TRAINING LOW LEVEL TERRRAIN FLIGHT
IN A SIMULATOR

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ABSTRACT

In this study the use of augmented feedback was investigated as a means of training low altitude perceptual motor flying skills in a flight simulator. Sixteen T-38 students pilots enrolled in Air Force undergraduate pilot training participated as subjects. Eight subjects in an experimental group were trained to fly low level in a simulated A-10 aircraft using special altitude prompts (lights on the glareshield and auditory tones in the headset) to assist them in discriminating altitude cues provided in the simulated visual environment. Eight subjects in a control group received training identical to that of the experimental group, less prompting. A computerized data record system captured a continuous record of altitude, vertical velocity, number of crashes, and other performance parameters on each of eight training trials and two test runs in which prompts were omitted. All subjects flew a total of ten runs. The prompted group achieved significantly lower altitude performance on two of four critical task segments compared to the control group during the training trials. However, subjects in the prompted group crashed significantly more times per trial than did subjects in the control group during the training. During the test runs performance of the two groups for altitude, vertical velocity, and frequency of crashes was not significantly different. The results of the study do not appear to warrant continued investigation of this technique for low level training.

PROBLEM: TERRAIN FLIGHT SIMULATOR TRAINING

Lack of adequate visual scene detail limits the usefulness of currently available computer generated imagery (CGI) for training low level flight. Present levels of detail and picture resolution are inadequate to produce desirable representation of ground patterns and features. Both ground textural patterns and vertical objects appear to be used as primary visual cues by pilots in judging aircraft height above the ground. Since present CGI limitations preclude adequate terrain detail, questions remain as to how to manipulate scene content and training techniques in order to optimize existing CGI capabilities. It is to be hoped that such developments can compensate to some extent for the current lack of scene fidelity.

LOW LEVEL ENVIRONMENT DEVELOPMENT:
RELATED RESEARCH

Touchdown Study

Studies at AFHRL/OT have focused upon the manipulation of visual content as media for training landing and terrain flight. In the first of these researchers investigated T-37 pilot landing performance in response to variations of checkerboard-like textural detail level superimposed upon the simulated runway touchdown area. The check sizes used were 4, 8, 16, and 25 feet for four experimental runways. Two other runways also were used; one a simulated Air Force runway with standard markings, and one completely bare except for a dashed centerline. A night runway scene was also added bringing the total number of runways to seven. Vertical velocity at touchdown was used as the performance indicator. Although the simulated aircraft vertical velocities at touchdown were much higher than those averaged in actual T-37 landings (32 feet per minute), the CGI texturing did significantly reduce vertical velocities at touchdown in the simulator ranging from 195 feet/minute for the night scene to 147 feet/minute for the four-foot texture pattern. In this study vertical velocity at touchdown was shown to decrease as a function of the amount of textural detail available to the pilot.

FOUR FOOT TEXTURE PATTERN RUNWAY

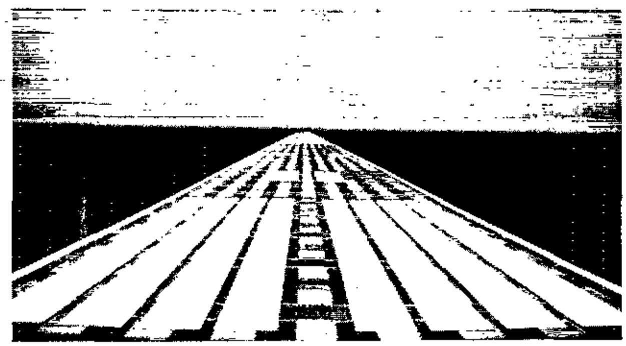

Figure 1

"Checkerboard Study"

In a subsequent study AFHRL/OT investigated the effects of three types of visual cues: texture patterns (checkerboards, 220, 440, or 880 feet on a side), vertical objects (present or absent), and aircraft shadow (present or absent), upon pilot performance during low level flight in a simulated A-10 aircraft. In this study pilots were instructed to fly 50 feet above the ground on an eleven-nautical mile course which consisted of eight flat valleys separated by low rolling hills. Hills were either 100 or 300 feet high. The pilots were scored on their ability to maintain aircraft altitude at 50 feet plus or minus 30 feet in the valley. Average altitude values were also collected at the crest of each hill. The pilots flew the course at 300 knots indicated airspeed plus or minus fifteen knots.

In general the pilots reported that all three types of visual cues were useful, however, the vertical object cues and texture patterns were of greater help than the aircraft shadow. Some pilots reported that the aircraft shadow was particularly useful in signalling impending contact with the ground. The vertical object cues, especially, the tree shaped cones of known height were subjectively very useful in gauging height above ground. The texture patterns were also reported as desirable, but to a lesser extent than the vertical object cues. Pilots reported a definite preference for the smallest texture pattern (220 feet square) over the two larger size patterns. They especially disliked flying over the largest texture pattern without vertical object cues. Pilots would have also preferred more irregular "natural" patterns rather than the highly regular checkerboard features.

440 FEET TEXTURING WITH VERTICAL OBJECTS

Figure 2

Both the texture patterns and the vertical object cues produced statistically significant differences in pilot performance. However, only the texture pattern cues produced a significant effect on the time within tolerance scoring for altitude in the valleys, and the average minimum altitude values in the valleys. The vertical object cues did have a significant effect on the average aircraft altitude at the top of the hills. Both the vertical object cues and the texture patterns significantly influenced the average minimum altitude values that occurred over each hill. The presence or absence of the aircraft shadow did not produce any significant effects. The amount of time (cumulative total) in the "crashed" condition (in contact with the ground) was low, with some pilots crashing into the simulated terrain more frequently than others. No significant differences were found for this performance parameter due to visual cue variables. Overall in this study, the terrain textural cues appeared to have a stronger effect on pilot performance than did the vertical object cues.

Terrain Cues

Data from the runway touchdown and checkerboard terrain studies provided some useful insights into the problems of modeling low level environments. For one, pilots found the checkerboard pattern effect visually monotonous, even distracting. Previous research (4) and (7) has suggested regular pattern texturing is important in conveying cues to the observer for surface slant orientation and that irregular textures are less effective in conveying surface slant cues. However, these findings were relevant to static rather than dynamic display content. Low level training would seem to involve a relationship between surface texture plus the motion cues conveyed in simulated flight. Research with random texture designs in a dynamic display context suggests motion cues can provide for reasonably accurate judgment of surface orientations (5). This effect appears to be based on velocity gradient information carried by texture rather than the texture gradient per se (2). In short, the motion component seems essential as a cueing element and there appears to be enough evidence from the literature and from current in-house studies to warrant testing the utility of the random pattern modeling for low level terrain flight training.

Vertical Objects Modeling

Another aspect of the problem of low altitude visual cueing is the modeling of vertical objects. A continuing problem is getting the maximum number of cues using the least number of computer graphic edges. The most edge-efficient object, it turns out, is a three-dimensional triangle, technically a tetrahedron. It uses six edges. In the checkerboard study, we used these shapes (sometimes referred to a "cones") for trees, with the point up. In working with an experimental CGI combat environment, researchers have found the "cones" to be more effective as cues when turned upside down so the broader base is more visible to the pilot. "Cones" have been used very effectively by pilots to evade simulated ground fire. Having the object point down seems to give a particularly accurate ground level cue. We also found that planning the use of cueing edges along a more or less defined flight path is more edge efficient since cues visibly usable by the pilot can be concentrated near his flight path rather than spread over a large area.

DEVELOPING A CGI LOW LEVEL ENVIRONMENT

The present low level flight CGI was developed applying experience, research findings, and inferences from previous CGI developments at AFHRL/OT. Random ground patterns, vertical object development, concentration of edges along the flight path, and the use of turns in the course were all derived from previous work. Other aspects of modeling were included with a view toward making the environment somewhat realistic. The environment was modeled to approach as nearly as a 2000-edge capacity permits, the irregular features likely to be seen in actual terrain flight. The 22-nautical mile flight path is bordered by hills which slope away from it at realistic rise angles. The width of the corridor ranges from 500 to 2000 feet and the elevation is 0 feet throughout. Heading change turns through the course increase from 23 to 45 to 60 to 90 degrees in order of increasing difficulty for low level flight. Inverted "cones" of several heights (25, 40, and 55 feet) are represented with the shape proportioned as a height cue following recommendations of Stenger et al (9).

LOW LEVEL TERRAIN CGI ENVIRONMENT

Figure 3

Environment Tryout

In subjective test flight evaluations ten instructor pilots reported the random ground pattern provided a useful altitude cueing. They confirmed that the inverted "cones" or trees were effective as altitude cues and that the peripheral cues provided by the hills along the flight path were also effective. Data from these tryout runs was recorded and analysed for use in developing parameters for an experimental training study. The concensus among pilots was that this imagery is the most effective produced to date for low level training in the Advanced Simulator for Pilot Training.

SKILL TRAINING STUDY

The basic visual perceptual skills for low level flight appear to be the hand-eye coordination behaviors involved in maintaining extremely low altitudes over a given terrain area. Many other aircrew skills are involved including navigation, systems monitoring, and communication. But the basic aircraft handling skills are critical. The thrust of the present research was to investigate training techniques for this task component.

Various methods have been considered for training low level flight. For present purposes in the simulator, the objective was to train the pilot to use available terrain cues as effectively as possible, under conditions of very limited terrain fidelity. Long-established methods of training visual discrimination have been reported by a number of researchers (10, 11, 6, 1, and 3). Relevant visual discriminations are established by providing some form of obviously distinguishable auxilliary stimuli in the presence of the more subtle discriminations to be learned. A two-step flow is implied: first, effective prompts must be developed and applied, then they must be removed as the relevant discriminations are transferred to the primary stimuli. To be effective prompts must indeed facilitate relevant discriminations, but there is the possibility that they may compete with, rather than compliment the primary cues. Since prompts may be initially useful but terminally detrimental, they must be removed as correct responses are transferred to discriminative stimuli. Prompt removal has been called fading or vanishing (8) and is to be accomplished in a gradual, systematic manner.

This technique has been used successfully in a number of educational and pschological contexts, but its usefulness for the present simulator task has not been investigated. In the present study the objective was to determine if prompting would facilitate development of visual judgment and concomitant aircraft control skills to a greater degree than equivalent training without prompting.

METHOD

Subjects

Sixteen T-38 student pilots enrolled in undergraduate pilot training at Williams Air Force Base participated as subjects. They were all undergoing the initial phases of the T-38 syllabus and none had received any form of low altitude training in the aircraft.

Procedure

Assignment of Subjects to Groups. The subjects were randomly assigned to one of two treatment groups as follows: The experimental group (N=8) received low level training as prompted by lights and audible tones in the cockpit. The prompts were computer actuated in response to specific altitude limits. The control group (N=8) received training identical to the experimental group, less prompting.

Experimental Training. Each subject was given a standardized five-minute in-briefing describing the training task. The briefing consisted of a video introduction, explanation of the flight route, primary visual references, and relevant flight procedures.

Subjects assigned to the experimental group received the altitude prompting from two small lights mounted in vertical array on the cockpit glareshield and from audible tones through the headset. During the briefing, they were told to use these altitude references as a means of attaining consistent low altitude during the training. When the subject exceeded 150 feet above ground level (AGL), the top light illuminated until descent below that altitude. When he descended below 35 feet AGL, the bottom light illuminated until ascent above that altitude. The audible prompts were presented simultaneously with the lights; a 1000 Hz tone for the 150-level, and a 600 Hz tone for the 35-foot level. Subjects in the experimental group were told to use the 35 foot prompt particularly as a low level performance guide and to try to associate the occurence of the prompt with the appearance of terrain features for this altitude, trying to maintain this altitude as much as possible.

Following this orientation, each subject was introduced to the A-10 cockpit of the ASPT by an instructor pilot who gave him a standardized, ten-minute familiarization and warmup exercise. This included a takeoff, several turns and a landing. He was also allowed to "crash" into the ground and "fly through" several simulated ground objects in order to establish these simulation effects before beginning the training exercise.

The subject was then initialized at the starting point of the low altitude training environment at 200 feet AGL. The subject was instructed to fly through the environment maintaining as low an altitude as possible without crashing into the ground or trees. He was instructed that consistency and smoothness of flight were important and that he should maintain an indicated airspeed of 280 to 300 knots. He was given an approximate throttle setting as an assist. He was further advised that turn points in the flight path would be the most difficult segments in which to maintain low altitude, and that he should make a special effort to stay low in the turns by using rudder. Finally, he was instructed that he could use any flying technique or ground track he preferred through the course so long as he maintained the minimal altitude possible without crashing. If the subject crashed, he heard a computer-actuated voice say "zero altitude" but he was able to continue to "fly out" of the crash condition and complete the training trial.

Each subject flew eight trails over the course, with each trial taking about 4.5 minutes at the required airspeed. At the end of each trial the subject was re-initialized at the same starting point and altitude. During the trials, no further verbal instruction or performance feedback was provided to the subject. Time elapsed for the entire exercise including the briefing was about one hour and ten minutes.

On the last three training trials of subjects assigned to the experimental group, the intensity of the light and tone prompts was faded as follows: trial six, 75 percent intensity; trial seven, 50 percent; and trial eight, 25 percent. Thus, by trial nine (the first test run), the prompts had been completely faded for the experimental group.

Following completion of eight consecutive training trials, all subjects were given two additional trials as a test of training effectiveness. During the two test runs the number of vertical objects (trees) in the CGI scene was reduced by 50 percent. Subjects were also instructed to maintain a more critical airspeed tolerance (300 KIAS, plus or minus 5 knots).

Performance Measures

Dependent measures for the simulated low level task were: mean altitude, mean vertical velocity, and frequency of crashes during training trials and test runs. The altitude measure and crash frequency were taken as indicators of the subject's ability to use available visual cues to maintain minimally low level safe flight. Vertical velocity measures were intended as an indicator of aircraft control and overall smoothness of flight. Measurements of these parameters were taken during the three most difficult turns (45, 60, and 90-degree heading changes). The start and stop of turn maneuvers for each subject on each trial were determined at the point where bank angle exceeded (start) and dropped below (stop) 15 degrees nearest the geographical x-y coordinates of turns. The measurement of a mean altitude during wings level flight was also taken as a general indicator of the altitude attained over the route for each trial. This was the residual of altitude sampling by the system across the entire flight course, less the turns and hills (150 and 200 feet high) placed at two points across the flight path. Performance measures were sampled at a rate of 30 Hz during all training and testing for each subject via a computerized data record system. Following data collection these data were re-sampled at a one Hz rate for reduction and analysis.

Experimental Design

A Lindquist type 1 experimental design was used. One-way analysis of variance was performed for altitude, vertical velocity, and crash frequency data to test treatment by subject by trials effects for each of these performance parameters.

RESULTS

Figures 4-7 show the mean altitude for each of the eight training trials for the experimental and control groups. Between group differences were found statistically significant across mean altitudes on both the 90-degree turn ($F= 5.82$, $p < .03$) and the 45-degree turn ($F=13.25$, $p < .005$) trials as illustrated in Figures 7 and 5 with the experimental group achieving the lower altitudes across trials. Although the experimental group's achieved trial means during wings level flight and the 60-degree turn were also numerically lower than the control group (Figures 4 and 6), these differences are not statistically significant.

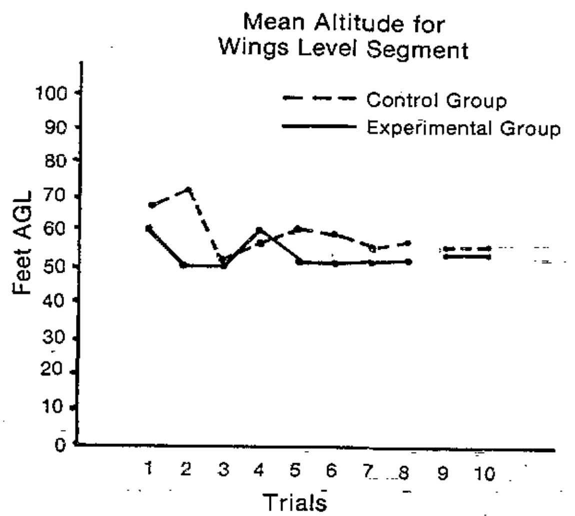

Figure 4

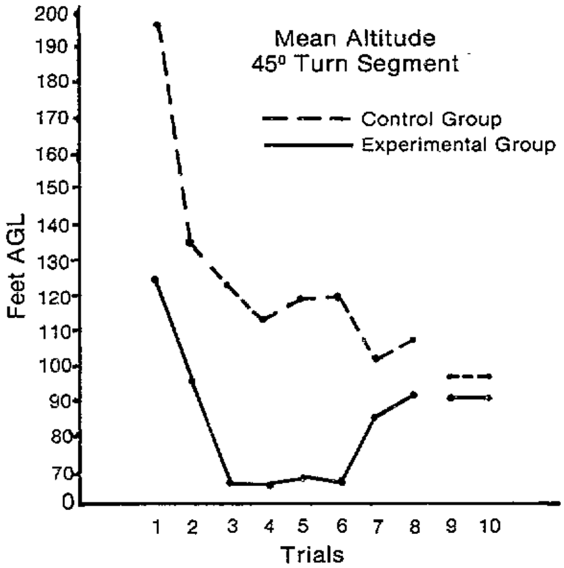

Figure 5

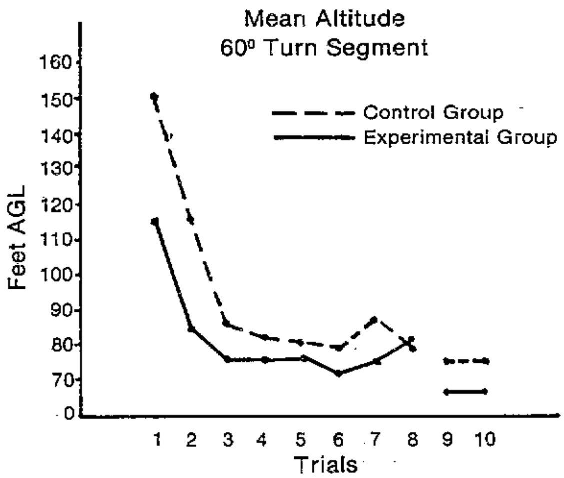

Figure 6

Achieved altitude performance during the testing condition is also shown in each of the figures as a two-trial mean plotted for trials nine and ten. None of these between group comparisons was statistically significant.

ANOVA comparisons of vertical velocity performance on all task segments for all trials revealed no significant findings. Frequency of crashes during the training trials did show a group effect. The control group subjects crashed significantly ($F=5.43$ $p<.03$) fewer times (.94 crashes per trial) than did the experimental group (1.86 crashes per trial). However, no reliable difference between the groups' crash performance was found during the test runs.

Aside from the treatment effects, the trials effects revealed by the ANOVAs for altitude during the training show consistent and highly significant practice effects for both groups as a result of the low level training. Learning curves for mean altitude across the eight training trials (combined group trial effects) were significant on all turns (45-degree - $F=9.65$, $p<.0001$; 60-degree - $F=10.93$, $p<.0001$; 90-degree - $F=8.21$, $p<.0001$).

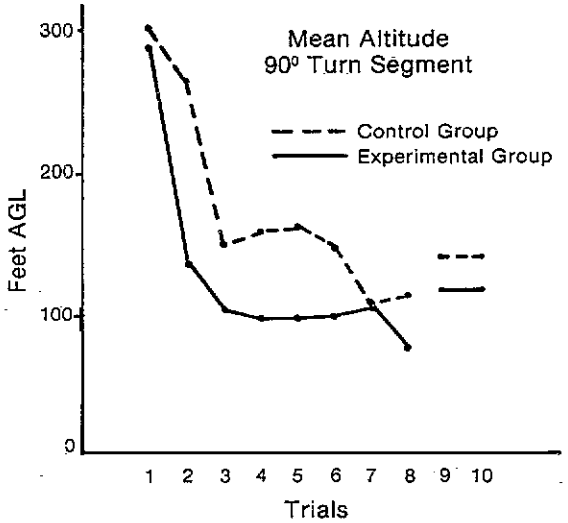

Figure 7

DISCUSSION

The purpose of this study was to assess the utility of a specific type of augmented feedback (audiovisual prompting) for training low altitude perceptual motor skills. The use of the prompts did enable subjects in the experimental group to achieve significantly lower altitude perfomance on two of the four critical task segments during the training trials. While in evidence, this effect was insufficiently powerful to produce reliable performance improvements over the control group during the test runs. This inadequacy appears to be a problem specific to the prompting technique and not the discriminative stimuli available to the subject via the computer imagery.

The CGI environment was effective. The highly reliable trials effect indicates that the visual imagery was indeed powerful in conveying altitude-relevant discrimination cues to the pilot and is also consistent with the plaudits this visual environment has received from a considerable number of pilots experienced in terrain flight.

While vertical velocity data provided no additional clues to performance differences between the groups, the crash frequency data present something of a puzzle. While it would seem that the 35-feet prompts could serve as a reasonably effective warning away from the ground during the training trials, the data indicate otherwise. Prompts seem to have interferred in some way with the subjects aircraft control, perhaps distracting them below 35 feet. If this is the case, this type of prompting is obviously inappropriate and dangerous for the task.

However, the specific process operable within the prompting, for the present, can only be speculated upon.

Returning to theory momentarily, the use of effective prompting presupposes a two-step flow: (1) the arrangement of suitable ancillary information by which transfer of desired behavior to relevant stimuli can be facilitated, and (2) an effective means for removing the prompts once the desired responses are established so that the learner no longer relies upon the ancillary information. The technique can be problematic. Prompts are actually additional information to an array of existing complex stimuli. As a mediational device, prompts must be sufficiently powerful to justify the additional information load. However, if prompts become too obtrusive, primary task-relevant stimuli may be over-shadowed precluding desired associational transfer, and defeating the objective of prompting.

It is not clear from the results or the above theory why the present prompting application produced less than a useful level of training. On the one hand they seemed too weak during trials to produce strongly differential training effects, at least for the altitude performance dimension. Conversely, as terrain avoidance cues (crash data), it seems the prompts were too obtrusive or in some other way inappropriate, to the point of possible performance interference at extremely low altitude. Aside from the training trial effects, training transfer to the test runs shows no differences in group performance for either altitude or crash frequency, the test runs being the crucial factor in the present effectiveness comparisons.

Perhaps variation of the prompting would significantly improve effectiveness. It is possible that the altitude limits set for the present study were not appropriate for the subject population, although the limits were arrived at systematically as a result of repeated trials by T-38 and research instructor pilots. Perhaps too, a more flexible or adaptive system of prompting in which the altitude limits of prompts vary as a function of student performance across trials would be effective. This is very speculative, and on the basis of present *evidence, it would seem hard to justify the time* and costs of developing such a prompting system. Results of the present study do not appear to warrant continued investigation of this technique for training low level flying skills.

Other substantive questions remain relative to training terrain flight in simulators which deserve investigation as research issues. Visual environment issues include influence of field of view upon low level training and techniques for improved modeling of object and texturing features. Training variables include investigation of task difficulty and task sequencing variables, and alternative performance feedback techniques for terrain flight training.

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