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Mission rehearsal poses new opportunities and new challenges for flight simulation. The general issue, how to promote transfer to the criterion task, is the same for mission rehearsal as it is for training. On the other hand, the goal of mission rehearsal is to promote sensitivity to or awareness of contextual details that are crucial to success of a specific mission while the goal of training is to develop generic skills. It is not clear, at this stage, what implications these different goals have for the design of simulators. For the navigation mission examined here we hypothesized that high workload and restricted visibility would distract attention from important navigation information and thereby slow development of navigation knowledge. Both experimental manipulations had the hypothesized effect under some experimental conditions but not under others. The differential effectiveness of the manipulation under different conditions offers some insight into the nature of the navigation-relevant information that can be enhanced by mission rehearsal.

Introduction

Within aviation and other technological work environments where operators control complex systems, simulators have found use primarily as devices for teaching or maintaining general skills. Mission rehearsal (familiarization of an experienced operator with a specific task scenario) offers a different opportunity for simulators to enhance operational performance. The use of mission rehearsal during the conflict in Bosnia (Defense Mapping Agency, 1997) demonstrates a perceived need in the operational community. In addition, there is a class of relatively common aviation incidents that can be characterized as misinterpretations by experienced pilots due to unfamiliarity with specific contextual details of a mission (Bone, 1997).

Workload

Underlying the interest in mission rehearsal is the belief that unfamiliarity with certain specific details of a scenario can disrupt smooth progress through that mission. From this perspective, a pilot who is rehearsing a mission should be given the opportunity to attend to those specific details. High workload is one feature of a rehearsal that might prevent that. Lintern and Wickens (1991) have reviewed data which suggest that high workload on one task can impede learning of another concurrent task.

The most direct evidence of the impact of workload on learning is from studies by Nissen and Bullemer (1987) and Lindberg and Garling (1982). Nissen and Bullemer (1987) demonstrated that the learning of response pattern could be slowed by a concurrent secondary task. Lindberg and Garling (1982) similarly showed that a concurrent secondary task could slow learning of distance and direction judgments in a simplified navigation task. The body of research in this area is vulnerable, however, to the criticism that the tasks considered were, at best, simplified abstractions of real-world tasks.

As a means of exploring the workload issue in this experiment, order of roll control was manipulated during rehearsal. Some subjects rehearsed on a system with first-order (velocity) roll dynamics during familiarization sessions and others rehearsed on a system with second-order (acceleration) roll dynamics. We assumed that by changing the roll dynamics in this manner we would change the difficulty of basic control. Subjects with second-order roll dynamics should have to pay more attention to flight control and would thereby have their attention diverted from navigation. We hypothesized that this would degrade the effectiveness of rehearsal.

From one perspective, this sort of manipulation falls into the category of a difficulty manipulation. There is considerable uncertainty expressed in the literature regarding the effects of transfer from easy to difficult and difficult to easy tasks (Holding, 1961; Lintern, Roscoe, & Sivier, 1990). In this study we chose to examine both directions of transfer by having all subjects fly systems with first- and second-order roll dynamics in separate (and counterbalanced) transfer trials. By this strategy we were able to assess the effects of transfer from easy to difficult and from difficult to easy conditions relative to the appropriate control conditions of easy-to-easy and difficult-to-difficult transfer respectively.

Visibility

There is uncertainty about the type of scenario-specific information that is crucial to a successful mission. In a navigation task of the type used in this experiment, it may be landmark knowledge, which is knowledge of specific details of a route to be followed (Golledge, 1991; Hirtle & Hudson, 1991). On the other hand, it may be survey knowledge, which is knowledge of layout and of relationships between features (Hirtle & Hudson, 1991). It is also possible that different types of navigational challenges will impose burdens on different types of knowledge. For example, a straight route between two waypoints may be supported effectively by recognition of individual features while a winding course between two waypoints may require a better sense of global spatial relationships.

This issue was examined by manipulation of visibility in rehearsal. The criterion mission was to navigate the route under restricted visibility. Some subjects rehearsed the route with unrestricted visibility and others with the mission level of restricted visibility. Transfer to the less difficult condition of unrestricted visibility was of some interest but was not tested in this experiment because the transfer trials already incorporated a rather complex set of issues.

We propose that rehearsal with restricted visibility will be advantageous if specific navigational features on or near the course are important but that rehearsal with unrestricted visibility will be advantageous when information some distance off course is needed for learning the spatial layout of the course. Individual legs varied in characteristics we hypothesized to be important. Some legs were rich and others poor in landmark and route knowledge and, while most legs were straight, one wound through a series of hills. We hypothesized that the winding leg and also legs poor in landmark and route knowledge would benefit from rehearsal with unrestricted visibility during rehearsal because that condition would offer subjects more opportunity to become attuned to off-course information.

Method

Subjects

The experimental design called for 48 subjects. Four whose runs resulted in missing data due to system crashes and another who did not return for a scheduled session were replaced.
Forty-eight pilots (34 male and 14 female) completed the experiment. All were working towards a private pilot license in the pilot training program at the University of Illinois and, as a result, had some prior navigational training. Individual levels of flight experience ranged between 30 and 120 hours with a median of 46 hours. All subjects had 20/20 vision or better (corrected or uncorrected) and were aged between 18 and 31 years.

Apparatus and Stimuli

Visual imagery was generated at an update rate of 50Hz with an Evans and Sutherland (E&S) SPX 500T image generator and projected by two Electrohome ECP 3000 color projectors onto screens each measuring 304.8 cm by 228.6 cm. The right-hand screen was placed directly in front of the viewpoint and the left-hand screen to the left at an angle of 115 degrees for a viewing angle of 112 x 38 degrees (27 degrees right to 85 degrees left of the centerline) at a viewing distance of 300 cm. An offset to the left was used because all waypoint turns but one were to the left. Consequently, most of the critical navigational information was located either straight ahead or to the left of the current heading.

Flight instruments were generated by an IRIS Silicon Graphics Computer and displayed in a head-down location on a separate monitor. Heading was displayed at the top of the screen in both analogue and digital forms. The analogue display gave subjects a better sense of direction of the turn while the digital display supported more precise judgments. Altitude above ground (AGL) was presented on a vertical analogue scale along the right side of the screen. A moving arrow on a stationary scale showed altitudes ranging from 0 to 200 feet. Above 200 feet the pointer went to the top of the scale and the altitude was represented digitally at the top of the screen in blue. The target altitude of 150 feet was represented in white and the rest of the scale was drawn in black. The attitude indicator showed a fixed aircraft symbol on a rotating artificial horizon with a pitch ladder. It also provided a measure of bank angle. No other flight parameters were presented.

Subjects sat in a chair directly in front of the simulation with the joystick mounted on the right arm. This joystick was a two-axis Flightstick, which gave control of pitch and bank angle. The bank angle was limited to 30 degrees and power was preset to maintain airspeed at approximately 85 knots. Yaw was preset at zero degrees for all trials and there was a six- to eight-knot crosswind directly from the left on all legs.

The Navigation Task

The simulated navigation area was approximately 13.5 by 13.5 nautical miles (Figure 1). The topography of the area included both flat and hilly terrain with rivers, roads and buildings. For this experiment, a low-fidelity version of the area was used for a rehearsal phase and a high-fidelity version was used for a transfer phase. Objects were distributed along the course to ensure that there were always one or more features in view to guide navigation. In the high-fidelity version of the area, these features had distinctive characteristics but care was taken to ensure that they were not placed directly on course (where they might have been used as indicators of direction to the next waypoint). The low-fidelity version of the area contained the same objects as in the high-detail world but differed in the appearance of those objects. Hills appeared to be more block-like than those of the high detail world and objects such as buildings and bridges were represented as gray blocks. In the development of this low-fidelity version, the intent was to use a level of detail that would be available with a less capable image generation system.

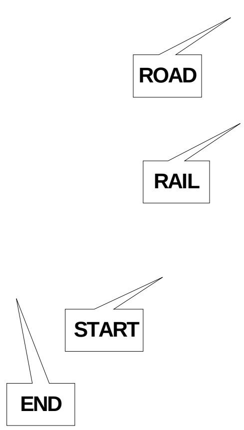

Figure 1. *The navigational area used for the rehearsal and transfer flights (The depicted course was shown only to the guided rehearsal groups and then only during their rehearsal flights)*

The course had seven legs of 38 nautical miles (nm) total length (individual legs ranged from 3.7 to 5.0 nm). The range in altitude of this course was 750 feet. As a secondary task, subjects were to maintain an altitude of 150 feet above ground level, which required vertical speeds of approximately ± 1500 fpm in the climbing and descending portions of the route. The course could be completed in approximately 27 minutes. A 6- to 8-knot variable crosswind from the left and light turbulence in pitch and roll were present to make the task more challenging. This ensured that the subjects were prevented from simply memorizing leg headings.

An automatic procedure was programmed to reset subjects 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 that leg with the course clearly indicated by a line superimposed on the scene. A message appeared on the monitor towards the end of each leg to advise subjects either that they had reached the end of the leg or that they were being reset.

A different navigation area was used to familiarize subjects with the simulation. It had a five-leg course that required approximately 15 minutes to complete. A path was marked on the ground to guide subjects along the designated course. Turns, climbs and descents were similar in magnitude to those required to navigate the course laid out in the other area.

Experimental Factors

Visibility. Visibility was either unrestricted (nominally fifteen miles) or restricted by haze (two miles). Unrestricted visibility permitted a view beyond the end of each leg (in the absence of physical obstructions) from the start point of that leg and also a view of features well to the side of the course. In contrast, restricted visibility only permitted a view of the area in close proximity to the current position. At the start of the first leg, for example, unrestricted visibility permitted a clear view of an upcoming mountain but with restricted visibility only a white haze was visible until the road and railway line came into view.

Control Stability. A first-order control system was used to implement a high-stability condition and a second-order control system was used to implement a low-stability condition.

Procedure

Three experimental phases (system familiarization, rehearsal and transfer) were run in sequence over two experimental sessions of two hours each. In the first session there were two familiarization trials (with the familiarization navigation area) and two low-fidelity navigation trials. The second session was scheduled either one or two days later. It started with the final low-fidelity familiarization trial. Two high fidelity transfer trials followed.

Familiarization. Subjects were familiarized with the control dynamics of the flight simulation. The primary task was to fly directly over a path marked on the terrain and the secondary task was to maintain an altitude of 150 feet AGL. Each subject completed two familiarization flights, the first with a first-order control system and the second with a second-order control system. Subjects were advised of the change in control order and of how that would change the task. Light turbulence in pitch and roll and a variable 6- to 8-knot crosswind directly from the left were included on both flights. After the completion of each flight, vertical and horizontal root mean squared (RMS) errors were displayed on the monitor. The meaning of these errors was explained to subjects.

Rehearsal. The rehearsal phase used the low-fidelity navigation area. Subjects were randomly assigned to one of four groups encompassing two levels of visibility and two levels of control stability. The task was to navigate along the predetermined course. Subjects were given a map of the area on which the route was clearly marked and were advised that they should fly this route by relating map symbols to landmarks shown in the simulation. As a secondary task, subjects were required to maintain an altitude of 150 feet AGL as in the familiarization session.

Transfer. The transfer phase followed the third rehearsal trial. The path was the same as flown in rehearsal. Subjects were given five minutes to study the map. They then flew the course twice without the map. Visibility was set at two miles (the restricted level used in familiarization) for both trials. Half of the subjects flew with first-order control first and half flew with second-order control first.

Dependent Measures

Lateral deviations from course and vertical deviations from the target altitude were measured for individual legs from the start of each leg up to a point 2000 feet from the endpoint of that leg. These errors were converted to RMS error scores.

Analyses

Each leg for both the rehearsal and transfer sessions was analyzed separately. Partial correlations between lateral and vertical performance measures were examined for the rehearsal and the transfer sessions to assess the feasibility of conducting univariate tests on the between-subjects effects. These correlations were at least moderately high in general (0.45+) thereby indicating that univariate tests would not be appropriate (Tabachnick & Fidell, 1989).

MANACOVAs were used to test the statistical significance of effects for the dependent measures of lateral and vertical error and for trials (three for rehearsal and two for transfer). RMS error performance on the familiarization trials was used as a covariate. The analyses conducted on the rehearsal data included multivariate tests of the trials effects and also of interactions with trials. Significant multivariate effects from tests on the combined transfer trials were followed by separate MANACOVAs on each of the two transfer trials to assess effects of the training factors on transfer performance at each level of stability.

Note for the discussion of results that, while it is tempting to consider horizontal and vertical errors separately, the logic of multivariate analysis (as supported by high correlations between the two measures) does not permit that. Error scores must be considered a unitary Horizontal-Vertical dimension.

Results

Figures 2-4 show mean horizontal RMS errors (transformed to their natural logarithms) for the second, fifth and seventh legs of the three rehearsal and two transfer flights.

Rehearsal Trials

There were significant effects for stability on all legs: lamba (6,38) for leg 1 = 8.99, $p < 0.001$; for leg 2 = 17.19, $p < 0.001$; for leg 3 = 14.22, $p < 0.001$; for leg 4 = 7.12, $p < 0.001$; for leg 5 = 9.90, $p < 0.001$; for leg 6 = 7.74, $p < 0.001$; for leg 7 = 7.20, $p < 0.001$. There were also significant effects for visibility on the first, sixth, and seventh legs, lamba (6,38) for leg 1 = 3.80, $p < 0.005$; for leg 2 = 2.19 $p < 0.065$; for leg 3 = 1.15, $p < 0.35$; for leg 4 = 2.03, $p < 0.09$; for leg 5 = 1.94, $p < 0.10$; for leg 6 = 2.78, $p < 0.02$; for leg 7 = 4.52, $p < 0.002$. Performance was better for the stable versus the unstable system and for unrestricted versus restricted visibility (Figures 2-4).

Transfer Trials

Significant effects of the Stability manipulation were found in rehearsal on the stable transfer trial in legs 2, 5, and 7, lamba (2,42) for leg 2 = 6.95, < 0.002; for leg 5 = 6.30, p< 0.004; for leg 7 = 4.31, p< 0.02 (Figures 2-4). Rehearsal on Low Stability led to poorer control in transfer to the stable system. There were no main effects of the Stability manipulation in rehearsal on the unstable transfer trial.

Significant effects of the Visibility manipulation were found in rehearsal on the stable transfer trial in legs 2 and 7, lamba (2,42) for leg 2 = 3.95, < 0.027; for leg 7 = 5.82, p< 0.006 (Figures 2 & 4). Only in Leg 7, where Low Visibility led to poorer control in transfer to the stable system, were the trends sufficiently clear to interpret. There were no main effects of the Visibility manipulation in rehearsal on the unstable transfer trial.

A significant interaction of Stability by Visibility was found in rehearsal on the unstable transfer trial in leg 5, lamba (2,42) for leg 5 = 2.77, < 0.07.

Discussion

Stability

The stability manipulation was introduced in rehearsal to test the hypothesis that high workload would divert attention from the navigational task to the control task. Under these circumstances, subjects should pay less attention in rehearsal to features on and near the course that would assist their navigation in the subsequent transfer trials. The rehearsal data indicate that this manipulation did affect the difficulty of the task. On all legs, rehearsal performance was better with the stable system.

The differential effects of rehearsal stability on the transfer trials were confined to the stable transfer trial of legs 2, 5, and 7. Use of stable control in rehearsal led to better performance on the stable transfer trials. Although this result is consistent with our workload hypothesis, it is also consistent with the popular high fidelity hypothesis.

Visibility

Effects of the visibility manipulation were evident only for legs 2 and 7. The visibility effects for Leg 2 cannot be interpreted with confidence, but the effects for Leg 7 show that subjects who rehearsed with unrestricted visibility performed better on the stable transfer trial. This is of particular interest because the transfer trials were run under the restricted visibility condition. Any high-fidelity conceptualization of transfer would predict that rehearsal with restricted visibility would be advantageous. In contrast, this result is consistent with our hypothesis that high visibility rehearsal would reveal information that could then be used effectively in a low visibility mission.

Conclusion

In this project, we have added to the somewhat meager data that show that high workload in training can disrupt learning. Furthermore, in contrast to those other data, we have shown this effect with a more complex and more realistic task.

In contrast to general training, which has the goal of developing generic skills, mission rehearsal seeks to promote sensitivity to or awareness of contextual details that are crucial to success of a specific mission. It is common to assume that high fidelity in rehearsal will ensure good mission performance. Here we challenge that assumption and show that the high-fidelity assumption does not account consistently for the data.

The contrasting hypothesis, following Lintern (1991), is that conditions that permit an operator to pay attention to critical mission details are more likely to develop the specific skills needed to accomplish a successful mission. In consideration of mission rehearsal effectiveness, fidelity is a spurious and bankrupt construct. There is now considerable evidence that no form of fidelity or similarity theory (whether physical or psychological) can account for important transfer effects (e.g., see Lintern, 1991). Notions of fidelity and similarity serve only to distract from exploration of the real issue, that being the specific type of manipulations that can make mission rehearsal effective.

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