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Using a Single Map Display Both for Navigational Planning and for Turn-by-Turn Vehicle Guidance: Configural Spatial Knowledge Acquisition

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Navigational driving systems have used traditional track-up map displays for guiding immediate turn-by-turn decisions and traditional north-up map displays for facilitating navigational planning and learning about environmental layout (configural spatial knowledge), because no single map display has been usable for both purposes. Rizzardo and Colle (2013) showed that north-up map displays could successfully guide turn decisions when a new spatial plus verbal advisory turn indicator was used, raising the possibility of designing single map displays that also are usable for spatial learning. Multimedia instructional design models, modified for spatial learning from navigation and driving, identified the sources of extraneous cognitive load that limit spatial learning from moving maps. Predictions include that participants can learn more from north-up map displays with the new advisory indicator than the traditional indicator. Experiment 1 showed that after college students (N = 96) drove through a virtual city guided by 1 of 3 map types or voice commands, most configural spatial knowledge was acquired using the new north-up display, then the traditional north-up map display, and the least with the traditional track-up map display. In Experiment 2, college students (N = 192) watched the same map sequences from either the new north-up or the track-up map display, but with a limited duration of their glances to the map display (no driving). Viewing spatial plus verbal north-up map displays produced significant spatial learning even with short glance durations, but not when viewing track-up displays even with long glance durations. Theoretical and design implications are discussed.

Keywords: map displays, multimedia learning theory, spatial knowledge acquisition, navigational systems, driving

Design and use of navigational guidance devices, being increasingly used, introduces both theoretical and practical challenges. Most guidance devices include a map display as the primary mode for delivering information. Current design handbooks have identified the need for map guidance systems to support two different tasks: turn-by-turn guidance and navigational planning. Additionally, they recommend that two types of map displays be used, a different map display to support each task (Campbell, Carney, & Kantowitz, 2012; Ross et al., 1996). For turn-by-turn guidance and route decision making, track-up maps are recommended, and are the default display setting for most Global Positioning System (GPS) navigational devices. Typical track-up map displays use an advisory turn indicator such as an arrow where the shaft is always vertical to indicate the current heading direction. To indicate turns, the arrow shaft bends and the map rotates beneath the arrow during the turn, ending with the shaft of the arrow once again vertical after the turn. For navigational planning and spatial knowledge information, north-up maps (used before a trip has started) are recommended. Typical north-up maps do not rotate; instead the arrow shaft rotates in the direction of the turn. The designs of these two map display types cater to different types of navigation information.

Existing map displays have not been able to facilitate both route decision making and spatial knowledge acquisition simultaneously and effectively. They primarily display immediate turn-by-turn decision-making guidance, the main priority when driving. The inability to find a single navigational map display that handles both tasks readily has been called the trade-off hypothesis, which 20 years of previous research has supported (Münzer, Zimmer, & Baus, 2012). However, providing one display that facilitates both tasks could help drivers with immediate route knowledge assistance and teach them about an environment so that they may evaluate the accuracy of instructions presented by the GPS, and later plan routes without it.

The problem is complex because there appear to be two different sets of cognitive processes operating concurrently that underlie these two different types of tasks. One set of cognitive processes is relevant to immediate decisions based on the information at hand or retrievable from long-term memory; deciding which di-

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rection to turn depends heavily on working memory. The second set of processes is relevant to learning about spatial information in an environment, episodic long-term memory learning. The goal of our research was to understand these processes to design a single display system that can effectively support both types of tasks.

Navigational Guidance and Decision Making: Working Memory

To understand navigational decision making, the operations of working memory need to be considered. We present the analysis using the multicomponent model of working memory, which consists of a central executive, two subsidiary memory systems, the phonological loop and the visuospatial sketchpad, and more recently the episodic buffer (Baddeley, 2001, 2007; Baddeley & Hitch, 1974). The central executive is responsible for processes such as attentional control, decision making, and coordinating the use of the three subsidiary systems and interactions with long-term memory. The phonological loop can retain sound or phonological representations either directly from auditory stimuli or indirectly by information obtained from the lexicon or other linguistic processes; it can communicate in both directions with long-term verbal memory. The phonological loop has other functions, such as supporting the control actions in switching tasks by maintaining information about upcoming tasks for the central executive (e.g., Baddeley, Chincotta, & Adlam, 2001). The visuospatial sketchpad can be fractionated into the capability of storing object visual images and the capability of storing spatial relations both visual and nonvisual. The episodic buffer stores multidimensional stimuli.

The preferential use of track-up maps for previous navigational guidance displays appears to be, at least in part, the result of using displays that emphasize spatial processing in working memory. For example, in surface vehicles the arrow advisory indicators have been used to spatially direct vehicles to turn locations. Track-up maps then are desirable because the arrow indicators retain stimulus-response compatibility, supporting decisions that often must be made under time pressure (Aretz, 1991; Chan & Chan, 2005; Fitts & Seeger, 1953; Klippel, Freksa, & Winter, 2006; Levine, 1982; Montello, 2010; Prabhu, Shalin, Drury, & Helander, 1996). Given that the base of the guidance arrow's shaft is always vertical and therefore always heading in the driver's actual heading direction, a bend in the indicator's arrowhead will always point left for left turns and right for right turns, providing spatial consistency. In contrast, north-up map guidance turn arrows, for all headings except going north, are misaligned to some extent with the driver's forward view. For example, when heading south, the indicator's arrowhead points to the driver's left for right turns and to their right for left turns. Heading misalignments lead to a stimulus-response disagreement and likewise, longer response times and more errors (Chan & Chan, 2005; Levine, 1982; Levine, Marchon, & Hanley, 1984). Navigational decisions when map versus heading misalignments are present require the central executive to use the visuospatial sketchpad to perform the transformations needed to resolve the mismatch. These transformations can be difficult and place a heavy load on working memory, creating problems. Often these transformations are attributed to mental rotation of maps, but as Rizzardo and Colle (2013) have argued, other types of transformations are reasonable possibilities.

Rizzardo and Colle (2013) pointed out that the heavy emphasis on visuospatial processing for navigational decision making might not be necessary. They developed a spatial plus verbal advisory indicator designed to be processed by the phonological loop as well as the visuospatial sketchpad. Figure 1 shows an example of Rizzardo and Colle's (2013) new dual spatial and verbal advisory indicator cue. A letter L or R was added to the end of the spatial turn arrow, providing a matching verbal cue to advise drivers of the upcoming turn direction. The arrow was presented in the center of the screen like most current GPS displays and the verbal cue was physically close to its tip, creating an integrated unit of verbal/spatial information, consistent with the proximity-compatibility principle (Wickens & Carswell, 1995). The letter was always presented upright regardless of heading. Using verbal cues to code left and right had previously been tried unsuccessfully, but those codes were informational; they were used to define the left and right sides of the spatial indicator cue at every heading angle, but they did not tell the participant what to do (Aretz, 1991; Prabhu et al., 1996). Rizzardo and Colle (2013) argued that to allow concurrent processing of a verbal indicator cue with the spatial indicator cue, the verbal cue should also be advisory. Otherwise, the verbal information would still need to be interpreted in terms of the confusing spatial information, retaining excessive visuospatial sketchpad processing. The new spatial plus verbal indicator could now be processed more efficiently by working memory. If there is an "L" at the tip of the arrow, the central executive can direct processing to focus some attention on the letter and then direct a phonological word be placed in the phonological loop's buffer. The visual letter "L" can be transformed into either the phonological word "ell" or "left" by this transformation. This visual-to-phonological word transformation depends on long-term memory retrieval from the lexicon but it is a well-described process even in simple memory span tasks. The phonological word stored in the phonological buffer can now be used for action control by the central executive, as it has been shown to do in switching experiments (Baddeley et al., 2001). Therefore, the central executive has information available from both the contents of the phonological buffer and the visuospatial sketchpad. The lighter load for concurrent processing of the verbal cue for turn information should thereby substantially reduce the load on central executive processing, which is no longer required to exclusively use information in the visuospatial sketchpad.

Rizzardo and Colle (2013) tested the effectiveness of spatial plus verbal indicator cues versus spatial-only arrow indicator cues for different and misaligned heading angles, as would be generated if a north-up map were used for turn-by-turn guidance. Participants used one of the two indicator cue types and made left–right turn decisions for arrows at 24 heading angles from 0° to 180° both clockwise and counterclockwise; turn decision times and errors were collected for 960 trials (two blocks of trials, each block with 24 heading direction rotations in 15° steps, on intersections from 10 different cities for both left and right turns). The results were clear-cut and the differences were large. The spatial plus verbal indicator cue produced significantly shorter reaction times (RTs) and fewer errors than the spatial-only indicator cue at all heading angles, including the zero heading angle equivalent to a track-up map display (Rizzardo & Colle, 2013). The implication of these results is that there is more map design flexibility; in particular, the

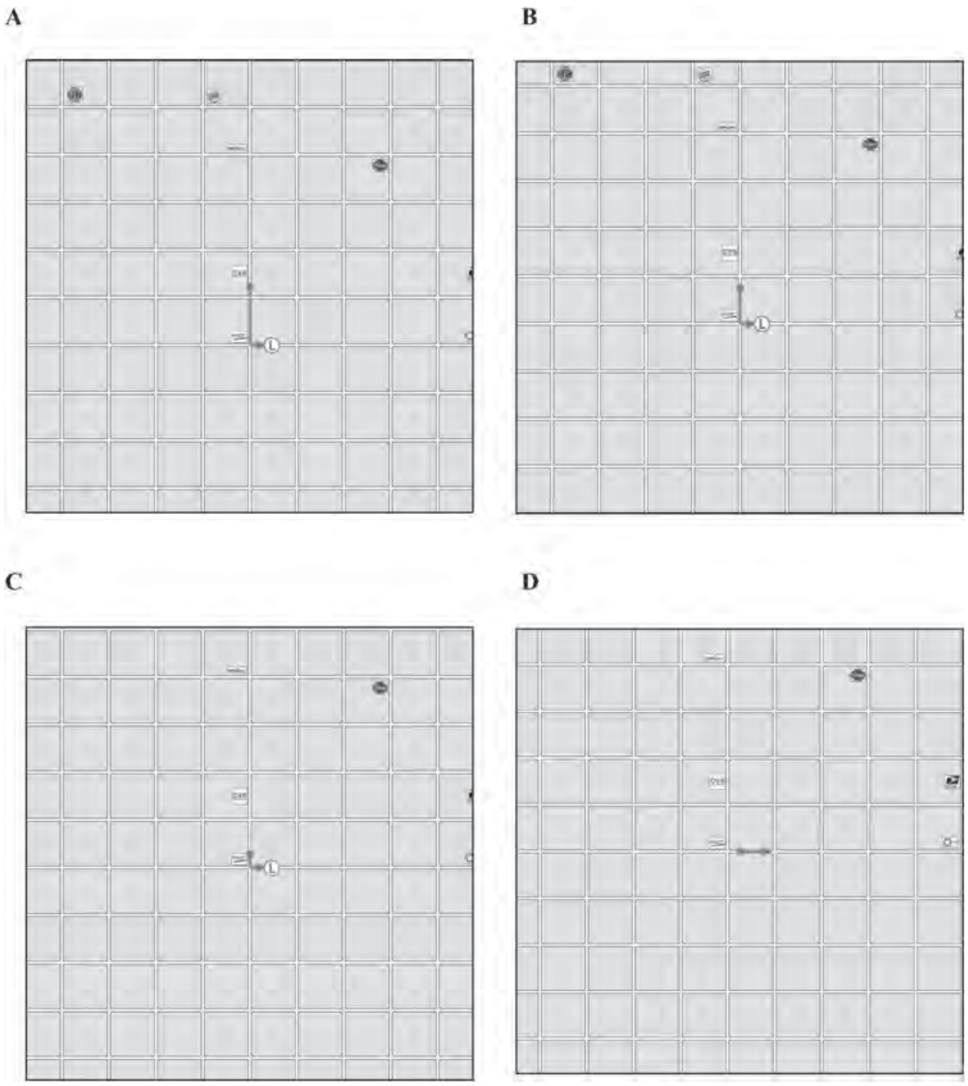

Figure 1. The progression of the left turn indicator arrow with verbal cue in a north-up map is shown in four panels. The first arrow appears a block and quarter before the turn then progresses for every half block traveled. Maps were in color with the indicator arrow and letter in red.

new spatial plus verbal indicator feasibly could be used with north-up maps.

Spatial Learning

Instructional Design Theory. Learning about spatial information in an environment, although not the immediate priority of most navigational guidance systems, could be useful for en route planning and acquiring knowledge of a region to evaluate system advice or for later use. Drivers can learn about the layout of a region by viewing the environment directly through the windshield as one information source, or by learning from a navigational map display as a second source. (Also people can drive without maps or study maps without driving.) To understand how spatial knowledge of the environment can be acquired, the processes leading to the effectiveness of instructional aids need to be considered. A major source is research and theoretical models on multimedia instructional design (Chandler & Sweller, 1991; Mayer, 2005, 2009; Schnotz, 2005; Sweller, 2005). It has been developed for teaching educational topics, such as how does a pump work. Thus, it has been focused on how visual or auditory textual descriptions and visual or auditory depictions such as pictures can be used effectively for instruction. Illustrations added to text often facilitate learning (multimedia principle) although some versions of illustrations are more effective than others. Verbal textual descriptions and illustrated depictions have separate representations in long-term memory. The theories of Mayer, Schnotz, and Sweller are different but they all have similar assumptions. All of the models build their dual-processing approach as modifications of Paivio (1971, 2006). But Schnotz (2005) clearly extends this by explicitly assuming that two-dimensional (2D) pictures have multiple representations; they

can be remembered both as visual image surface representation and also as a comprehended depiction, comparable with the representation levels described for text by Kintsch and van Dijk (1978).

Our multimedia spatial learning from navigation approach is a modification of these models but is closest to Schnotz's (2005). First, our approach extends current models for instructional aid because it now applies to acquiring spatial knowledge while driving; besides text and 2D visual imagery, we add representations for three-dimensional (3D) spatial knowledge: Siegel and White's (1975) configural spatial memory representations and the other two types of spatial memory representations, landmark and route spatial memory. Multimedia spatial learning applies to learning from both direct and indirect sources of information, such as the physical driving environment and the map display. As with text and visual imagery, representations may be transformed so if a driver sees a map with the word McDonalds (or the McDonalds icon) next to a turn arrow or hears the phrase "turn right at McDonalds," she or he can relate it to a 3D representation of the building that will be seen at the turn ahead. Lastly, all three multimedia models incorporate working memory assumptions; however, they do not adopt the complete multicomponent working memory model, which has been found to be applicable to navigational learning (Garden, Cornoldi, & Logie, 2002; Meilinger, Knauff, & Bülthoff, 2008).

Importantly, all three models use a tripartite division of cognitive load that is distinguished by the factors describing their impact on learning: intrinsic, extraneous, and germane cognitive load (Chandler & Sweller, 1991; Sweller, Chandler, Tierney, & Cooper, 1990). These factors are also important for multimedia spatial learning. Extraneous cognitive load, which is most relevant to the present research, is caused by aspects of the material or activities present during instruction that are not relevant or important for the concepts to be learned. For example, to reduce extraneous cognitive load, the map materials used in both Experiments 1 and 2 have been designed to facilitate spatial knowledge acquisition. Intrinsic cognitive load is produced by the inherent difficulty of learning the concepts; configural spatial information requiring the determination of spatial relationships among multiple landmarks at multiple spatial locations has been found to be the most difficult type of spatial memory to acquire. Germane load is produced by effective learning activities engaged in by learners (including those who are driving).

Types of spatial memory representations. Navigating through large-scale environments can lead to the acquisition of landmark, route, and configural (survey) spatial knowledge (Siegel & White, 1975). Landmark knowledge refers to learning what important objects or physical features are present in an environment (e.g., an Olive Garden restaurant is in the area). The landmarks could be coded as visual images, verbal names, or descriptions. Route spatial knowledge refers to learning the sequence of spatial acts needed to get from one location to another in an environment, which may be represented as propositions, possibly coding the equivalent of locative adjectives, such as "turn left at the Wendy's" or "go straight under the bridge," or spatial categories (Amorapanth, Widick, & Chatterjee, 2010; Kemmerer & Tranel, 2000; Kosslyn, 1994; Tranel & Kemmerer, 2004). Landmark adjectives or spatial categories are used with an egocentric reference, making left/right distinctions with respect to one's body. Configural spatial knowledge refers to learning the layout of the environment such that people know the approximate angular and distance relations among sets of landmarks in a quasi-euclidean sense. The underlying memory representations have been described as both egocentric and allocentric (object-to-object world-referenced), but allocentric memory representations appear to be more likely with movement through large-scale environments (e.g., Burgess, 2008). Landmarks may help code spatial relations such as knowing the direction toward the library from the front of Walmart. We focus on configural spatial knowledge because it is the most flexible, allowing people to consider possible alternative routes for going from one arbitrary location to another. Although Siegel and White argued that landmark, route, and then configural spatial knowledge are learned in this sequence, it has been found that configural spatial knowledge about aspects of an environment can be learned concurrently with route knowledge (Colle & Reid, 1998; Gillner & Mallot, 1998; Montello, 1998). However, this acquisition appears to depend somewhat on structural features for some aspects of an environment (Colle & Reid, 2000, 2003). Fortunately, it has also been shown that a learning aid such as a map can greatly facilitate configural spatial learning of even complex environments. Learning the layout by briefly studying a map can be as effective as extensive, sometimes years of, direct experience (Ruddle, Payne, & Jones, 1997; Thorndyke & Hayes-Roth, 1982). However, locations are learned in relation to the map orientation used during learning, unlike an environment learned from direct experience (Evans & Pezdek, 1980). Furthermore, attempting to learn from a map not held at a constant orientation also appears to hamper configural spatial knowledge acquisition (Aretz, 1991; Münzer, Zimmer, & Baus, 2012; Prabhu et al., 1996; Rodes & Gugerty, 2012; Wickens, Liang, Prevett, & Olmos, 1996).

Learning While Driving: Sources of Cognitive Load

Track-up maps with spatial arrow indicators are easy to use for turn-by-turn decision making; heading-aligned arrows make few demands on the visuospatial sketchpad. However, the concurrent process of abstracting the relative spatial locations of landmarks for acquiring configural spatial knowledge also depends on the visuospatial sketchpad; its intrinsic load is high. Physical rotations of the map add a substantial extraneous load. Relating the landmarks is made more difficult and drivers have to perform transformations on visuospatial sketchpad contents to assess these relations, similar to instructional aids with poorly designed illustrations. Given the immediacy of turn-by-turn decisions, the central executive must prioritize using the visuospatial sketchpad for making turn decisions. Spatial learning is still reduced because of its substantial intrinsic load and the extraneous cognitive load produced by the operations and transformations required to relate rotated map segments into a configural layout representation. There are no rotated map segments when north-up maps with only a spatial arrow indicator are used, eliminating this substantial source of extraneous cognitive load, so the central executive has more visuospatial sketchpad memory available for increased spatial learning. However, it is important to consider all sources of extraneous load to determine how they will affect learning. The extraneous cognitive load affecting learning configural spatial

knowledge directly from the map displays is different for each display. The spatial-only track-up display should have the greatest extraneous cognitive load because of the difficulty in interpreting the rotating physical map segments. The spatial-only north-up map display has a stable orientation for learning the layout but the turn decision-making problems when viewing misaligned rotating turn indicators should increase cognitive load. Thus, spatial-only north-up maps are likely to have substantial extraneous cognitive load, although less than that for spatial-only track-up maps because turn decision problems only exist for some of the turns. The spatial plus verbal north-up map and its stable orientation should create the least amount of extraneous cognitive load for acquiring configural spatial knowledge because cognitive load on the visuospatial sketchpad from decision making with the new spatial plus verbal advisory turn indicator was shown to be reduced (Rizzardo & Colle, 2013). Thus, multimedia theory predicts that the displays as map aids should lead to the most configural spatial learning when using the spatial plus verbal north-up map, then the spatial-only north-up map, and the least when using the spatial-only track-up map display. Driving without a map should lead to the least amount of spatial learning because of the multimedia principle (Mayer, 2009) and map aids have enhanced configural spatial learning (Ruddle et al., 1997; Thorndyke & Hayes-Roth, 1982). Experiment 1 was a naturalistic evaluation using a driving simulation, which assesses the configural spatial knowledge acquired while driving. Participants drove through a virtual environment of a city while being guided by one of the three map displays systems or the fourth no-map voice only guidance condition.

Glance Durations: The Split-Attention Principle

The split-attention principle is relevant when people learn from two sources of information that are physically or temporally separated. In educational situations, this separation can occur when a piece of text describes a diagram, which has to be integrated to be understood; it arises from the cognitive load produced by reorienting and searching for the relevant information in the other source when switching (Ayres & Sweller, 2005). The situation is somewhat different in driving but appears to be based on the same principle. Drivers have two sources of information: the environment and the map display. These can be somewhat redundant, and may not have to be integrated for spatial learning. However, a large part of drivers' cognitive processes when viewing the environment is controlling the vehicle and engaging with other vehicles, signs, and pedestrians—tasks irrelevant to spatial learning. In addition, the map is moving, forcing the driver to reorient and search for temporal distance information whenever there is time free from paying attention to the road. The longer that a driver can view a map before looking away the less the cognitive load should be.

Measuring driving demands for the many different driving conditions is difficult. Driving is not a homogeneous task; sometimes it is very demanding and sometimes relatively easy, varying with environmental conditions (Crundall & Underwood, 1998). Learning while driving, by itself, is underspecified because more demanding driving conditions impose a greater cognitive load, which should limit learning. However, demand appears to be related to the amount of time that a driver can safely spend looking away from the road environment, or glance duration, which varies inversely with driving difficulty. Drivers spend a high percentage of time viewing the road to keep the vehicle in position, and monitoring traffic and pedestrian activity (Rockwell, 1972). Glance durations have been measured for perceptual-motor tasks such as tuning a radio or dialing a telephone. Mean glance durations (often less than 2 s) varied considerably with the difficulty of the driving task (longer on test tracks than on roads or simulated roads) and standard deviations about the glance duration means were large (Green & Shah, 2004). Some tasks (e.g., tuning a radio) may take multiple glances to complete.

Experiment 2 evaluated the spatial learning differences for map types with varying demands by manipulating the duration of glances to the moving map as a simplified method for controlling extraneous cognitive load by manipulating windows of time available for a glance to the map display. Experiment 1 did not identify the amount of time available for map study and how much time was used for cognitive processing directed at driving. To manipulate study time experimentally, we used a discrete homogeneous cognitive classification task instead of a driving simulation as the primary task. This classification task was displayed for fixed intervals of time, instead of a continuous driving display, and each interval required a cognitive classification decision requiring foveal vision. Participants were instructed to be 100% correct. With shorter time intervals, more classifications and switches have to be made when studying the maps (greater cognitive demand). The advantage of a discrete classification task is that glance duration windows are explicitly defined and controlled, forcing shorter glance durations (analogous to driving under more difficult conditions), instead of just observing how drivers use glance durations. The classification task also hampers participants from thinking about the map after their eyes return to the primary classification task display (possible with easy driving conditions) while eliminating learning spatial information directly from the virtual environment. Besides the time needed for the cognitive classification decision, the remainder of the glance window is available for foveal map study. Effective study time has been found to be an important parameter in many learning tasks (Anderson & Schooler, 1991; Metcalfe, 2009; Metcalfe & Kornell, 2003, 2005).

Experiment 1

The three different map display conditions (and the auditory no-map condition) guided participants as they drove through a virtual city. All three map displays had the same physical characteristics and content, except for the manipulated map differences. These characteristics reflected current recommendations and relevance for configural spatial knowledge acquisition.

Physical Displays

The display screen used by the three navigational displays with maps was large, reflecting the trend of larger GPS device screens in surface-vehicle dashboards, and was located to the right of a driver and below the bottom of the simulated windshield at a location appropriate for a dashboard, requiring an eye/head movement for foveal vision. Larger screens have more room for larger maps, showing more streets and icons representing landmarks.

Maps on the three types of displays were not updated continuously; they were only updated twice per city block. Slower updates

have been recommended to reduce the distractibility of navigational displays (National Highway Traffic Safety Administration, 2012).

Map Content

Landmarks at corners were used for guidance, as recommended by Miller and Carlson (2011). Putting landmarks on maps and using them to guide drivers, instead of or in addition to distance-to-turn information commonly used by current GPS navigational systems, have advantages (May & Ross, 2006; May, Ross, & Bayer, 2005; May, Ross, & Osman, 2005; Miller & Carlson, 2011). Passengers who are guiding a driver and familiar with a region also appear to commonly use landmark directions such as "Turn right up ahead at the Wendy's" (Burnett, 2000). Landmarks also are thought to be an important component of configural spatial knowledge representations (Foo, Warren, Duchon, & Tarr, 2005; Siegel & White, 1975; Thorndyke & Hayes-Roth, 1982). Landmark icons were used on the maps to represent the errand destinations the participants drove to in the virtual city. Landmarks were common and familiar businesses, with recognizable logos used as icons and as signs seen in the environment.

Map Design Comparisons

The four different navigational displays were evaluated by using them to guide participants to multiple destinations in a virtual city. The important comparison was between the configural spatial knowledge acquired using the three different map display designs. As described in the introduction, the spatial plus verbal cue north-up map should have the lowest cognitive load and therefore more spatial knowledge should be acquired, and the spatial-only cue track-up map should have the highest cognitive load and the least knowledge acquired. The spatial-only cue north-up map should be intermediate, depending on the number of difficult decisions to be made. The no-map auditory-only advisory cue display should show the amount learned directly from the virtual environment. Free recall of landmark names was used as a measure of landmark knowledge. No differences in percent free recall were expected among the three different map display designs.

Method

Participants. Students from undergraduate psychology courses (48 female, 48 male, M_{age} = 18.9 years, range: 18–29 years) participated in the experiment who were randomly assigned so there were 24 participants in each of four map type conditions (12 of each gender). They were required to have normal or corrected to normal vision for acuity, normal color vision, normal hearing, and a valid driver's license. English was required to be their first language. Participants reported that 72% of them had used a GPS device as a driver; this did not exclude them from the study, but participates in earlier studies of GPS navigation were excluded.

Route of simulated travel. Figure 2 shows a plan-view map of a virtual city with the names and locations of the landmarks (errand destination names are underlined) and the route traversed to reach them. Starting at Starbucks in the far west side, drivers headed east, ending in the far east side; the route included 16 turns

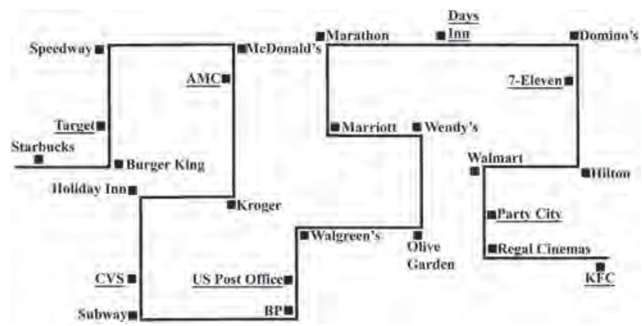

Figure 2. The participants traveled a predetermined route with 16 turns and eight destinations, starting at Starbucks in the far west side of the environment, heading east, and ending in the far east side. Errand destination landmarks are underlined.

(balanced with eight left and eight right turns) without doubling back over previously driven streets. Also, north-south travel was balanced so turn decisions were made four times while heading north and four times heading south.

The route included a total of 25 landmarks with a starting landmark, a turn landmark at each of the 16 turn corners, and eight errand destination landmarks. Errand destination landmarks identified locations where participants nominally performed a task; they were positioned in the middle of a block along the route for participants to stop at during their drive through the virtual city. Destination landmarks were placed randomly but balanced so that they were equally often on the left and right sides of the road (defined by the direction of travel). Turn landmarks were randomly placed on one of the four corners of the 16 turns, balancing for left or right turns and the four possible corner placements: before-adjacent, inside, catty corner, and after-adjacent.

Navigation displays: Map types. The 132 navigation map segments per map 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. × 10 in. (25.4 × 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 found online and resized to 60 pixels wide. Landmarks and landmark icons were chosen from common and familiar businesses such as restaurants, hotels, and drugstores, but participants also reviewed the list of landmark icons. Corner icons were positioned so the turn indicator arrows or verbal cues never obscured the logo. Landmark logos and positions were the same across all conditions. The names and positions of all 25 landmark icons are shown in Figure 2.

Figure 1 shows an example of the north-up map with the verbal cue added to the turn indicator. The letters L and R were located at the tip of the arrow inside a white circle with a red border and the verbal cue always remained upright regardless of the angle of the arrow. Figure 1 is also indicative of the plain red arrows that appear on the spatial-only north-up maps. Figure 3 shows an example of the track-up map display and its plain red arrow, rotating so that the heading direction remains at the top of the screen. For all map displays, turn indicator arrows always indicated an upcoming turn at least one block in advance of the turn

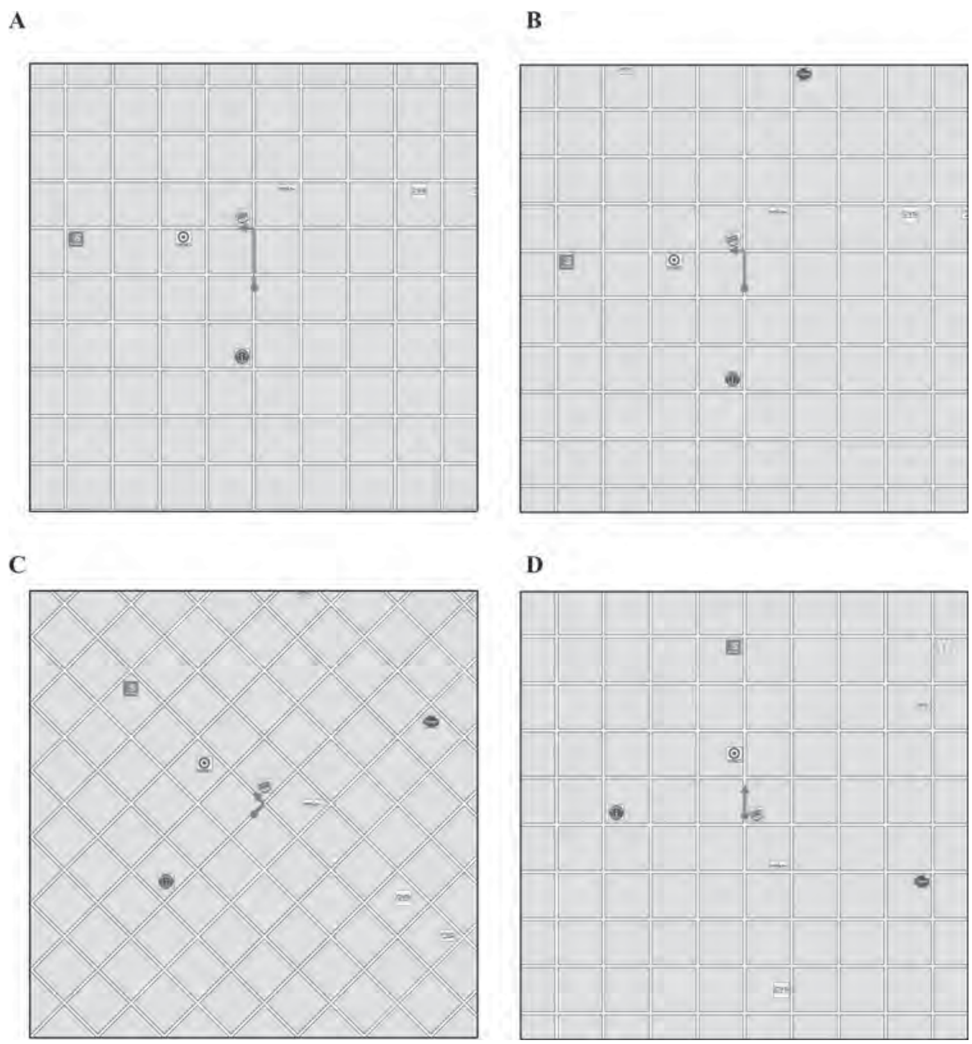

Figure 3. Four track-up navigation maps with spatial-only turn indicators showing the transitions of a left turn. Maps and icons were in color with the spatial-only indicator arrow in red.

corner, which always had a landmark icon at it to show drivers where to turn. Figures 1 and 3 show the series of maps to display the indicator arrow making 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 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.

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; instead, auditory turn-at-landmark instructions for each turn were added (.wav files of male voice, 1 s in duration) and triggered at the same point as those indicator arrows for the other map conditions. An example of an auditory direction is, "Turn Right at the Hilton."

Driving environment and simulation. Participants drove through a hypothetical city-street virtual 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 × 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 (180 m × 180 m). Edges of city blocks consisted of a row of buildings formed by facades 5 m wide and a maximum of 10 m tall. Buildings were randomly textured 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 façcade of the business at that location. These image files (in jpeg and tif formats) were sized to be proportional to the building's physical size. Additionally, each landmark façcade 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. Any sky visible in the original photo was erased so the program's simulated sky showed above the façcade instead,

Figure 4. A screenshot depicting the corner landmark Burger King with a parking lot placed on the inside corner of the intersection, in the virtual city in Experiment 1, allowing the driver to see the corner landmark as they approached. The driver saw the simulation in color.

further integrating the landmark into the city simulation. Figure 4 shows a screen shot of the façcade of the Burger King landmark building with its parking lot, located on the inside corner. Parking lots were inserted along the route before every errand destination landmark, before landmark buildings that were positioned on corners of intersections that were difficult for drivers to see, and randomly at nonlandmark locations throughout the route. Perspective views of the virtual scene had geometric fields-of-view of ± 45° left to right and ± 20° top to bottom.

Equipment. Two computers, which communicated with each other, were used to present the driving simulation, present the navigation maps, and collect online performance responses. Computers were Duo or Quad CPU PCs with video cards sufficient for the simulation's frame rate and crisp graphics. Figure 5 shows the set-up with the left monitor showing perspective views of the driving simulation and the right monitor showing navigation maps. The center of the maps on the monitor screen was located 65 cm horizontally to the right of the center of the driving display (horizontal visual angle = 47°) and it was located 35 cm vertically below the center of the driving display (vertical visual angle = 30°). Monitors (22 in. diagonal, 60 Hz, 0.282 mm dot pitch) were identical with digital video interface (DVI) connections to their computers.

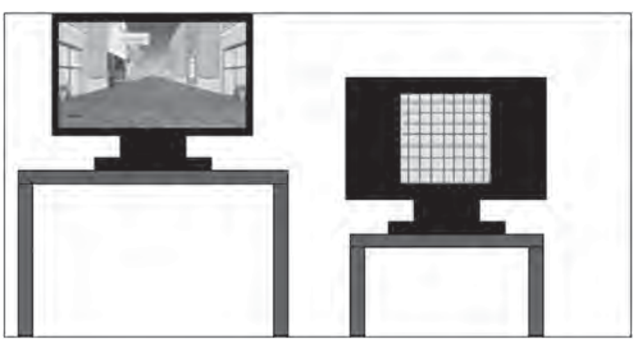

Figure 5. The monitors were configured the same for Experiments 1 and 2, and the navigation maps were displayed on the right monitor in both experiments. In Experiment 1 the driving simulation was shown on the left monitor. In Experiment 2, the target and distracter shapes were shown on the left monitor.

A steering wheel was fixed to a table directly in front of the chair where participants sat, with its gas and brake pedals (Logitech Wingman Formula Force GS, 6505 Kaiser Dr. Fremont, CA 94555) below the driving monitor. Location of pedals was adjusted so each participant could easily control them. The steering wheel was centered on the driving monitor (top of the wheel was 30.5 cm from its front surface). The driving computer presented the driving virtual environment on the driving monitor using input from the steering wheel, gas, and brake pedals and the map computer presented the navigation moving map displays to the map monitor using a SuperLab 4.0 program (Cedrus Corporation, P.O. Box 6309, San Pedro, CA 90734).

The SuperLab program simulated 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 1/4 block and 3/4 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. A trigger in the driving simulation computer sent a TTL signal to the map computer to update the driver's progress on the map. TracerDAQ PCI-DIO24 digital I/O boards (Measurement Computer Corporation, 10 Commerce Way, Norton, MA 02766) in the driving and map computers generated and received the TTL signals.

The SuperLab program in the navigation map computer also collected the drivers' intention-to-turn decision responses on two momentary contact microswitches (Apem 810, 26010 Pinehurst Drive, Madison Heights, MI 48071) mounted on the steering wheel supports near the wheel's rim. Their normally open and common pins were wired in parallel to the switch pins of response keys on a Cedrus RB-730 response pad (Cedrus Corporation, P.O. Box 6309, San Pedro, CA 90734), set in reflective mode, to produce accurate millisecond timing.

Procedure

Driving and navigating. Participants sat facing the virtual driving display and controlled the car with the steering wheel and pedals, navigating through the virtual city guided by simulated GPS navigational maps using one of the three map display types or the no-map auditory condition. They were instructed to maintain a speed of 20 mph–25 mph using a digital speedometer at the bottom left of the simulation screen (maximum speed set at 25 mph).

Participants assumed the role of a visitor to a city who is attending a convention. They were given errands to perform, requiring them to drive to its location. The simulated GPS map system guided them to these eight errand destinations using one of three map display systems or by auditory commands in the no-map condition. Participants started at Starbucks and it was pointed out to the track-up participants they were heading east. North-up participants were only told the top of the map was always oriented north.

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 heard the name of the next errand destination and errand task to perform (e.g., "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.

Participants were instructed to use the landmarks for turn decisions but were also instructed to learn the locations of the landmarks from the environment and from the maps. This intentional learning instruction was used instead of incidental learning (e.g., Münzer et al., 2012) because we wanted to have participants trying to learn from their maps and surroundings so as to evaluate the spatial knowledge acquisition possible with each display. Follow-up studies should then investigate spatial knowledge acquisition under other conditions.

Intention-to-turn decisions. Drivers also made intention-to-turn decisions in response to the turn indicator icons shown on the navigation maps (or the auditory commands), pressing the microswitch button on the steering wheel under their left thumb 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. Response times were measured from the onset of the first instance of the turn indicator arrow, as shown in Panel A of Figures 1 and 3. Pressing the wrong button or a lack of response were scored as errors. The auditory turn-at-landmark instructions from the no-map condition were presented as error messages for wrong responses and also if a participant did not respond with a turn decision by the time of the turn indicator's third phase, as shown in Panel C of Figures 1 and 3.

Instructions and practice. Participants in each map type condition were shown examples of their assigned map type display, and the properties were explained. Participants also practiced driving and navigating using their map type in a different city and with icons unrelated to those used for the test. 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 with the buttons on the wheel in response to the turn arrow indicators or auditory commands.

Free recall of landmark names. When the navigation test trial was completed, participants had to free recall the names of as many of the 25 landmarks they could remember by writing the names on a lined response sheet. They were not given a time limit.

Sketch map task. For the configural knowledge sketch map task, participants drew a freehand map of the virtual environment on an 18 in. × 24 in. sheet of drawing paper. The paper was blank, except for a point-up arrow in the top left-hand corner, with the long dimension of the paper oriented horizontally on the desk, which participants kept in that orientation. 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 added paper to avoid squashing their map, and then shown a sample freehand drawn map of a different layout with different landmarks. Participants were given the names of all 25 landmarks listed in random order to use as a checklist and were required to place and label all of them.

Configural spatial knowledge measurement. Configural knowledge acquisition was evaluated from participants' sketch maps. The angles between all possible pairs (300 i, j pairs) of the 25 landmarks were found for the sketch map locations produced by participants. Angles, $R_{i,\,j}$, were formed by a line between locations of each landmark pair and a vertical line connected to landmark i on the sketch map. The vertical reference line was arbitrary because the reference was common to all landmark points and common to all landmarks.

The absolute value of the angular difference between the landmark pairs on the sketch maps and in the target virtual environment was used to measure configural knowledge of the layout of the driving environment. Angular sketch map measures of configural spatial memory were first developed by Colle and Reid (1998) and in subsequent articles; sketch map angular error was shown to be comparable with the more common directional pointing response measure. Additionally, Douglas and Colle (2010) showed that this relationship held for the data from 25 independent groups taken from published journal articles.

The absolute angular difference, θ(i, j), was used as a measure of angular error between responses and actual landmark locations (Batschelet, 1981). It was calculated as $\theta(i, j) = \text{Min}\,(|R_{i,\,j} - T_{i,\,j}|, 360 - |R_{i,\,j} - T_{i,\,j}|)$, where $R_{i,\,j}$ denotes the angle between the pair of landmarks (i, j) on a sketch map, $T_{i,\,j}$ denotes the angle between the pair of landmarks (i, j) as they existed in the virtual environment, and Min (a, b) returns the minimum of a and b. The absolute angular difference θ(i, j) has a minimum of 0° (completely accurate), a maximum of 180°, and a chance level of 90°.

The 300 unique absolute angular error scores from all possible pairs of the 25 landmarks were used to create three different mean scores, representing pairs formed from two types of landmarks, destination and nondestination landmarks. There were eight errand destinations, 16 turn landmarks, plus the starting landmark Starbucks, producing 17 nondestination landmarks. These two types of landmarks created three types of landmark pairs: destination/destination (28 pairs), nondestination/nondestination (136 pairs), and destination/nondestination (136 pairs). Mean absolute angular error was computed for each of these three landmark pair categories.

Results and Discussion

A .05 level of confidence was used as a significance level for all comparisons in both experiments. Greenhouse-Geisser corrections for violations of sphericity were used for repeated-measure effects and are reported as, p_{gg}. Uncorrected degrees of freedom are reported, but Greenhouse-Geisser epsilon, ε_{gg} is reported where relevant. Partial eta squared, η_p^2, is reported as a measure of effect size. Cohen's (1969) recommended categorization of effect sizes for ANOVAs is $\eta_p^2 \geq .01$ for small, $\eta_p^2 \geq .06$ for medium, and $\eta_p^2 \geq .14$ for large effect sizes. Analyses of configural spatial knowledge, free recall of landmarks, and intention-to-turn response times were conducted with gender added as a between-subjects orthogonal factor, but no significant main effects of gender or interactions of gender with any of the other factors were found.

Configural spatial knowledge. Mean absolute angular error data were analyzed using a 4 × 3 mixed factorial ANOVA with a between-subjects factor of map display type (spatial plus verbal north-up, spatial-only north-up, spatial-only track-up, no-map/auditory directions only) and a repeated-measures factor of landmark pair type (destination/destination, destination/nondestination, nondestination/nondestination). Figure 6 shows the mean absolute angular error for the four map display types for each of the three types of landmark pairs. There was a large statistically significant main effect of map display type, $F(3, 92) = 4.92$, $MSE = 650.79$, $p = .003$, $\eta_p^2 = 0.14$. As predicted, overall mean absolute angular error was smaller for the spatial plus verbal north-up than for the spatial-only track-up map display (overall $M = 66.8°$ vs. 81.8°, respectively) with spatial-only north-up map display intermediate ($M = 75.0°$). For comparison, 95% confidence intervals for between-subjects effects about these overall means in a mixed design were ± 5.97° (Loftus, 2002). Performance with the no-map condition, from which spatial knowledge could only be acquired from direct experience with the virtual environment, produced a mean absolute angular error of 80.0°, implying that configural spatial knowledge acquired when using the traditional spatial-only track-up display was no better than it was when acquired from experiencing the virtual environment directly.

Map display type did not interact with landmark pair type, $F(6, 184) = 1.21$, $MSE = 99.90$, $\varepsilon_{gg} = .546$, $p_{gg} = .309$, $\eta_p^2 = 0.04$. So, follow-up analyses could compare the overall means of the main effect of map display type. Importantly, the predicted pairwise comparison of spatial plus verbal north-up and spatial-only track-up was statistically significant, $F(1, 46) = 13.0$, $MSE = 616.39$, $p < .001$, $\eta_p^2 = 0.22$. This very large effect is critically important both theoretically and for future display design and it was also significant when compared with the family wise critical $\alpha_{critical} = .0167$ obtained from Hochberg's (1988) modified Bonferroni procedure for three groups. The mean angular error for the two map display types which represent currently existing display types, the spatial-only north-up and the spatial-only track-up, were not significantly different, $F(1, 46) = 2.27$, $MSE = 734.97$, $p = .139$, $\eta_p^2 = 0.05$. In contrast, the pairwise comparison of the two north-up display types, spatial plus verbal north-up and spatial-only north-up, produced an $F(1, 46) = 4.46$, $MSE = 531.84$, $p = .040$, $\eta_p^2 = 0.09$, which is less than the nominal alpha, but greater than Hochberg's $\alpha_{critical} = .025$. By Cohen's (1969) categorization, the difference between these two north-up map displays was a medium effect, and the difference between the spatial-only track-up and north-up map displays was a small effect. The spatial-only north-up map display was expected to have an intermediate cognitive load depending on variables such as how often difficult turns were made and the overall difficulty of the configural spatial learning task. In this experiment it appears that for mean absolute angular error the spatial-only north-up map had a cognitive load more similar to the spatial-only track-up map than the spatial plus verbal north-up map. These results are important both theoretically and practically for future display design because they are consistent with the argument that the important distinction is not just between north-up versus track-up maps; an unstable map orientation is only one aspect of what impairs spatial learning. Instead the results are more consistent with multimedia explanation of acquiring configural spatial knowledge.

Figure 6 also shows that configural spatial memory was better between destination landmark pairs than it was between nondestination landmarks, $F(2, 184) = 46.6$, $MSE = 99.90$, $\varepsilon_{gg} = .546$, $p_{gg} < .001$, $\eta_p^2 = 0.34$, a very large effect. This suggests that errand destinations were more important and indeed mean absolute

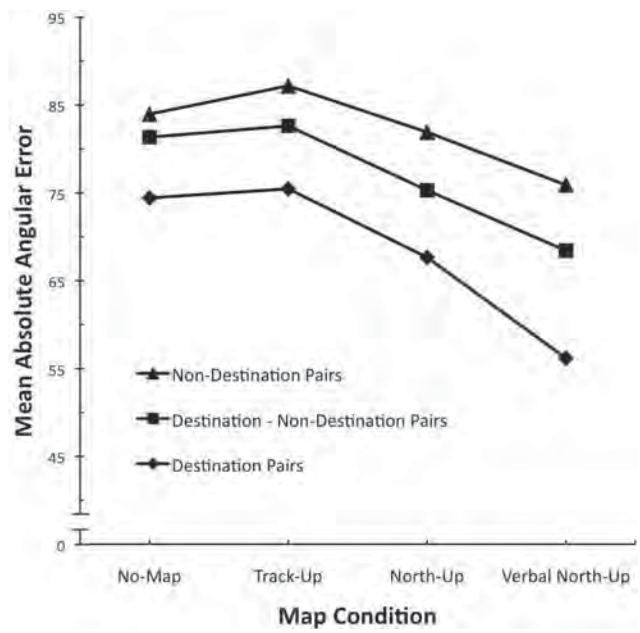

Figure 6. Mean absolute angular error taken from sketch maps for different types of landmark pairs for each the four types of map design conditions in Experiment 1. Destination landmarks refer to landmarks where the vehicle was stopped to run an errand. Nondestination landmarks were landmarks used to denote turns and the starting landmark.

angular error of the destination-destination spatial relations for the spatial plus verbal north-up map was reduced to 56°.

Landmark recall. Landmark memory is important for interpreting the configural spatial memory results. Landmarks are important aspects of both route spatial knowledge and configural spatial knowledge (Siegel & White, 1975), and landmark knowledge may confound the measurement of configural spatial memory. This makes it important to show that the angular error differences obtained for the different types of map displays were unlikely to have been produced by landmark knowledge differences. If the map type differences in configural spatial knowledge were a result of participants having learned the landmarks only, and not because of having learned the spatial relations between landmarks, then comparable differences attributable to map displays should also be found in the free recall of the landmarks.

Percentages of free recalled destination and nondestination landmark names were analyzed using a 4 × 2 mixed factorial ANOVA, with the between-subjects factor of map display type and a repeated-measure factor of landmark type (destination, nondestination). As Table 1 shows, there was no evidence for map display differences in landmark free recall. Both the main effect of map display type and the interaction of map display type with landmark type were not statistically significant, $F(3, 92) = 0.62$, $MSE = 305.47$, $p = .603$, $\eta_p^2 = 0.02$, and $F(3, 92) = 0.67$, $MSE = 209.08$, $p = .572$, $\eta_p^2 = 0.02$, respectively. These results suggest that the map display differences in configural spatial memory did not depend on differential landmark knowledge.

In contrast, the differences in configural spatial knowledge for the three types of landmark pairs (destination/destination, destination/nondestination, nondestination/nondestination) were mirrored by differences in free recall of landmark knowledge within these landmark pairs. In neither case did the type of landmark pair interact with type of map display. As Table 1 shows, drivers again treated the destination landmarks as more important than the nondestination landmarks; they recalled a higher percentage of destination landmarks than nondestination landmarks, $F(1, 92) = 92.9$, $MSE = 209.08$, $p < .001$, $\eta_p^2 = 0.50$. This was a very large effect, and these landmark recall differences corresponded with the improved configural spatial memory found overall for destination landmark pairs versus nondestination pairs, as shown in Figure 6. Thus, landmark differences for configural spatial knowledge could have been produced at least in part by landmark memory differences.

Table 1
Percent Free Recall of Landmarks in Experiment 1

	Map types			
Landmark type	No-map	Track-up	North-up	Verbal north-up
Destination	72.4 (16.1)	70.3 (13.7)	67.0 (14.6)	66.2 (21.0)
Nondestination	50.5 (13.4)	47.1 (18.0)	46.6 (14.7)	50.8 (15.5)
M	61.4	58.7	56.8	58.5

Note. No-map refers to the auditory instructions condition, track-up refers to the spatial only track-up map display, north-up refers to the spatial only north-up display, and verbal north-up refers to the spatial plus verbal north-up map display. The within-group standard deviations are in parentheses.

Two follow-up ANOVAs looked at this relationship between landmark knowledge and configural spatial knowledge. Absolute angular error scores were obtained separately from only landmarks that were free recalled and also from only landmarks that were not recalled. A repeated-measures factor of recall type was added to the original ANOVA, producing a 4 × 3 × 2 design. The important results were that the main effect of map display type was still significant with the means ordered in the same way, and that there were no interactions with map type. The landmark type × recall type interaction was significant; not-recalled landmarks had greater angular error than recalled for destination/nondestination and nondestination/nondestination landmark pairs but by only 2° for destination/destination, but this result was confounded because 20% of the 23% missing cases for not-recalled pairs came from destination/destination pairs where both landmarks were recalled. The second ANOVA eliminated this confound by analyzing only recalled landmarks (only 3% missing cases) using the original 4 × 3 design. The results were clear-cut. The main effect of map type was significant and comparable with the original analysis and there was no interaction with landmark type, but there no longer was a significant main effect of landmark type; all three landmark pair types had about the same angular error of the original destination-destination landmark pairs (e.g., for spatial plus verbal north-up: destination/destination = 56°, mean of all three types = 64°, supporting the interpretation that the landmark pair differences were produced by landmark, not configural spatial memory.

Intention-to-turn decisions. Although our focus was on spatial learning, we collected data relevant to navigational guidance while participants drove through the virtual environment. These data address the same question addressed by Rizzardo and Colle (2013) but with much less power. Each participant made only 16 intention-to-turn responses while driving through the virtual environment; each one was a response to an advisory cue from one of the displays. The task also was inherently more variable than Colle and Rizzardo's focused reaction time (RT) study because intention-to-turn responses were collected under dual task conditions in which driving was the primary task. Therefore, drivers may not have been looking at the map when it changed, delaying the intention-to-turn response. An important result is that percent error was low and comparable for all conditions (*M*s = 2.87% for spatial plus verbal north-up, 1.30% for spatial-only track-up, 3.91% for spatial-only north-up, and 3.13% for the no-map). Because of this floor effect, percent error data could not be analyzed using an ANOVA (93% of the cells had no errors).

To evaluate the effects of heading on response time, the largest differences should be found by comparing responses when heading south with those when heading north; a 4 × 2 × 2 mixed factorial ANOVA with between-subjects factor of map display type and repeated-measures factors of heading (north, south) and turn type (left, right). The north/south heading and left/right responses were balanced, but because of a mistake means were based on three right turns and one left turn heading north and two right turns and two left turns heading south. Mean intention-to-turn response times of correct responses for the intention-to-turn decisions in each of the four subcategories were analyzed. Data from four participants were missing because they made no correct responses for at least one of the subcategories (two left and two right turns).

Participants should only have difficulty when heading south only when using the spatial-only north-up map display. The im-

portant interaction is the heading direction by map type display, which was not statistically significant, but the three-way interaction between map display type, heading, and turn direction was, $F(3, 88) = 3.66$, $MSE = 2576757$, $p = .015$, $\eta_p^2 = 0.11$. The only other significant effect was a main effect for turn direction, $F(1, 88) = 6.34$, $MSE = 2635945$, $p = .014$, $\eta_p^2 = 0.07$. Right turns had longer intention-to-turn response times than left turns. As Table 2 shows, the mean response times were similar for all conditions for left turns, which was supported by no significant interaction between heading direction and map display in a follow-up ANOVA of just left turns, $F(3, 90) = 1.22$, $MSE = 1529688$, $p = .307$, $\eta_p^2 = 0.04$. However, a follow-up ANOVA of just right turns was statistically significant with a medium effect size, $F(3, 90) = 2.74$, $MSE = 3627866$, $p = .048$, $\eta_p^2 = 0.08$. A pairwise comparison of heading differences for the spatial-only north-up map display versus the spatial-only track up map display produced a medium effect size, $F(1, 44) = 4.70$, $MSE = 6068869$, $p = .036$, $\eta_p^2 = 0.10$, which is less than the nominal alpha, but greater than Hochberg's $\alpha_{critical} = .0167$. Pairwise comparisons of spatial plus verbal north-up map displays with the other two map displays were not statistically significant. Thus, given their lower power to detect differences, these data were not inconsistent with the more definitive data of Rizzardo and Colle (2013).

Experiment 2

When using realistic driving in Experiment 1, it was found that greater configural spatial knowledge could be acquired from a north-up map display with a spatial plus verbal turn indicator than with a spatial-only track-up map display. However, Experiment 1 did not explore the generality of these results when driving conditions might be more difficult, increasing cognitive load and limiting glance duration. In addition, studying spatial learning when using map learning aids concurrently with direct environmental experience assesses the combined effect of learning from both sources of information, which cognitive load research has shown may be counterproductive (redundancy principle; Schnotz, 2005). Although the environmental contribution appeared to be modest, its effect on map learning can only be definitively excluded by investigating map learning without direct environmental experience. Currently, very little is known about how people integrate information from map segments while learning about a larger environment.

Experiment 2 manipulated maximally available glance duration windows, forcing shorter glance durations, instead of just observing how drivers use glance durations, by having participants perform a visual cognitive classification task (instead of the driving task) while attempting to learn about the environment from the same sequence of map displays used in Experiment 1. Glance duration window was manipulated by using a cognitive classification task for the primary task and systematically varying its stimulus presentation rate. During both the dual task and single task conditions, map segments on the map displays were updated at a constant rate comparable with the update rate produced the average speed in Experiment 1. Based on the results of Experiment 1, learning configural spatial knowledge from the track-up maps should be impaired more than learning from a spatial plus verbal north-up map, that is, track-up maps should require greater nominal glance duration windows for equivalent configural knowledge acquisition. On the other hand, the absence of learning from direct experience could produce additional limits on the spatial knowledge that is acquired.

Method

Participants. Introductory psychology students (126 women and 66 men, $M_{age} = 20.1$ years, age range: 18–29 years) participated for course credit and were required to have a current driver's license and 142 had previously used a GPS while driving. An equal number ($N = 24$) of participants were randomly assigned to each of the eight experimental conditions. Participants from Experiment 1 were not eligible. As with Experiment 1, gender was added as a between-subjects factor for all of the dependent variables, but no significant main effects of gender or interactions of gender with any of the other factors were found.

Equipment. Equipment was the same as in Experiment 1, except that the steering wheel and pedals were not used. The monitors and their layout were the same (see Figure 5). The map monitor displayed the navigation maps, controlled by a SuperLab 4.0 program, as in Experiment 1. Stimuli for the cognitive classification task were presented on the left monitor and were controlled by a second SuperLab 4.0 program. Participants responded

Table 2
Intention-to-Turn Mean Response Time for North and South Headings in Experiment 1

Heading	Map display type			
	No-map	Track-up	North-up	Verbal north-up
Right turns				
South	1,615 (1,188)	1,622 (1,324)	2,960 (2,823)	1,934 (1,454)
North	1,556 (705)	2,349 (694)	1,557 (932)	1,414 (1,025)
S-N Difference	59	−727	1,403	520
Left turns				
South	1,418 (519)	1,409 (1,241)	1,379 (575)	1,207 (1,184)
North	1,496 (589)	1,092 (444)	1,624 (1,181)	1,834 (2,752)
S-N Difference	−78	318	−1245	−627

Note. Response times are in milliseconds. No-map refers to the no-map auditory instructions condition, track-up refers to the spatial only track-up map display, north-up refers to the spatial only north-up map display, and verbal north-up refers to the spatial plus verbal north-up map display. The within-group standard deviations are in parentheses.

using the middle key on a Cedrus RB-730 response pad located in front of the cognitive classification task monitor. The TTL connection linked the two computers to synchronize the two SuperLab 4.0 programs.

Map displays. Participants viewed the same maps and landmarks and followed the same route, turning at the same turn landmarks and stopping at the same destination landmarks as in Experiment 1 and the map display types were identical to those in Experiment 1 except that the spatial-only north-up display was not used. Navigation maps were triggered by the SuperLab 4.0 program controlling the cognitive classification task, instead of by the driving simulation. Regardless of the stimulus onset asynchrony (SOA) of the cognitive classification task, map segments were always updated at intervals of 9.3 s, which simulated a driver traveling at 25 mph.

For every map update, a fixed number of stimuli were presented on the cognitive classification task monitor, depending on the presentation rate of the cognitive classification task, 10 stimuli per map update for the 0.93 s SOA, five for the 1.86 s SOA, two for the 4.65 s SOA, and zero stimuli presented for no-cognitive classification task (single task).

Cognitive classification task. Stimuli in the cognitive classification task were geometric shapes, presented one at a time in the center of the left monitor's screen. Participants decided if a shape on the screen was a target shape before it was removed, pressing a key if a target stimulus was presented and doing nothing if a distracter stimulus was presented, a go-no/go response. Thus, the task was expected to put a working memory load on the visual component of visuospatial working memory rather than the spatial component or the phonological loop. Shapes taken from Microsoft Office, 2003 were divided into four categories based on shape similarity. One shape from each of the four categories was randomly selected as a target shape and the remaining 12 shapes were distracter shapes as Figure 7 shows. Sizes of displayed shapes were proportional to the square shown in Figure 7, which had screen size sides of 5.1 cm.

SOAs were generated by SuperLab so that a new stimulus shape immediately followed the previous one, following it with a zero

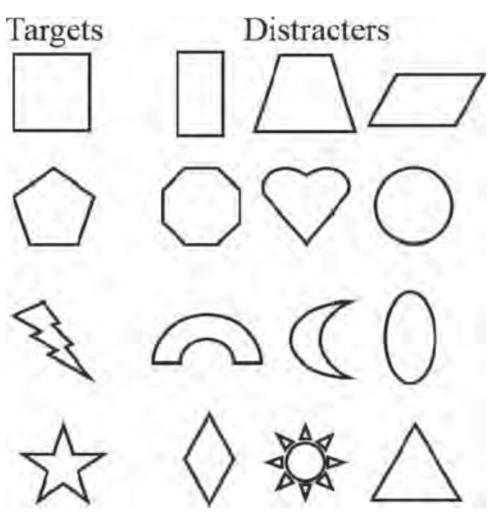

Figure 7. Shows the four target shapes and the 12 distracter shapes for the classification task in Experiment 2.

interstimulus interval. Presentation order was determined by randomly selecting multiple copies of the stimuli without replacement while satisfying the restrictions that for successive blocks of 40 stimuli, there were 10 target shapes and 30 distracter shapes and for two successive blocks (80 stimuli) each of the 16 shapes was used exactly five times. The sequence also was constrained so that a shape could not be repeated immediately. A list of 1,320 shapes was created and it was used for the fastest rate. The medium and slow rate conditions used the same list but it was truncated at 660 stimuli and 264 stimuli, respectively. A no-task control condition without a cognitive classification task was also programmed on the cognitive classification task computer so that maps were updated every 9.3 s.

Procedure. Participants in all conditions were seated with an upright posture in a chair positioned so that their eyes were about 64 cm from the front of the cognitive classification task monitor. They were to press the middle key of the response pad whenever one of the four target shapes appeared on the screen. Pressing the key while a target shape was on the screen was scored as a hit. Failing to press the key in time was scored as a miss. Pressing the key when a distracter shape was on the screen was scored as a false alarm. Participants were told that their primary task was the cognitive classification task and that they were to try to get 100% hits and to avoid any misses or false alarms. For the three conditions with SOAs of 0.93 s, 1.86 s, and 4.65 s, participants performed both the cognitive classification task and the map-reading task. For the no-cognitive classification task condition, participants only viewed the successive navigation maps transitioning at 9.3 s per map.

Participants were told that the maps on the right navigation map monitor showed the navigation activities of a driver who was visiting the city to attend a conference and had to run some errands. The participants were instructed to observe these maps and in particular, to pay attention to the layout of the landmarks because they would be tested on their knowledge of the city after the experiment. It was emphasized that map viewing was secondary and they were only to glance at the map screen if they could do so without making any misses or false alarms on the cognitive classification task.

Participants received three practice trials before starting the testing, only the cognitive classification task, only observing a sequence of navigation map updates using the same maps used as practice in Experiment 1 (and also given a question that tested their knowledge of the layout displayed on the map sequence), and both the cognitive classification task at the same presentation rate condition as the test trials and the map display task. This practice trial was identical to the procedure used during testing except that the maps came from a different region with different landmarks and the practice trial was shorter in duration.

After experiencing all destinations on the test route through the city and the relevant cognitive classification presentations, participants were given a free recall test, then they sketched a map of the region, as in Experiment 1, and scored in the same way. Other dependent variables included the percentage of hits, misses, and false alarms on the cognitive classification task, which were collected by the SuperLab program.

Results and Discussion

Configural spatial knowledge. Mean absolute angular error from the sketch maps was again used to measure configural spatial knowledge acquired from the sequential series of maps experienced by participants. A 2 × 4 × 3 mixed factorial ANOVA with between-subjects factors of map type (spatial plus verbal north-up, spatial-only track-up) and cognitive classification task glance duration window (SOAs of 0.93 s, 1.86 s, and 4.65 s, 9.30 s/no primary task), and a repeated-measures factor of landmark pair type (destination/destination, destination/nondestination, nondestination/nondestination) was used to analyze the data.

Mean absolute angular error was smaller for spatial plus verbal north-up maps (M = 68.0°) than for spatial-only track-up maps (M = 84.7°), $F(1, 184) = 51.5$, $MSE = 774.02$, $p < .001$, $\eta_p^2 = 0.22$, as in Experiment 1. For comparison, 95% confidence intervals for these overall between-subjects means in a mixed design were ± 3.96° (Loftus, 2002). Importantly, as Figure 8 shows, there also was a statistically significant interaction of map type and glance duration window, $F(3, 184) = 3.73$, $MSE = 774.02$, $p = .012$, $\eta_p^2 = 0.06$. The mean angular error decrease as the glance duration window increased was 31.8° for spatial plus verbal indicator north-up map displays, as shown in the left panel of Figure 8, but only 9.9° for spatial-only indicator track-up map displays, shown in the right panel. Two follow-up 4 × 3 mixed factorial ANOVAs on each map type separately showed that there was a significant and very large main effect for glance duration window for the spatial plus verbal north up map display alone, $F(3, 92) = 17.5$, $MSE = 719.97$, $p < .001$, $\eta_p^2 = 0.36$, but no statistically significant main effect for glance duration window for the spatial-only track-up map display, $F(3, 92) = 1.95$, $MSE = 828.07$, $p = .127$, $\eta_p^2 = 0.06$. Given the significant main effect for glance duration window for the spatial plus verbal north-up map display we compared the three longer glance duration windows (1.86 s, 4.65 s, and 9.30 s) pairwise with the shortest glance duration window of 0.93 s, using Hochberg's (1988) modified Bonferroni procedure for the four groups. The difference between SOAs of 0.93 s and 1.86 s, the smallest difference in mean absolute angular error, was still significant by both nominal and Hochberg's criteria, $F(1, 46) = 6.39$, $MSE = 646.50$, $p = .015$, $\eta_p^2 = 0.12$, with all of the larger pairwise differences also statistically significant.

Thus, these results suggest that participants could acquire substantial configural spatial knowledge with an increase of only 0.93 s (1.86 s–0.93 s) in glance duration window when they learned from the spatial plus verbal north-up map display, but they learned little or no configural spatial knowledge from the spatial-only track-up map display regardless of the map study times available for the full set of glance duration windows. These results suggest that the advantage of spatial plus verbal north-up map displays holds across a wide range of glance time availabilities, corresponding to the difficulties of driving in different situations. In contrast, little or no configural spatial knowledge was acquired when using the spatial-only track-up maps including in the single-task map-only condition with an effective glance duration window of 9.3 s.

In the overall main 2 × 4 × 3 ANOVA, not only was the main effect of landmark pair type statistically significant, but its interaction with map display type was also statistically significant, $F(2, 368) = 14.3$, $MSE = 125.32$, $\varepsilon_{gg} = .548$, $p_{gg} < 0.001$, $\eta_p^2 = 0.07$ and $F(2, 368) = 14.7$, $MSE = 125.32$, $\varepsilon_{gg} = .548$, $p_{gg} < .001$,

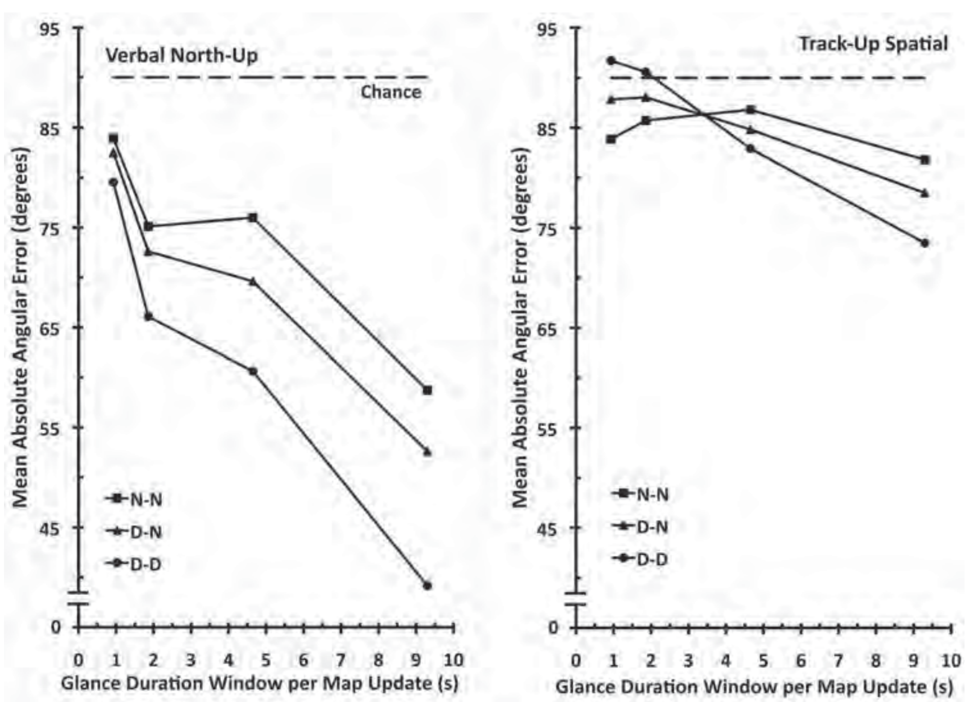

Figure 8. For Experiment 2, mean absolute angular error for spatial plus verbal north-up map and spatial-only track-up map displays as a function of the glance duration window per map update in Experiment 2. Landmark types are N = nondestination, D = destination.

η_p^2 = 0.07, respectively. Averaged across glance duration windows, the difference between the nondestination/nondestination landmark pairs minus the destination/destination pairs was 12.1° for the spatial plus verbal north-up map displays but only 0.13° for the spatial-only track-up map displays. Two follow-up 4 × 3 mixed factorial ANOVAs on each map type separately showed that there was a significant and very large main effect for landmark type for the spatial plus verbal indicator cue north up map display alone, $F(2, 184) = 30.6$, $MSE = 118.33$, $p < .001$, $\eta_p^2 = 0.25$, but no statistically significant main effect for landmark type for the spatial-only track-up map display, $F(2, 184) = 0.01$, $MSE = 132.30$, $p = .931$, $\eta_p^2 = 0.00$. For the spatial plus verbal north-up map display, the difference between nondestination/nondestination and destination/nondestination pairs, the smallest difference, was significant by both nominal and Hochberg's criteria, $F(1, 92) = 15.3$, $MSE = 53.0$, $p < .001$, $\eta_p^2 = 0.14$. For both of the follow-up 4 × 3 ANOVAs of each map type separately, the interaction of landmark pair type and glance duration window were not statistically significant.

In the main 2 × 4 × 3 ANOVA, the interaction of landmark pair type with glance duration window was significant, $F(6, 368) = 4.92$, $MSE = 125.32$, $\varepsilon_{gg} = .548$, $p_{gg} = .002$, $\eta_p^2 = 0.07$. These respective landmark pair differences between destination/destination and nondestination/nondestination landmark pairs were 13.94° for the 9.3 s glance duration window, averaging across map types, but only −1.73° for the 0.93 s glance duration window. The effect of landmark type was larger when participants had longer intervals to study the maps. The three-way interaction of landmark pair type, glance duration window, and map type was not statistically significant, $F(6, 368) = 0.06$, $MSE = 125.32$, $\varepsilon_{gg} = .548$, $p_{gg} = .985$, $\eta_p^2 = 0.00$.

The differences between spatial plus verbal north-up map displays and spatial-only track-up map display in Figure 8 are striking and unexpected from the results of Experiment 1 (see Figure 6). Thus, landmark pair differences in configural spatial knowledge acquisition primarily occurred when using the spatial plus verbal north-up map displays with longer glance durations.

Landmark recall. Percent free recall was used to assess the acquisition of destination and nondestination landmark knowledge and analyzed using a 2 × 4 × 2 mixed factorial ANOVA with between-subjects factors of map display type and cognitive classification task glance duration window, and a repeated-measures factor of landmark type (destination, nondestination). The main effect of map type, $F(1, 184) = 2.02$, $MSE = 284.80$, $p = .157$, $\eta_p^2 = 0.01$, and all interactions with map type were not statistically significant; with glance duration window: $F(3, 184) = 0.66$, $MSE = 284.80$, $p = .575$, $\eta_p^2 = 0.01$; with landmark type: $F(1, 184) = 0.94$, $MSE = 241.91$, $p = .335$, $\eta_p^2 = 0.01$; and with both factors: $F(3, 184) = 0.26$, $MSE = 241.91$, $p = .855$, $\eta_p^2 = 0.00$. As Table 3 shows, differential landmark knowledge was not confounded with the configural spatial knowledge differences found for the two map display types.

The only two significant effects were the two very large main effects of glance duration window and landmark type, $F(3, 184) = 40.9$, $MSE = 284.80$, $p < .001$, $\eta_p^2 = 0.40$, and $F(1, 184) = 215$, $MSE = 241.91$, $p < .001$, $\eta_p^2 = 0.54$, respectively. As Table 3 shows, free recall increased from 33.2% to 60.0% as the glance duration window increased, and the percentage of destination landmarks recalled was higher than nondestination landmarks.

As in Experiment 1, follow-up ANOVAs looked at this relationship between landmark knowledge and configural spatial knowledge by obtaining absolute angular error scores from recalled and not-recalled landmarks and using them in comparable ANOVAs. The result for map type was similar; the main effect was still significant and did interact with landmark pair, and recall/not recall. The ANOVA of only recalled landmarks using the original 2 × 4 × 3 design revealed that the main effects of both map type and glance duration window were significant and comparable with the original analysis, and again landmark pair type was no longer significant. Two additional ANOVAs on each map type separately (as in the original analyses) showed that landmark pair type was not significant for both map types, but glance duration window was still significant for spatial plus verbal north-up though not for spatial-only track-up. These results support the interpretation that angular error differences for landmark pairs were produced by landmark type, not configural spatial memory, but glance duration windows produced differences in configural spatial memory. For only recalled landmarks, the map type means for each glance duration window had about the same angular error as the original destination/destination landmarks means (e.g., spatial plus verbal north-up, SOA = 9.3 s: destination/destination = 35° mean of all three landmark pairs = 40°; for spatial-only track-up, SOA = 9.3 s: destination/destination = 72°, mean of all three landmark pairs = 77°). The contrast between Experiments 1 and 2 is striking. Landmark recall was similar in both experiments; it was better for destination landmarks and

Table 3
Percent Free Recall of Landmarks in Experiment 2

	Glance duration window				
Landmark type	0.93 s	1.86 s	4.65 s	9.3 s	*M*
Verbal north-up map					
Destination	44.8 (15.6)	62.0 (17.5)	61.0 (18.9)	71.4 (14.0)	59.8
Nondestination	22.6 (14.5)	40.4 (14.2)	40.9 (14.8)	48.3 (18.0)	38.0
M	33.7	51.2	50.9	59.8	48.9
Track-up map					
Destination	44.8 (19.1)	59.4 (20.6)	59.9 (13.3)	71.4 (16.3)	58.8
Nondestination	20.6 (12.7)	30.6 (15.4)	36.3 (17.7)	48.8 (14.5)	34.1
M	32.7	45.0	48.1	60.1	46.4

Note. Track-up refers to the spatial only track-up map display, and verbal north-up refers to the spatial plus verbal north-up map display. The within-group standard deviations are in parentheses.

improved as glance duration increased in Experiment 2, but in both experiments it did not depend on map display type. Configural spatial knowledge acquisition acted very differently. Glance duration window affected configural spatial knowledge acquisition for spatial plus verbal north-up map displays but not for spatial-only track-up map displays. Landmark recall also affected track-up maps differently in Experiment 2 than in Experiment 1. In Experiment 1, differential landmark pair recall affected angular error for spatial-only track-up map displays. In Experiment 2, landmark pairs were recalled differentially but this recall was unrelated to the angular error measure. Thus, not only was there little evidence for configural knowledge acquisition for the track-up map displays in Experiment 2, unlike Experiment 1, but the relations of landmark and configural knowledge acquisition appeared to differ.

A major difference between Experiments 1 and 2 is that in Experiment 1 participants could learn about the environment from direct experience and from the map displays, but in Experiment 2 they could only learn from the map displays, possibly attributable to the absence of this direct experience in Experiment 2. Learning could have occurred solely from the environmental experiences or because of the relationship between these experiences and the track-up map displays. Spatial plus verbal north-up maps acted similarly in both experiments.

Cognitive classification task. Performance on the cognitive classification task was checked to confirm both the effectiveness of the experimental manipulation and that the differences in configural spatial knowledge acquisition and free recall of landmarks were not attributable to differences in primary task performance. Percentages of hit and false alarms were obtained from these conditional proportions, so that the no-response data was completely determined by the hit and false alarm percentages.

Overall the mean percentage of hits was 98.7% and the mean percentage of false alarms was only 0.556%. Although a ceiling effect limited variability making interpretation difficult (percent hits was 100% for 40% of participants), a 2 × 3 between-subjects ANOVA with factors of map type (spatial plus verbal north-up, spatial-only track-up) and cognitive classification task glance duration windows (SOAs of 0.93 s, 1.86 s, 4.65 s), was used to analyze the percentage of hits and percentage of false alarms, separately.

Importantly, there did not appear to be any difference between the two map types. The main effect of map display types was not statistically significant, $F(1, 138) = 0.653$, $MSE = 2.98$, $p = .420$, $\eta_p^2 = 0.00$. Mean percentage of hits was 98.6% with spatial plus verbal north-up maps and 98.8% with spatial-only track-up maps. Overall, the percentage of hits did increase as glance duration window increased (*M*s = 97.6%, 99.2%, 99.4%), $F(2, 138) = 16.0$, $MSE = 2.98$, $p < .001$, $\eta_p^2 = 0.19$, but this was only a 1.8% increase and, more importantly, it was unrelated to the map display types, given that the interaction of map type and glance duration window was not statistically significant, $F(2, 138) = 0.95$, $MSE = 2.98$, $p = .388$, $\eta_p^2 = 0.01$.

A comparable ANOVA on the percentage of false alarms yielded similar results. The main effect of map type and the interaction of map type and glance duration window were not statistically significant, $F(1, 138) = 0.92$, $MSE = 1.48$, $p = .339$, $\eta_p^2 = 0.01$, and $F(2, 138) = 0.67$, $MSE = 1.48$, $p = .513$, $\eta_p^2 = 0.01$, respectively. Mean percentage of false alarms was 0.653% with spatial plus verbal north-up maps and 0.459% with spatial-only track-up maps. A small decrease (*M*s = 1.291%, 0.221%, 0.156%) in the percentage of false alarms as glance duration window increased was found, $F(2, 138) = 13.2$, $MSE = 1.48$, $p < .001$, $\eta_p^2 = 0.16$.

Overall, the experimental manipulation was successful. Classification task performance was near the goal of having 100% correct performance, which required participants to limit their glance times to the map displays in order to achieve these high levels of performance. There was no evidence that classification task performance was different for the two types of map displays; the differences between the two map display types in configural spatial knowledge acquired cannot be attributed to different classification task performance. Second, the small differences in percent hits and percent false alarms cannot account for the large configural spatial knowledge increases produced by the glance duration window increases.

A 2 × 3 ANOVA on the medians, as recommended by Ratcliff (1993) for skewed distributions, of response times for hit responses obtained from each participant also found no significant differences due to map display type. The main effect of map type and the interaction of map type and glance duration window were not statistically significant, $F(1, 138) = 0.86$, $MSE = 6713.26$, $p = .354$, $\eta_p^2 = 0.01$, and $F(2, 138) = 2.79$, $MSE = 6713.26$, $p = .065$, $\eta_p^2 = 0.04$, respectively. Response time did increase significantly with increases in glance duration window, $F(2, 138) = 176$, $MSE = 6713.26$, $p < .001$, $\eta_p^2 = 0.72$. This was a very large effect. Means were 472 ms, 594 ms, and 783 ms for nominal glance windows of 0.93 s, 1.86 s, and 4.65 s, respectively. These primary task response times will be used to estimate the actual time available for studying the map displays.

Glance duration estimation. By manipulating the glance duration window, limits on glance durations could be imposed on participants, given that participants had to maintain performance on the cognitive classification task to near 100% for hits and 0% for false alarms. However, the glance duration windows are an upper limit on glance durations. To estimate the actual glance durations (when the map display was being viewed) two factors need to be considered. One factor is the saccadic eye movement latency to move from the cognitive classification task monitor to the map monitor (about 200 ms, Carpenter, 1988) and then the latency to go back again (about 200 ms) to inspect the next target or distracter stimulus. The second factor is the processing time needed to classify a stimulus as target or distracter with a ballpark estimate of 500 ms. The shortest mean classification response time for hits was 472 ms, which was sufficient for near 100% correct classifications. In a previous preliminary single task deadline experiment we obtained an estimate of 460 ms. Adding processing time to the time needed to make an eye movement from the cognitive classification task monitor to the map monitor (200 ms) and back again (200 ms) requires a total ballpark time of 500 ms + 200 ms + 200 ms = 900 ms, equivalent to almost the entire glance duration window for the shortest SOA of 930 ms, leaving little or no time for actually studying the map monitor. By subtracting 900 ms from the glance duration windows for all but the map only condition, the estimated glance durations for the SOAs of 1.86 s and 4.65 s would be 0.96 s and 3.75 s, respectively (with map only staying at 9.3 s). These estimates are provided to illustrate the nature of the issue. More direct measures of actual glance durations with experimental control of switching times

should lead to more accurate estimates. However, an implication of Experiment 2 is that configural spatial knowledge could be acquired from short glances to the sequence of maps being displayed, when the spatial plus verbal indicator north-up map display was used for guidance during driving.

General Discussion

Two experiments tested the acquisition of spatial learning when college students had an opportunity to learn from moving maps. In Experiment 1, a map display guided drivers through a virtual city to eight sequential destinations, providing them with both maps and virtual views as two sources of information about the layout of important landmarks in the city. During the route, drivers made 16 turns with each turn being identified by a familiar icon logo on the sequential maps and by its landmark building in the virtual environment. The spatial learning task was difficult; drivers were asked to learn 25 different landmarks and their locations. They were then asked to sketch a map of the entire region after completing their trip.

The results showed that when a north-up map display with the new spatial plus verbal advisory indicator was used, drivers learned the most compared with the other three guidance displays. Less configural knowledge was acquired while using the traditional spatial-only north-up map, which was nominally intermediate but not statistically different than a traditional track-up map. Learning from the voice commands without a map was relatively poor and the similarity of the results of no map and track-up suggests it was difficult to learn about the city from direct experience without a map aid and most difficult to learn from the track-up map. On the other hand, it was not clear if learning from either of the two north-up map displays depended on drivers being able to compare map information with the direct 3D prospective views from the virtual environment. Also, the generality of the results was unclear. The driving task itself could have been easy; drivers did not have to look for pedestrians, other vehicles, or stop signs or lights. Experiment 2 addressed these issues.

In Experiment 2, students learned from the same sequence of maps used in Experiment 1, but they did not have to drive and they did not have direct experience with the virtual city. For participants using the north-up map with the spatial plus verbal advisory indicator, the group that could exclusively study the map sequence as it updated obtained the best performance (both experiments); angular error was 39° for all of the destination/destination landmarks (free recalled or not) or 35° for all three landmark types that were free recalled. Groups who viewed the maps and had to glance away more often, as drivers would have to under more difficult driving conditions, learned less about the environment. But even short glance durations to the spatial plus verbal north-up map produced reduced angular error. In contrast, performance with the track-up map displays was uniformly poor for all conditions.

Recall of landmarks produced a different pattern of results. Participants learned the landmark names equally well regardless of the type of map or voice display used. A higher percentage of destination landmarks than nondestination were recalled and higher percentages were recalled when participants had longer durations to glance at the maps. On the other hand, this landmark recall was related to the angular error produced by different landmark types, which appeared to be a consequence of whether they were recalled or not, because angular error differences for landmark types were eliminated when only recalled landmarks were analyzed. These results, however, support the conclusion that the differences in angular error produced by the map display types were unlikely to have been attributed to differential landmark knowledge, which could have been stored as verbal declarative memory representations.

Theoretical Implications

Although the focus of the present research was on spatial learning, distinguishing the cognitive processes responsible for immediate decision making and spatial learning provides a focus for the important variables for each task type, still allowing for a consideration of their interaction. The difference between the two north-up maps was subtle but important for spatial learning, as well as for turn decision making. The multimedia spatial learning approach additionally cautions about how the results can be applied and other variables that need to be considered. For example, the effectiveness of the spatial plus verbal indicator for spatial learning is unlikely to generalize to most current GPS guidance systems, which use distance-to turn-directions, not landmarks, and only show a very limited region about the represented vehicle. The components and structure of the maps themselves are important for learning from them, as research with educational diagrams has shown (Mayer, 2009; Schnotz, 2005). The history of multimedia research has been to investigate the effectiveness of learning materials and procedures for educational topics, an approach that we believe can identify both effective map content and the cognitive processes responsible for their effectiveness. In addition, the domain of driving provides opportunities for studying the interactions between spatial learning from the redundant sources of direct viewing experience and from maps, as the differences between Experiments 1 and 2 showed.

Design Considerations

The results provide strong evidence against the trade-off hypothesis that a single display can be good at either facilitating configural spatial knowledge acquisition or at providing good turn-by-turn navigational guidance, but not both (Münzer et al., 2012; Münzer, Zimmer, Schwalm, Baus, & Aslan, 2006). Experiments 1 and 2 clearly showed that the spatial plus verbal north-up map displays were good at facilitating the acquisition of configural spatial knowledge. Additionally, Rizzardo and Colle (2013) clearly showed that the spatial plus verbal north-up map display was good at providing immediate turn decision guidance. The combined results strongly suggest that a single map display can be used effectively both for turn-by-turn guidance and for the acquisition of configural spatial knowledge, useful for navigational planning. Without acquiring configural spatial knowledge of a previously unfamiliar region, a driver has no basis for evaluating the system's advice, which may be incorrect or misinterpreted by a driver with such serious negative consequences as driving into a lake (Forbes & Burnett, 2007; Johnson, 2011). However, if you know that you are driving along a large lake toward your right side, you may be more cautious when told to turn right. Also, Burnett and Lee (2005) pointed out that when drivers know the layout of an area it allows her or him to choose alternate routes, reroute in

the face of traffic jams or construction blockages, or navigate for others after the fact.

Designs for single map-type systems should explicitly consider both immediate decision-making needs and navigational planning and understanding the spatial layout needs. The decision-making needs (e.g., recommended lane selection) appear to be the easier of the two to address, but as pointed out previously, the parameters of the map component of the display related to spatial learning are less obvious. However, in our pilot research we found informal evidence for online planning using the new map display when several drivers took shortcuts to errand destinations (modified instructions prevented this) while viewing the map display because the physical map was easy to read. With a better understanding of the cognitive spatial processing and semiotics, navigational systems can be designed to encourage such human-machine interactions. We believe that the current research is a start in the right direction. It not only raises challenging theoretical questions about the nature of the cognitive processing underlying spatial knowledge acquisition and navigational decisions, but it raises the possibility of being able to field navigational systems that are more useful to drivers and safer to use.

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