EYE MOVEMENT STRATEGIES IN NAVIGATIONAL TASKS

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Abstract

Navigation is an essential part of many military and civilian tasks. Cardinal direction navigation tasks are good candidates for the development of training and of tests that assess individual differences in skill levels. Participants in the following study used learned strategies to perform a cardinal direction task using both a 3-D and a heading map presented side by side. The participants' eye movements were recorded throughout a test phase of 24 displays. Various regions of interest (ROI) on each map were designated for data analysis. We hypothesize that depending on the strategy utilized, participants will use a particular set of eye movements respectively.

1 Introduction

Prior research has shown that some navigation tasks, such as judging cardinal directions, are quite difficult and show extremely wide individual differences [Gugerty and Brooks *in press*]. This proposed research project focuses on: (1) understanding the cognitive processes involved in navigation, and (2) applying this understanding by developing training in navigation skills, and by developing navigation tests that can improve job-classification decisions and aid training by diagnosing individual attributes.

Navigation involves keeping track of ones current location and planning routes to new destinations. We focus here on navigational skills involving the use of *maps*, the most common navigational tool. Using maps to navigate usually requires the navigator to coordinate two cognitive reference frames, the *egocentric*, or body-centered, frame, which uses directional terms such as "ahead" and "right", and the *environmental*, or world-centered, frame, which uses terms such as "north" and "east" and compass headings. Considerable research has shown that coordinating reference frames is a key difficulty in a variety of navigation tasks [Aretz 1991; Gugerty and Brooks *in press*]. The current research project will focus on a cardinal direction task to understand eye movement strategies in formulating an answer to the question, "Using compass headings, which side of the building is the red car parked on?" Participants will use both a 3 dimensional map and the heading map to answer this question.

Research [Gugerty and Brooks *in press*] shows that (1) cardinal direction judgments are difficult, with performance accuracy averaging less than 67%, and (2) when egocentric and environmental reference frames are misaligned, these judgments are much more difficult, in that both errors and response times are increased. This research also showed very wide individual difference in performance. For example, for two large samples of Air Force recruits, accuracy of cardinal direction judgments was distributed bimodally, with about one third of the participants averaging 32% correct and the remaining participants averaging 80% correct (Figure 1). In contrast, experienced navigators – Air National Guard fighter pilots –made more accurate cardinal direction judgments than either of these groups, although the pilots were affected by reference frame misalignment in a similar manner to the novice navigators (see Figure 2). In summary, the cardinal direction research shows that this navigation task is much more difficult than other navigation tasks, more affected by reference frame misalignment, and prone to show wide individual differences in performance.

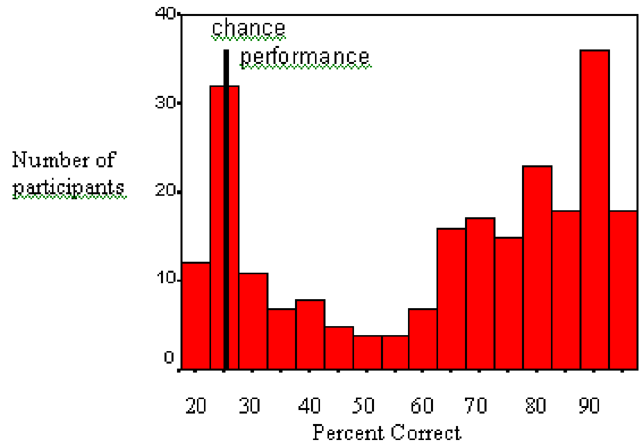


Figure 1. Frequency distribution (histogram) showing the number of participants (from a group of 223 Air Force trainees) who achieved various levels of accuracy at the cardinal-direction judgment task. Note that someone performing at chance would get 25% correct, since each problem had four possible answers.

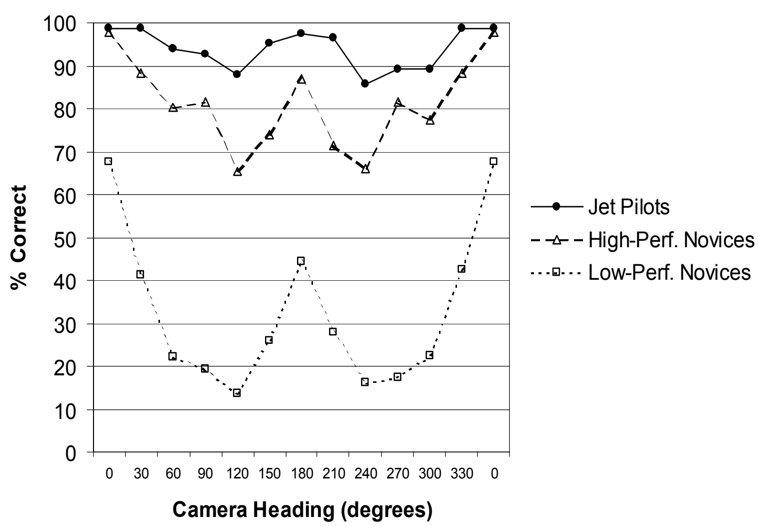


Figure 2. Accuracy of cardinal direction judgments as a function of degree of misalignment of environmental and egocentric reference frames for three groups of participants. 0° (north aircraft heading on map) represents no misalignment and 180° (south) represents maximum misalignment.

This study examined participants' eye movements in the cardinal direction task. Participants were asked to use a strategy taught to them by experimenters to solve the task. The strategies are discussed in greater detail later in the paper. We hypothesized that subjects who gave correct answers utilized a specific ordering of saccades within each strategy they learned to formulate these answers. These findings could later be applied to training programs that teach pilots how to better determine their cardinal direction while in flight.

2 Methods

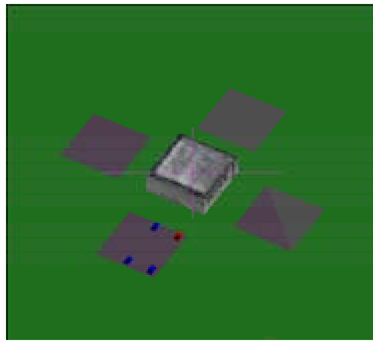
Participants' eye movements were monitored during each task using a video-based corneal refection eye tracker. The device being used is a table mounted monocular system that captures single Purjinki images and is situated on a remote pan-tilt unit. The system used is the ISCAN RK-726PCI High Resolution Pupil/Corneal Reflection Processor. This processor operates at a sample rate of 60Hz and eye position can be determined with accuracy typically better than 0.3 degrees over a +/- 20-degree horizontal and vertical range using the pupil/corneal reflection difference. The maximum spatial resolution of the calculated Point of Regard (POR) provided by the eye tracker is 512x512 pixels per eye. In practice, however, it is difficult to generate a graphics window that will match the dimensions of the video display. The screen resolution being used for the application is 640pixels wide x 480pixels high. The answer screen image (compass) is 350pixels wide x 340pixels high and all other images are 640pixels wide x 299pixels high.

This unit allows non-invasive tracking of a subject's eye as the subject's head moves slightly. The system's camera shines an infrared beam of light into the subject's eye and then processes the reflection from the corneal and pupil movements to provide POR coordinates. Minimal movement is required for accurate tracking however, so a chin rest placed two feet away from the camera will be utilized to ensure stabilization. The camera is placed under a flat screen, 27-inch, Sony NTSC television set which is used to display the stimulus.

3 Experiment

The experiment conducted was a between subjects design using eight students from Clemson University. Students were divided into two groups and received instructions on how to perform a cardinal direction task. Each group was given a different strategy with which to perform the task and experimenters taught each strategy to the participant prior to engaging the eye tracker. Therefore, each participant was only taught the 3D image rotation strategy or the heading referencing strategy, both of which are discussed in greater detail in sections 3.1 and 3.2 respectively.

The cardinal direction task asks the participant to identify where on a map an object is located in relation to another object. For example, "What side of the building is the red car parked on?" This was to be accomplished by comparing data from two side-by-side maps and using one of the learned strategies. One map shows a picture of a parking lot as the pilot is approaching in three-dimensional form (Figure 3). The other shows an overhead display of an aircraft approaching a target in two dimensions (Figure 4). The overhead map also displays which direction is north to give the participants a frame of reference. An example task is shown below figures 3 and 4. Answers were given in the form of directions such as North, South, East and West; however, since minimal movement is required for proper eye tracking, participants used gaze to indicate their answer so mouth movements did not disrupt calibration.



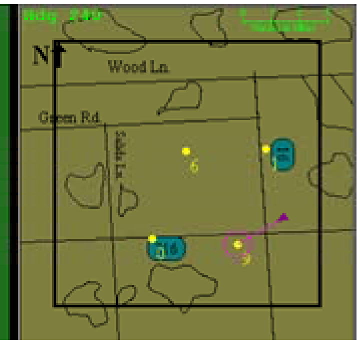


Figure 3 Figure 4

Example Cardinal direction task: Given that your aircraft's location and heading is shown by the arrow on the north-up map, and the 3D view shows target 9, ahead of the aircraft, is the parking lot with the cars north, south, east, or west of the building in the 3D view? Answer: East

After each scene was displayed, participants indicated their readiness to answer by knocking on the table. The experimenter then advanced the screen using a key press to display an answer screen (Figure 5). The screen displayed a compass configuration allowing the participant to gaze at their desired answer for at least three seconds. This answer screen also ensured the exclusion of erroneous eye movements on the map images if the subject's eyes wandered while answering the question. POR data was then generated for the corresponding regions to indicate fixations around the participant's answer. The experimenter could also view the participant's answer on the upper left Sony black and white monitor and record their response. Once the answer was given, the experimenter advanced to the next bitmap using a key press to begin the next task.

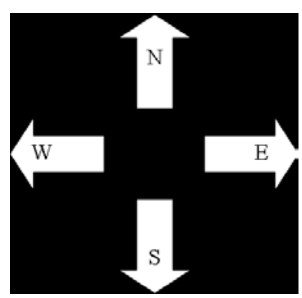


Figure 5: Answer Screen

3.1 Training

Participants went through a training process administered using a laptop computer to adequately learn their respective strategies. First, an initial training task was administered lasting approximately 7 to 8 minutes. This step allowed participants to read through a series of slides explaining the procedures in the experiment and helped familiarize them with the basic cardinal direction task. Strategies were not discussed at this point and both groups received the same initial training. This process was self-paced.

Next, the experimenter taught the participant their randomly assigned strategy using specific, standardized instructions (Appendices A and B). Participants were then shown two examples of their strategy with arrows overlaid on the bitmaps for further illustration. The participant was then asked to verbally walk the experimenter through an unlabeled practice trial to so the experimenter could determine if the strategy had been properly understood. If the participant failed to produce the correct answer, their error was explained and another bitmap was shown. The participant was then asked to try to again walk the experimenter through the problem. This series of steps was repeated until the experimenter was assured that the participant fully understood his or her assigned strategy.

After receiving the explanation of the strategy, the participant was again given the opportunity to practice 24 problems, this time using their newly learned strategy.

Following training, the participant was shown a series of 24 bitmap images and asked to use their strategy to determine the correct direction of the cars in the parking lot. Eye movements were only tracked during the testing of the final 24 bitmaps. Performance was measured as the number of maps correct out of 24. In order to record the eye tracking data, regions of interest were pre-designated and numerically labeled but were not visible to the participant. This allowed the data to be easily viewed to determine if the participant correctly performed their strategy.

The two strategies are described below and are depicted using the cardinal direction problem shown in Figures 3 and 4, in which the aircraft is headed to the southwest and the vehicles are in the east parking lot.

3.2 3D Image Mental Rotation Strategy

In this strategy, the first step is to use the 3D view and the egocentric reference frame to describe the bearing from the building to the parking lot with the cars, e.g., for Figures 3 and 4, "the lot with the cars is in front of the building and to the left". The second step integrates the egocentric description of this bearing into the reference frame of the map. This is done by applying the relative directions to the map, that is, by imagining where the parking lot with the cars would be located on the map if one were viewing the target building from the perspective of the aircraft. This step seems to involve mental rotation of the 3D configuration until it is aligned with the aircraft heading on the map. The third step involves determining the exocentric map bearing from the target building to the imagined lot with the cars, and reporting this direction. This strategy is referred to as *3D-first mental rotation*.

3.3 Heading Referencing Strategy

The other strategy that was administered to a group is the *heading referencing* strategy. In this strategy, the first step is to identify the aircraft heading from the map and give it a label, e.g., "towards the southeast", or "from the northwest." The second step is the one in which exocentric and egocentric reference frames are coordinated. This is done by mentally aligning the current heading (expressed as an exocentric-cardinal direction) with egocentric forward in the 3D view. So, given the problem in Figures 1 and 2, for the first two steps a participant might say, "We're headed southwest, so this is southwest (pointing to the top of the 3D scene)." Once the current exocentric heading has been integrated into the 3D view, it acts as a reference direction and other directions (or bearings) in the 3D view can be inferred from it. Thus, in the third step, the bearings of the parking lot(s) at the top of the 3D scene are identified, e.g., "If forward is southwest, then this is south (pointing to the upper left lot) and this is west (pointing to the upper right lot)". Finally, in the fourth step, the bearings of other lots (e.g., the north and east lots) are inferred based on the bearings identified in Step 3 and the spatial arrangement of the objects in the 3D view, and then a response is made. This strategy is called heading referencing because it involves using an exocentric heading as a reference within the 3D view.

4 Results

After testing the 8 subjects, performance data (answers correct) and eye movements were collected and analyzed. One participant in the heading referencing condition was excluded due to not properly understanding instructions. Each participant's scanpaths were analyzed to determine if the participant was using his or her respective strategy. While analysis was somewhat subjective, each map was analyzed to determine if a pattern emerged that resembled the expected pattern of either the 3D First strategy or the heading reference strategy. It was then noted whether a subject answered correctly or incorrectly and if they were using their strategy at that time.

Hypothesized patterns of eye movements will now be discussed; for purposes of explanation, a grid with relative regions of interest has been superimposed over the map in Figure 6. In the 3D First strategy, it was hypothesized that participants would first look at region 12 and then to the parking lot with the cars (regions 16 or 17) to form an angle. Then they were to mentally transpose that angle to the right side of the map, mentally rotate the angle to coincide with the heading direction of the airplane, and formulate a final direction of the airplane (regions 15 and 20). One participant's scanpath, who exhibited eye movement data consistent with the 3D first strategy that he was taught can be seen in Figure 7. In the heading reference strategy, participants were first expected to look at regions corresponding to the map arrow (regions 15 and 20) and then look at regions 2,7.or 12 to orient themselves on the 3D map. They would then look to the left and right of these regions (regions 6,11 and 7) to determine the direction of these parking lots relative to the map's center (region 17).

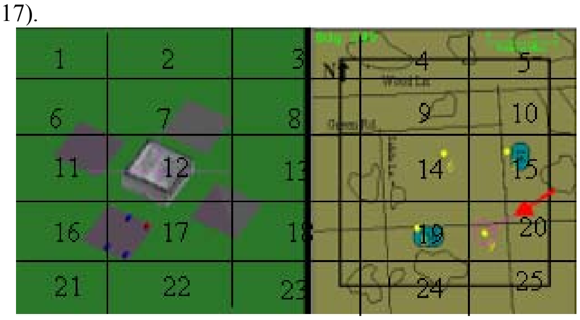


Figure 6

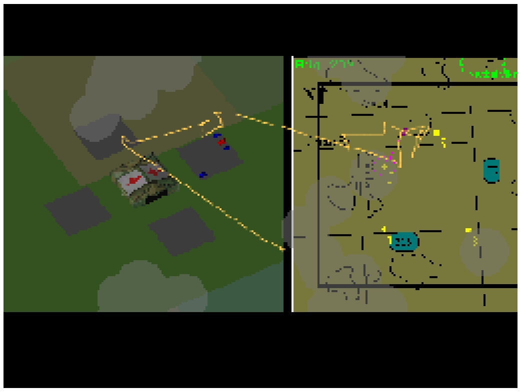


Figure 7

After the analysis, it was found that individuals using the heading referencing strategy answered 76.4% correctly while those using the 3-D first strategy answered correctly 66.7% of the time. As can be seen from the graph (Figure 8), there is not a notable difference between the participants' performances despite the different strategies; however, subject scores were quite high ranging from 20 to 24 (out of 24).

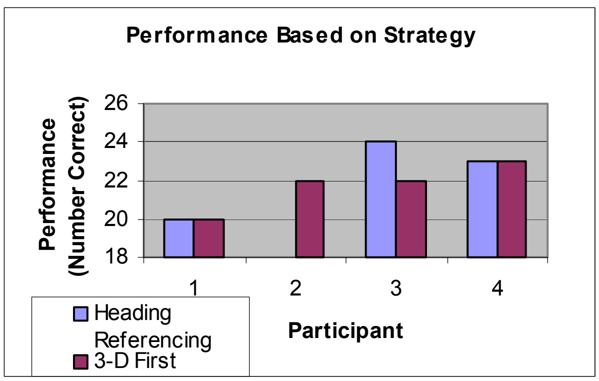


Figure 8

It was also found that subjects who were taught the heading referencing strategy used their strategy on 50% of the trials, and the 3-D first strategy was used on 74% of the trials. After conducting a one-sample t-test it was found that a significant number of subjects did not use each strategy.

Despite this finding, the maps were further analyzed to uncover additional eye movement patterns. Some individuals exhibited eye movements in which they did not look directly at the arrow in the heading referencing map such as in Figure 9. Since ROI entrances and exits were recorded, it is possible that subjects viewed these portions of the maps in their periphery. Some participants also exhibited a back and forth motion, with eye movements moving from one map to the other in a horizontal motion. One participant in particular consistently looked ahead of the arrow in the heading referencing strategy before referring to the 3-D map as can be seen in Figure 10.

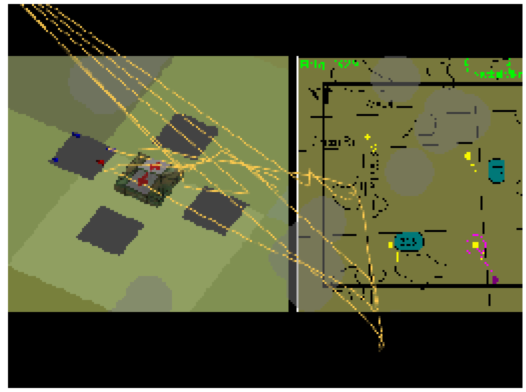


Figure 9

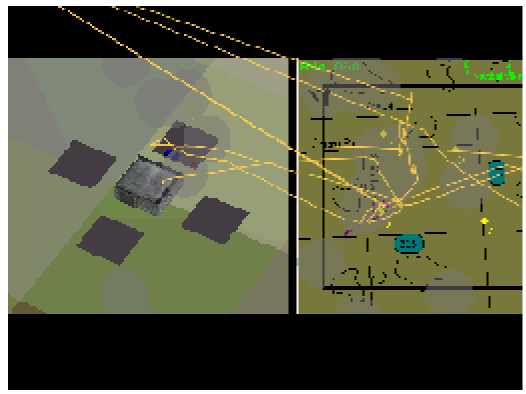


Figure 10

5 Discussion

The current study was completed as a mechanism to gain a better understanding of the strategies that participants will use when given specific training. Eye movement data was recorded and analyzed to determine if an individual utilized the strategy they were taught and if one strategy was superior to the other in terms of performance. It was hypothesized that depending on the strategy utilized, participants would use a particular set of eye movements respectively.

The analyses showed that there does not appear to be a significant difference in the performance (number of correct answers) depending on the strategy used. Additionally, the results showed that individuals did not use the strategy they were taught a significant percentage of the time.

Although the hypothesis was not supported in the current study, some alternative explanations should be considered. One notable drawback in our data analysis may be the subjective means by which we analyzed the eye movement data. Specific sequences of eye movements are essential in determining if the appropriate strategy was used. Although analyzing scanpaths is a logical way to determine the strategy followed, it leaves a large amount of room for error because of the subjective nature of a scoring procedure. Alternatively, better results may be found if a more objective means of analyzing the patterns of eye movements was applied.

Additionally, another possibility for not finding the results we expected could be due to the ways in which individuals applied a specific strategy. Specifically, in the 3D first strategy, a key component was to rotate an angle that was formed from the previous map. Although such an angle can be drawn on paper and can be taught through a strategy, the corresponding eye movements may not be evident in the actual eye movement data. Although we found this to be the case for few participants, many participants' scanpaths were inconclusive on angle formation. For example, when a person uses the strategy and mentally rotates this angle, they may not rotate it in eye movements, rather, they may rotate it in their "mind's eye". This does not necessarily imply that they were *not* using the strategy taught, rather, they didn't form the angles with their eyes the way that was expected initially.

For future research on the cardinal direction task, we recommend that it may be more beneficial to give individuals less training, thus, most likely resulting in more incorrect answers. Although, when applying a chosen strategy in a real work domain, the goal is to minimize mistakes; however, while comparing different strategies for research purposes, individuals giving more incorrect answers may provide more insight given different strategies.

Future research may explore adding more sensitive measures, such as response time, to determine differences in the two strategies. Cardinal direction navigation tasks are good candidates for the development of training and of tests that assess individual differences in skill levels. Applying the aforementioned recommendations to ongoing research would aid in moving a step closer to this development.

6. References

ARETZ, A.1991 The design of electronic map displays. In *Human Factors*, 33, 85-101

GUGERTY, L. AND BROOKS, J. in press. Seeing where you are heading: Integrating environmental and egocentric reference frames in cardinal direction judgments, *Journal of Experimental Psychology*, Applied.

Appendix A

<u>Heading Referencing Strategy training</u>

Now I'm going to show you a strategy for solving the kind of problems you just worked on. I'd like you to learn this strategy and use it while you are solving some more of these problems in the next phase of the study.

1. Here is a problem. In this strategy, first look at the map and figure out what direction the plane is heading in. Here it's headed to the southwest. [point from base of arrow to SW]

2. Then look over to the 3D view. The direction the plane is heading in is always towards the top of the 3D view, so this direction is southwest [point upward from base to tip of arrow]

3. Since this is southwest [point to tip of arrow], then this must be south [point from tent to S] and this must be west [point from tent to W].

4. Since this is the west lot [point to the W], this must be east [point to E]. And since this is south [point to S], this must be north [point to the N]. So the cars are in the north lot.

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5. I'll go through the strategy on a new problem. First look at the map and figure out what direction the plane is heading in. Here it's headed to the east. [point from base of arrow to E]

6. Then look over to the 3D view. The direction the plane is heading in is always towards the top of the 3D view, so this direction is east [point upward from base to tip of arrow]

7. Since this is east [point to tip of arrow], then this must be west [point to the W], this must be north [point to N]. And this is south [point to S]. So the cars are in the south lot.

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8. Now you apply the strategy to this problem. Please point to the figures and tell me in words how you are doing it.

[If they apply the strategy correctly, say:]
That's correct. We're done with the strategy training. Please try to you use this strategy on every problem in the next phase of the study. Here is a diagram that will remind you how the strategy works. You can refer to it anytime during the next set of problems. [give the diagram]

[If they apply the strategy incorrectly, go on to the next slide and say:]

9. That was not quite right, so I'll go through the same problem using the strategy. First look at the map and figure out what direction the plane is heading in. Here it's headed to the southeast. [point from base of arrow to SE]

10. Then look over to the 3D view. The direction the plane is heading in is always towards the top of the 3D view, so this direction is southeast [point upward from base to tip of arrow]

11. Since this is southeast [point to tip of arrow], then this must be south [point from tent to S] and this must be east [point from tent to E]. So the cars are in the east lot.

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12. Now you apply the strategy to this problem. Please point to the figures and tell me in words how you are doing it.

[If they apply the strategy correctly, say:]
That's correct. We're done with the strategy training. Please try to you use this strategy on every problem in the next phase of the study. Here is a diagram that will remind you how the strategy works. You can refer to it anytime during the next set of problems. [give the diagram]

[If they apply the strategy incorrectly, go on to the next slide and say:]

13. That was not quite right, so I'll go through the same problem using the strategy. First look at the map and figure out what direction the plane is heading in. Here it's headed to the west. [point from base of arrow to W]

14. Then look over to the 3D view. The direction the plane is heading in is always towards the top of the 3D view, so this direction is west [point upward from base to tip of arrow]

15. Since this is west [point to tip of arrow], then this must be east [point to the E], this must be north [point to N]. And this is south [point to S]. So the cars are in the south lot.

We're done with the strategy training. Please try to you use this strategy on every problem in the next phase of the study. Here is a diagram that will remind you how the strategy works. You can refer to it anytime during the next set of problems. [give the diagram]

Appendix B

3D First Strategy training

Now I'm going to show you a strategy for solving the kind of problems you just worked on. I'd like you to learn this strategy and use it while you are solving some more of these problems in the next phase of the study.

1. Here is a problem. In this strategy, first look at the 3D view [point to center of 3D view] and notice where the cars are relative to the tent. So if you flew up to the tent and turned to fly to the cars you would make this angle pointing to the right. [point from base of angle to tent to cars]

2. Then look over to the map and imagine what this same angle would look like on the map [point to angle on map].

Since this part of the angle shows where the plane is heading [ON 3D VIEW point from base of angle to tent; then ON MAP point from base of angle to where it bends], you have to rotate the angle to line it up with where the plane is heading on the map. This is where the plane is heading. [point to plane and then to the circle where the plane is headed]

3. Here the angle has been rotated to line up with where the plane is heading. [ON MAP point from base of angle to where it bends]

So now this part of the angle points to the lot with the cars [ON MAP point from where the angle bends to tip of arrow], just like this part of the angle points to the cars in the 3D view [ON 3D view point from where the angle bends to cars].

Now you can read from the map the direction to the lot with the cars [ON MAP point from where angle bends to tip of arrow and then move in same direction to point to edge of map]. In this case, the cars are in the north lot.

4. I'll go through the strategy on a new problem. First look at the 3D view [point to center of 3D view] and notice where the cars are relative to the tent. So if you flew up to the tent and turned to fly to the cars you would make this angle pointing to the left. [point from base of angle to tent to cars]

5. Then look over to the map and imagine what this same angle would look like on the map [point to angle on map].

Since this part of the angle shows where the plane is heading [ON 3D VIEW point from base of angle to tent; then ON MAP point from base of angle to where it bends], you have to rotate the angle to line it up with where the plane is heading on the map. This is where the plane is heading. [point to plane and then to the circle where the plane is headed]

6. Here the angle has been rotated to line up with where the plane is heading. [ON MAP point from base of angle to where it bends]

So now this part of the angle points to the lot with the cars [ON MAP point from where the angle bends to tip of arrow], just like this part of the angle points to the cars in the 3D view [ON 3D view point from where the angle bends to cars].

Now you can read from the map the direction to the lot with the cars [ON MAP point from where angle bends to tip of arrow and then move in same direction to point to edge of map]. In this case, the cars are in the south lot.

7. Now you apply the strategy to this problem. Please point to the figures and tell me in words how you are doing it.

[If they apply the strategy correctly, say:]

That's correct. We're done with the strategy training. Please try to you use this strategy on every problem in the next phase of the study. Here is a diagram that will remind you how the strategy works. You can refer to it anytime during the next set of problems. [give the diagram]

[If they apply the strategy incorrectly, go on to the next slide and say:]

8. That was not quite right, so I'll go through the same problem using the strategy. First look at the 3D view [point to center of 3D view] and notice where the cars are relative to the tent. So if you flew up to the tent and turned to fly to the cars you would make this angle pointing to the left. [point from base of angle to tent to cars]

9. Then look over to the map and imagine what this same angle would look like on the map [point to angle on map].

Since this part of the angle shows where the plane is heading [ON 3D VIEW point from base of angle to tent; then ON MAP point from base of angle to where it bends], you have to rotate the angle to line it up with where the plane is heading on the map. This is where the plane is heading. [point to plane and then to the circle where the plane is headed]

10. Here the angle has been rotated to line up with where the plane is heading. [ON MAP point from base of angle to where it bends]

So now this part of the angle points to the lot with the cars [ON MAP point from where the angle bends to tip of arrow], just like this part of the angle points to the cars in the 3D view [ON 3D view point from where the angle bends to cars].

Now you can read from the map the direction to the lot with the cars [ON MAP point from where angle bends to tip of arrow and then move in same direction to point to edge of map]. In this case, the cars are in the east lot.

11. Now you apply the strategy to this problem. Please point to the figures and tell me in words how you are doing it.

[If they apply the strategy correctly, say:]
That's correct. We're done with the strategy training. Please try to you use this strategy on every problem in the next phase of the study. Here is a diagram that will remind you how the strategy works. You can refer to it anytime during the next set of problems. [give the diagram]

[If they apply the strategy incorrectly, go on to the next slide and say:]

12. That was not quite right, so I'll go through the same problem using the strategy. First look at the 3D view [point to center of 3D view] and notice where the cars are relative to the tent. So if you flew up to the tent and turned to fly to the cars you would make this angle pointing to the right. [point from base of angle to tent to cars]

13. Then look over to the map and imagine what this same angle would look like on the map [point to angle on map].

Since this part of the angle shows where the plane is heading [ON 3D VIEW point from base of angle to tent; then ON MAP point from base of angle to where it bends], you have to rotate the angle to line it up with where the plane is heading on the map. This is where the plane is heading. [point to plane and then to the circle where the plane is headed]

14. Here the angle has been rotated to line up with where the plane is heading. [ON MAP point from base of angle to where it bends]

So now this part of the angle points to the lot with the cars [ON MAP point from where the angle bends to tip of arrow], just like this part of the angle points to the cars in the 3D view [ON 3D view point from where the angle bends to cars].

Now you can read from the map the direction to the lot with the cars [ON MAP point from where angle bends to tip of arrow and then move in same direction to point to edge of map]. In this case, the cars are in the south lot.

We're done with the strategy training. Please try to you use this strategy on every problem in the next phase of the study. Here is a diagram that will remind you how the strategy works. You can refer to it anytime during the next set of problems. [give the diagram]