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# Multipurpose Map Designs for GPS Surface-Vehicle Navigation: Spatial Knowledge and Advisory Functions

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# MULTIPURPOSE MAP DESIGNS FOR GPS SURFACE-VEHICLE NAVIGATION: SPATIAL KNOWLEDGE AND ADVISORY FUNCTIONS

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By

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I HEREBY RECOMMEND THAT THE THESIS PREPARED UNDER MY SUPERVISION BY Caitlan Rizzardo ENTITLED MULTIPURPOSE MAP DESIGNS FOR GPS SURFACE-VEHICLE NAVIGATION: SPATIAL KNOWLEDGE AND ADVISORY FUNCTIONS BE ACCEPTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF Master of Science.

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# ABSTRACT

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Multipurpose Map Designs for GPS Surface-Vehicle Navigation: Spatial Knowledge and Advisory Functions

Current car navigation systems primarily utilize track-up maps with spatial turn arrows, which facilitate turn decision-making but do not facilitate acquisition of spatial knowledge of the region. North-up maps do facilitate acquisition of regional spatial knowledge, however, these displays sometimes have arrows heading in directions misaligned with a driver's forward view, such as when the car is heading south. Drivers have difficulty making turn decisions in these misaligned maps because of stimulus-response reversals (Chan & Chan, 2005; Levine, 1982; Levine, Marchon, & Hanley, 1984; Montello, 2010). A new display was designed using a fixed orientation north-up map and added a verbal cue to the traditional turn arrow. People are able to concurrently process verbal and spatial information (Baddeley & Hitch, 1974; Paivio, 1971; Paivio, 2006). The new verbal north-up map was compared with traditional north-up and track-up maps, and a no map aid with auditory turn instructions. Participants drove through a simulated environment and made left or right intention-to-turn responses to the map indicator or the auditory instructions. Following the driving simulation, participants drew a sketch map of the region, which was scored to evaluate configural spatial knowledge. Results showed participants using the verbal north-up map acquired more accurate configural spatial knowledge and showed no evidence of decrement in performance for intention to turn times.

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# I. INTRODUCTION

People today travel extensively and are likely to encounter busy traffic areas in unfamiliar cities. An effective global positioning navigation system, or GPS, that is incorporated into vehicles could be a travel-aid that facilitates efficient navigation and ease of use, increasing driver safety. In order to be effective, navigation aids need to have a person-computer interaction that takes advantage of the strengths of human navigational skills and processing, while providing support for their limitations. This is especially true for modern display technology, which cannot be easily modified for human needs by the users themselves. As Aretz and Wickens (1992) pointed out, paper maps are easily manipulated to coincide with the demands of a user. Users can turn maps, fold them and write on them. However, electronic maps must have any flexibility explicitly designed into them before they are introduced to users. Interface design for GPS navigation systems is therefore important because few corrections can be made after the product is sold. For newer models of cars, GPS navigation systems are being directly installed into the console, a trend that is likely to continue and become increasingly common. This trend has potential design advantages because there is more space available for a larger map display.

Drivers use maps for at least two major purposes. They are used for moment-by-moment online processing activity such as deciding where to turn next and which way to drive in unfamiliar areas. However, maps are also used to learn other information about a region, such as the overall spatial layout and the location of important landmarks or destinations. This more general information could also be used to assist online processing beyond confirming the driver's location, such as when a driver rejects the guidance provided by a navigational system map and takes an alternative route which he or she believes has advantages, or avoids potential problems, or the environment is not accurately reflected on the map.

**Using Maps for Navigational Guidance**

**Types of map displays.** Most electronic GPS map display units have the capability to display two different types of moving maps: track-up and north-up map displays. Both map types use a symbol, such as an arrow, to represent the car's location on the map. Both map types also represent the map moving beneath the car's symbol however, they differ in how the car's apparent journey is accomplished. Track-up maps in GPS systems are implemented by keeping the car's arrow icon continually pointed toward the top of the display. As a driver makes a turn, this turn is shown on the display by having the map rotate beneath the car icon. In a track-up map the heading angle, defined as the orientation of the directional arrow, remains aligned with the user's forward field-of-view (Aretz & Wickens, 1992). Because the map is always consistent with the driver's forward field-of-view, turn indicators on the map are also consistent with the turn directions in the driver's actual environment.

North-up map displays also represent the car as an arrow imposed on top of a segment of a map of the local region. However, these displays represent movement differently than track-up maps. Instead, the car's arrow symbol rotates when a turn is made and the arrow can be pointing in any direction on a 360° circle. The map does not rotate but as the car moves forward, will shift in the direction opposite the car arrow's heading.

These two types of map displays, north-up maps and track-up maps, have advantages and disadvantages for online moment-by-moment turn decision-making and for learning about spatial relations in the environment.

**Turn decision-making.** For drivers traveling an unfamiliar route, it is a priority to have information quickly available for decision-making. Track-up maps are the default display on most current automobile GPS map navigational systems because they facilitate left-right turn decisions. The map view can easily be projected forward onto the driver's worldview through the windshield (Aretz & Wickens, 1992). So, if a driver is supposed to turn left at the next intersection the map displays this as an arrow pointing to the left of the map display. This is consistent with the principle of stimulus-response compatibility (Fitts & Seeger, 1953; Kornblum, Hasbroucq, & Osman, 1990; Montello, 2010), which leads to faster encoding of the information. A driver who sees an arrow pointing to the left side of the screen will turn the top of the steering wheel to the left, and expect the car icon on the map to also turn left at the intersection.

In contrast, north-up displays can create stimulus-response reversals for left-right decisions using typical spatial arrow icons. Such reversals for turn advisories are generated most severely when a driver is heading south. In this case the arrow icon is pointing down before the turn is indicated, and as shown in Figure 1 when an arrow pointing south is bent to advise the driver to make a left turn, the arrow actually points to the right side of the display. Similarly, an arrow that represents a turn to the right will point to the left side of the display screen. Chan and Chan (2005) argued that when faced with an incompatible stimulus-response situation, users must perform an additional cognitive process that reverses the spatial codes, resulting in increased response times and more errors. An extensive literature on You-Are-Here (YAH) static maps has shown that when people read such misaligned maps, their left-right turn decisions are slower and more error prone (Levine, 1982; Levine, Marchon, & Hanley, 1984; May, Peruch, & Savoyant, 1995; Montello, 2010). Levine (1982) pointed out that users assume that "up" on a map corresponds with forward in their environment, and when the map is not aligned with the user's forward point of view this can cause map users to make incorrect wayfinding decisions. Research has found that wayfinders will walk in the opposite direction when just-seen maps do not match the then-explored environment, especially at 180° of misalignment (Levine, Marchon, & Hanley, 1984). Additionally, trying to interpret misaligned maps can create confusion and frustration (Montello, 2010). Klippel, Freksa, and Winter (2006), in their design outline for creating maps to use during emergency situations such as building evacuations, specifically emphasized that matching the alignment of the map to what is forward in the actual environment is the most important facet aside from the YAH symbol. Mentally combining the structure of the actual environment with that present on the map can be a fragile process (Montello, 2010). Designing maps should consistently reflect the real-world structure of cognitively salient patterns (Klippel, Hirtle, & Davis, 2010).

North-up maps are only aligned with a user's field-of-view when a user is heading due north. Both Shepard and Hurwitz (1984) and Aretz and Wickens (1992) have attributed the problems of misaligned north-up moving maps to the user's need to mentally rotate the image of the map so that it is aligned with their forward, or egocentric, field-of-view. Thus, mentally rotating images would be analogous to physically rotating a paper map to align with their forward point of view. As with physical map rotation, mental map rotation should take a longer amount of time the larger the difference between the orientation of the original and the image being rotated (Shepard & Hurwitz, 1984). However, mental rotation's effect on processing time for misaligned maps and turn indicators may not be so simply explained (Viita, 2006; Viita & Werner, 2006). Maps with a left or right turn arrow icon superimposed on city streets were presented either upright or as rotated displays. Viita and Werner found that response times and errors only increased beyond ±50° of misalignment. Little or no difference was found for rotations of less than ±50°. These results suggest that no mental rotation was necessary for a 100° range of map rotation. Although these results are not consistent with mental rotation research, they are not inconsistent with troublesome You-Are-Here maps, which have been typically rotated by more than ±50°.

Based on these results, track-up maps would be recommended over north-up maps because they lead to faster turn decisions and fewer errors over the entire range of misalignment rotation.

## Learning From Maps

**Configural knowledge acquisition.** Besides providing navigational guidance, maps also can provide users with knowledge about the layout of a region and the location of potentially important destinations in the region. Configural spatial knowledge (sometimes called survey knowledge) refers to the representation of spatial relationships between objects such as landmarks that allows a person to demonstrate knowledge of the layout of an environment (Siegel & White, 1975). For navigation, configural spatial knowledge can help people to decide to override any bad advice from the GPS guidance system. People have driven down railroad tracks and almost into a lake after bad advice from GPS navigation systems (Forbes & Burnett, 2007). In addition, GPS guidance may be unable to adapt to changes in traffic or construction or it may be temporarily unavailable. Finally, people can plan more efficient routes than the algorithms of navigation systems, or routes that are more compatible with their driving habits, if they have spatial knowledge of a region. When Saffell (2008) asked participants about their experiences using GPS for navigation, typical comments included the realization they could have planned a shorter or more efficient route themselves. A system that supports configural spatial knowledge acquisition should help users decide to take a shortcut, plan a detour when a road is blocked unexpectedly, or the system should place a turn advisory into context so that turns onto railroad tracks or into lakes are more likely to be avoided.

North-up map displays have helped people to acquire more spatial knowledge of a region than have track up map displays (Aretz, 1990). Unlike with track-up map displays, landmarks such as restaurants and stores maintain their relative positions and orientations on the screen in north-up map displays; the vehicle icon does most of the moving and turning. The stable map is more compatible with a stable environment the people drive through, which appears to aid in spatial knowledge acquisition as predicted by allocentric models of spatial knowledge acquisition (Aretz, 1991). If a person has acquired configural spatial knowledge then they can place landmarks in an environment in relation to other landmarks, which allows a user to find their way from one point to another using many different routes (Foo, Warren, Duchon, & Tarr, 2005; Thorndyke & Hayes-Roth, 1982). People may also want to learn about the area during the first drive through, and not need a GPS subsequently; so stable maps are additionally useful because configural spatial knowledge can be acquired more rapidly from map study than direct experience. This was shown by the comparable point-to-point distance estimations of people who had many months' experience in a building versus people who had studied a map (Thorndyke & Hayes-Roth, 1982). Their results were replicated using a virtual environment and controlled training trials (Ruddle, Payne, & Jones, 1997). Willis, Holscher, Wilbertz, and Li (2009) saw similar results when their participants had comparable distance estimation and angular error scores but the group using a mobile map (GPS-based system) as they walked the route took almost half an hour more to learn the layout than those who studied a map. People are already predisposed with strategies for learning from static maps. Thorndyke and Stasz (1980) saw strategies such as mental image formation and verbal labeling from participants told to memorize the spatial layout from a map. Thorndyke and Stasz point out that encoding strategies are dependent on different types of information, including spatial/visual and verbal, that maps show simultaneously. Additionally, there were individual differences between participants, even within their level of expertise, for which strategies they decided to use. Thus, an optimal navigational guidance system would support configural spatial knowledge acquisition by balancing how this information is presented.

**Driving and Using Guidance Systems**

Users need to attend to different tasks as they drive with a navigation system. Because of the distance between looking out of the windshield and looking down at the display, the two tasks of driving and reading the map usually cannot be done simultaneously. Drivers are processing information from both of these tasks interchangeably, in what will be called the Driving-Guided Navigation processing model. While driving, people must look out of the windshield to pay attention to the geometry and characteristics of the road, traffic in front, alongside or crossing their path, and hazards, etc. They also must navigate, deciding whether to continue along the road or to turn, in order to reach their goal destination. Navigational aids may help them navigate, but they have at most only a few seconds to look at the display while driving. Controlling the vehicle safely is clearly their primary task. The information that can be extracted from a navigational map display and the speed of its acquisition depends on the design of the map display and the cognitive processes required to extract the information. Different information may be required for the two purposes of using a map, turn advice or advisories and knowledge of the region.

While looking at the map, people may be given information about the surrounding area and told which way to turn. The turn advisories are the priority information. Information about the area's layout is first for confirming the driver's correct or incorrect present location and secondly for constructing a mental map of that area. The type of cognitive processing used is limited by and depends on what type of information is on the navigational aid. Some GPS systems use auditory instructions to direct drivers along a route. This can be advantageous because turn advisories can be given verbally instead of via spatial displays. However, auditory instructions can also be problematic. Drivers have reported turning off the auditory commands because they are (a) annoying, (b) not timed correctly to provide information at the best time for the driver, and (c) the distance-to-turn information provided is confusing (Saffell, 2008). Other types of verbal information include the words "left" or "right" displayed on the map screen. However, most navigation systems use turn arrows as indicators, which is a spatial representation. Learning the layout of a region also requires spatial processing. This may or may not be possible depending on the map display. Current GPS navigation systems make creating a mental map difficult because they (a) use track-up maps, (b) display limited regions around the vehicle, (c) do not refer to visually distinct landmarks that can be easily identified through the windshield. Navigation system design needs to take cognitive processes and user preferences into account.

## Visual/Spatial and Verbal Processing

**Working memory.** Several lines of research have suggested that verbal and spatial processing are distinct cognitive processes, each with their own characteristics and memory representations. However, cognitive processes may be able to convert one type of representation to another. The multi-component theory of working memory separates verbal processing from visual and spatial processing (Baddeley & Hitch, 1974; Baddeley, 2001; Baddeley, 2007). Working memory components include: the phonological loop, the visuo-spatial sketchpad, an episodic buffer, and a central executive mechanism. The phonological loop is composed of a phonological store and rehearsal process that encodes verbal types of information like auditory or visual language, or may recode other types of information into a phonological form. Studies introducing subjects to similar sounding letters or sounds show that this component is sensitive to interference from too similar items being encoded all at once (Baddeley, 1966).

The visuo-spatial sketchpad processes non-verbal information. It appears to have separate sub-components for visual versus spatial non-verbal information. Its spatial processing tends to be affected more by interfering spatial tasks such as patterned finger tapping than verbal type tasks, and vice versa (Della Sala, Gray, Baddeley, Allamano, & Wilson, 1999). During dual-task experiments using a verbal task and a spatial task, there was little interference (Repovš & Baddeley, 2006).

The episodic buffer has been added to the multi-component model more recently. Its purpose is to integrate information from these two subsystems, possibly with further information from long-term memory (Baddeley, 2001).

**Long-term memory.** Paivio (1971; Paivio, 2006) has also argued that verbal and visual information are processed separately but are able to communicate with the other. This research has focused on episodic recall or recognition of words and pictures without mnemonic instructions, as well as on use of imagery instructions. Typically, pictures of objects are learned more readily than concrete words, which are learned more readily than abstract words. Words can create images, which can provide redundant useful information, leading to additive recall effects (Paivio, 1991). Similar to the purpose of Baddeley's episodic buffer (2001; Baddeley, 2007, Baddeley & Hitch, 1974), Paivio has proposed that there are "interunit connections" allowing information from both verbal and visual modes to be integrated and used.

Thus, verbal coding could support online left-right decision-making when spatial indicators are difficult to process, such as during misalignments. Mayer and Moreno (2010) described the importance of Baddeley's multi-component model and Paivio's dual coding model for facilitating meaningful learning in multimedia presentations. Appropriately integrating visual/spatial information with verbal textual information has been shown to enhance meaningful learning. Morett, Clegg, Blalock, and Mong (2009 ) discussed this principle as it could apply to maps used for navigation and discovered that presenting dual-modality information led to higher scores on measurements for configural knowledge, such as creating a route between two destinations they had previously studied on a map. Thus, the proper integration of verbal with spatial and visual information may improve navigational map displays and may allow them to serve the dual purposes of guiding navigation and facilitating learning the spatial relations of a region.

## Multifunction Map Displays

While some systems allow users to choose either track-up or north-up maps, there is currently no system that concurrently utilizes the advantages of both. The current study addresses a potential new map display that can both support acquiring configural spatial knowledge of a region and provide guidance to aid online turn decision-making.

**Enhanced spatial indicators.** One potential solution to the design issue for dual purpose map displays is to use north-up maps, but to provide a more effective turn indicator which is as effective when going south as when going north. Previous research has attempted to create such navigational displays. Aretz (1991) used an augmented north-up map that attached a wedge to an airplane icon. Figure 2 shows an example of this map where the wedge had three differently colored lines; a blue line represented the left edge of the pilot's forward view, a yellow line represented the right edge, and a black centerline bisecting the wedge to represent the pilot's forward direction. Participants who used the wedge map were compared to those who used typical north-up and track-up maps. Wedge map users did as well as track-up map users when navigating and as well as north-up map users when reconstructing a map of the region. However, Aretz's experiment dealt with flight guidance in piloting situations, not with driving. Unlike GPS automobile navigation systems, his map icons only provided reference points for interpreting the map; they did not provide route guidance.

Prabhu, Shalin, Drury, and Helander (1996) used a similar wedge icon on north-up maps in a driving simulation. They studied a version of north-up maps that added verbal coding to a wedge placed at the tip of the plane icon (a black triangle), as seen in Figure 2. The north-up wedge display was no better than north-up and track-up displays at a navigational task, but was better than track-up maps when participants were required to generate an alternate route, which is a measure of configural spatial knowledge. They also studied another map display, a heading separated map. This was oriented north-up and would rotate 180° when the driver started to head south creating instances where both track-up and north-up are useful. This map display appeared to be useful for both navigation and creating alternate routes. Although the north-up wedge map did not lead to better navigation, this could be due to the letters L and R at the corners of the wedge being only informational, and not also advisory. By having the letters present at all times, the subjects were never given a command that could have made it easier to know where to turn.

**North-up maps with verbal cues.** Another way to gain the benefits of track-up and north-up map displays is to add a non-spatial visual turn indicator such as an advisory verbal cue, in addition to the advisory spatial turn indicator. By using two advisory cues that do not interfere with each other, we can provide concurrent verbal and visual simultaneously to human users. As has been found with instructional design, both types of information need to be integrated appropriately.

***Processing static map displays of verbally and spatially displayed turn advisories***. In a previous experiment I replicated Viita and Werner's (2006; Viita, 2006) research on participants' response times to decide if a rotated but static spatial indicator represented a left or right turn (Rizzardo & Colle, 2011). However, I also used another group of participants who made left-right decisions with a new spatial plus verbal cue advisory icon. I avoided using auditory turn commands because of the common reports from participants that they turn off that component of their GPS unit (Saffell, 2008). This new condition had the same red arrow pointer, but it added a verbal mnemonic cue, a red letter L or R inside a white circle with a red border, placed at the tip of the arrow point. The letter was always upright. Putting the letter at the tip of the arrow, which is critical for turn information, is consistent with the proximity compatibility principle as discussed as it relates to display design by Wickens and Carswell (1995; Wickens, 1999), as well as with the display principles in instructional design (Mayer & Moreno, 2010). According to the proximity compatibility principle, and its Gestalt underpinning, the physical proximity of the turn letter and the arrow tip supports the perceptual proximity and creates an integrated unit of valuable information. This keeps the turn letter and arrow close to the car icon's location on the map, which should be easier to understand than some current GPS systems that puts supporting verbal information out in the margins of their displays. Unlike the verbal labeled wedge in Prabhu et al. (1996) or the color-coded edges in Aretz (1991) that labeled the icon sides, the verbal letter in my display icons told the participant which direction to turn, besides being informational at the tip of the arrow point. It was advisory, not just informational.

As Figures 3 and 4 show, mean response times and error curves for the new verbal plus spatial icons, arrow rotations for angles from zero to ±180° were much flatter and the overall response times were lower, especially outside the misaligned ±45° region. The control group with only the traditional spatial indicator replicated the results that Viita and Werner (2006) found, mean response times were relatively flat within about ±45° but increased rapidly with increases of rotational misalignment. Thus, these data suggest that the proposed verbal plus spatial indicator can be interpreted and cognitively processed rapidly without being influenced by rotational misalignments.

**Driving with Guided Navigation**

The new verbal cue seems to provide turn advisory information from which it is easy to decide left from right, even on north-up maps that are misaligned from the user's forward point of view. However, my previous research used a static display, which was the participants' single and primary task. In contrast, the reading and using of maps while driving is only one of the tasks at hand and not the primary one.  Also, although response times for the new verbal north-up advisory indicator on maps indicated that they would be effective on misaligned north-up maps, I was not able to test if these north-up maps facilitated the acquisition of spatial knowledge. Drivers have only a few seconds to look at a navigational aid and those brief glimpses could limit their acquisition of spatial knowledge.

The current experiment attempted to address these two issues by having drivers control a simulated vehicle in a virtual environment, going to destinations while following a prescribed route specified by navigational maps. Importantly, both spatial knowledge and response times to turn advisories, which were indicated on the GPS displays, were measured.

Each of the three advisory indicators was displayed on a map that was designed for future use. The map area showed a larger region than most existing maps. In addition, the map included landmark icons, which were used for both turn directions and to indicate destination locations. Distance-to-turn directions were not used; people have trouble estimating distance, especially while moving, and landmark directions have been shown to give easy to understand information (Burnett, 2000; May, Ross, & Bayer, 2005). Finally, the maps provided turn advisory information 135 m in advance so that users had about 13 s of advance notice on when a turn would be necessary. Finally, maps were only updated every 90-100 m, not continuously. These characteristics were designed to enhance the usability of the new map's displays.

The new verbal spatial advisory indicator on a north-up map display was compared with a traditional spatial only advisory indicator on both a north-up map display and a track-up map display. In addition, I had a no-map condition in which only auditory advisory directions were used.

For all conditions, I collected measures to evaluate (a) the acquisition of configural spatial knowledge about the layout of the region and (b) ease of following online navigational guidance. Measures of sketch map angular accuracy were used to assess configural knowledge acquisition. As discussed previously, static maps have been found to lead to rapid development of configural spatial knowledge (Ruddle, Payne, & Jones, 1997; Thorndyke & Hayes-Roth, 1982; Willis, Holscher, Wilbertz, & Li, 2009) and north-up maps are better than track up maps for acquiring configural knowledge (Aretz, 1990; Aretz, 1991). Thus, as discussed above, north-up maps, both spatial only and verbal spatial, should lead to better spatial knowledge acquisition than track-up maps. Additionally, there are two types of landmarks that drivers encounter. Each landmark requires the driver to perform different tasks. Drivers actually stop at destination landmarks, whereas drivers are only told to turn at non-destination landmarks. People must locate and remember their destination through a series of turns, as well as stop there, but only need to locate non-destination landmarks preceding that individual turn. The personal association and importance placed on the destination landmarks could affect measures of angular accuracy, so expected measures of the relationships between pairs of landmarks that have both destinations, both non-destinations, or mixed pairs with one of each, were estimated separately.

While it is expected that a stable map will lead to configural knowledge, verbal spatial north-up maps could have an advantage over spatial only north-up maps when used during driving. Surface-vehicle drivers have very small windows of time available to inspect and learn from navigational maps. Research suggests that drivers look away from driving for no more than 2s to drive safely (*Keeping drivers' eyes on the road*, 2001). Under many circumstances this is a shorter time than pilots have available during many segments of a flight. When a driver looks at the map he or she has to assess advisory turn information as well as use the map to learn about the spatial region. If it takes a driver longer to assess the turn information, as it should for spatial only indicators compared to verbal spatial indicators, then they should learn less about the spatial region. Thus, drivers using verbal spatial advisory indicators could acquire more spatial knowledge than drivers using spatial only advisory indicators on the same north-up maps because they have more functional time available to study the maps. The no-map condition serves as a control group to see what configural knowledge drivers can acquire without a map.

To measure intention-to-turn responses, participants were asked to respond by pressing a left or right turn button mounted on the steering wheel. As with the experiment using static displays, verbal north-maps are expected to have comparable response times across degrees of misalignment. Participants using track-up maps, because of their alignment with the driver's forward field of view, and no-map travel aids, because of their auditory instructions, are also expected to have similar response times. The north-up map should have longer response times when the vehicle is heading south because misalignment produces left and right reversals on the display. One caveat is that response time differences may not be as easily detectable in this simulation study as they were in the previous static study. Response times in this study were based on only 16 intention-to-turn responses as participants drove along the prescribed route. Only eight of these turns related directly to heading, four when heading south versus four when heading north. This is considerably less than in the static display experiment, in which participants responded to 960 trials but did not have to drive through an environment.

There might be more variability because there are so fewer instances of right and left turn judgments to compare.

## II. METHOD

### Participants

A total of 96 students from undergraduate psychology courses, 48 female and 48 male, aged 18 to 30, participated in the experiment. The participants were randomly assigned so there were 24 participants in each of four groups, north-up spatial-only, track-up spatial-only, north-up verbal cue plus spatial and no-map auditory directions, with 12 participants of each gender. They were required to have normal or corrected to normal vision for acuity and color vision, normal hearing, and a valid driver's license. English was required to be their first language. Participants were asked if they had used a GPS device as a driver before, of which 72% said they had, although this was not an exclusion criterion for the study. Participants from earlier studies of GPS navigation were ineligible for the study.

### Materials

**Route of simulated travel.** Figure 5 shows a plan view map of a simulated city with the names and locations of the errand destinations and the route traversed to reach them. The route was designed so it included 16 turns with a turn landmark at each of these corners, a starting landmark, and placement of eight errand landmarks. The participants' starting location was in the far west side of the environment, heading east, ending in the far east side, so the route could include 16 turns without doubling back over previously driven streets. The 16 turns were balanced so there were eight left turns and eight right turns. Also, north-south travel directions were balanced so participants traveled and had a turn decision to make while heading north four times and south four times. Distance traveled between turns was always more than three city blocks long to ensure the turn indicator arrows could give the participants at least one block's notice about an upcoming turn.

Errand destination landmarks identified locations where participants nominally performed a task. These eight errand landmarks were positioned along the route for participants to stop at during their drive through the simulation. Placement was random but balanced so destination landmarks were on the left and right sides of the road (defined by the direction of travel) equally often. Corner landmarks were positioned at all 16 route turns so participants knew where to turn; placement was also randomized, balancing across left or right turn and the four possible corner placements: before-adjacent, inside, catty corner, and after-adjacent.

**Navigation displays: Map types.** Three different types of map displays were created, a track-up map with a spatial turn direction icon, a north-up map with a spatial turn direction icon, and the new north-up map with the verbal plus spatial turn direction icon. A fourth map type condition was the no-map condition, which used auditory directions to guide participants to each of the errand destination landmarks so participants did not see a map. The 132 navigation maps per condition used to simulate a GPS navigational system were created in Photoshop by first designing an overall map, including the street grid, city blocks, and landmark icons, then cutting 10 in. x 10 in. (25.4 x 25.4 cm) frames incrementally along the predetermined route. Directional and turn indicator arrows for each condition were imposed on the route for each frame.

Landmark icons were created using company logos designed prior to 2010 found online from establishments such as restaurants, hotels, and drugstores, then resized to 60 pixels wide. Corner icons were positioned so the turn indicator arrows or verbal cues never obscured the logo. The landmark logos and positions were the same across all conditions. The names and pictures of all 25 landmark icons are shown in Appendix A.

As Figures 6 and 7 show, the turn indicator icons were plain red arrows for the north-up spatial-only and track-up spatial-only map conditions and their length was half of a city block. Turn indicator arrows always gave the participant a warning of at least one block in advance of an upcoming turn. Figure 6 shows the series of maps to display the indicator arrow for a turn. Panel A shows the long full-block arrow that alerts the driver to a turn. Panels B and C show the next two map displays in which the car icon moved in half-block increments to shorten the arrow until the turn was completed. Panel D shows the final map in which the completed turn was made and the regular straight half-block arrow has returned. The north-up verbal plus spatial condition used the same red arrows, but the letters L and R were used to indicate a left and right turn, respectively, should be made. The letters L and R were located at the tip of the arrow inside a white circle with a red border, as shown in Figure 8.

Both north-up conditions had navigation maps that were always oriented with the northern side of the map at the top of the screen. The track-up maps were always oriented so the directional arrow was pointing toward the top of the map. Navigation maps were viewed on the monitor placed to the right of the driving simulation monitor. In the no-map condition, the map computer was covered so participants could not see the map but the auditory instructions for each turn were triggered at the same point as indicator arrows for the other map conditions. All of the auditory instructions were .wav files recorded by a male voice, who also recorded the error messages for all map conditions. The turn direction always came before the landmark to turn at; an example of an auditory direction is, "Turn Right at the Kroger." The turn information segment of the auditory commands was 1 second long.

**Driving environment and simulation.** Participants drove through a simulated hypothetical city street environment created using Presagis Creator software (Presagis, 4700 De La Savane, Suite #300 Montreal, Quebec Canada H4P 1T7). City streets, blocks, and buildings were constructed using a programming grid, consisting of square programming units, each measuring 5 m x 5 m. The total area of the city region consisted of 20 by 20 city blocks with a 10 m street separating adjacent blocks. City blocks were 36 by 36 programming units in length and width, so they were 180 m on each side. The edges of the city blocks were made up of a row of buildings formed by facades 5 m wide and a maximum of 10 m tall. The buildings were randomly textured by the program with computer-generated pictures of the outer facades of buildings, such as brick or windows, except for the building facades signifying landmarks. The facade of each landmark building was represented by a photograph image of a typical façade of the business at that location. These image files were in jpeg and .tif formats, and they were sized to be proportional to the building's physical size. Additionally, each landmark façade had an identifying sign, matching the icon on the navigation map, which jutted out over the street so a driver could reliably identify the business at that location. If any sky was visible in the original photo, it was erased so the program's simulated sky showed above the façade instead, further integrating the landmark into the city simulation. Figure 9 shows a screen shot of the façade of the Burger King landmark building with the parking lot located on the inside corner. Parking lots were inserted along the route before every landmark. For landmark buildings that were positioned on corners of the intersection that make it difficult for the driver to see as they approach, the parking lots were inserted so participants can see ahead to the landmark before they reach the intersection. The perspective view of the simulated scene had geometric fields-of-view of ±45° left to right and ±20° top to bottom. Figure 10 shows a screen shot of the simulation, which includes the starting landmark Starbucks.

**Equipment.** Two computers inside a testing booth, which communicated with each other, were used to present the driving simulation, present the navigation maps, and collect on-line performance responses. Perspective views of the city environment generated by the driving simulation were displayed on the left monitor and the navigation maps were displayed on the right monitor. The steering wheel participants used to steer the car through the city was centered on the left monitor with the top of the steering wheel 30.5 cm from the front surface of the monitor. It was fixed to a table directly in front of the chair where participants sat. The monitor was an HP L2245wg TFT LCD monitor with a 22 in. diagonal (47.5 cm x 30.0 cm) screen. The video card was an ATI Radeon HD 2400XT with 256 MB of video memory with a DVI connection to the monitor. The gas and brake pedals (Logitech Wingman Formula Force GS, 6505 Kaiser Dr. Fremont, CA 94555) were below the monitor; the experimenter adjusted the location of the pedals so participants could easily control them. The computer that presented the driving simulation with input from the steering wheel, gas and brake pedals was an HP

Compaq dc7900 Convertible Minitower with an Intel® Core™ Duo CPU E8600 with 3.33-GHz processors and 3.49 GB of RAM, using a Windows XP operating system.

The second computer presented the navigation moving map displays using a SuperLab 4.0 program (Cedrus Corporation, P.O. Box 6309, San Pedro, CA 90734). The computer was a HP Compaq dc7900 Convertible Minitower with an Intel® Core™2 Quad CPU Q8200 with 2.33-GHz processors and 3.24 GB of RAM, using a Windows XP operating system. The maps were displayed on a HP Compaq LA2005wg TFT LCD monitor with a 22 in. diagonal (47.5 cm x 30.0 cm) screen connected to the monitor with a DVI connector. The video card was an ATI Radeon HD 3600 Series with 512 MB of video memory. The center of the maps on the map monitor was located 64.8 cm horizontally to the right of the center of the driving display and it was located 34.9 cm vertically below the center of the driving display. The horizontal visual angle between the center of the two displays was 47° and the vertical visual angle was 30°.

A SuperLab program was used to simulate a GPS moving map navigation system by presenting a new map after each half city block increment of travel in the driving simulation program, which had triggers at the ¼ block and ¾ block points on each city block. When a participant drove past a trigger, it produced a new map update to show a participant's progress along the route.

The trigger in the driving simulation computer sent a TTL signal to the map computer to indicate a trigger point was reached and to update the progress of the participant along the route. The TTL signal was generated by a TracerDAQ PCI-DIO24 digital I/O board (Measurement Computer Corporation, 10 Commerce Way, Norton, MA 02766) located in the driving simulation computer. An identical I/O board in the moving map computer received the TTL signal, which SuperLab took as input to present the next map in the sequence.

The SuperLab program in the navigation map computer also collected the intention-to-turn decision responses that participants made. Two microswitches (Apem 810, 26010 Pinehurst Drive, Madison Heights, MI 48071) were mounted onto the cross panel supports of the steering wheel near the wheel's rim. The normally open and common pins of each momentary contact microswitch were wired in parallel to the switch pins of one of the response keys on a Cedrus RB-x730 response pad (Cedrus Corporation, P.O. Box 6309, San Pedro, CA 90734), which was set in reflective mode. Thus, accurate millisecond timing was retained for these external switches.

**Procedure**

**Driving and navigating.** Participants sat facing the simulation display and controlled the car via the Logitech steering wheel and pedals. Participants were instructed to maintain a speed of 20-25 mph using a digital speedometer at the bottom left of the simulation screen. The car was additionally programmed with the maximum speed set at 25 mph because of the sensitivity of the gas pedal. Participants were responsible for driving through a simulated city guided by a simulated GPS navigational map, either a track-up map, north-up map, verbal north-up map, or a set of auditory directions displayed by the SuperLab program.

The participants assumed the role of a visitor to a city who is attending a convention. They were given errands to perform that required them to drive to a specified location. The simulated GPS map system guided them to these eight errand destinations using turn arrow indicators and icons representing the landmarks to turn at and the errand destinations or auditory commands in the no-map condition.

Participants stopped the car when they reached each errand destination and said, “I’m here.” The car stopped in the middle of the street; participants did not have to park the car or enter a parking lot. Immediately after arriving at an errand destination, a participant was given the name of the next errand destination and errand task to perform. Errands and tasks were verbally described such as “Your next destination is the Post Office, where you need to mail a package home.” All participants performed the same eight errands and went to the same eight errand destinations in the same order. Errand destination locations were always located in the center of a city block and they were preceded by an adjacent parking lot. The list of errand destinations and the errand task statement is shown in Appendix B.

**Intention-to-turn decisions.** In addition to driving through the environment and stopping at the errand destinations, participants were asked to make intention-to-turn decisions in response to the turn indicator icons shown on the navigation maps (or the auditory commands). The microswitch button on the steering wheel under their left thumb should be pressed if they intended to turn left and the one under their right thumb if they intended to turn right. Correct decisions were to be made as quickly as possible, but errors were discouraged. Presentation of stimuli, timing, and collection of responses were controlled by SuperLab.

**Instructions and practice.** Participants in each map type condition were shown examples of the map type display they would be using to navigate and their properties were explained to the participants. A copy of these instructions is in Appendix C. They also received practice in driving and navigating using the map type. Participants controlled the driving simulator using the steering wheel and pedals. Their assigned map type guided them. They were required to make a left and right turn, as well as stop at an errand destination landmark. They also practiced making intention-to-turn decisions in response to the turn arrow indicators or auditory commands. Prior to the driving and navigating test, each participant was shown a list of the landmark icons to review and could ask the experimenter about icons if they did not recognize one. Again, the list of landmark icons is shown in Appendix A.

**Free recall of landmark names.** When the navigation test trial was completed, participants had to free recall the names of all landmarks by writing the names on a lined response sheet. Instructions and a sample response sheet are given in Appendix D.

**Sketch map data.** For the configural knowledge sketch map task, participants drew a freehand map of the simulated environment on an 18 in. x 24 in. piece of paper. The paper was blank, except for an arrow in the top left-hand corner with the long dimension of the paper oriented horizontally. Participants were told that the arrow showed the top of the map was north. First they were instructed on drawing conventions, such as keeping the size of their landmark squares and street widths consistent, labeling their landmarks, and asking for extra paper to avoid squishing their map, and then shown a sample freehand drawn map. Participants were required to place all 25 landmarks on the map. They were given the names of all 25 landmarks listed in random order to use as a checklist. Appendix E contains the sample sketch map, which was drawn on another 18 on. x 24 in. piece of paper, and Appendix F contains the sketch map instructions.

## III. RESULTS

### Configural Spatial Knowledge

**Landmark pairs: Angular error.** Configural knowledge acquisition was evaluated by having participants sketch a map of the city. Maps were evaluated by finding the x and y coordinates of the center of all 25 landmarks. The angles between all possible pairs (300 pairs) of the 25 landmarks were calculated from these (x, y) coordinates using the north axis or vertical map direction as a reference line for both the responses and the pairs of target landmarks. The absolute value of the angular difference between the landmarks on the sketch maps and the actual angle between the pairs of landmarks in the simulated environment was calculated and used as the absolute angular difference score. Equation 1 shows the computation that was used.

$$Absolute\,Angular\,Error\,f\,orObj\,ectPair(i,j) = Min[\left|R_{ij} - T_{ij}\right|, 360 - \left|R_{ij} - T_{ij}\right|] \quad \text{Eq. (1)}$$

Participants had to remember two types of landmarks during the sketch map task: destination and non-destination. There were eight errand destinations the participants were directed to visit along their route. There were 16 turn landmarks the participants were directed to turn at in their route, plus the starting landmark Starbucks, which produced 17 non-destination landmarks. These two types of landmarks created three types of landmark pairs: destination-destination (28 pairs), non-destination (136 pairs), and destination-non-destination (136 pairs). The mean absolute angular error was computed for each of these three pair categories. The mean absolute angular error data were analyzed using a 4 x 3 mixed factorial anova with a between-subjects factor of map type (verbal north-up, north-up, track-up, no-map) and a within-subjects factor of landmark pair (Destination-Destination, Destination – Non-Destination, Non-Destination – Non-Destination).

Figure 11 shows the mean absolute angular error for the four map types for each of the three types of landmark pairs. As Figure 11 shows, overall mean absolute angular error was smallest for the verbal north-up map, which was 66.8° compared with 75.0°, 81.8°, and 80.0° for the north-up, track-up and no-map types, respectively. The main effect of map type was statistically significant, $F(3, 92) = 4.92$, $MSE = 650.79$, $p = .003$. However, map type did not interact with landmark pair type, $F(6, 184) = 1.21$, $MSE = 99.90$, $p = .301$. As Figure 11 also shows angular error was smaller when both landmarks were destinations ($M = 68.4°$) than when both landmarks were non-destinations ($M = 82.2°$) with the mixed pairs in-between. There was a main effect for landmark pair type, $F(2, 184) = 46.63$, $MSE = 99.90$, $p < .001$. The data show that participants had a better memory for the spatial locations of destinations than for non-destinations. The complete anova is given in Appendix G.

In order to determine if the map types besides verbal north-up produced differences in performance, a 3 x 3 mixed factorial anova without the verbal north-up map condition was performed. Importantly, no significant differences among the remaining map types were found. The main effect of map type and the interaction of map type and landmark pairs were not statistically significant, $F(2, 69) = 1.22$, $MSE = 729.97$, $p = .301$, and $F(4, 138) = 0.35$, $MSE = 110.90$, $p = .843$, respectively. However, there still was a main effect of landmark pair type, $F(2, 138) = 23.14$, $MSE = 110.90$, $p < .001$. Appendix H contains the complete anova table.

**Starting location: Angular error.** Figure 12 shows the absolute angular error for judgments between Starbucks, the route's starting landmark, and each of the other 24 landmarks. Similar to the above analysis of angular error, the mean angular error was lower for verbal north-up, 33.96°, than for north-up, 44.38°, track-up, 65.06°, and no-map, 69.14°. I used a 4 x 24 mixed factorial (map type, landmark location) anova and found there was a main effect for map type, $F(3, 92) = 7.76$, $MSE = 20860.76$, $p < .001$, which was also found in my analysis of all landmark pair types (destination, destination-non-destination, non-destination), The main effect for landmark location was statistically significant, $F(23, 2116) = 8.72$, $MSE = 967.49$, $p < .001$, however there was also an interaction between map type and landmark location $F(23, 69) = 2.68$, $MSE = 967.49$, $p < .001$, which was not found in the analysis of landmark pair types. The Greenhouse-Geisser epsilon for the error term was .590. Using this value to correct the degrees of freedom did not change the results. The corrected $p_{gg} < .001$.

In order to determine if the map types besides verbal north-up produced differences in performance, a 3 x 24 mixed factorial anova without the verbal north-up map condition was performed. Unlike the landmark pair types anova, the main effect for map type was still statistically significant, $F(2, 69) = 3.77$, $MSE = 26955.62$, $p = .028$. The means suggest that the spatial north-up map produced lower absolute angular error than the track-up and no-map conditions for starting location-landmark pairs. As with the overall anova, both the main effect of landmark location and the interaction of map type with landmark location were statistically significant, $F(23, 1587) = 5.81$, $MSE = 1056.35$, $p < .001$ and $F(46, 1587) = 2.66$, $MSE = 1056.35$, $p < .001$, respectively.

An additional 2 x 24 mixed factorial anova of just the map types of track-up and no-map indicated that these two map type conditions were not statistically significant, $F(1, 46) = 0.15$, $MSE = 31086.96$, $p =.697$. As with the above analyses, both the main effect of landmark location and the interaction effect for map type and landmark location were statistically significant, $F(23, 1058) = 4.11$, $MSE = 1166.16$, $p < .001$ and $F(23, 23) = 3.90$, $MSE = 1166.16$, $p < .001$, respectively. The interactions in all three of the anovas are not easy to describe, but they appear to reflect smaller map type differences close to the starting location and differential effects in at some of the landmark locations along the route. Appendix I contains the anova tables for the starting landmark analyses.

**Free Recall of Landmarks**

After completing the driving simulation participants were asked to free recall the landmarks from the map display. I analyzed these data using a 4 x 2 mixed factorial anova, with the between-subjects factor for map type (verbal north-up, north-up, track-up, no-map) and a within-subjects factor for type of landmark (destination, non-destination). As Figure 13 shows, unlike the angular error data, the participants' free recall did not differ for the four map types, $F(3, 92) = 0.62$, $MSE = 305.47$, $p = .603$. Overall mean percent recall was 53.7%, 51.2%, 52.7%, and 55.5%, for the verbal north-up, north-up map, track-up map, no-map and map types, respectively. Map type also did not interact with landmark type, $F(3, 92) = 0.67$, $MSE = 209.09$, $p = .572$. However, participants were more likely to recall destination landmarks ($M = 69\%$) than non-destination landmarks ($M = 49\%$). The main effect of landmark type was statistically significant, $F(1, 92) = 92.91$, $MSE = 209.09$, $p < .001$. Thus, similar to the angular error data, destination landmark performance was better than non-destination performance Importantly, these effects of landmark types and recall do not appear to be producing the map type differences in spatial knowledge acquisition. Appendix J contains these anova tables.

**Intention-to-Turn Decisions**

Participants made 16 intention-to-turn responses, each one in response to the presentation of a turn indicator on a map. Eight of the intention-to-turn responses were from turns taken while the vehicle was heading north or heading south. Turns were classified in four subcategories formed from two repeated-measures factors, heading direction (north, south) and turn direction (left, right) combined factorially. The dependent variable was the mean response time of the turn decisions in each of the four subcategories. Because of a mistake, there were not two turns in each of the four categories. For right turns, there were three heading north and two heading south responses, but for left turns, there was one heading north and two heading south responses.

North-up maps produce misaligned turn arrow indicators when vehicles are heading south. Thus, with traditional spatial advisory indicators intention-to-turn response times for heading south should be slower than heading north response times. However, if the verbal north-up map design effectively minimized or overcame the spatial misalignment problem, then heading differences should be minimized or eliminated for these maps. Unlike north-up maps, there are no misaligned headings for track-up maps. Thus, no heading differences were expected for track-up maps. Because auditory (no-map) displays had no spatial misalignments, heading differences were also not expected for this map condition.

**Response time.** To test for heading direction differences the four map types were factorially combined with the two repeated-measures factors of heading and turn direction to analyze intention-to-turn mean response times in a 4 x 2 x 2 mixed factorial anova. Figure 14 shows the mean response times for right turns. Map types are on the horizontal axis with heading south data shown as filled circles and heading north data shown as open circles. Traditional north-up maps had the largest mean differences between heading north and heading south response times (*M* = 1385 ms difference), as expected because this map display had a 180° misalignment for south-going turns. Mean differences between north versus south for the verbal north-up, track-up, and no-map conditions were noticeably lower, at -520 ms, 727 ms, and -59 ms, respectively (negative time differences indicated that mean south-going responses were faster than going north responses). There was a three-way interaction between map display condition, turn direction, and heading, $F(3, 88) = 3.66$, $MSE = 2576757.50$, p = .015, which was significant apparently because, as Figure 15 shows, comparable differences were not found for left turns. Overall, right turns had longer intention to turn times than left turns (*M* = 1878 ms and 1432 ms, respectively); the main effect for right-left turn direction was significant, $F(3, 92) = 4.94$, $MSE = 478552.77$, $p = .029$. No other main effects were found to be significant. The complete anova table is in Appendix K.

The significant three-way interaction was followed up by analyzing right and left turn data separately using two 4 x 2 mixed factorial anovas with between-subjects factor of map display type and a repeated-measures factor of heading direction. For right turns, as shown in Figure 14, heading direction interacted with map display type, $F(3, 90) = 2.74$, $MSE = 3627866.09$, p =.048. There was no main effect of heading direction, $F(1, 90) = 1.48$, $MSE = 3627866.09$, $p = .226$. This interaction was followed-up using four repeated-measures anovas on heading direction (north vs. south) to analyze each map type separately. Importantly, a significant difference for heading direction was present for the spatial north-up map condition, $F(1, 21) = 5.85$, $MSE = 4246088.71$, p = .025, but there was there was no effect for heading direction for the other three map types; $F(1, 23) = 1.82$, $MSE = 1779490.76$, $p = .190$ for verbal north-up, $F(1, 23) = 0.82$, $MSE = 7733147.30$, $p = .375$ for the track-up condition, and $F(1, 23) = 0.05$, $MSE = 806496.06$, $p = .822$ for the no-map condition. The anova table for these analyses is in Appendix L.

The follow-up analysis of left turns, using a 4 x 2 mixed factorial anova with a between-subjects factor of map display and a repeated-measures factor of heading direction, did not find a significant main effect for heading direction, $F(1, 90) = 0.891$, $MSE = 1362920.36$, $p = .348$, a significant main effect for map display type, $F(3, 90) = 0.44$, $MSE = 787222.25$, $p = .725$, or an interaction between heading direction and map display, $F(3, 90) = 1.22$, $MSE = 1529687.88$, $p = .307$. Figure 15 shows the mean response times for left turns heading north and south. There is a visibly flatter trend across map conditions, and surprisingly south-going response times are not slower for the north-up condition, as they are for right turns. The mean differences between heading north versus south for the north-up, verbal north-up, track-up, and no-map are 245 ms, 626 ms, -318 ms, and 78 ms respectively. The anova tables for these analyses are in Appendix M.

**Percent error.** A comparable 4 x 2 x 2 anova could not be conducted on the percent error data because there were few trials and few errors on the trials. There were 96 participants assigned to the four map types and the anova requires four cells for each participant for the 2 x 2 repeated-measures of heading and turn direction. Therefore, there were 384 cells in the 4 x 2 x 2 anova. However 93% of the cells had no errors in them. This floor effect would have severely truncated the estimated variability in any anova and distorted the results. The mean percent error for the map display types were 2.87% for verbal north-up, 1.30% for track-up, 3.91% for spatial north-up, and 3.13% for the no-map type.

## Gender Analyses

Each experimental condition was balanced for gender. I analyzed configural spatial knowledge, free recall, and intention-to-turn responses adding gender as a between-subjects factor, and found no main effects of genders or interactions of gender with any of the other factors. The anova tables for these anovas can be found in Appendix N.

# IV. DISCUSSION

The results provided evidence that both of the desirable attributes of navigational map systems characterized performance when the new verbal north-up map display was used. Not only could participants use the map to learn about the layout of the region, but the verbal advisory cue also provided turn guidance about as effectively as turn arrows on track up displays, which are typically used now.

## Using Maps to Learn the Layout

The results clearly showed that the verbal north up displays lead to greater spatial knowledge acquisition. These results were found for both measures of configural spatial knowledge, absolute angular error for multiple pairs of landmarks (destination, destination-non-destination, non-destination) and a single absolute angular error of all landmarks from the starting position at Starbucks. This is an important conclusion because of the limitations imposed on map study while driving. Instead of a seeing a large area all at once, akin to using a paper map, participants only saw segments of the region at a time. Additionally, they only had a brief time to study each segment while also paying attention to the driving task. Importantly, the data also suggest that this spatial knowledge was in addition to any knowledge obtained by viewing the environment directly by viewing it in the virtual environment; there was less absolute angular error for the verbal north-up displays than for the no-map displays. Thus, these results are consistent with research showing that people can learn configural knowledge about an area rapidly when using a map compared with direct experience (Ruddle, Payne, & Jones, 1997; Thorndyke & Hayes-Roth, 1982; Willis, Holscher, Wilbertz, & Li, 2009).

The spatial acquisition task was not trivial. Participants were tested on the locations of 25 different environmental landmarks, not just a handful. Yet, participants using the verbal north-up display had only 34° of absolute angular error for all landmarks relative to the starting position and only 56° absolute angular error for pairs of destination landmarks. Characteristics of landmarks were important. Participants acquired more accurate spatial knowledge of landmarks at errand destinations than landmarks identifying the locations at which to turn. However, this improved accuracy of destination landmarks did not affect the evaluation of map types; the same pattern of results was found for the three different types of landmark pairs. The results suggest that the difference in map types was a result of configural knowledge acquisition, not of landmark type knowledge acquisition. Although more destination landmarks than non-destination landmarks were free recalled, these differences did not produce statistically significant differences among the four map types.

The results for the north-up map with a spatial only advisory turn indicator were mixed. Mean absolute angular error for the spatial north-up map was not statistically different from the track-up and no-map displays for the multiple pair measures for any of the landmark pair types although its means were nominally smaller. However, absolute angular error measured from the starting position was smaller for the spatial north-up display than for track-up and no-map displays. Previous research found better configural spatial knowledge acquisition for participants in varying environments while using north-up maps. Perceived stability of landmarks, as is typical of north-up maps, is important when first navigating a complex environment and then creating alternate routes, as shown by participants walking through a virtual "forest" (Foo, Warren, Duchon, & Tarr, 2005). Creating alternate routes means the wayfinder can remember the relative placement of landmarks and has gained configural spatial knowledge (Siegel & White, 1975). Additionally, participants who drove while using a north-up map were able to then create alternate routes (Prabhu, Shalin, Helander, & Drury, 1996), and similar results were found in aviation studies for pilots using a fixed-orientation map (Aretz, 1991; Aretz & Wickens, 1992).

One reason why less spatial knowledge was acquired with spatial north-up map displays may have been that these participants had less functional time available to study the maps. While people are driving they need to attend to traffic, potential hazards, and their present position, as outlined in the Driving-Guided Navigation processing model. They have a short amount of time to look at a navigation aid, split between understanding route advisories and observing the layout of the area. With a traditional north-up map, there is considerable time devoted to understanding the turn indicators, especially if the heading direction is misaligned with the driver's forward view. This leaves less time to observe the layout of landmarks in the region. The turn indicators on a verbal north-up map however, are easy to understand quickly, and so there is more time left to devote to learning about the layout of their environment.

**Turn Decisions**

The verbal north-up map kept decision times low, which was especially important for response times when heading in misaligned directions. In this display, although the turn arrow was misaligned, the verbal cue was not, and drivers did not have to spend time on spatial stimulus reversals. The verbal information shown by the L or R placed at the end of the turn arrow appeared to be processed separately from the misaligned turn arrows, providing a clear-cut turn command. These results are consistent with both the dual-coding theory of processing (Paivio, 1971; Paivio, 2006) and the multi-component theory of working memory (Baddeley, 2001; Baddeley, 2007 Baddeley & Hitch, 1974).

These results were also consistent with the results from the experiment with static map displays, which had 960 response time trials. Despite misalignments, those participants had stable response times for the verbal indicators. Additionally, their mean response times at a perfect alignment of 0° were lower even than those with the track-up indicators. The verbal spatial turn indicator on north-up maps was not expected to be easier to understand than a spatial turn indicator already aligned with the user's forward point of view, so a letter on the end of the turn arrow could be providing better confirmatory information. A criterion for replacing an old map display should be that the new display maintains the benefits of the old display it was attempting to improve upon, and the new verbal north-up map had response times comparable to the traditional track-up maps.

**Design Implementation**

The new verbal north-up display is understandable and can be easily fit into modern vehicles. Currently, there is an increasing trend for GPS map navigation systems to be installed directly in the dashboard. This allows the dimensions of the display to be larger than portable devices, and so the console can accommodate the 10 in. x 10 in. (25.3cm x 25.4cm) display screen that can show more of the surrounding area and landmarks.

The new verbal map design not only uses verbal/spatial advisories on a larger screen with a fixed orientation north-up map, it gives turn advisories with respect to upcoming landmarks, and so uses turn-at-landmark information. Current GPS systems typically use distance-to-turn information, which may not be optimal because people have trouble estimating distances, and the drivers' estimate of the remaining distance has to be updated repeatedly as they drive (Burnett, 2000; May, Ross, & Bayer, 2005). Implementing turn-at-landmark directions should be easy for modern displays although current systems have not typically used landmarks for navigation. Most modern devices already have the database and search functions that allow the driver to find businesses according to category. The current experiment only used landmarks in order to clarify the information being used by the participants. However, if the new display were to be incorporated into vehicles, a potential problem arises because of environments or turns in which prominent landmarks are not available at a desired turn. If landmarks are not available, drivers can still use the street names displayed on the map, which were not included on the map or virtual simulation for research purposes. Street names provide additional information as drivers track their own progress and watch for upcoming turns. For example, in residential areas there are fewer unique landmarks to help the driver navigate and the slower pace could provide enough time to read the map and recognize the actual street sign. However, the maps used in this study did not have street names. Landmark buildings and signs are easier to see from a distance in the physical world and to match icons on the map. Street name text is small and may be difficult to read during the little time a driver has to study the map. Also, landmarks for commonly known stores and restaurants may be more salient to the driver, making them easier to use as anchors for configural knowledge. Turn-at-landmark information reflects how people give instructions to each other, and is preferred over distance-to-turn instructions (May, Ross, & Bayer, 2005). Additionally, while street names can be presented at different orientations and could cause clutter; as the sketch map measure shows, not all landmarks along a route need to be shown for the driver to gain configural knowledge.

Some situations may require alterations or additions to this design. This study had roads laid out in a grid to mimic the layout of a city. In many environments there are roads that meet at varying angles or, like a Y in the road, branch out without distinct turns. Indicators showing turns onto diagonal roads should be able to be displayed as they are for perpendicular intersections. The map display would have to be accurate as to the angle of the turn. A road that branches into several diagonal streets has more than two choices for a turn decision, which could cause confusion when following the turn indicator. In this case street names could provide clarity about which road the route follows. Street names could serve as landmarks themselves; drivers would then know the proximity of one street to another and integrate that with their prior knowledge of the area. Outside of city driving, different environments may have landmarks spread across a greater distance. Because of the fixed orientation of north-up maps, features of the terrain may serve as landmarks. If north is kept consistent then judgments about the other cardinal directions are easy to make and add to other known facts about the area, like the shoreline is to the west, or downtown is south of an airport. Traveling on highways at a greater speed could mean that turn information needs to be given even more in advance. One possibility is for the off-ramp number or preceding mile marker signs to serve as landmarks to turn at and which are represented by distinct icons on the map.

Although the priority of most navigation aids is to provide route instructions, the benefits of good spatial presentation help people overcome their total reliance on such devices, which, as was pointed out in the introduction, can lead to serious problems such as driving into a lake or onto railroad tracks. Such technology should serve as a helper and resource, instead of as a crutch. When drivers can learn about unfamiliar environments in one or fewer times than with current track-up displays, then they will not need to use the device every time.

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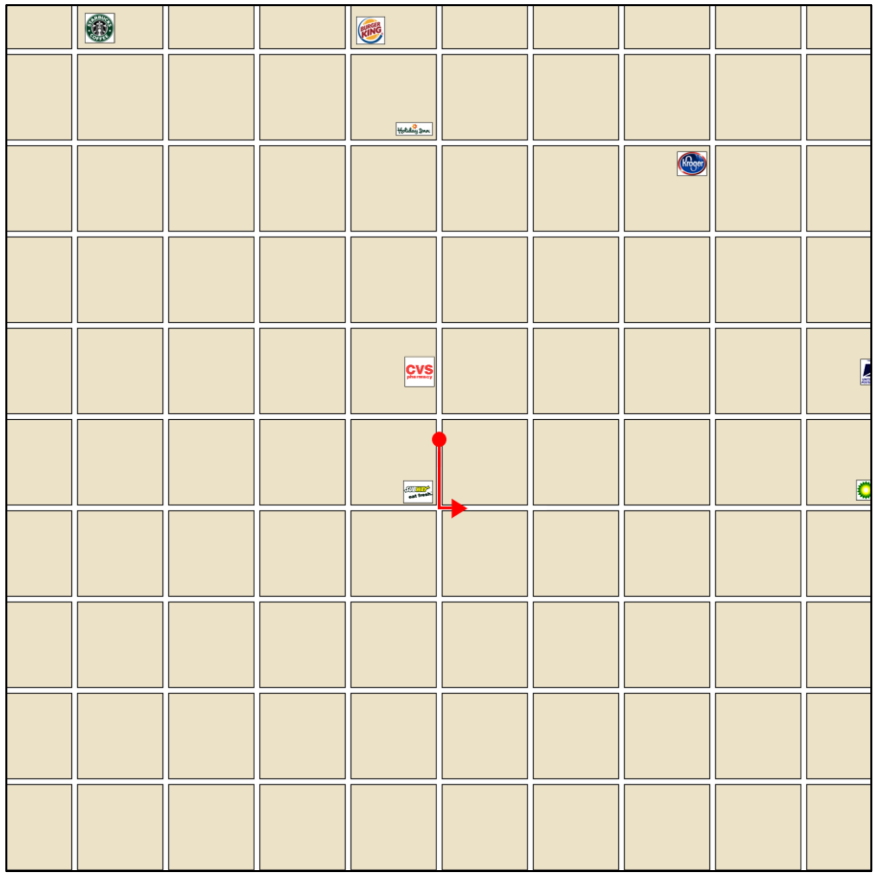


*Figure 1.* Shows the north-up map with a south-going spatial turn arrow indicating a left turn and pointing to the right side of the display.

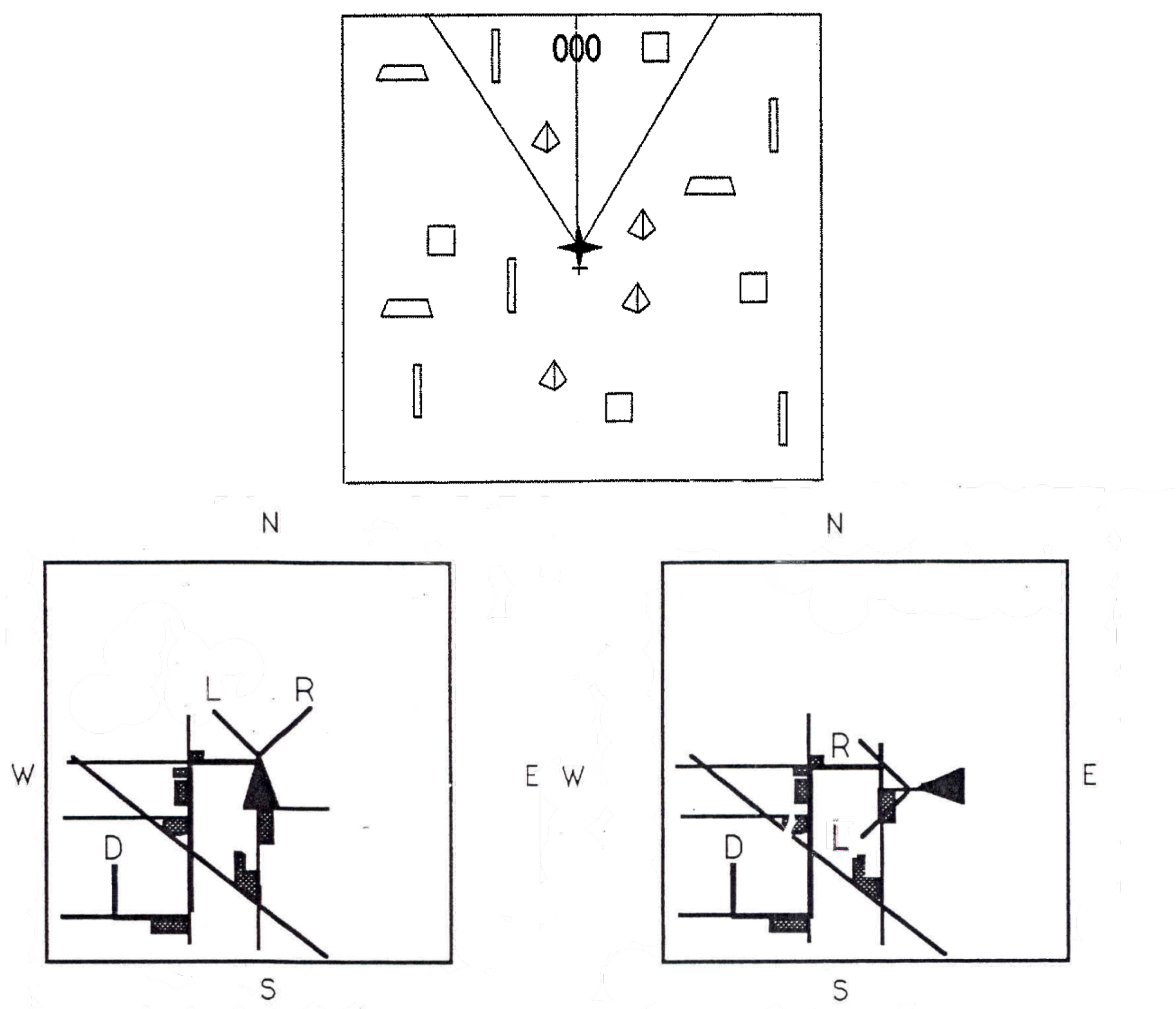



*Figure 2.* The map display in the top center is an example of the north-up plus wedge map designed by Aretz (1991). The left edge was colored blue, the centerline remained black, and the right edge was colored yellow. The map on the bottom left is an example of the north-up plus wedge (NUW) map showing the participant driving north, as designed by Prabhu, Shalin, Drury, and Helander (1996). The map on the bottom right is the north-up plus wedge map with the participant driving west.

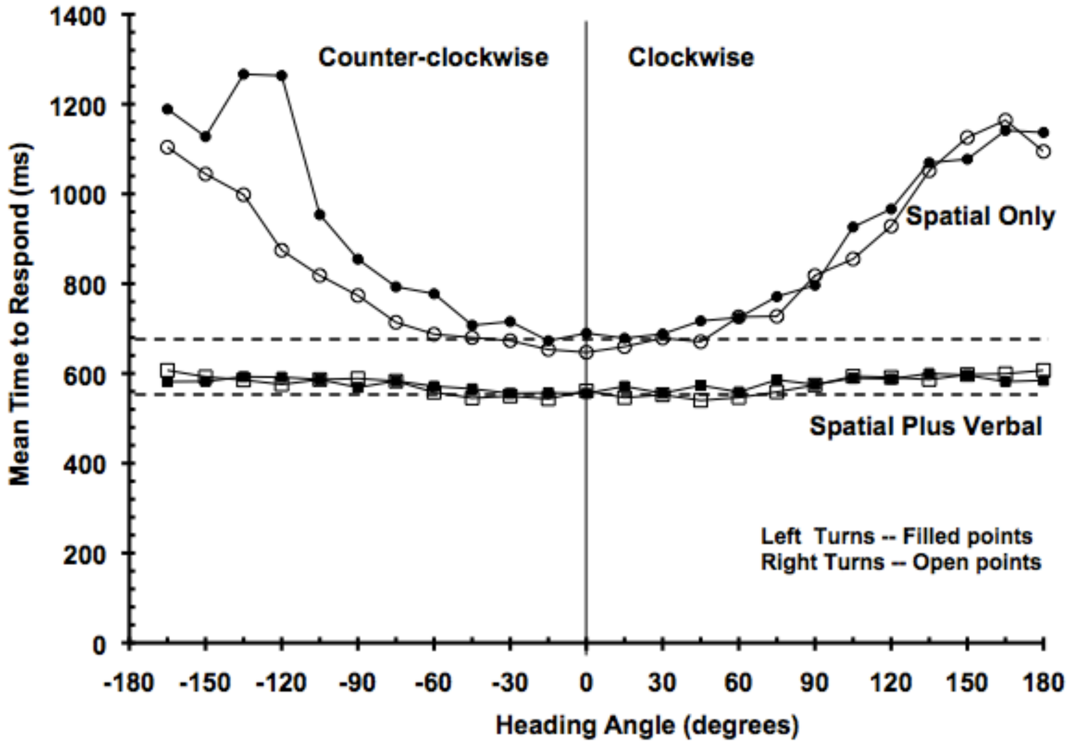



*Figure 3.* Shows the mean response times for participant groups who viewed spatial only turn indicators and participants who viewed spatial plus verbal turn indicators.

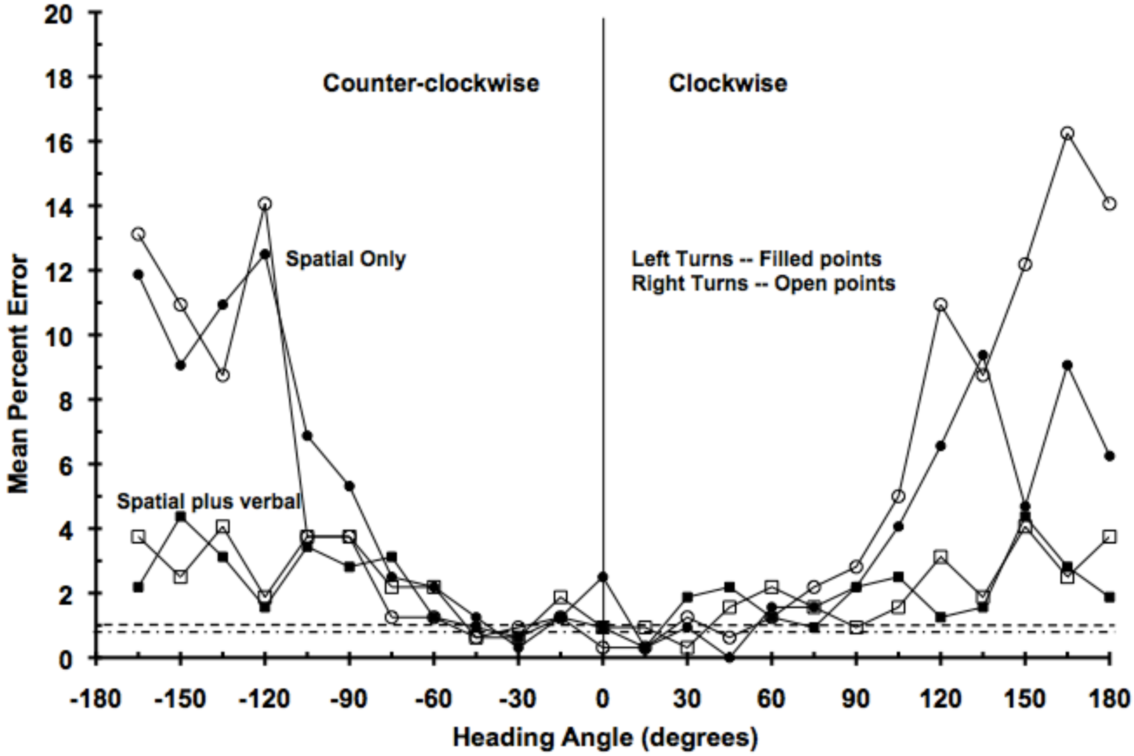



*Figure 4.* Shows the mean percent errors for participant groups who viewed spatial only turn indicators and participants who viewed spatial plus verbal turn indicators.

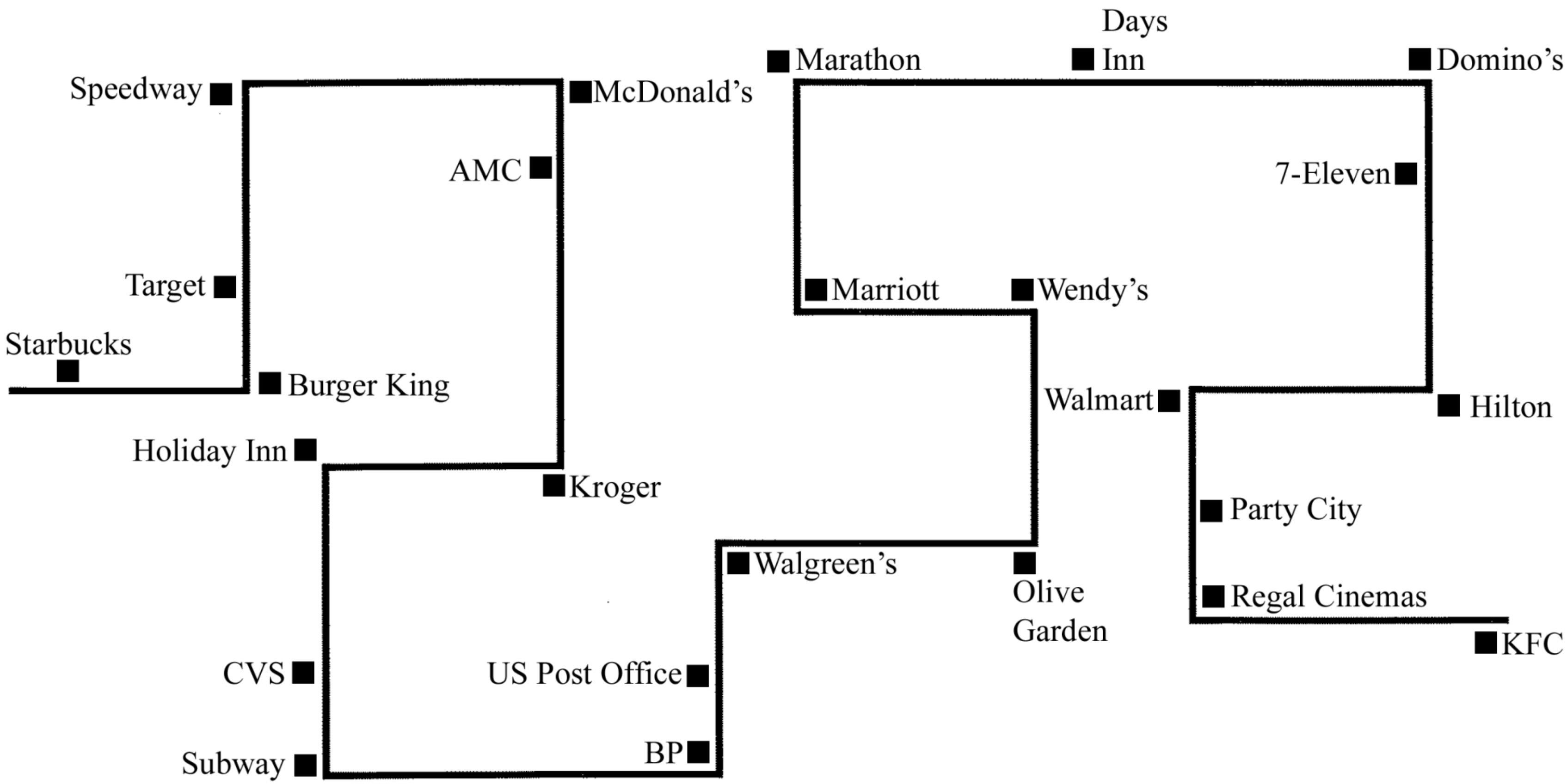



*Figure 5.* Shows the route and landmarks used in the navigation.

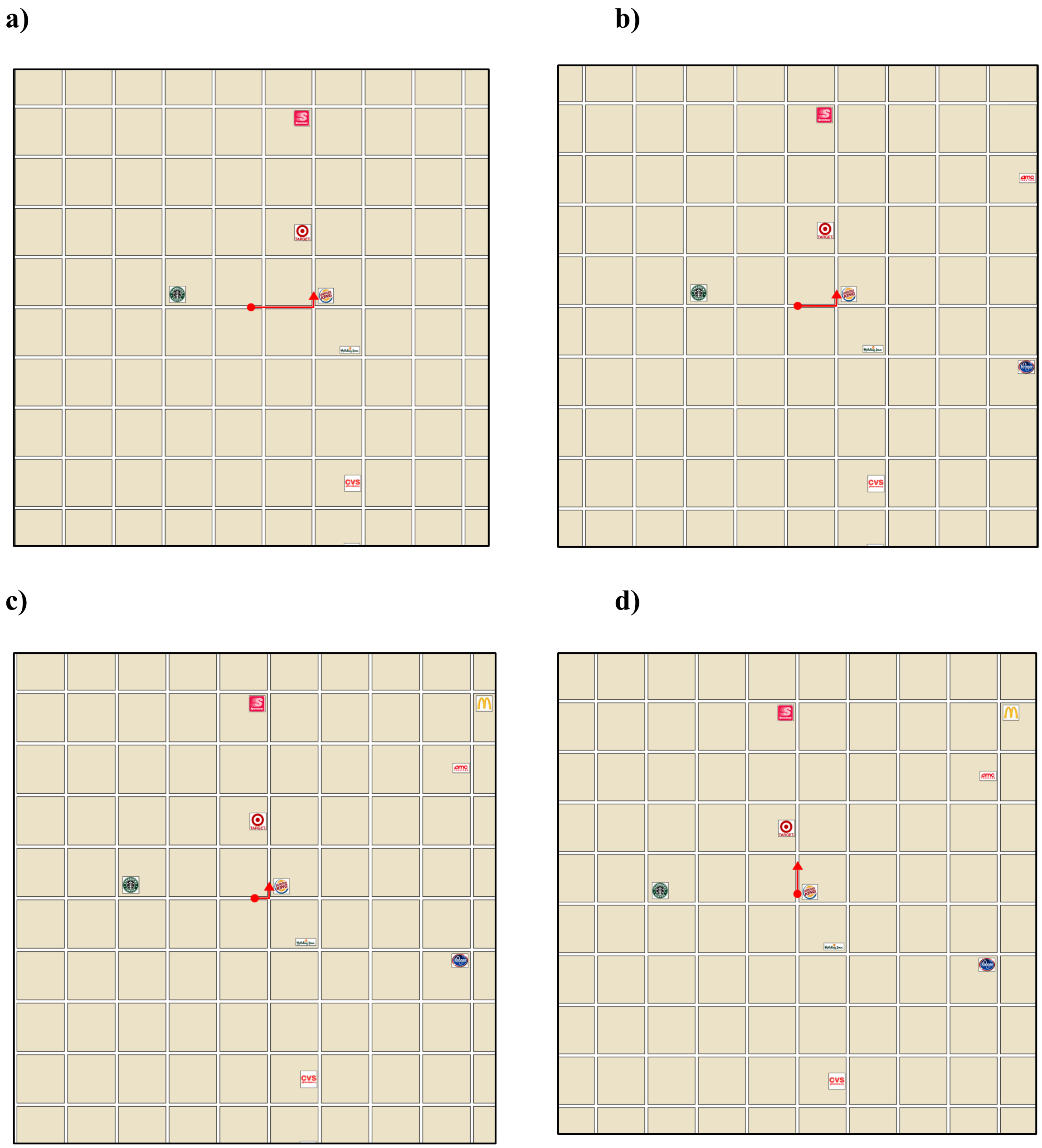



*Figure 6.* Four north-up navigation maps with spatial-only turn indicators showing the transitions of a left turn.

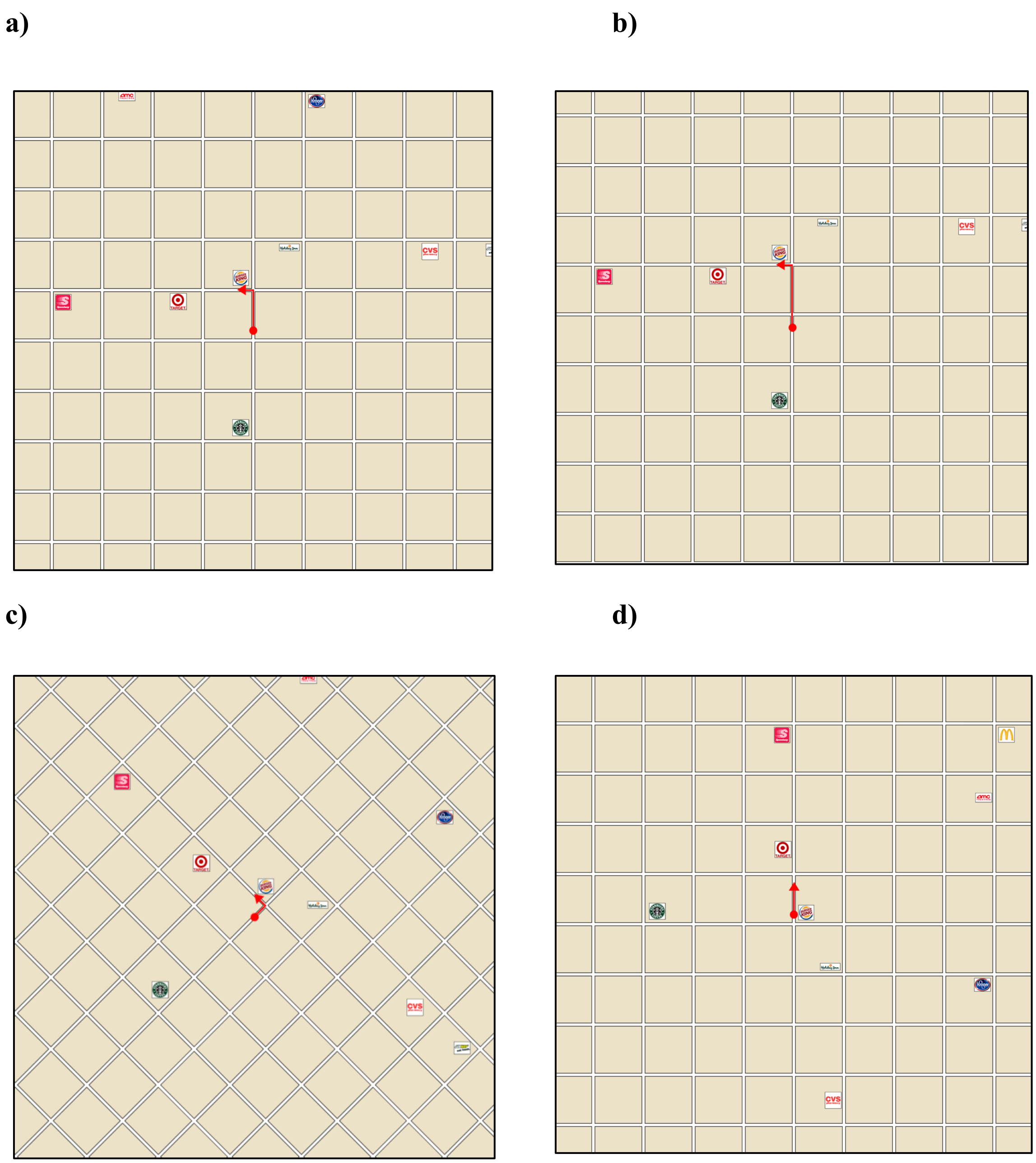



*Figure 7.* Four track-up navigation maps with spatial-only turn indicators showing the transitions of a left turn.

a) b)

c) d)

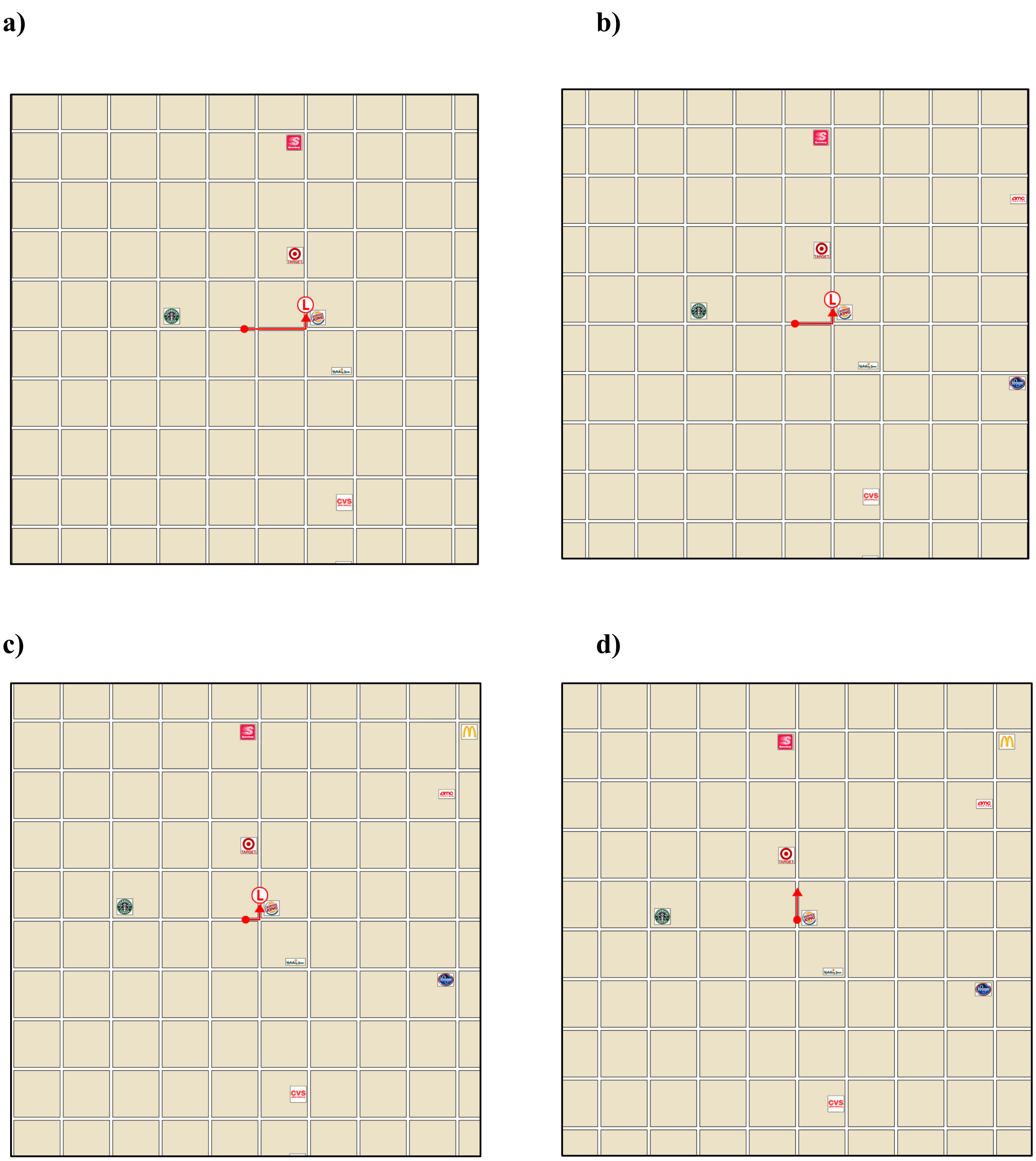



*Figure 8.* Four north-up navigation maps with verbal plus spatial turn indicators showing the transitions of a left turn. .


*Figure 9.* A screenshot depicting the corner landmark Burger King with a parking lot placed on the inside corner of the intersection, allowing the driver to see the corner landmark as they approach.


*Figure 10.* A screenshot of the driving simulation shows the participant's fields-of-view.

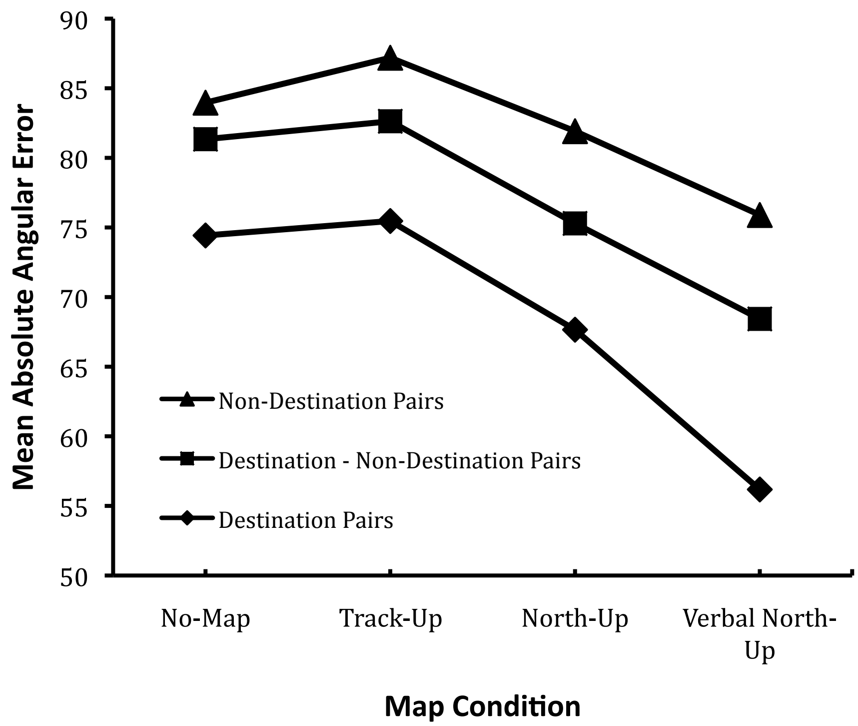



*Figure 11.* Mean absolute angular error taken from sketch maps for different types of landmark pairs for each the four types of map design conditions. Destination landmarks refer to landmarks where the vehicle was stopped to run an errand. Non-destination landmarks were landmarks used to denote turns and the starting landmark.

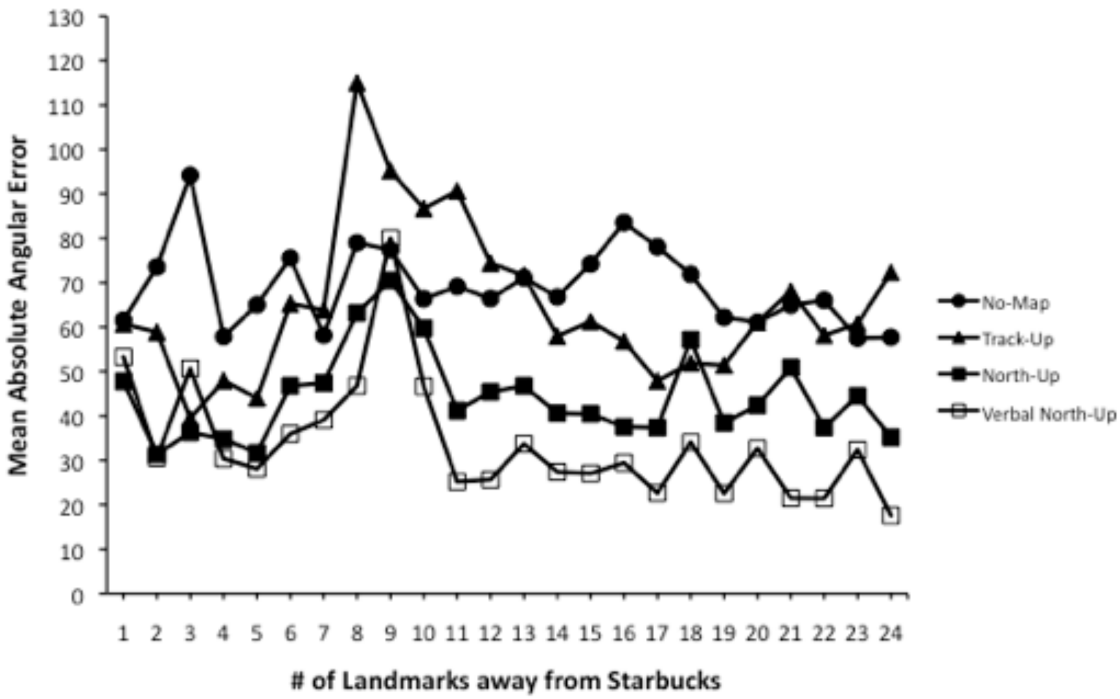



*Figure 12.* Mean absolute angular error taken from the starting landmark, Starbucks, and each of the other 24 landmarks along the prescribed route in the order in which they were encountered.

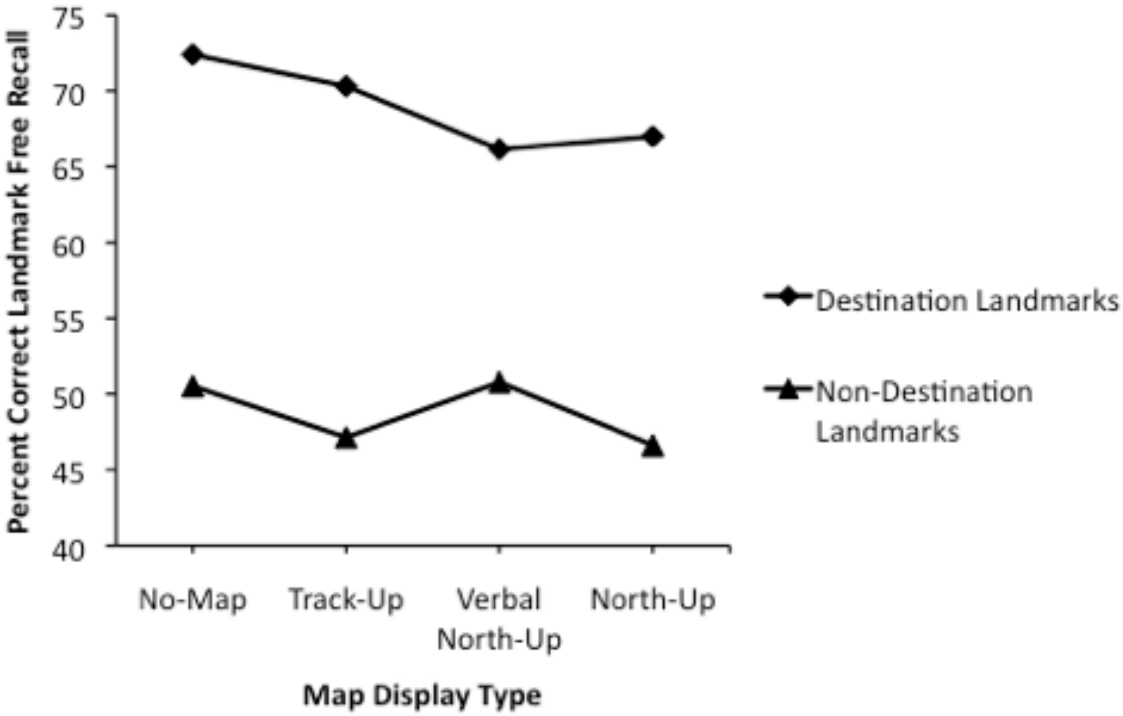



*Figure 13.* Mean percent recall of destination and non-destination landmarks for each of the four map types learned during the driving simulation

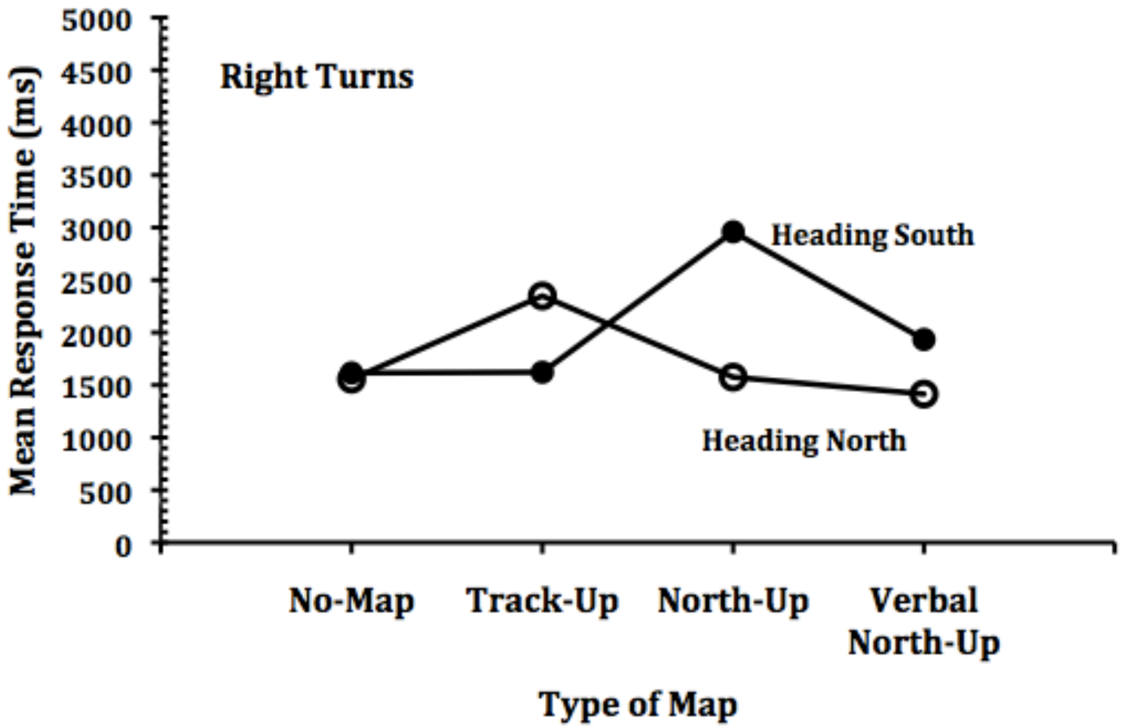



*Figure 14.* Mean response times for right turns for participants heading north or heading south in the four map display conditions.

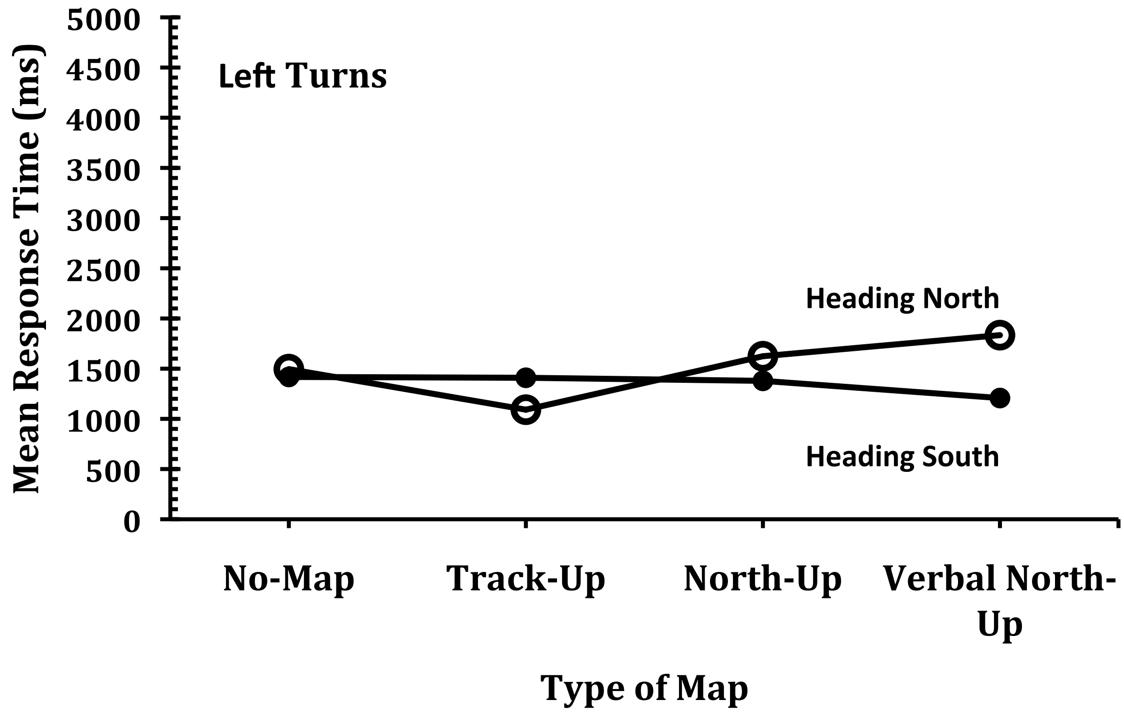



*Figure 15.* The mean response times for left turns for participants heading north or heading south in the four map display conditions.

*Appendix A*

| | |
|---|---|
| 7 Eleven | AMC Theaters |
| BP Gas Station | Burger King |
| CVS | Days Inn |
| Domino's Pizza | Hilton |
| Holiday Inn | KFC |
| Kroger | Marathon Gas Station |
| Marriott | McDonald's |
| Olive Garden | Party City |
| Regal Cinemas | Speedway Gas Station |
| Starbucks | Subway |
| Target | United States Postal Service |
| Walgreen's | Walmart |
| Wendy's | |

*Appendix B*

*The 8 errand destinations and the task statements read aloud for each by the experimenter.*

| Errand Location | Task Statement |
|---|---|
| Target | go to the TARGET, where you need to buy a shirt for a meeting. |
| AMC | Your next errand is at the AMC MOVIE THEATER, where you've decided to buy a gift card for a colleague; you can resume driving. |
| CVS | Your next destination is CVS, where you need to pick up a prescription; go ahead. |
| U. S. Post Office | Your next destination is the U. S. POST OFFICE, where you need to mail a package; go ahead. |
| Days Inn | Your next errand is at the DAYS INN, where you need to get your notes from your hotel room; go ahead. |
| 7-Eleven | Your next errand is at the 7-11 where you need to fill your rental car with gas; go ahead. |
| Party City | Your next errand is at the PARTY CITY, where you need to pick up supplies for the conference's banquet; go ahead. |
| KFC | Your next destination is KFC, where you want to get some lunch before your meeting; go ahead. |

*Appendix C*

**Instructions for Map-Driving (Cait Thesis) Experiment**

**VN - North-Up + Verbal Map Instructions 18 Sept 2010**

**[Should have Experimenter Protocol with you]**

- Take to Test Booth, 423J --Make sure they bring all their possessions, NO drinks, food, pets, or children. **DO NOT** let them push the pedal or else it will start the simulation
- Have them sitting in the green chair against the back and move the chair until they are
  1. lined up with the eye position line
  2. have centered themselves with the wheel
  3. can comfortably reach the pedal

**Instructions**

In this experiment you will be taking the role of a person visiting an unfamiliar city to attend a convention. While you are there you will have several errands to perform before you go to the convention. You will drive a car through the simulated city while being guided by a GPS navigation system. This GPS system is unlike current car navigation systems, so I will describe how the guide works. The GPS map is the only guidance you will get, except if you make an error then you will get a voice correction.

**Describing the Map**

The map that you will see on this screen [*press start key*] is both similar and different from the map in current GPS navigation systems. Just like in current systems, the driver is guided by an arrow that shows the upcoming turns. However, this red dot represents your car [*point*] and it is attached to a red arrow that travels through the streets. The red arrow shows you [*motion along the longer segment*] which direction you are heading and gives you at least 1 city block's warning for upcoming turns. So when you see the turn arrow appear, that means you have to <u>cross</u> one intersection and travel one block before your turn.

The map <u>is always</u> oriented with North on top. When the car is going north, then left and right turns will head toward the left and right sides of the map, like with this left turn [*point to car going north on the static map*].

However, when the car is going south [*press Start*], the arrow will be heading down, and left turns will travel to the right side of the map and right turns travel to the left side of the map, like with this left turn [*point to left turn going to the right on the static map*].

This can make deciding which way to turn difficult. The map you will be using helps the driver by providing a code letter at the tip of the arrow. [*Point to letter in the same static map*] If a red L is present, then you should make a left turn. If a red R is present, then you should make a right turn. So, this map has an L to designate that the car should make a turn to the Left after traveling across an intersection and one block.

Current GPS systems tell you to turn in a certain number of yards. Notice here the picture icons on the map [*point to Albertson's icon*]. This map uses the picture icons as landmarks to help the driver know where to turn. The icons show the logos of restaurants, hotels, stores and other commonly known businesses. If you can't recognize an icon, ask me for help. It is important to watch out for all of the landmarks because you will use them to navigate the city while you run errands, which I will tell you about as you drive along the route. There will be an icon of a business at each of your turns and at each of your errand destinations.

[☞ *say slowly* ☞] The landmark icons you turn at will always be located in the corner of the city block. The errand destinations are always in the middle of a block. It is important to pay attention to these errand destinations and where they are located, as well as the turn landmarks and their locations because you will be tested on this later. Your job with this map is to learn the layout of the landmarks in the city, so be sure to look at the entire map as you drive.

**Instructions: Practice using the turn buttons**

While you are driving, you'll be telling me which way you'll be turning AS SOON AS YOU KNOW. When the turn arrow and cod letter come on, I'd like you to immediately tell me about these upcoming turns by saying "Right Turn" or "Left Turn" out loud so I can hear you.

Do you have any questions?

Let's practice looking at the map and reporting upcoming turns. You will not be driving yet, but watch the red arrow travel along the route and remember to say 'Right Turn' or 'Left Turn' as soon you know which turn the arrow and code letter are showing. Ready? Ok, let's start. [*Press start*]

***If the participant asks about the arrow moving say, "The arrow will move in a second."**

***If the participant responds twice say, "You only have to say which turn it is once."**

**Instructions: Practice driving simulation**

The landmarks will be on the map, like you just saw, and these businesses will also be in the simulated city [*point to buildings in simulation*]. The city walls will show you pictures of the actual front of each landmark's building. The building landmarks in the simulated city correspond to the landmark logos on the navigation map. So, the map tells you what building landmarks to look for while you are driving. The simulated city will be shown on this display [*point*] as you drive using the steering wheel and pedals. The navigation map will be shown on this display [*Press Start*]. By following its red arrows it shows you your route and where to turn. Remember that the red dot represents your car and the red turn arrow <u>and letter</u> tells you which direction to turn. The red arrow will give you at least 1 block's warning before you need to make a turn, and I will let you know what your next errand destination is after you reach each one. Notice that the map shows you a larger view of the city than most GPS navigation systems so you get a better idea of where businesses are located. Your location on the map also does not update as often because turn information is presented farther in advance.

The map will guide you to each of your errands. When you reach your errand destination in the city you should <u>stop the car</u> in front of it and say <u>out loud</u>, "I'm here." You don't have to pull over. I will then tell you the destination of your next errand and when to resume driving.

Please put your hands on either side of the wheel with your thumbs resting on the black buttons and <u>keep them there</u> for the whole experiment. You will use these buttons to tell me when you know which way to turn, instead of saying 'Left Turn' or 'Right

Turn' out loud. Try to respond as fast as you can as soon as the turn arrow and letter come on. The computer will be recording the time it takes you to respond. However, try not to make errors. When you turn the steering wheel, it's okay if your hands move, but return them to this position with your thumbs resting on the turn buttons.

Try to drive at a speed of about 20-25 mph. Use the speedometer at the bottom left of the display [*point*]. Note that the car's speed is limited to a maximum of 25 mph. The gas and brake pedals are the same as in a normal car. You can use the entire road, but if you happen to hit a

wall in the simulation, the car will stop, and you will need to reverse. I will tell you how to reverse if this happens, but be careful of corners and most importantly, follow the map.

**[*****To reverse***:** you hold down the top gray button under your left thumb, turn the wheel, and gently push the gas pedal. You have to completely brake before you let go of the gray button again to switch back to Drive.****]**

Do you have any questions?

Let's try the driving task with the wheel and pedal while using the navigation map. Your first errand is to stop at the Jack in the Box for a burger. Remember to fully stop your car at the landmark and say out loud, "I'm here." Remember, press the Left or Right turn *button* immediately after the red turn arrow gives you the block and a half warning.

Any questions? Are you ready? Ok, let's start.

**[*Make sure that the subjects:**

- **Are responding for the turn**
- **Are braking completely at the Jack in the Box and saying "I'm here"**

– [*the subject reaches JACK IN THE BOX]*

Good. You can keep driving while following the red arrow.

**[**If the subject is a good driver you can end the Practice session by pushing Start on the last map update**]**

**After the Subject finishes the Practice Route:**

Good. Do you have any questions about the driving task or using the navigation map?

- Close Vega (push esc) and then click on "cdrivingsim" on the Desktop (may need to readjust pedal for participant)
    - For Test route when it asks for list filename, type (case sensitive): List29Aug2010.txt
    - Starting position x: 55
    - Starting position y: 2095
    - Heading: -90

**Instructions: Test Trial**

Now let's start the actual experiment. This experiment will be just like the practice driving simulation you just went through. You will use a similar map to navigate the city but this test trial takes place in a completely different city with completely different landmarks than the practice. Here is a list of the landmark icons you will see on the navigation map. Please look at each one and tell me if you don't recognize them. [*hand the landmark icon list to them*] If you ever can't recognize one on the map or a sign in the city, let me know. Some logos people usually have trouble with are Walmart [*point to Walmart*], the Holiday Inn [*point to Holiday Inn*], Regal Cinemas [*point to Regal Cinemas*] and Party City [*point to Party City*].

[*wait until subject hands back the icon list*]

Imagine that you are in a city you've never visited before for a convention, and have several errands to run before your meeting. I will tell you the upcoming errand destination, just as I did for Jack in the Box in your practice. Remember to use the map to see where your next turn should be and follow the red arrow through the route. Often there are one-way streets. Make sure to press the right or left turn buttons AS SOON AS you know which way to turn when the turn arrow and letter come on. Use the landmark icons on the navigation map plus the actual building landmarks and streets to learn where things are located in the simulated city. Your knowledge of landmark locations *will be tested* later.

Do you have any questions? [*Press Start and start the stopwatch*]

As you can see from the map you have started your errands by getting a drink at STARBUCKS.

1. The destination for your next errand is to go to the TARGET, where you need to buy a shirt for a meeting. Remember to stop the car and tell me, "I'm here," when you get to your errand destination.

Okay, begin driving. [*if participant gets a turn decision wrong they should hear an audio response correcting them]*

[*they should respond for a LEFT turn at the upcoming BURGER KING*]

>> participant reaches the TARGET

2. Good. Your next errand is at the AMC MOVIE THEATER, where you've decided to buy a gift card for a colleague; you can resume driving.

[*they should respond for a RIGHT turn at the SPEEDWAY GAS STATION*]

[*they should respond for a RIGHT turn at the MCDONALD'S*]

>> participant reaches the AMC MOVIE THEATER

3. Good. Your next destination is CVS, where you need to pick up a prescription; go ahead.

***First landmark that the subject can't see on the map until they drive closer***

- **If they ask where it is say, When you get closer to the landmark it will show up; the red arrow will take you there.**

[*they should respond for a RIGHT turn at the KROGER*]

[*they should respond for a LEFT turn at the HOLIDAY INN*]

>> participant reaches the CVS

4. Good. Can you still see and recognize all the icons on the map? Your next destination is the U. S. POST OFFICE, where you need to mail a package; go ahead.

[*they should respond for a LEFT turn at the SUBWAY RESTAURANT*]

[*they should respond for a LEFT turn at the BP GAS STATION*]

>> participant reaches the U. S. POST OFFICE

5. Good. Your next errand is at the DAYS INN, where you need to get your notes from your hotel room; go ahead.

[*they should respond for a RIGHT turn at the WALGREEN'S*]

[*they should respond for a LEFT turn at the OLIVE GARDEN*]

[*they should respond for a LEFT turn at the WENDY'S*]

[*they should respond for a RIGHT turn at the MARRIOTT*]

[*they should respond for a RIGHT turn at the MARATHON GAS STATION*]

>> participant reaches the DAYS INN

6. Good. Your next errand is at the 7-11 where you need to fill your rental car with gas; go ahead.

[*they should respond for a RIGHT turn at the DOMINO'S PIZZA*]

>> participant reaches the 7-11

7. Good. Your next errand is at the PARTY CITY, where you need to pick up supplies for the conference's banquet; go ahead.

[*they should respond for a RIGHT turn at the HILTON]*

[*they should respond for a LEFT turn at the WALMART*]

>> participant reaches the PARTY CITY

8. Good. Your next destination is KFC, where you want to get some lunch before your meeting; go ahead.

[*they should respond for a LEFT turn at the REGAL CINEMAS*]

>> participant reaches the KFC

Good. You have finished running your errands and can follow the red arrow to the conference location.

[Experiment ends**, stop stopwatch]**

This ends the driving part of the experiment. We will go to another room to do some additional tasks.

**[Exit programs for next experimenter]**

**In Refrigerator Room**

1. Read the free recall instructions
2. Give them their Landmarks Free Recall sheet
3. After they finish, Read Sketch Map Instructions
4. Have them perform the map sketch according to the corresponding instructions

   - You need to watch subject during the sketch map drawing.
   - <u>Immediately</u> correct them if they're drawing it wrong, as many times as you need to

5. Use the Experimenter's sketch map checklist and mark off all entries.
6. Have subject add any missing information or correct wrong format

7. Give subject the blurb and show them out of the lab

*Appendix D*

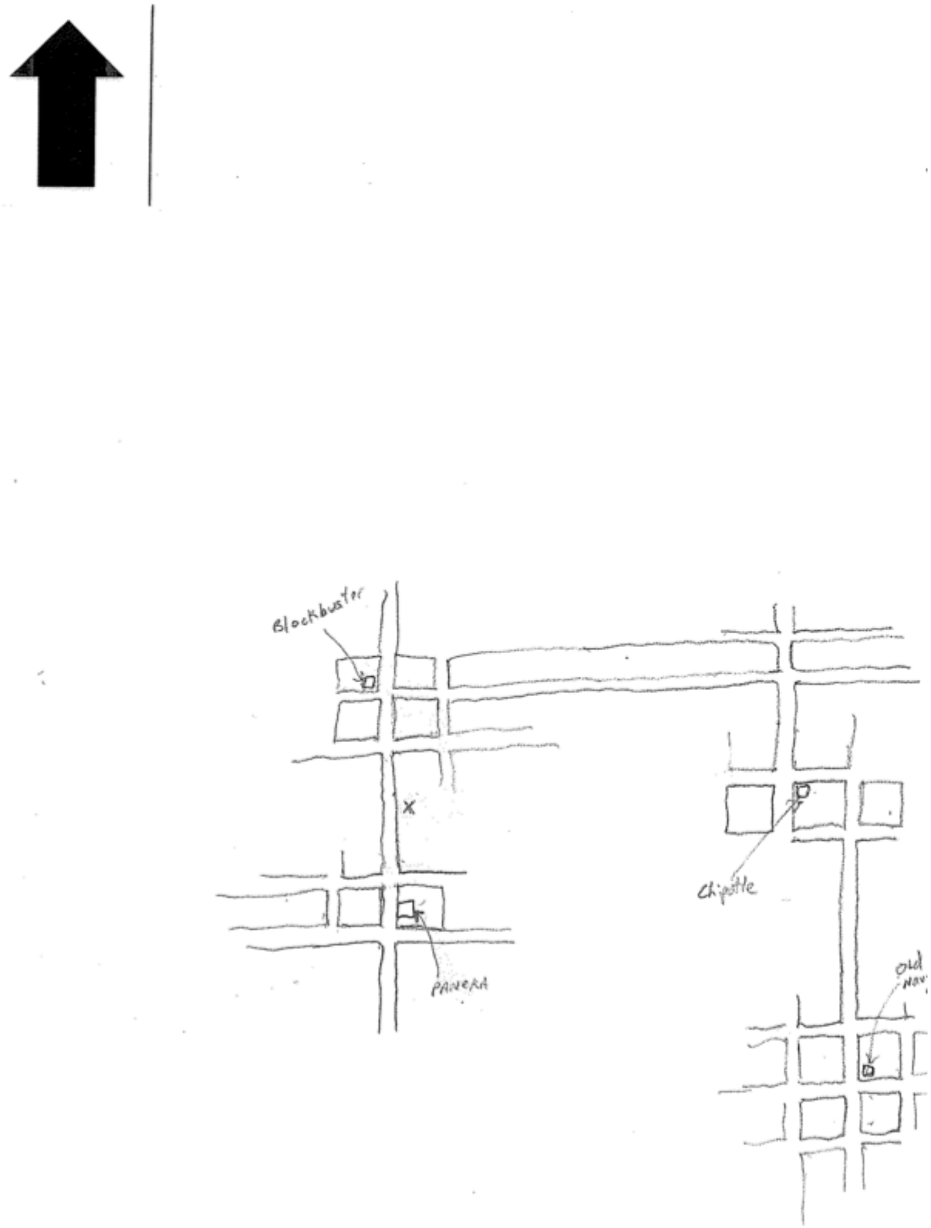
*Instructions for the Landmark Free Recall Measure*

**Landmark Recall** **File Name:______**

We would like you to recall the landmarks that were displayed on the driving navigation map that you saw. As we explained some of the landmarks were corner landmarks and some were errand destination landmarks. We would like you to recall all of them. Recall as many as you can. You can write them down in any order. Please write the name of the business that the map icon represented. Please write the name of one business on each line. The number of lines is irrelevant. Just try to write down as many names as you can in whatever order they occur to you.

*Appendix E*

*Sample Sketch Map*



*Appendix F*

*Sketch Map Instructions*

Now, I'd like you to show me what you learned about the environment that you saw on the map display. I want you to sketch a map of this entire region on a blank sheet of paper. Draw the map to scale as accurately as you can. You need to include all of the landmarks –both the errand destination landmarks where the car stopped and the corner landmarks where turns were made.

**[Put sample sketch map on the desk]**

Here is a sample sketch map from another city. It has only 4 landmarks, but it shows you the format for drawing a sketch map. I'd like you to sketch in the main streets that were driven on. Draw the streets as narrow double lines such as these. [*Point to streets near star*]. You should include a single city block if it had a landmark on it. City blocks should be drawn about this size [*Point to city block with Blockbuster on it*] but, you don't have to draw in all of the blocks and cross streets, if the car didn't travel on them. A bigger section can represent several blocks, like this section that represents 3 blocks. [*Point to the block with X*] Note, however that it is still the size of 3 city blocks combined. Also, notice that some sections have no streets or blocks on there, like this one [Point to empty area]. You don't need to draw these because the car didn't drive through them, but you can draw them if it helps you remember the layout.

You should show the location of each landmark by drawing a small square box to show its location. The box's size should be like this one. [*Point*] You also need to write its name near the box with an arrow connecting the name to the box, like this. [*Point to Panera*] It doesn't matter where the arrow touches the box. It just let's us know the name of the landmark that's there. These simplifications may help you focus on where the landmarks were located. Drawing their locations correctly is most important.

Notice the black arrow on the top of the sample sketch map. There will be one on your blank paper too. The arrow shows that the top of the map is north. Orient all streets and landmark locations on your sketch map so that they are consistent with this direction. Note that the arrow does not show the direction the car started driving in, it merely shows the North direction.

You can add streets, landmark boxes, names, arrows, and city blocks to the sketch map in any order. Here's a list of all of the landmarks to help you. [Hand list of landmark names to subject]

Make sure that you include all of these landmarks on your sketch map. Check off a name on the list when you add the box and name to the sketch map. This will help you know which ones you still need to add to the map. Note that the names on this list are in random order.

It is important that you draw your sketch map as accurately as possible and to scale. If you need to put a landmark that's off the paper I'll add more paper to a side of your sketch map. If you squeeze it on the paper, you'll distort your map. So if someone wanted to add a gas station 15 blocks north of blockbuster, then I'd attach some paper to the top of the sketch map

[*Point to top map edge*]. If you are not certain where a landmark was located, put it where you think it most likely was, based on your memory.

Do you have any questions?
[Put blank paper on desk] Okay, here's the blank paper to draw on.
Remember to draw to scale and as accurately as possible.

**[Stay in the map sketch room for the entire time. Check their map early and often for mistakes]**

# *Appendix G*

## 4 (map display) x 3 (landmark-pair) ANOVA for Configural Spatial Knowledge

4 x 3 ANOVA for Map Display Type by Landmark Pair Type

| Source | | | *SS* | *df* | *MS* | *F* | *p* |
|---|---|---|---|---|---|---|---|
| *Between Subjects* | | | | | | | |
| May Display Type (1) | | | 9610.819 | 3 | | | |
| 1 | M | May Display Type | 9610.819 | 3 | 3203.606 | 4.923 | 0.003 |
| Error | | | 59872.869 | 92 | 650.792 | | |
| *Within Subjects* | | | | | | | |
| Landmark Pair Type (2) | | | 9316.904 | 2 | | | |
| 2 | L | Landmark Pair Type | 9316.904 | 2 | 4658.452 | 46.632 | 0.000 |
| Map Display Type x Landmark Pair Type (3) | | | 727.541 | 6 | | | |
| 3 | M x L | Map Display Type x Landmark Pair Type | 727.541 | 6 | 121.257 | 1.214 | 0.301 |
| Error | | | 18381.109 | 184 | 99.897 | | |

## *Appendix H*

## 3 (map display, without verbal north-up) x 3 (landmark-pair) ANOVA for Configural Spatial Knowledge

| Source | | | *SS* | *df* | *MS* | *F* | *p* |
|---|---|---|---|---|---|---|---|
| *Between Subjects* | | | | | | | |
| May Display Type (1) | | | 1783.618 | 2 | | | |
| 1 | M | May Display Type | 1783.618 | 2 | 891.809 | 1.222 | 0.301 |
| Error | | | 50367.871 | 6 | 729.969 | | |
| *Within Subjects* | | | | | | | |
| Landmark Pair Type (2) | | | 5132.157 | 2 | | | |
| 2 | L | Landmark Pair Type | 5132.157 | 2 | 2566.079 | 23.139 | 0.000 |
| Map Display Type x Landmark Pair Type (3) | | | 155.615 | 4 | | | |
| 3 | M x L | Map Display Type x Landmark Pair Type | 155.615 | 4 | 38.904 | 0.351 | 0.843 |
| Error | | | 15303.892 | 138 | 110.898 | | |

# *Appendix I*

## 4 (map display) x 24 (starting landmark pairs) ANOVA for Configural Spatial Knowledge

| Source | | | *SS* | *df* | *MS* | *F* | *p* |
|---|---|---|---|---|---|---|---|
| *Between Subjects* | | | | | | | |
| Map Display Type (1) | | | 485407.259 | 3 | | | |
| | 1 M | Map Display Type | 485407.259 | 3 | 161802.420 | 7.756 | 0.000 |
| Error | | | 1919189.849 | 92 | 20860.759 | | |
| *Within Subjects* | | | | | | | |
| Starting Landmark (2) | | | 194043.293 | 23 | | | |
| | 2 S | Starting Landmark Pairs | 194043.293 | 23 | 8436.665 | 8.72 | 0.000 |
| Map Display Type x Starting Landmark (3) | | | 179120.054 | 69 | | | |
| | 3 M x S | Map Display Type x Starting Landmark | 179120.054 | 69 | 2595.943 | 2.683 | 0.000 |
| Error | | | 2047197.272 | 2116 | 967.485 | | |

*Appendix I continued*

## 3 (map display type) x 24 (starting landmark pairs) ANOVA for Configural Spatial Knowledge

| **Source** | | | ***SS*** | ***df*** | ***MS*** | ***F*** | ***p*** |
|---|---|---|---|---|---|---|---|
| *Between Subjects* | | | | | | | |
| Map Display Type (1) | | | 203041.680 | 2 | | | |
| 1 | M | Map Display Type | 203041.680 | 2 | 101520.840 | 3.766 | 0.028 |
| Error | | | 185937.696 | 69 | 26955.619 | | |
| *Within Subjects* | | | | | | | |
| Starting Landmark (2) | | | 141186.571 | 23 | | | |
| 2 | S | Starting Landmark Pairs | 141186.571 | 23 | 2806.547 | 5.811 | 0.000 |
| Map Display Type x Starting Landmark (3) | | | 129101.182 | 46 | | | |
| 3 | M x S | Map Display Type x Starting Landmark | 129101.182 | 46 | 2806.547 | 2.657 | 0.000 |
| Error | | | 1676428.838 | 1587 | 1056.351 | | |

*Appendix I continued*

## 2 (map display type) x 24 (starting landmark pairs) ANOVA for Configural Spatial Knowledge

| **Source** | | | ***SS*** | ***df*** | ***MS*** | ***F*** | ***p*** |
|---|---|---|---|---|---|---|---|
| *Between Subjects* | | | | | | | |
| Map Display Type (1) | | | 123210.664 | 1 | | | |
| 1 | M | Map Display Type | 123210.664 | 1 | 123210.664 | 7.173 | 0.010 |
| Error | | | 790113.28 | 46 | 17176.376 | | |
| *Within Subjects* | | | | | | | |
| Starting Landmark (2) | | | 180214.573 | 23 | | | |
| 2 | S | Starting Landmark Pairs | 180214.573 | 23 | 7836.590 | 8.315 | 0.000 |
| Map Display Type x Starting Landmark (3) | | | 43844.730 | 23 | | | |
| 3 | M x S | Map Display Type x Starting Landmark | 43844.730 | 23 | 1906.293 | 2.023 | 0.003 |
| Error | | | 997133.409 | 1058 | 942.470 | | |

*Appendix J*

4 (map display type) x 2 (landmark pair) ANOVA for Free Recall

| Source | | | *SS* | *df* | *MS* | *F* | *p* |
|---|---|---|---|---|---|---|---|
| *Between Subjects* | | | | | | | |
| Map Display Type (1) | | | 568.644 | 3 | | | |
| | 1 M | Map Display Type | 568.644 | 3 | 189.548 | 0.621 | 0.603 |
| Error | | | 28103.027 | 92 | 305.468 | | |
| *Within Subjects* | | | | | | | |
| Landmark Pair Type (2) | | | 19425.659 | 1 | | | |
| | 2 L | Landmark Pair Type | 19425.659 | 1 | 19425.659 | 92.908 | 0.000 |
| Map Display Type x Landmark Pair Type (3) | | | 420.532 | 3 | | | |
| | 3 M x L | Map Display Type x Landmark Pair Type | 420.532 | 3 | 140.177 | 0.670 | 0.572 |
| Error | | | 19235.840 | 92 | 209.085 | | |

## *Appendix K*

## 4 (map display) x 2 (heading direction) x 2 (turn direction) ANOVA for Response Times

| Source | | | *SS* | *df* | *MS* | *F* | *p* |
|---|---|---|---|---|---|---|---|
| *Between Subjects* | | | | | | | |
| May Display Type (1) | | | 8235071.3 | 3 | | | |
| | 1 M | May Display Type | 8235071.3 | 3 | 2745023.767 | 0.963 | 0.414 |
| Error | | | 250800000.00 | 88 | 2850468.723 | | |
| *Within Subjects* | | | | | | | |
| Heading Direction (2) | | | 739355.077 | 1 | | | |
| | 2 H | Heading Direction (North vs. South) | 739355.077 | 1 | 739355.077 | 0.278 | 0.599 |
| Map Display Type x Heading Direction (3) | | | 8074764.036 | 3 | | | |
| | 3 M x H | Map Display Type x Heading Direction | 8074764.036 | 3 | 2691588.012 | 1.011 | 0.392 |
| Error | | | 234200000.00 | 88 | 2661070.978 | | |
| Turn Direction (4) | | | 16720619.12 | 1 | | | |
| | 4 T | Turn Direction (Left vs. Right) | 16720619.12 | 1 | 16720619.12 | 6.343 | 0.014 |
| Map Display x Turn Direction (5) | | | 8285910.588 | 3 | | | |
| | 5 M x T | Map Display x Turn Direction | 8285910.588 | 3 | 2761970.196 | 1.048 | 0.376 |
| Error | | | 232000000.00 | | | | |
| Heading Direction x Turn Direction (6) | | | 7295031.511 | 1 | | | |
| | 6 H x T | Heading Direction x Turn Direction | 7295031.511 | 1 | 7295031.511 | 2.831 | 0.096 |
| Map Display Type x Heading Direction x Turn Direction (7) | | | 28318634.68 | 3 | | | |
| | 7 M x H x T | Map Display Type x Heading Direction x Turn Direction | 28318634.68 | 3 | 9439544.894 | 3.663 | 0.015 |
| Error | | | 226800000.00 | 88 | 2576757.495 | | |

*Appendix L*

## 4 (map type) x 2 (heading direction) anova for Response Times for Right Turns

| Source | | | *SS* | *df* | *MS* | *F* | *p* |
|---|---|---|---|---|---|---|---|
| *Between Subjects* | | | | | | | |
| May Display Type (1) | | | 11369961.49 | 3 | | | |
| | 1 M | May Display Type | 11369961.49 | 3 | 3789987.165 | 1.041 | 0.378 |
| Error | | | 327500000.00 | 90 | 3639214.597 | | |
| *Within Subjects* | | | | | | | |
| Heading Direction (2) | | | 5380826.535 | 1 | | | |
| | 2 H | Heading Direction | 5380826.535 | 1 | 5380826.535 | 1.483 | 0.226 |
| Map Display Type x Heading Direction (3) | | | 29829776.62 | 3 | | | |
| | 3 M x H | Map Display Type x Heading Direction | 29829776.62 | 3 | 9943258.874 | 2.741 | 0.048 |
| Error | | | 326500000.00 | 90 | 3627866.091 | | |

*Appendix L continued*

## Heading South vs. North ANOVA for Right Turns in North-Up Map Displays

| **Source** | | | ***SS*** | ***df*** | ***MS*** | ***F*** | ***p*** |
|---|---|---|---|---|---|---|---|
| *Between Subjects* | | | | | | | |
| Heading Direction (1) | | | 24830315.051 | 1 | | | |
| 1 | H | Heading Direction | 24830315.051 | 1 | 24830315.051 | 5.848 | 0.025 |
| Error | | | 89167862.935 | 21 | 4246088.711 | | |

*Appendix L continued*

## Heading South vs. North ANOVA for Right Turns in Verbal North-Up Map Displays

| **Source** | | | ***SS*** | ***df*** | ***MS*** | ***F*** | ***p*** |
|---|---|---|---|---|---|---|---|
| *Between Subjects* | | | | | | | |
| Heading Direction (1) | | | 3244366.681 | 1 | | | |
| 1 | H | Heading Direction | 3244366.681 | 1 | 3244366.681 | 1.823 | 0.190 |
| Error | | | 40928288.055 | 23 | 1779490.785 | | |

*Appendix L continued*

## Heading South vs. North ANOVA for Right Turns in Track-Up Map Displays

| **Source** | | | ***SS*** | ***df*** | ***MS*** | ***F*** | ***p*** |
|---|---|---|---|---|---|---|---|
| *Between Subjects* | | | | | | | |
| Heading Direction (1) | | | 6342469.167 | 1 | | | |
| 1 | H | Heading Direction | 6342469.167 | 1 | 6342469.167 | 0.820 | 0.375 |
| Error | | | 177900000.000 | 23 | 773147.299 | | |

## Heading South vs. North ANOVA for Right Turns in No-Map Displays

| **Source** | | | ***SS*** | ***df*** | ***MS*** | ***F*** | ***p*** |
|---|---|---|---|---|---|---|---|
| *Between Subjects* | | | | | | | |
| Heading Direction (1) | | | 41772.000 | 1 | | | |
| 1 | H | Heading Direction | 41772.000 | 1 | 41772.000 | 0.052 | 0.822 |
| Error | | | 18549409.333 | 23 | 806496.058 | | |

# *Appendix M*

## 4 (map type) x 2 (heading direction) anova for Response Times for Left Turns

| Source | | | *SS* | *df* | *MS* | *F* | *p* |
|---|---|---|---|---|---|---|---|
| *Between Subjects* | | | | | | | |
| Map Display Type (1) | | | 2361666.740 | 3 | | | |
| 1 | M | Map Display Type | 2361666.740 | 3 | 787222.247 | 0.440 | 0.725 |
| Error | | | 160900000 | 90 | 1787709.146 | | |
| *Within Subjects* | | | | | | | |
| Heading Direction (2) | | | 1362920.356 | 1 | | | |
| 2 | H | Heading Direction | 1362920.356 | 1 | 1362920.356 | 0.891 | 0.348 |
| Map Display Type x Starting Landmark (3) | | | 5605596.356 | 3 | | | |
| 3 | M x H | Map Display Type x Heading Direction | 5605596.356 | 3 | 1868532.118 | 1.222 | 0.307 |
| Error | | | 137700000.000 | 90 | 1529687.677 | | |

# *Appendix N*

## 4 (map display) x 3 (landmark-pair) x 2 (gender) ANOVA for Configural Spatial Knowledge

| Source | | | *SS* | *df* | *MS* | *F* | *p* |
|---|---|---|---|---|---|---|---|
| *Between Subjects* | | | | | | | |
| May Display Type (1) | | | 9610.819 | 3 | | | |
| 1 | M | May Display Type | 9610.819 | 3 | 3203.606 | 4.955 | 0.003 |
| Gender (2) | | | 1063.29 | 1 | | | |
| 2 | G | Gender (Male vs. Female) | 1063.29 | 1 | 1063.29 | 1.645 | 0.203 |
| Map Display Type x Gender (3) | | | 1916.18 | 3 | | | |
| 3 | M x G | Map Display Type x Gender | 1916.18 | 3 | 638.727 | 0.988 | 0.402 |
| Error | | | 56893.399 | 88 | 646.516 | | |
| *Within Subjects* | | | | | | | |
| Landmark Pair Type (4) | | | 9316.904 | 2 | | | |
| 4 | L | Landmark Pair Type | 9316.904 | 2 | 4658.452 | 46.339 | 0.000 |
| Map Display Type x Landmark Pair Type (5) | | | 727.541 | 6 | | | |
| 5 | M x L | Map Display Type x Landmark Pair Type | 727.541 | 6 | 121.257 | 1.206 | 0.305 |
| Gender x Landmark Pair Type (6) | | | 98.167 | 2 | | | |
| 6 | G x L | Gender x Landmark Pair Type | 98.167 | 2 | 49.083 | 0.488 | 0.615 |
| Map Display Type x Gender x Landmark Pair Type (7) | | | 589.501 | 6 | | | |
| 7 | M x G x L | | 589.501 | 6 | 98.25 | 0.977 | 0.442 |
| Error | | | 17693.441 | 176 | 100.531 | | |

# *Appendix N continued*

## 4 (map display) x 2 (gender) ANOVA for Percent Correct Free Recall of Landmarks

| **Source** | | | ***SS*** | ***df*** | ***MS*** | ***F*** | ***p*** |
|---|---|---|---|---|---|---|---|
| *Between Subjects* | | | | | | | |
| Map Display Type (1) | | | 238.000 | 3 | | | |
| 1 | M | Map Display Type | 238.000 | 3 | 79.330 | 0.522 | 0.668 |
| Gender (2) | | | 2.667 | 1 | | | |
| 2 | G | Gender | 2.667 | 1 | 2.667 | 0.018 | 0.895 |
| Map Display Type x Gender (3) | | | 62.667 | 3 | | | |
| 3 | M x G | Map Display Type x Gender | 62.667 | 3 | 20.889 | 0.137 | 0.937 |
| Error | | | 13370.667 | 88 | 151.939 | | |

*Appendix N continued*

## 4 (map display) x 2 (gender) x 2 (heading direction) x 2 (turn direction) for Response Times

| Source | | | *SS* | *df* | *MS* | *F* | *p* |
|---|---|---|---|---|---|---|---|
| *Between Subjects* | | | | | | | |
| May Display Type (1) | | | 9104418.665 | 3 | | | |
| 1 | M | May Display Type | 9104418.665 | 3 | 3034806.222 | 1.058 | 0.371 |
| Gender (2) | | | 307275.386 | 1 | | | |
| 2 | G | Gender (Male vs. Female) | 307275.386 | 1 | 307275.386 | 0.107 | 0.744 |
| Map Display Type x Gender (3) | | | 9383234.513 | 3 | | | |
| 3 | M x G | Map Display Type x Gender | 9383234.513 | 3 | 3127744.838 | 1.09 | 0.358 |
| Error | | | 241000000.00 | 84 | 2868627.314 | | |
| *Within Subjects* | | | | | | | |
| Heading Direction (4) | | | 1040717.056 | 1 | | | |
| 4 | H | Heading Direction (North vs. South) | 1040717.056 | 1 | 1040717.056 | 0.39 | 0.534 |
| Map Display Type x Heading Direction (5) | | | 9574512.89 | 3 | | | |
| 5 | M x H | Map Display Type x Heading Direction | 9574512.89 | 3 | 3191504.297 | 1.195 | 0.317 |
| Gender x Heading Direction (6) | | | 5291196.71 | 1 | | | |
| 6 | G x L | Gender x Landmark Pair Type | 5291196.71 | 1 | 5291196.71 | 1.981 | 0.163 |
| Map Display Type x Gender x Heading Direction (7) | | | 4813946.993 | 3 | | | |
| 7 | M x G x L | | 4813946.993 | 3 | 1604648.998 | 0.601 | 0.616 |
| Error | | | 241000000.00 | 84 | 2671074.898 | | |
| Turn Direction (8) | | | 17180916.43 | 1 | | | |
| 8 | T | Turn Direction (Left vs. Right) | 17180916.43 | 1 | 17180916.43 | 6.642 | 0.012 |
| Map Display Type x Turn Direction (9) | | | 8678484.195 | 3 | | | |
| 9 | M x T | | 8678484.195 | 3 | 2892828.065 | 1.118 | 0.346 |
| Gender x Turn Direcion (10) | | | 3366119.459 | 1 | | | |
| 10 | G x T | | 3366119.459 | 1 | 3366119.459 | 1.301 | 0.257 |
| Map Display Type x Gender x Turn Direction (11) | | | 10635547.77 | 3 | | | |
| 11 | M x G x T | | 10635547.77 | 3 | 3545182.59 | 1.371 | 0.257 |
| Error | | | 2.17E+08 | 84 | 2486635.272 | | |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Heading Direction x Turn Direction (12) | | | 7071921.812 | 1 | | | |
| 12 | H x T | Heading Direction x Turn Direction | 7071921.812 | 1 | 7071921.812 | 2.696 | 0.104 |
| Map Display Type x Heading Direction x Turn Direction (13) | | | 27918468.69 | 3 | | | |
| 13 | M x H x T | Map Display Type x Heading Direction x Turn Direction | 27918468.69 | 3 | 9306156.228 | 3.547 | 0.018 |
| Gender x Heading Direction x Turn Direction (14) | | | 2086902.742 | 1 | | | |
| 14 | G x H x T | Gender x Heading Direction x Turn Direction | 2086902.742 | 1 | 2086902.742 | 0.795 | 0.375 |
| Map Display Type x Gender x Heading Direction x Turn Direction (15) | | | 4060313.128 | 3 | | | |
| 15 | M x G x H x T | Map Display Type x Gender x Heading Direction x Turn Direction | 4060313.128 | 3 | 1353437.709 | 0.516 | 0.672 |
| Error | | | 220400000.00 | 84 | 2623556.353 | | |