Rehearsal versus Map Study as Preparation for a Flight Navigation Exercise

Randall Bone, University of Illinois at Urbana-Champaign, Institute of Aviation, Savoy, Illinois, and **Gavan Lintern,** Defense Science and Technology Organization, Melbourne, Victoria, Australia

A flight simulator and a computer-generated depiction of an environment with both natural and cultural features were used to teach and test navigation knowledge. Conditions of guided rehearsal, unguided rehearsal, and map study were used to familiarize participants with the navigation environment. A subsequent route-following test of navigation knowledge in the simulated environment showed that unguided rehearsal was better than map study or guided rehearsal for the development of route knowledge. In addition, a pointing task revealed that unguided mission rehearsal was as good as map study for the development of survey knowledge. Actual or potential applications of this research include the use of simulator-based mission rehearsal for military flight operations.

INTRODUCTION

In navigation, unfamiliarity with an area commonly induces a sense of discomfort. Subjectively, the danger of a navigational error seems much higher in an unfamiliar area than in a familiar one. Often the only practical means of overcoming unfamiliarity is via simulation, with which it is possible to prepare for a mission through unfamiliar terrain by rehearsing the mission as closely as the simulator will permit. However, despite the intuitive appeal of simulated mission rehearsal, no published data show benefits of mission rehearsal in contrast to forms of preparation such as study of maps or other briefing material.

The experiment reported here was designed to test whether rehearsal in a simulator could enhance the preparation of aviators for navigation through unfamiliar terrain. The navigational task and scenario had diverse features designed to help us assess how navigational performance might be enhanced and what dimensions of knowledge and performance might benefit from mission rehearsal.

REPRESENTATIONAL ISSUES

Two forms of navigational knowledge could be affected differently by different forms of rehearsal. Route knowledge involves understanding how to proceed from point to point by following a set of procedures and is characterized by appreciation of sequential locations without appreciation of global relationships (Hirtle & Hudson, 1991). Survey knowledge is the map-like understanding that supports generalization beyond learned routes and permits one to locate objects within a global frame of reference (Hirtle & Hudson, 1991).

The normal mode of preparation for a navigation exercise is to use maps and other briefing materials. These are, however, incomplete representations of the space they depict. Of particular relevance for this experiment is that there is always a scale transformation in transfer from map to world. In contrast, a simulated rehearsal scene can accurately represent size differences between features and their spatial relationships. That information could potentially support acquisition of route knowledge during rehearsal and its transfer to the real environment. However, it is possible that map study supports better acquisition of survey knowledge by display of layout and spatial relations for locations not within visual range of each other and for locations off the route. Although route knowledge can support navigation of a fixed route, survey knowledge

Address correspondence to Gavan Lintern, Air Operations Division, Defense Science Technology Organization, P.O. Box 4331, Melbourne, Victoria 3001, Australia; gavan.lintern@dsto.defence.gov.au. **HUMAN FACTORS,** Vol. 41, No. 3, September 1999, pp. 467–473.

remains important in aviation because it supports adaptive behavior when a route needs to be modified with minimum warning.

This is an issue for navigation by visual reference, which is a key component of many flight missions. Stewart (1986), in his commentary on the loss of an Air New Zealand DC-10 at Mt. Erebus, Antarctica, in 1979 noted that "if (the captain) had previous experience of the area…the distinctive shape of the island would have been recognized and would have instantly indicated…position" (p. 194). It is not uncommon for pilots to land at an incorrect airport that is of similar layout and close to the desired airport (Bone, 1998), and a recent incident of this type involving a major commercial airline has been reported (Scott, 1997). Such events can result in accidents because the wrong runway can be too short or otherwise unsuitable for the aircraft. Accidents and incidents involving landings at the wrong airport occur predominantly in good visual flight conditions, not in poor conditions, as might be expected (Antunano, Mohler, & Gosbee, 1989; Bone, 1998). Experience with distinguishing and embedding features not provided in maps (e.g., style of buildings, type of surrounding vegetation) could help pilots avoid this sort of error.

Guided Practice

Guidance is the use of additional task constraints or information that will help the performer reduce deviations from an ideal performance. Guided practice can help a learner approach near-errorless performance during training. A specific assumption of the guided practice research is that only relatively successful performances facilitate the acquisition of desired skills (Welford, 1968). However, research results do not universally favor guidance over the more common instructional method of providing knowledge of results in conjunction with unguided practice. Holding and Macrae (1964, 1966; also see Macrae & Holding, 1965) have tested the effects of guidance with mixed results. Although one of their experiments showed an advantage for guided practice, others showed no advantage and sometimes a disadvantage.

It is also possible that guidance will disrupt learning of navigational skills. Participants will presumably need to attend to various natural and cultural features during practice to learn to recognize them for later performance of the task. The addition of guidance in training would remove any immediately compelling need to attend to that information. Lintern (1980) has shown that acquisition of landing skill can be disrupted by the presence of guidance information that distracts attention from important perceptual information. Whether this type of effect would be present in a navigational task is unknown. Thus it is not possible at this stage to predict whether guidance would facilitate or disrupt familiarization of a navigation task.

Outline of the Experiment

This experiment was configured to assess the differences between rehearsal (with and without guidance) and map study. Following rehearsal or map study, participants were required to navigate through an environment and also to point to objects within the navigational database but out of sight. To ensure that all participants were faced with a transfer task, we enhanced the visual fidelity of the test task in relation to that of the rehearsal task. This manipulation was intended to be analogous to the change in fidelity that occurs in transfer from a simulator to an aircraft.

Three hypotheses are examined: that unguided rehearsal would result in better route knowledge than would map study; that guided rehearsal would produce better route knowledge than unguided rehearsal; and that map study would result in better survey knowledge than unguided rehearsal. Survey knowledge was assessed after rehearsal or map study with the pointing task, and route knowledge was then assessed by a test of navigation performance (without guidance) in simulated flight.

METHOD

Participants

The participants were 36 active pilots (31 men, 5 women). Their median age was 23 years, and their median total reported flight time was 272.5 h. All participants had a private pilot license (or the military equivalent) and prior experience in cross-country navigation (median = 80.0 h). They were paid $7.50 for a session that lasted slightly longer than 1 h.

Simulator

The navigation mission was undertaken in a simulator, which was composed of a joystick, simplified helicopter-like dynamics, and a computer-generated visual scene. The control was a FlightStick model joystick manufactured by CH Products. A top pushbutton was used to start each trial, and the trigger was used to signal start and stop times for the pointing task. The joystick permitted first-order control of pitch and bank angle. Airspeed was set to 115 knots, though airspeed varied throughout the flight to a minor extent in climbs and descents. Thrust and yaw were automatically set by the system.

Flight instrumentation was displayed on a Silicon Graphics 16-inch (40.64 cm) color monitor located 90 cm in front of the participant's eyepoint. The monitor was positioned so that it did not restrict the view of the computer-generated visual scene. A radar altimeter located on the right side of the monitor displayed altitude above ground level (AGL). An attitude indicator located in the center of the display showed the chosen pitch attitude as well as bank angle. The system was limited to a maximum bank angle of 30°. The heading indicator was located at the top of the monitor; it was removed from the flight display for the testing session.

The visual scene was generated with an Evans and Sutherland SPX500T image generator with an update rate of 50 Hz. Two Electrohome ECP 3000 color projectors were used to project the images on two screens, each measuring 228.6 cm high and 304.8 cm long. One screen was positioned 300 cm in front of the participant, and the other was offset to the participant's left at the same distance, adjoining but set at a 115° angle to the other screen. The two screens allowed a 38° vertical × 112° horizontal viewing angle (27° to the right and 85° to the left of centerline). All but one of the turns within the navigational environment were to the left. The center screen was adequate for straight-ahead flight, but the left screen provided additional useful detail for turns to the left.

The Navigation Task

The navigation area was approximately 13.5 × 13.5 nautical miles (nm). The topography of the area included both flat and hilly terrain with rivers, roads, and buildings. A course of five legs of 22.3 nm total length (individual legs ranged from 3.7 to 5.0 nm) was to be flown through the environment. The range in altitude of this course was 750 feet. Maintenance of 150 feet AGL required vertical speeds of approximately ±1500 feet/min in the climbing and descending portions of the route.

An automatic procedure was programmed to reset the participants' simulation to the start point for the next leg (with heading aligned with the course of that leg) if elapsed time for the current leg was 30% greater than a criterion time. That criterion time had been established from the time taken by an experimenter to fly it with the guidance available.

The low-detail world used in the rehearsal flights contained all the same objects as the high-detail world but differed in the appearance of those objects. In the low-detail world the portrayed hills appeared to be more block-like than those of the high-detail world. Additionally, all objects such as buildings and bridges were represented as gray blocks. In development of this representation, the intent was to use a level of detail that would be available with a less-expensive image generation system.

Procedure

Participants were randomly divided into three groups: map study, unguided rehearsal, and guided rehearsal.

Familiarization

Participants were given a practice flight of approximately 5 min through a low-detail navigation area that was not part of the area used in the remainder of the experiment. They were required to follow a route depicted by a red line. They were instructed to use 30° of bank for at least one turn because this was what they would be using in the subsequent trials. The primary purpose of this session was to familiarize participants with the characteristics of the simulator and with the control requirements of the main experimental task.

Mission Rehearsal

After familiarization, participants were given the preparatory experience specific to their group. The map study group studied the predetermined route on a map of the navigation environment. They studied the map as they chose for 12 min and then were required to spend another 12 min mentally tracing the path, stating aloud landmarks that they would pass along the route and the heading they would be required to fly for each leg.

Both the guided and unguided rehearsal groups were exposed to the navigation task by the requirement that they fly twice along the predetermined route in the low-fidelity version of the simulated environment. On the first flight participants followed the path and observed as they deemed appropriate. During the second flight they were required to identify landmarks as they passed them and to state the approximate heading for each leg. Each of these flights lasted approximately 12 min.

For the guided rehearsal group, a red line showed the predetermined route. This group did not have access to the map on either of the rehearsal flights. The unguided rehearsal group flew the same low-detail depiction as the guided rehearsal group but without the red line and with the map for route information. Participants in this group were given approximately 30 s to examine the map's detail and its legend prior to the first rehearsal flight. The intent was to be sure that they understood the map layout without being able to actually study the route or the simulated area.

Testing

There were two testing tasks. The first was to point to each of several targets. Participants were placed at the start of a leg and on the course heading of that leg at 150 feet AGL. They were stationary but could pivot via the joystick. They were to start the trial by squeezing the trigger on the joystick after a prompt and then pivoting in the estimated direction of the target as if they were going to fly toward it. The time required to point to the target and the bearing error to the target were recorded. There were either two or three targets for the start point of each leg. The targets were partitioned into three types: on or within 30° of the current leg (four targets), on or near another leg but within 30° of the course heading of the current leg (three targets), and on or near another leg but more than 75° from the course heading of the current leg (six targets). The first type (on the current leg) was viewed as a test of route knowledge. The other two types were viewed as tests of survey knowledge.

The second task was a test flight through the high-detail depiction of the navigational area. The heading indicator was removed from the flight display. The guidance was not shown, and participants were not given access to a map. They were to navigate to the best of their ability from waypoint to waypoint solely by their memory of the navigational environment. Horizontal and vertical root mean square (RMS) errors from the desired course and from the prespecified altitude were recorded.

RESULTS

Each of the recorded values was transformed to its natural logarithm to approximate more closely the assumptions of normality and equality of variances. The significance of differences between means was examined with single-factor multivariate analyses of variance (MANOVAs), which included all relevant univariate tests. Rehearsal condition (two levels in rehearsal and three levels in testing) was the independent factor. Wilks's lambda was used as the criterion. For analyses in which three groups were tested, a significant lambda ($p < .05$) was followed by multivariate planned comparisons on the orthogonal contrasts of map study versus unguided rehearsal and of unguided rehearsal versus guided rehearsal. Univariate tests on single dependent measures were conducted after demonstrated multivariate significance between two levels of an independent variable.

When multiple performance measures are used in an experiment, the decision to use univariate versus multivariate tests of significance should be based on the strength of the partial correlations between them (Tabachnick & Fidell, 1989). If those correlations are low, the performance measures may be viewed as independent of one another, and univariate tests are preferable. If the partial correlations are high, the performance measures must be viewed as interdependent (e.g., speed and accuracy are interdependent in a speed-accuracy trade-off paradigm), and multivariate tests are required.

In such a case the univariate tests are informative about the control strategy in trading off attention over the two dimensions of performance. They are not, however, a reliable indicator of ability or knowledge as it relates to either dimension of performance.

In the absence of any specific guidance from Tabachnick and Fidell (1989) regarding what should be regarded as a low correlation, .3 was selected as a cutoff value below which the association between variables could be considered trivial.

Mission Rehearsal Session

The mission-rehearsal performances of the guided and unguided rehearsal groups were analyzed by MANOVA with $\log_e$ RMS horizontal and vertical errors as performance measures. Based on relatively high correlations with the dependent measures, gender and cross-country time were entered as covariates. Multivariate tests were used because three of the partial correlations between performance measures exceeded .3. By these tests, performance was significantly better for guided rehearsal on all legs: Leg 1, lambda(2, 19) = 34.90, $p < .001$; Leg 2, lambda(2, 19) = 9.25, p = .002; Leg 3, lambda(2, 19)= 16.03, $p < .001$; Leg 4, lambda(2, 19) = 58.83, $p < .001$; Leg 5, lambda(2, 19) = 53.85, $p < .001$.

Testing Session: Pointing Task

Participant performance in the map study, guided rehearsal, and unguided rehearsal groups was analyzed by MANOVA with $\log_e$ time-to-target-acquisition and $\log_e$ bearing error as performance measures. Univariate measures were considered valid for the current leg and > 75°-bearing other-leg target sets (partial correlations = .20 and .02) but not for the < 30°-bearing other-leg target set (partial correlation = .36). The only significant result was for bearing error with the > 75°-bearing other-leg target set, $F(2, 31) = 5.04$, $p = .013$. Paired contrasts showed a significant difference between the guided and unguided rehearsal groups, $F(1, 31) = 9.77$, $p = .004$. Bearing error was lower for the unguided rehearsal group. Bearing error for the map study group lay between bearing errors for the other two groups but was not significantly different from either.

Testing Session: Navigation Trial

Performance in the map study, guided rehearsal, and unguided rehearsal groups was analyzed by MANOVA with $\log_e$ RMS horizontal and vertical error as performance measures. Gender and cross-country time were entered as covariates. Multivariate tests were used because partial correlations between dependent measures exceeded .30 (range: .48–.59). Wilks' lambda was significant for Leg 1, lambda(4, 60) = 9.31, $p < 0.001$; Leg 3, lambda(4, 60) = 3.25, $p = .018$; and Leg 4, lambda(4, 60) = 2.53, $p = .049$. For Leg 1, the paired contrast of the unguided rehearsal group with the map study group was significant, lambda(2, 31) = 11.19, $p < .001$. Leg 3 showed significant paired contrasts of the unguided rehearsal group with the map study group, lambda(2, 31) = 3.63, $p = .039$, and with the guided rehearsal group, lambda(2, 31) = 5.62, $p = .008$. For Leg 4, the paired contrast of the unguided rehearsal group with the guided rehearsal group was significant, lambda(2, 31) = 4.86, $p = .015$. The directions of the trends are shown in Figure 1.

DISCUSSION

Unguided mission rehearsal proved to be better preparation than map study for the test of route knowledge. There has been considerable discussion of the use of a simulator for mission rehearsal, but these data are the first to offer objective support for this approach to preparing for a flight mission. In two of the five navigation legs of the test flight, unguided rehearsal demonstrated a clear and statistically significant advantage over map study.

The availability of guidance in rehearsal had a negative effect on navigational performance in the test phase when guidance was no longer available. Those effects were evident primarily on altitude control in this experiment. The guidance manipulation was directed at affecting navigational performance, so any differences in vertical error among groups can be taken as an attentional or workload effect. Especially when course deviation errors are similar, differences in altitude error suggest that participants were working harder or

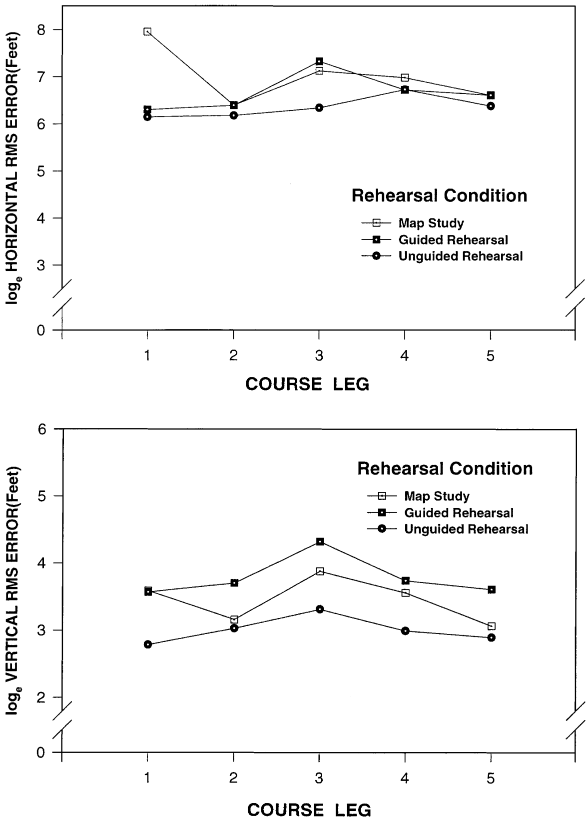

Figure 1. Mean lateral and vertical RMS errors (transformed to their natural logarithms) for the test flight of the map study, guided rehearsal, and unguided rehearsal groups.

diverting more attentional resources from vertical control to achieve a satisfactory level of horizontal control.

Participants who rehearsed with the guidance were able to maintain an accurate course on all but one leg in the test trial, but they did so at some cost in cognitive workload, as shown by their relatively large vertical error. Thus although these participants could identify sufficient visual features for good navigation, that identification apparently demanded more effort. This higher level of effort continued through all legs of the navigation task, suggesting that it is a particularly robust effect. In contrast, participants in the unguided rehearsal group maintained a low level of vertical error, indicating that they had to divert relatively little attention to detection and recognition of navigational features.

Guided rehearsal might assist performance in a subsequent unguided test trial if navigational errors or workload during unguided rehearsal were so great that they would disrupt familiarization with the course. In this experiment horizontal errors were larger during unguided rehearsal, but only once did a participant in that group stray so far from course that the automatic reset procedure was activated. The similarity of vertical error scores during guided and unguided rehearsal suggests that there was no difference in workload between these two conditions. This lack of disruptive errors or of differential workload may have precluded the possibility of any enhancement in the test trial from guided rehearsal.

The negative potential of guidance is that it may divert attention from the navigational features that should be attended to if mission rehearsal is going to enhance performance on a navigational exercise. The enhanced rehearsal performance with guidance indicates that participants did attend to the guidance feature with a possible cost in attentiveness to navigational features. The lowered performance in the test flight suggests that this inferred diversion of attention from the navigational features had a deleterious effect. We continue to believe that guidance can assist in transfer to an unguided exercise, but only if it focuses attention on critical information. For constant guidance, as used here, workload or error must be so high for unguided rehearsal that they preclude meaningful learning, or else some form of adaptation or withdrawal as tested by Lintern (1980) will be necessary.

Map Study for Development of Survey Knowledge

Survey knowledge remains important even for a prespecified course because unanticipated events may require a diversion to a new course. The prevailing view in the literature is that survey knowledge is better developed by map study than by active rehearsal of a specific route (Thorndyke & Hayes-Roth, 1982; Williams, Hutchinson, & Wickens, 1996). Although they do not necessarily invalidate the results of those other studies, our results show no advantage for acquisition of survey knowledge from map study over that from active rehearsal of a specific route. Whereas guided rehearsal resulted in poor acquisition of survey knowledge, as revealed by the > 75°-bearing other-leg target set of the pointing task, unguided participation of the rehearsal or of the map study form resulted in equally good acquisition of survey knowledge.

The conflicting ideas regarding the acquisition of survey knowledge indicate that a more comprehensive test of survey knowledge is needed. An active control test in which participants are required to divert to a new waypoint or to adjust the route while partway through a preplanned route would seem to offer a more valid test of this issue. It was not possible to undertake such a test of survey knowledge in the present experiment, but it is an approach we plan to consider for future work.

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Randall Bone is a human factors specialist at the MITRE Center for Advanced Aviation System Development. He received his M.S. in psychology in 1998 from the University of Illinois at Urbana-Champaign.

Gavan Lintern is head of human factors at the Defence Science & Technology Organisation, Air Operations Division, Australia. He received his Ph.D. in psychology in 1978 from the University of Illinois at Urbana-Champaign.

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