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Analyzing Situation Awareness During Wayfinding in a Driving Simulator

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Abstract

Learning a route through an unfamiliar area requires an ongoing awareness of one's position in the world. We investigated how subjects established this "situation awareness" in a driving simulator. After learning a route, subjects' visual and spatial abilities were tested by having them follow the route in a world with altered landmarks. We found that subjects used one of two different ways to orient themselves. One group of subjects relied almost exclusively on visual scene recognition, being aware of their position only at decision points along the route. The other group, in contrast, used a more spatial representation of their environment, being aware of their position between decision points as well.

Introduction

Although situation awareness (SA) has been studied most extensively in the context of aviation, it is relevant to other kinds of tasks as well. In particular, it is relevant to the more mundane task of driving, which requires SA in the literal sense of being aware of where and how one is situated within the world. Driving is both a source of great convenience and great danger in our lives (in 1993 in the US, over 7 million vehicles were involved in accidents, causing 2.6 million personal injuries and 36,000 fatalities). Consequently, much effort has been directed towards trying to understand the “human factors” component in vehicle accidents. Measures of basic visual performance have turned out to be only weakly predictive of accident rates (Hills, 1980). Instead, what is predictive are measures of cognitive abilities related to and subserving SA, such as being able to divide attention between multiple targets (Owsley et al., 1991; Ball and Rebok, 1994). As such, SA would appear to be a key factor in driving safety.

Given the importance of SA, it has been suggested that recent attempts to improve driving safety by adding “intelligence” to the car without duly considering the human driver may be counterproductive (Owens et al., 1993). As in the case of aviations, there is great concern that intelligent devices (collision warning systems, automatic cruise control, etc.) may decrease SA and so increase drivers’ risk. The same issue has been raised for head-up displays, which superimpose visual information on the driver’s forward view. If this information is similar to the actual scene—as in some experimental navigational aides—there is a real possibility that SA could be lost.

A better understanding of how drivers maintain SA is needed if intelligent devices are to be designed and used appropriately. The goal of our study was to learn about one particular aspect of SA: how drivers remain oriented within their environment, that is, how they establish a sense of being at a certain place in the world. As such, we view SA as describing the quality of the interaction between an actor and its environment for a particular task (Flach, 1995).

In our experiment, subjects learned to drive a simple route through a virtual world in a driving simulator. As soon as subjects had learned the route (ad so reached a definite level of competence and presumably SA), we assessed their spatial knowledge and visual memory of scenes along the route. We used “ex-situ” (out-of-world) tests of spatial and visual abilities, as well as more direct “in-situ” tests. The ex-situ tests, of course, “miss the phenomenon [i.e., SA]” (Sarter and Woods, 1991). However, they can reveal mechanisms underlying SA and also aid in interpreting the results of in-situ tests. For example, we used ex-situ tests to categorize subjects according to their visual and spatial knowledge, and then used this categorization to account for their behavior in a subsequent in-situ test.

Materials and Methods

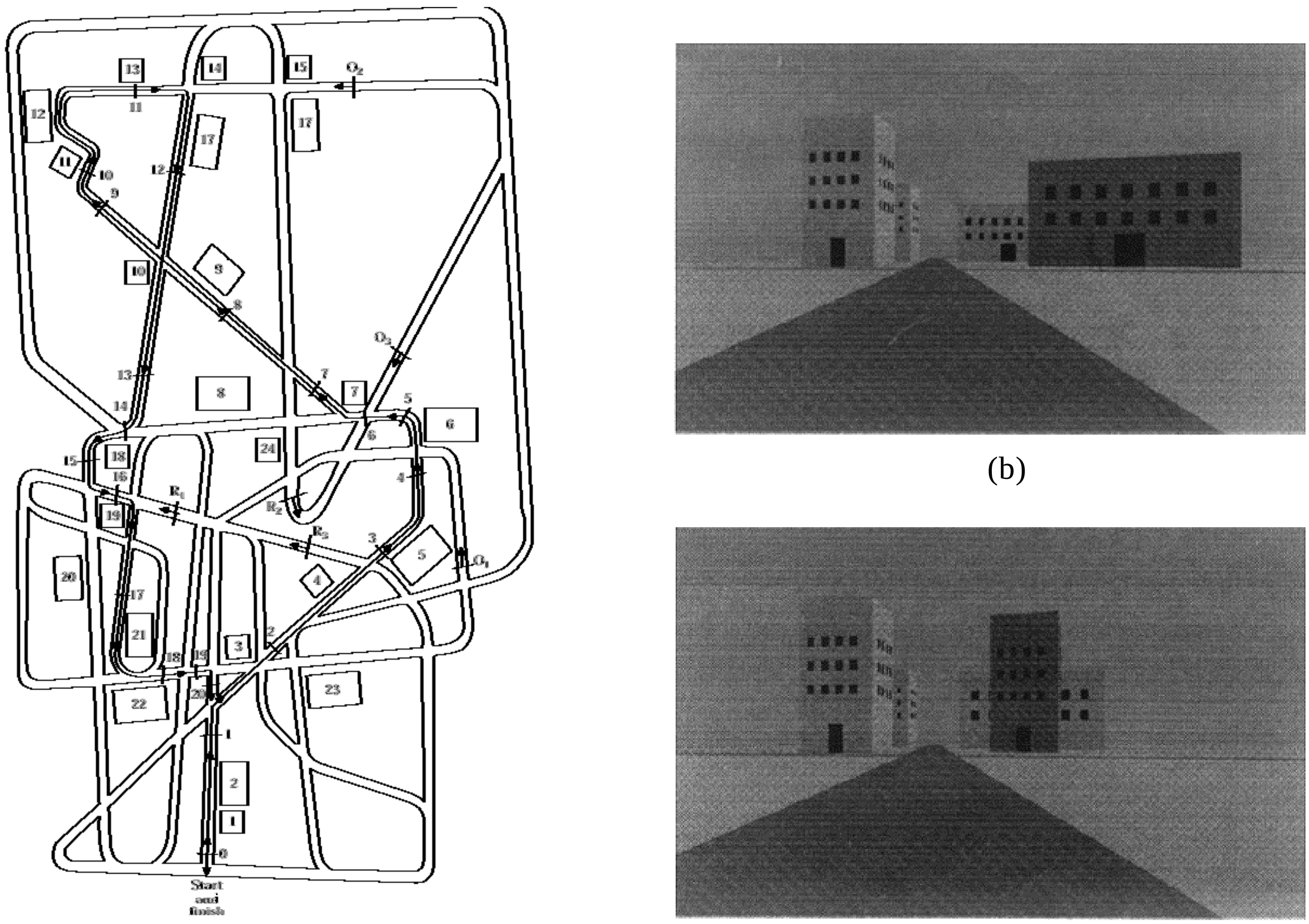
Driving Simulator and Virtual World

The driving simulator consisted of the front two-thirds of a Nissan 240SX convertible. Steering wheel torque was generated an AC motor attached to the steering column, generating a peak torque of 5.6 Nm and a sustained value of 2.8 Nm, corresponding to the lower end of the range of torques that occur in normal driving. Audio feedback was in the form of low-frequency engine noise, with frequency proportional to driving speed. An Indigo Extreme2 workstation (Silicon Graphics, Inc.) updated both care and world models, and rendered the virtual world, which was projected onto a wall 3.5 m in front of the driver (image 60° wide x 40° high). Average frame rate was 12 frames / sec.

The virtual world consisted of a road system with about 50 intersections laid out on a green, textured ground plane of size 350 x 630 meters (Figure 1a). There were 24 rectangular buildings, mainly along the route subjects had to learn. Half the buildings were “wide” (28m wide x 15 m deep x 12 m high) and half were “tall” (10 m wide x 10 m deep x 16 m high). Of the twelve wide (or tall) buildings, half were blue and half were red. Each road section and each intersection had its own unique configuration of buildings (e.g., Figure 1b). There were no other cars or road users in the world.

Learning Phase

During the learning phase, subjects had to learn a 1770 m long route. Subjects could control their own speed and direction. They were led along the route by verbal directions from the experimenter. Instructions consisted of the phrases “take the next right” or “take the next left” and did not contain any landmark information. Subjects repeated the drive until they could follow the route correctly without any help from the experimenter. As learning progressed, the experimenter offered instructions only for the turns which the subjects had not yet memorized. Subjects indicated which turns they know by using heir directions signals before they turned.



(b)

(a)

(c)

Figure 1. (a) Map of the world showing buildings and the route subjects had to learn. (b) Scene 11 as it appeared during learning. (c) Scene 11 as it appeared during the "in-situ" test.

Test Phase

Following the learning phase, subjects wer given two ex-situ tess and one in-situ test (order of tests was: ex-situ test B, in-situ test, ex-situ test A).

Ex-situ Test A: Sketch Maps

Subjects were given a blank sheet of paper (11 x 17 inches) and asked to draw a sketch map of the route.

Ex-situ Test B: Visual Scene Recognition

Subjects viewed two sets of 24 static views or "snapshots" of the world (Figure 1b). Each set contained identical snapshots, composed of 21 views of scenes along the route, and 3 views of areas that subjects had never visited. In the *ordered* set, snapshots were in the order encountered along the route. In the *randomized* set, snapshots were placed in random order.

For each snapshot, subjects had to decide as quickly as possible whether they should turn right, left, or follow the road. Subjects were told to guess if they did not recognize a scene. Reaction times of all responses were recorded (resolution 14 ms). Subjects also rated the familiarity of the scene on a scale of 0.0 (completely unfamiliar) to 1.0 (very familiar).

The 21 route snapshots were divided into three class of 7 snapshots each, according to the decision subjects had to make: (i) *no choice* road sections, where the visible road offered no choice; (ii) *passive intersections*, where there was a choice, but the route followed went straight ahead; (iii) *active intersections*, where subjects had to decide to turn left or right.

In-situ Test: Detecting Building Changes

This test followed ex-situ test B and was performed in the driving simulator. Subjects drove the route they had previously learned, but now 11 o f the 24 buildings were changed in some way. Subjects were not told in advance what these changes could be. While driving along the route, subjects had to verbally indicate any differences they noticed. The experimenter recorded what the subjects said and how they were driving.

The 11 target buildings changed in either color (red or blue), shape (tall and thin or short and wide), or both color and shape. Figures 1b and 1c illustrate a change in building shape at an active intersection (which was noticed by 11 of the 16 subjects). Buildings could also change their location (cross to the other side of the street). Subjects, however, did not generally think of these “location changes” as the change in location of an identifiable building; rather, they interpreted it as the simultaneous disappearance of an old building and appearance of a new one (especially if the color and shape differed as well).

Subjects

Sixteen subjects participated as paid volunteers (10 men and 6 women; ages 19 through 25). All subjects were naïve as to the purpose of the experiment.

Results and Discussion

Subjects learned the route with an average of 7.7 repetitions. The minimum required was 6 (5 subjects) and the maximum was 10 (2 subjects). The time taken for one traversal of the route varied between 2-3 minutes. Only one subject realized that the start and finish of the route were at the same location.

Ex-situ Test A: Sketch Maps

Sketch maps obtained from subjects rarely reflected the correct (Euclidean) metric relationships identifiable locations in the virtual world, even for distinct locations that directly followed each other. Turns and bends were typically drawn as right-angled turns even when they were not so in the virtual world. This may in part be due to the limited field of view in the driving simulator, which made it hard to judge sharp bends and turns; however, similar distortions have also been found in sketch maps of subjects who had earned a real-world space (Tversky, 1981). Areas with many turns of curves were enlarged at the expense of long straight road segments.

Sketch maps generally preserved the linear relationships between road segments and also depicted distinct locations in the world where subjects had developed a *sense or awareness of being in a particular place*. In most sketch maps, it was easy to recognize the 8 distinct places

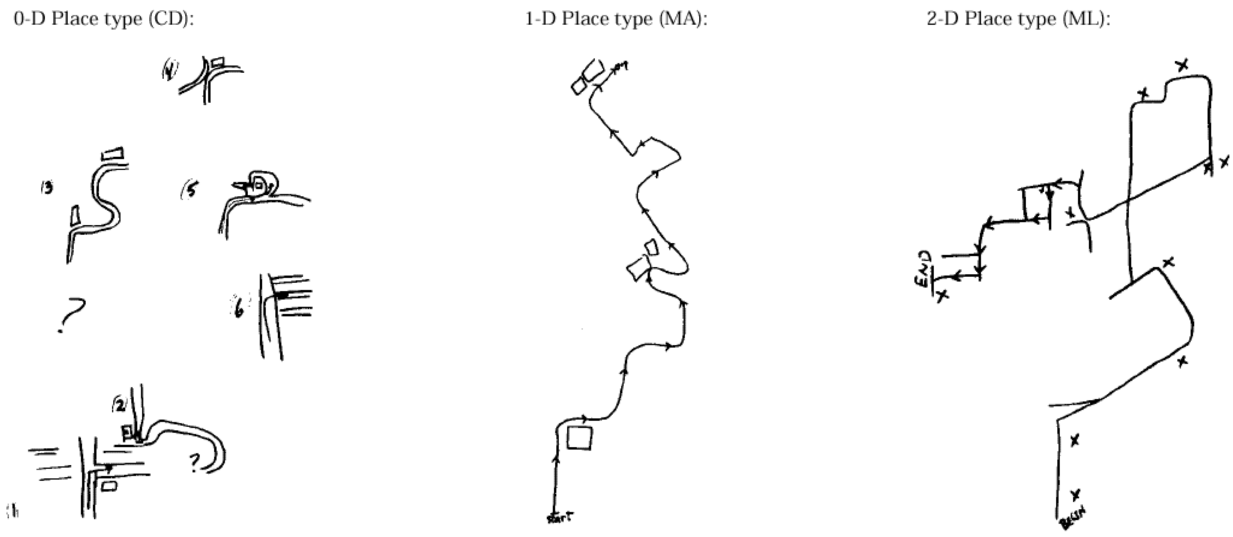


Figure 2. Representative samples of the three types of sketch maps.

located along the route. Based on how these places were connected, three types of sketch maps could be distinguished (Figure 2):

- ***0D Connection*** (Unconnected). Isolated places, with some local spatial structure. Places sometimes include information for their recognition. (3 subjects)
- ***1D Connection***. Places that had been encountered sequentially are explicitly connected in sequence, but there is little global structure. (8 subjects)
- ***2D Connection***. Places that had been encountered sequentially are connected sequentially; some of the places not encountered sequentially are connected spatially. (5 subjects)

Ex-situ Test B: Visual Scene Recognition

Averaged over all subjects, there were only small effects of presentation order and intersection type on scene recognition. In the ordered presentation, direction responses were 75% correct for passive intersections and 66% correct for active intersections. Performance was slightly—but not significantly—worse during the random presentation for active intersections (57% correct). Familiarity ratings for active and passive intersections did not differ, nor was there a significant difference between ordered and random presentations. Reaction times (RTs) for the direction responses were surprisingly long and varied considerably from subject to subject. The mean (±SEM) for the median RTs for order representations was 3.0 (±0.3) sec, and for random presentations 3.3 (±0.3) sec.

However, grouping the subjects according to their sketch map type uncovered an interesting pattern: for the 2D connection group, the mean percentage correct direction responses dropped from 81% in the ordered presentation to 56% in the random presentation; familiarity ratings dropped from 0.73 to 0.59, and RTs increased from 3.3 to 4.3 seconds. All subjects in the 2D group showed this drop in performance. In contrast, neither the 0D nor the 1D connection group showed this decrease in performance during the random presentation; in fact, direction responses improved slightly for the 1D connection group.

In-situ Test: Detecting Building Changes

First, it was verified that subjects could still follow the route in the original world (all subjects could). Next, subjects followed the route through a world in which some buildings had been changed. Any navigation errors could be interpreted as lapses in SA due to these changes; indeed, subjects who got lost tended to notice fewer building changes (3.25 vs. 5.6; the difference was statistically insignificant). Building changes were noticed far more often at active intersections (77%), where subjects had to turn left or right, than at passive intersections or straight road sections, where they could simply follow the road (26%). This difference was independent of the type of building change.

Four subjects (two each from the 0D and 1D connection groups) missed a total of 7 turns. Apparently, the wayfinding actions of these subjects were "triggered" by visual scenes; if a scene was not recognized because of a building change, they would miss the turn. Interestingly, non of the subjects in the 2D connection group made any navigation errors.

Conclusions

All subjects in our study had reached approximately the same level of competence, that is, they could all follow the route. Thus, the differences in performance encountered on the various tests are unlikely to reflect different stages in spatial learning: rather, they would appear to reflect differences in handling the wayfinding problem itself. We found that subjects could be divided into three groups based on the structure of their sketch maps (0D, 1D, and 2D connection types). Only the 2D group showed a significant effect of presentation order in the scene recognition test; and it was the only group for which building changes did not cause navigation errors.

The consistent differences in performance in these groups point towards two strategies in wayfinding: one visually dominated and the other spatially dominated. These different strategies have implications for the kind and extent of situation awareness subjects develop. The visual strategy relies on the visual recognition of active intersections along the route (e.g., "turn right at the red building"). If a particular intersection is not recognized (due to a change in one of the buildings, say) the turn will be missed. Subjects using this strategy apparently have little SA between active intersections.

The spatial strategy relies on a mental map incorporating aspects of the environment's spatial structure. Although subjects still recognize scenes and landmarks visually, they do not use this recognition to guide their navigation. Their ability to orient themselves via a mental map would explain why they preformed better during the ordered presentation of the snapshots than during the randomized presentation.. These subjects apparently have SA not only at active intersections, but everywhere along the route.

Our description of these two wayfinding strategies is of course rather crude and simplistic, but it does capture the extremes of the range of possibilities. It is also too simplistic to rigidly assign each subject to either one or the other strategy type—subjects may use different strategies at different parts of the route, and might switch strategies depending on the exact details of the task. Thus, the above interpretation of our results in terms of SA is rather tentative and should only be considered as a working hypothesis.

In any event, it is interesting that subjects with nearly identical levels of wayfinding performance have such different levels—and perhaps even types—of situation awareness. When evaluating navigational aids and head-up displays, it may be important to take these different ways of maintaining SA into account.

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