thesis experiment participants typically would have had somewhat more college experience because most students were first year college students in the introductory psychology course. Those participating in the spring thesis experiment would typically have had six months more college experience than those in the fall pilot experiment. However, it is unclear why six months of college experience should have improved performance on this spatial learning task and why it should have attenuated the effects of icon type and map rotation. A Spring Quarter study also would not include
first year students who dropped out from the Fall Quarter. Remaining students might be expected to be more capable and more highly motivated academically. This could have led to improved overall performance. However, overall differences in participants’ memory abilities between the two experiments are an unlikely explanation because free recall results, unlike the spatial memory results, were similar for the both experiments. Academic performance is more likely to be related to verbal abilities than to spatial abilities. It was found that there were a greater percentage of GPS navigation system users in the Spring versus the Fall sample, but the results of an analysis of only GPS nonusers in the primary thesis experiment was similar the analysis of all of its data. There were no consistent effects of icon type and map rotation.

The one major change between the two experiments was the placement of the initial direction of travel arrow on the sketch maps. In the pilot experiment it was on the lower right hand side on the maps. In the primary thesis experiment it was on the upper left hand side of the map. It was moved because the errors made by some participants suggested that they took the arrow to indicate the starting location as well as the starting direction, drawing the starting object at that point. Moving the arrow to the top eliminated the possibility that the arrow could indicate the starting location and direction because the map had to drawn below it. Thus, the arrow changes could have produced the overall increase in accuracy and the elimination of the effects of map type and map rotation. One speculative possibility is that the low arrow produced the type of confusion produced by incorrect online navigational guidance in current systems, which was described in the introduction. The arrow is suggesting one possibility and their spatial memory may have been suggesting another one. The conflict may have increased the
importance of memory representations for producing reasonable sketch maps, making the measures more sensitive to variables affecting memory representations. It is also possible that reduced overall angular error in the primary thesis experiment attenuated the effects of the experimental manipulations because participants were too good, creating a data floor on the error scores. With the data floor, participants could not perform any better. This explanation is less likely because the data is still substantially above zero error, especially for the freehand sketch maps.

If the speculative conflict hypothesis is correct, then the theoretical and practical implications of the results of the pilot experiment can be considered. Both Hunt’s (1993, 2003) distinctiveness theory and Paivio’s (1971, 2007) dual coding theory imply that specific visual/specific voice would be better than generic visual/specific voice. The results of the pilot experiment did support Hunt’s distinctiveness theory. Those who experienced the specific visual/specific voice condition had less average angular error than those who experienced the generic visual/specific voice. This was true for both measures of configural knowledge and for the recall task. The results of the thesis experiment also partially support Paivio’s dual coding theory. No conclusions can be made, however, since the pilot experiment and subsequent analyses were not constructed to completely evaluate dual coding theory. The support of Hunt’s distinctiveness theory and the partial support of Paivio’s dual coding theory indicates that the inclusion of specific landmarks should aid in configural knowledge acquisition. Therefore drivers could potentially be less dependant on the in-vehicle navigation displays.

If the pilot experiment is ignored and the primary thesis experiment is interpreted, then both generic icons and specific icons should lead to equal configural knowledge
acquisition. The results of the thesis experiment would also indicate that north up maps and track up maps lead to equivalent configural knowledge acquisition. Since north up maps and track up maps lead to similar configural knowledge, track up maps should be used for in-vehicle navigation systems. Previous research has indicated that track-up maps make the navigating task easier (Gugerty & Brooks, 2001, 2004; Shepard & Hurwitz, 1984; Presson & Hazelrigg, 1984; Aretz, 1991; Aretz & Wickens, 1992; Levine, 1982; Kim, Han, Nam, Park, & Han, 1997) or recommended that track up maps be used when turn decision need to be made (Kim, Han, Nam, Park, & Han, 1997; Richter & Klippel, 2002). However, in terms of making the configuration easy to remember, it appears that any combination of specific/generic visual, specific/generic voice, and north or track up map, are equally effective.

Several analyses showed an effect of icon type. Specifically, those experiencing generic visual/ specific voice displays, GS, performed better than those experiencing specific visual/ generic voice displays for both number of correct turns in the route memory descriptions and in free recall. From Paivio’s dual-coding theory, I had expected that those experiencing specific visual/generic voice representations would have performed better than those experiencing generic visual/specific voice representations because specific visual icon are pictures that should generate an imagery code as well as a verbal code. However, I may have misapplied Paivio’s dual coding theory (1971, 2007) to my experimental situation. I had assumed that specific visuals would be more likely to elicit dual coding by enabling the participant to both imagine the specific visual picture presented and to attach the verbal description of the restaurant name. I also assumed that the auditory names were not likely to elicit specific visual representation of
the restaurant. These assumptions were based on research that recall of pictures was better than concrete words, which was better than abstract words (Paivio, 1971; 2007). However, it is possible that the specific visual icons were not sufficient to elicit an associative verbal name. I had entertained this possibility by noting that for specific visual/ generic voice icons, dual coding may occur but that auditory information would add little. I had also assumed that verbal restaurant names would not elicit an associated nonverbal pictorial image, but the restaurant names themselves may have spontaneously elicited the formation of an associated nonverbal or pictorial code.

The lack of a map effect in the thesis experiment demonstrates our incomplete understanding of the mechanisms underlying configural spatial knowledge acquisition in this simulated navigation. The primary dependant variable in the thesis experiment was absolute angular error. Absolute angular error was used as an indication of configural knowledge acquisition. Those seeing a north-up map should have displayed better configural knowledge acquisition than those seeing the track up map when drawing their maps. As indicated by previous studies (Gugerty and Brooks, 2001, 2004; Shepard and Hurwitz, 1984; Presson and Hazelrigg, 1984; Aretz, 1991; Aretz & Wickens, 1992; Levine, 1982; Kim, Han, Nam, Park, & Han, 1997), those who use north-up maps perform better at configural knowledge acquisition tasks than those who use track-up maps. This result has been a consistent finding in many research studies (Gugerty and Brooks, 2001, 2004; Shepard and Hurwitz, 1984; Presson and Hazelrigg, 1984; Aretz, 1991; Aretz & Wickens, 1992; Levine, 1982; Kim, Han, Nam, Park, & Han, 1997), including the author’s own pilot study. Finding no difference between those seeing the
track up map and those seeing the north up map in the thesis experiment was both surprising and unsettling.

Pre-pilot testing was used to determine the complexity of the environment encountered. However, the environment chosen may have been too simple to elicit the effects expected. Future research should examine the level of complexity of the environment used. A more complex environment could elicit the effects found in the pilot study.

The current experiment set out to examine the use of landmarks with in-vehicle navigation systems and how they could improve configural and route knowledge acquisition. This study only examined the type of landmarks used and did not directly compare directions including landmarks with directions containing the standard distance to turn information. Additional research should be conducted that directly compares the different types of landmark presentation with standard distance to turn directions.
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APPENDIX A

SUBJECTIVE COMMENTS ABOUT IN-VEHICLE NAVIGATION SYSTEMS.

Participants were prompted for both “good things” and “complaints.” Each separate participant is represented by a unique eight digit identifier. The comments include both participants from the pilot and the actual thesis.

Yellow comments indicate and inefficient path realization
Blue indicates insufficient information/too slow to present information
Green highlight indicates a workload comment

GP3ASP36

Complaint: It’s hard to read and drive at the same time and I had to pull over and take it out of my car so it could find a satellite

Good: It has saved me many times.

GP3MSP06

Complaint: None

Good: Its very clear and is more useful than a road map

GP3MSP11

Complaint: None

Good: The GPS system really gives a good leadway to where you are going, it also helps you to point out any good landmarks.

GP3MSG005

Complaint: Sometimes I get confused if the automated system fails to talk to me. But while looking at the screen, I get confused most of the time.

Good: It’s helpful in a situation whereby you have no idea on where you are going. Even if you miss a turn, it can help you to come back to where you were before.
APPENDIX A CONTINUED

G1ASS006

Complaint: The one I used did not have the construction and detours on it so I got a little lost.
Good: It lets me know before I need to turn. Also, it got me to where I needed to be.

G1ASS010

Complaint: None
Good: I think it’s very helpful and unique.

G1AGS012

Complaint: Too slow.
Good: Go us where I need to be.

G1MSS013

Complaint: Sometimes the GPS system got a little confusing and didn’t have any alternative routes.
Good: GPS systems come in handy

G1AGS016

Complaints:
Good: Easy to travel with

G1MSG024

Complaints: Connecting to a satellite – receiving info fast enough
Good: Its hard to get lost unless I haven’t upgraded my maps 😊(smiley included)

G1AGS028

Complaints:
Good: Very helpful and Accurate!
APPENDIX A CONTINUED

G1MSG029

Complaints: It took us the longest route possible to get there. When I realized where we were, I could have gotten there a lot faster with my own directions.

Good: It is very accurate and easy to follow/understand.

G1ASS033

Complaints: It’s hard to use at first until you get used to it.

Good: I was extremely lost in downtown Chicago, if it weren’t for our GPS I would have been lost a lot longer than I was!

G1MSS034

Complaints: None, it got me to my destination.

Good: If you made the wrong turn, it got you back on track. Very accurate.

G1AGS039

Complaints:

Good: On the highway it will show the exit ramps, with full detail. Shows all streets around area.

G1MSS044

Complaints:

Good: It helps when you get lost so you don’t waste time or gas trying to find your way back.

G1AGS051

Complaints: I could not navigate with it unless my passenger was the one operating it.

Good: It told us exactly how many miles, or parts of a mile, we had to travel until we turned onto our next street. It was really handy for complicated back streets.
G1ASG052
Complaints:
Good: It was really cool to be able to see where I was and also where I wanted to go.

G1MGS054
Complaints: It didn’t have all the addresses for privately owned buildings or family businesses
Good: It has a very good map

G1ASS057
Complaints: I don’t like it when there are certain areas that turn by turn guidance is not available.
Good: It is pretty easy to follow

G1AGS058
Complaints: The GPS system that my family had didn’t even have where we lived on it, didn’t always have the most updated information.
Good: If the GPS had info about the area I was in it was very helpful.

G1MGS069
Complaint: Didn’t always choose the best path.
Good: Makes it easy to know when you’re lost and how to find your way back.

G1MSS082
Complaint: Some are not as up to date as others. The one I used was a year behind and needed the more recent software installed.

G1AGS085
Complaint:
Good: It helps a lot. I got lost using it once but it helped me get to my destination anyways.
APPENDIX A CONTINUED

G1ASG098

Complaint: Sometimes it takes you the long way around for getting to a destination.

Good: Clear descriptions

    Important streets and landmarks given usually

G1MGS093

Complaint: It sometime required unnecessary “U” turns.

Good: It is very useful

G1AGS096

Complaint: No up to date system like, road construction, accidents

Good: They are fun to have better to use than a map. The new ones have satellite imagery.

G1AGS101

Complaint: Some roads were not on the system

Good: It was very good at giving clear directions

G1MGS104

Complaint: It sometimes thought you were on a slightly different road for a few seconds.
(I considered this different but important)

Good: I never got lost, loved it.

G1ASS106

Complaint:

Good: Would have gotten lost without it!

G1ASG108

Complaint: None

Good: Very helpful on the ocean. I was able to save a location and return to it using the GPS
APPENDIX A CONTINUED

G1MSS113
Complaint:
Good: Its best when it’s an en proxpxxe(???) destination.

G1MSS117
Complaint: Told different way to go even though I knew a shorter way.
Good: Helps get to unfamiliar places easily.

G1AGS122
Complaint: No complaints
Good: Very straight forward not to much info so it wasn’t confusing.

G1MSS123
Complaints: None
Good: It was very helpful and got us to our destination.

G1ASS141
Complaints: None
Good: It helps when you have no sense of direction, like me.

G1MSS142
Complaints: Went too fast
Good: Used good landmarks

G1MSG143
Complaints: Never use it in the inner city of Boston Mass. Just being there makes it confusing. Never go into a tunnel.
Good: It good device that will direct you to any place you need to go You won’t get lost with it.
APPENDIX A CONTINUED

G1MGS146

Complaints: None

Good:

G1ASG147

Complaints: None

Good: Easy to understand

G1ASG149

Complaints: None

Good: Much easier than pulling out a map to find where to go.

G1ASG150

Complaints: None

Good: Great for getting you where you need to go, especially when finding alternative routes due to traffic, etc.

--------------------------------------------------------

G1MSS157

Complaints: Sometimes the GPS voice waits until just before you turn to tell you to turn which can be dangerous

Good: It makes traveling in an unknown place a lot easier.

--------------------------------------------------------

G1ASG125

Complaints: Restaurants, bathrooms, meals, police station

Good: Very helpful when you are lost and need to get somewhere in a hurry.
APPENDIX B
EXAMPLE OF THE FREEHAND MAP
APPENDIX C
EXAMPLE OF THE STREETMAP PARTICIPANTS RECEIVED
APPENDIX D
RECALL INSTRUCTIONS AND LINES FOR FREE RECALL OF RESTAURANTS

Recall Instructions
During your trip, you encountered a number of restaurants. We would like you to try to recall the names of as many of them as you can. Please write them down in the column below. You may write them down in any order. Please write the name of one object on each line. The number of lines is irrelevant.

____________________
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APPENDIX E
THE FIRST RESPONSE SHEET FOR THE ROUTE DESCRIPTION

Pathway Description
Describe the path you traveled during your trip.
APPENDIX E (CONTINUED)
THE SECOND RESPONSE SHEET FOR THE ROUTE DESCRIPTION

Pathway Description

Page 2.
APPENDIX F
DEMOGRAPHICS QUESTIONNAIRE

Please Circle One Answer per Question

Year: Freshman Sophomore Junior Senior

Have you ever been to Denver, Colorado?: Yes No
If yes, did you driver or navigate while in the city?: Yes No
Are you licensed to drive a car? Yes No
Have you ever navigated using a GPS system Yes No

If No, then you are finished.

If Yes, please answer the remainder of the questions.

I have navigated using a GPS system as a: driver passenger both
I have used a GPS system:
Only one time 2-10 times 10–50 times More than 50 times
What was the longest trip length in which you used the(miles)? ___________________
What was the shortest trip length in which you used the system (miles)? ________________
Have you used the system in a city? Yes No
Have you used the system on the highway? Yes No
Have you ever used the Points of Interest Features on a GPS system? Yes No

Please write what, if any, complaints did you have about the GPS system?

Please write what, if any, good things to say about it?
APPENDIX G
STARTING INSTRUCTIONS FOR THE EXPERIMENT

Thank you for participating in this experiment. We are interested in how people use map systems such as those used in cars for finding an unknown location. These map systems guide you by presenting a map while speaking to you. It tells you how to get to your destination. You will watch a presentation that simulates an in car-navigation system. The map has an arrow to represent the current position of your car. It points in the direction you are heading. Icons on the map will represent different landmarks. In this simulation, all landmarks will be restaurants or places you can eat at. The map will also show nearby roads.

The simulation will move you through an area that is unfamiliar to you. It will speak to you as if you were driving. Try to imagine that you are driving using this navigation system. Pay attention to the spoken directions and where the map tells you you are driving. After you finish this simulated drive, your memory of the region will be tested. Pay attention to the streets where you drive, the restaurant locations and other important aspects that would allow you to describe this area accurately.

Do you have any questions?

Go ahead and hit the space bar to begin.
APPENDIX J
FREEHAND MAP INSTRUCTIONS

Free Hand Map Instructions

I'd like you to sketch a map of the environment you just drove through on this blank paper. [hand blank sheet] Please do not draw on this sheet until I say you can begin. Draw it to scale and as accurately as you can. Include all of the restaurants that you passed on your trip. Just draw a square to show the location. Then write the name next to it with an arrow connecting the box and the name. It doesn't matter where the arrow touches the box. It's just to let us know which box you are naming. Here is an example of a map. [hand sample map] It is for another region with three restaurants that are not ones on your list. It's just to let you know what I'd like to see. Notice the three squares with names next to them Max & Ermas, Fridays, and Ruby Tuesdays. [point to the 3 squares] Also, notice the arrows connecting the names to the squares. [point to the arrows]

I'd also like you to sketch in the streets in the region you drove through. Look at the sample map. Show the streets as double lines so that you can more readily show the city blocks. [point to double lines] Write down street names if you know them. The streets should be connected to form a coherent map of the region so that someone could find the path from one restaurant to another by traveling on the streets. You should include all of the streets that you traveled on. Also, include other streets to form a map of the entire region.

Note the arrow at the top of the blank paper and on the example. The arrow shows the direction you were traveling when you started your virtual trip. Orient all streets and restaurant locations so that they are consistent with this direction of travel. The arrow is not showing specifically where you started, it merely shows direction.

Streets, restaurant squares, names, and arrows can be added to the sketch map in any order [emphasize]. You should place one box with a name for each of the restaurant that you passed. Here is a list of all the restaurants that you passed [hand list of restaurants]. The names are listed in random order [point to the list of restaurant names]. You can add them to the map in any order you want. However, check off a name after you add it. You must put a box and name for each name on the list. If you are not sure where certain items belong, put them where you think they most likely were, based on your memory of the trip. It is important to draw your map as accurately as possible. If you want to sketch in a street or square but have run out of room on that side of your blank map, let me know. I'll add paper to that side of your map, so the map scale remains constant. So, if someone wanted to add another restaurant to the right of Max and Ermas, I'd attach some paper on the right edge of the sample map. [point to map edge]

Do you have any questions?
Okay, then sketch your map. But remember ---try to sketch it as accurately as possible.
CHECK SKETCH MAP USING CHECKLIST to see if it has everything.
APPENDIX K
PARTICIPANT CHECK SHEET FOR FREEHAND MAP AND STREET MAP

Check off each one after you have sketched it on your map.

_____ Pizza Hut              _____ Burger King
_____ Arby's                 _____ Starbucks
_____ McDonald's             _____ Kentucky Fried Chicken
_____ Taco Bell              _____ Bob Evans
_____ Skyline
APPENDIX L
RESPONSE SHEET FOR STREET MAP
Now I want you to sketch another map doing the same thing you just did, except this time I've given you the street layout [hand street map]. You just need to draw in the blocks for the restaurants and label them.

As before, there is an arrow in the upper left hand corner of the map. It again shows the direction you were traveling when you started your virtual trip. The arrow is not showing specifically where you started, it merely shows the direction.

Here is another checklist [hand list of names]. Once again, please include all restaurants.

Do you have any questions?

Go ahead and begin.
APPENDIX N
INSTRUCTIONS FOR ROUTE LINES

Now I am going to have you draw path lines on the maps you just drew. In other words, you are going to draw a line indicating how you traveled from one landmark to the next. The line should be continuous and should pass by all the landmarks on your map.

I would also like you to number the landmarks in the order, which you passed them. In this example, the person first passed Ruby Tuesdays. Therefore, there is a one placed next to Ruby Tuesdays [point to the number 1]. Note that there is a line connecting the number and the restaurant box. Please do this for all of the numbers and restaurants. This is merely to reinforce which landmark you are actually labeling. The next landmark you passed was Fridays’s. Therefore there is a two next to Fridays. The path line should pass all of the landmarks and all of the landmarks should be numbered a distinct number, 1 through 6.

Please do not erase anything of your original map. Leave all of the landmarks and streets where you originally placed them. You may erase and change your path line if you need to.

You are going to do this first to you drawn map and then the street map [hand them their drawn map]
APPENDIX O
INSTRUCTIONS FOR ROUTE DESCRIPTION

On the next page, I want you to describe your path through the environment. Write this down in your own words. Please include all the restaurants in the environment and underline each one when you use it. Also, explain which direction you turned (left or right) and the number of blocks you passed between turns. You may also include the street names as landmarks or to clarify the route however, they are not required.

Here is an example of how your paragraph might look using a route through a small city. [hand participant example and restaurant list]

Note that all restaurants are underlined and that the paragraph describes landmarks in an order in which you had experienced them. It also includes all turns, blocks, and street names.

Write your paragraph on the lined paper provided [hand participants lined sheet]. Write the paragraph in your own words, but remember to make it follow the same order as you encountered in the environment. Please write on the lines. We have included extra large spaces between the lines in case you need to insert information later. At the bottom of the example sheet is a list of all restaurants in the environment [point to restaurant checklist]. They are listed in random order. Please include them all in your paragraph, checking each one off as it is used. If you are unsure about where an eating establishment was located, just place it somewhere based on your best memory.

If you have any questions, please ask me now.

You can start.
APPENDIX P
ROUTE DESCRIPTION EXAMPLE.

From the Max and Ermas on Inca and West 12th Avenue proceed four blocks to Fridays on the corner of West 14th Avenue. Turn right at Fridays and drive toward Ruby Tuesdays on the corner of West 14th Avenue and Elati St. Turn right at Ruby Tuesdays…
### APPENDIX Q
ROUTE DESCRIPTION CHECK SHEET FOR PARTICIPANTS

Check off each one after you have sketched it on your map.

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>_____ Pizza Hut</td>
<td>_____ Burger King</td>
</tr>
<tr>
<td>_____ Arby's</td>
<td>_____ Starbucks</td>
</tr>
<tr>
<td>_____ McDonald's</td>
<td>_____ Kentucky Fried Chicken</td>
</tr>
<tr>
<td>_____ Taco Bell</td>
<td>_____ Bob Evans</td>
</tr>
<tr>
<td>_____ Skyline</td>
<td></td>
</tr>
</tbody>
</table>
APPENDIX R
GENERAL SCORING INSTRUCTIONS FOR FREEHAND MAP AND STREET MAP

Each landmark placed on the map was marked with a dot in the center. An 8.5 inch by 8.5 inch transparency with grid marks was placed atop each map. Both the x-axis and the y-axis of the grid transparency was marked in equal increments from 1 to 100. The zero, zero point was located in the lower left hand corner of the transparency. The zero, zero point was placed in the lower left hand corner of the freehand map, regardless of additional attached sheets. The x, y coordinate for each landmark was recorded. If additional sheets had been attached to the freehand map sheet, then additional transparencies were used to determine the x, y coordinate for the landmarks.

Absolute angular error calculation method
1. Consider the center of the originating landmark as “i”
2. Consider the center of the ending landmark as landmark “j”
3. Put the x, y coordinates for each landmark center into the equation to calculate the angle between the landmarks.

\[ \theta = \tan^{-1}\frac{Y_i - Y_j}{X_i - X_j} \]

4. The computed angle \(\theta\) is reported using the standard mathematical polar coordinate system in which zero is on the right (“east”) and degrees increase counterclockwise. See figure below on the left. These angles were transformed to a new polar coordinate system in which zero is on top (“north”) and degrees increase clockwise, as is usually found on protractors (see outside numbers on the protractor in the figure below on the right). These protractor polar coordinates are more commonly reported in spatial memory research. Both angular coordinates yield the same angular error differences.

Mathematical Polar Coordinates
Protractor Polar Coordinates
APPENDIX R CONTINUED

5. The angular error was calculated between the angle created by the participants two landmarks and the actual angle in the in-car navigation map using the formula:

\[
\text{Absolute angular error} = \text{Minimum (} |\theta_p - \theta_a|, 360 - |\theta_p - \theta_a|),
\]

where \( \theta_a \) is equal to the correct angle between the two landmarks and \( \theta_p \) is equal to the corresponding angle in a participant’s sketch map.
APPENDIX S

CONTRAST TABLE FOR NAME IDENTITY ANGULAR ERROR ANALYSIS

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<th>MS</th>
<th>F</th>
<th>p</th>
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<td>1194.676</td>
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Note. The factors shown above the contrasts are for information purposes only. Contrasts were used as the primary statistic and calculated separately in Excel. The information only factors are from Systat.
### APPENDIX T
### CONTRAST TABLE FOR ORDERED IDENTITY ANGULAR ERROR ANALYSIS

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*Note.* The factors shown above the contrasts are for information purposes only. Contrasts were used as the primary statistic and calculated separately in Excel. The information only factors are from Systat.
### APPENDIX U

**CONTRAST TABLE FOR TURNS ANALYSIS**

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*Note.* The factors shown above the contrasts are for information purposes only. Contrasts were used as the primary statistic and calculated separately in Excel. The information only factors are from Systat.
APPENDIX V
CONTRAST TABLE FOR BLOCK ANALYSIS

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Note. The factors shown above the contrasts are for information purposes only. Contrasts were used as the primary statistic and calculated separately in Excel. The information only factors are from Systat.
APPENDIX W
CONTRAST TABLE FOR FREE RECALL OF LANDMARKS

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*Note.* The factors shown above the contrasts are for information purposes only. Contrasts were used as the primary statistic and calculated separately in Excel. The information only factors are from Systat.
APPENDIX X
FREEHAND MAP SHEET FOR THE PILOT EXPERIMENT
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## APPENDIX AB

### CONTRAST TABLE FOR FREE RECALL OF LANDMARKS FOR PILOT EXPERIMENT

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APPENDIX AC
BETWEEN AND WITHIN SUBJECTS CONTRASTS FOR THESIS VERSUS PILOT STUDY

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Key
- E1: Experiment 1 (Halves)
- E2: Experiment 2 (Thesis v. Pilot)
- N: Icon (Number)
- R: Map Rotation
- K: Map Type (Free v. Street)
### APPENDIX AD
CONTRAST TABLE FOR NAME IDENTITY ANGULAR ERROR ANALYSIS FOR PILOT VERSUS THESIS

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**APPENDIX AD CONTINUED**

**Within Subjects**

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**Note.** The factors shown above the contrasts are for information purposes only. Contrasts were used as the primary statistic and calculated separately in Excel. The information only factors are from Systat.
## APPENDIX AE

CONTRAST TABLE FOR ORDERED IDENTITY ANGULAR ERROR ANALYSIS FOR PILOT VERSUS THESIS

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## Within Subjects

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**Note.** The factors shown above the contrasts are for information purposes only. Contrasts were used as the primary statistic and calculated separately in Excel. The information only factors are from Systat.
# APPENDIX AF

## CONTRAST TABLE FOR FREE RECALL OF RESTAURANTS FOR PILOT VERSUS THESIS

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APPENDIX AG
CONTRAST TABLE FOR NAME IDENTITY ANALYSIS FOR GPS NON-USERS ONLY

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| 6 K Map Type                               | 62.264 | 1  | 62.264    | 0.517 | 0.474 |
| Map Type x Map Rotation (7)                | 18.436 | 2  |           |        |        |
| 7 K x R Map Type x Map Rotation             | 18.435 | 1  | 18.435    | 0.153 | 0.696 |
| Map Type x Icon (8, 9)                      | 178.401 | 2  |           |        |        |
| 8 K x N Map Type x Number of Representations | 1.802  | 1  | 1.802     | 0.015 | 0.903 |
| 9 K x M Map Type x Modality                | 176.599 | 1  | 176.599   | 1.467 | 0.229 |
| Map Type x Map Rotation x Icon (10, 11)    | 93.082 | 2  |           |        |        |
| 10 K x R x N Map Type x Map Rotation x Number of Representations | 85.600  | 1  | 85.600    | 0.711 | 0.401 |
| 11 K x R x M Map Type x Map Rotation x Modality | 5.026  | 1  | 5.026     | 0.042 | 0.839 |
| **Error**                                   | 11801.069 | 98 | 120.419   |        |        |

*Note.* The factors shown above the contrasts are for information purposes only. Contrasts were used as the primary statistic and calculated separately in Excel. The information only factors are from Systat. SS's will not add exactly due to unequal N's.
## APPENDIX AH

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### APPENDIX AI
### CONTRAST TABLE FOR TURNS ANALYSIS FOR GPS NON-USERS ONLY

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## APPENDIX AJ
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<td>Icon (2, 3)</td>
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## APPENDIX AK

CONTRAST TABLE FOR FREE RECALL OF LANDMARKS FOR GPS NON-USERS ONLY

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APPENDIX AL
CONTRAST TABLE FOR NAME IDENTITY ANALYSIS FOR WOMEN ONLY

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APPENDIX AM
CONTRAST TABLE FOR ORDERED IDENTITY ANALYSIS FOR WOMEN ONLY

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<td>Map Rotation (1)</td>
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## APPENDIX AN

### CONTRAST TABLE FOR TURN ANALYSIS FOR WOMEN ONLY

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<td>Icon (2, 3)</td>
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<td>0.162</td>
<td>0.688</td>
</tr>
<tr>
<td>4 R x N Map Rotation x Number of Representations</td>
<td>0.232</td>
<td>1</td>
<td>0.232</td>
<td>0.162</td>
<td>0.688</td>
</tr>
<tr>
<td>5 R x M Map Rotation x Modality</td>
<td>1.236</td>
<td>1</td>
<td>1.236</td>
<td>0.862</td>
<td>0.356</td>
</tr>
<tr>
<td>Error</td>
<td>130.398</td>
<td>91</td>
<td>1.433</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Note.** The factors shown above the contrasts are for information purposes only. Contrasts were used as the primary statistic and calculated separately in Excel. The information only factors are from Systat. SS's will not add exactly due to unequal N's.
### APPENDIX AO

**CONTRAST TABLE FOR BLOCK ANALYSIS FOR WOMEN ONLY**

<table>
<thead>
<tr>
<th>Source</th>
<th>SSQ</th>
<th>df</th>
<th>MS</th>
<th>F</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Between Subjects</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Map Rotation (1)</td>
<td>0.432</td>
<td>1</td>
<td>0.432</td>
<td>0.359</td>
<td>0.550</td>
</tr>
<tr>
<td>1 R Map Rotation</td>
<td>0.432</td>
<td>1</td>
<td>0.432</td>
<td>0.359</td>
<td>0.550</td>
</tr>
<tr>
<td>Icon (2, 3)</td>
<td>0.265</td>
<td>2</td>
<td>0.132</td>
<td>0.136</td>
<td>0.713</td>
</tr>
<tr>
<td>2 N Number of Representations (Icon: 2 vs. 1)</td>
<td>0.164</td>
<td>1</td>
<td>0.164</td>
<td>0.136</td>
<td>0.713</td>
</tr>
<tr>
<td>3 M Modality (Icon: Visual vs. Voice)</td>
<td>0.103</td>
<td>1</td>
<td>0.103</td>
<td>0.086</td>
<td>0.770</td>
</tr>
<tr>
<td>Map Rotation x Icon (4, 5)</td>
<td>0.052</td>
<td>2</td>
<td>0.044</td>
<td>0.037</td>
<td>0.848</td>
</tr>
<tr>
<td>4 R x N Map Rotation x Number of Representations</td>
<td>0.044</td>
<td>1</td>
<td>0.044</td>
<td>0.037</td>
<td>0.848</td>
</tr>
<tr>
<td>5 R x M Map Rotation x Modality</td>
<td>0.008</td>
<td>1</td>
<td>0.008</td>
<td>0.007</td>
<td>0.934</td>
</tr>
<tr>
<td>Error</td>
<td>109.428</td>
<td>91</td>
<td>1.203</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Note.* The factors shown above the contrasts are for information purposes only. Contrasts were used as the primary statistic and calculated separately in Excel. The information only factors are from Systat. SS's will not add exactly due to unequal N's.
# APPENDIX AP

CONTRAST TABLE FOR FREE RECALL OF RESTAURANTS FOR WOMEN ONLY

<table>
<thead>
<tr>
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<th>df</th>
<th>MS</th>
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<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Between Subjects</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Map Rotation (1)</td>
<td>0.726</td>
<td>1</td>
<td>0.726</td>
<td>0.755</td>
<td>0.387</td>
</tr>
<tr>
<td>1 R Map Rotation</td>
<td>0.726</td>
<td>1</td>
<td>0.726</td>
<td>0.755</td>
<td>0.387</td>
</tr>
<tr>
<td>Icon (2, 3)</td>
<td>6.642</td>
<td>2</td>
<td>3.321</td>
<td>6.533</td>
<td>0.012</td>
</tr>
<tr>
<td>2 N Number of Representations (Icon: 2 vs. 1)</td>
<td>0.387</td>
<td>1</td>
<td>0.387</td>
<td>0.402</td>
<td>0.528</td>
</tr>
<tr>
<td>3 M Modality (Icon: Visual vs. Voice)</td>
<td>6.282</td>
<td>1</td>
<td>6.282</td>
<td>6.533</td>
<td>0.012</td>
</tr>
<tr>
<td>Map Rotation x Icon (4, 5)</td>
<td>1.395</td>
<td>2</td>
<td>0.698</td>
<td>1.313</td>
<td>0.255</td>
</tr>
<tr>
<td>4 R x N Map Rotation x Number of Representations</td>
<td>0.140</td>
<td>1</td>
<td>0.140</td>
<td>0.145</td>
<td>0.704</td>
</tr>
<tr>
<td>5 R x M Map Rotation x Modality</td>
<td>1.262</td>
<td>1</td>
<td>1.262</td>
<td>1.313</td>
<td>0.255</td>
</tr>
<tr>
<td>Error</td>
<td>87.496</td>
<td>91</td>
<td>0.961</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Note. The factors shown above the contrasts are for information purposes only. Contrasts were used as the primary statistic and calculated separately in Excel. The information only factors are from Systat. SS's will not add exactly due to unequal N's.
Curriculum Vitae

Tiffany Saffell is a teaching assistant in the Department of Psychology at Wright State University. She received her Bachelor of Science degree in 2004 from Denison University and is currently pursuing a Ph. D. in Human Factors in the Department of Psychology at Wright State University.

Publications and Presentations


