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16. Abstract

Eighteen instrument-rated pilots were flown in two-hour simulated solo missions during which the frequency of traffic, ATC warnings, and ATC clearances were varied, while the visibility of the target was held constant at 100%. In order to observe the target, the pilot was required to make a simple, overt observing response; i.e., the pilot had to press a button on his control wheel. If traffic was present, a burst of flashes became visible through the windshield. Button presses in the absence of traffic produced no stimulus. Each pilot was advised that his IFR mission occurred under VFR conditions and that it was his primary responsibility to maintain visual vigilance, although ATC would endeavor to warn him of possible conflicting traffic. Two values of traffic frequency were programmed independently of two values of ATC traffic warning frequency. The frequency of competing behavior was varied by independent scheduling of two values of ATC clearance frequency.

The data revealed main effects from ATC clearances and from traffic warnings. Significant interactions were obtained for clearances by traffic warnings and for traffic by traffic warnings.

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FREQUENCY OF ANTI-COLLISION OBSERVING RESPONSES BY SOLO PILOTS AS A FUNCTION OF TRAFFIC DENSITY, ATC TRAFFIC WARNINGS, AND COMPETING BEHAVIOR

I. Introduction.

Topics related to collision avoidance that have been researched in the past include the conspicuity of the target lights[1 2 3 4] and the interaction of target resolution and visibility with visual scanning.[5 6] Studies of human vigilance are numerous, but the techniques available have not yet been applied to collision avoidance. The current study applies the operant technique developed by Holland for the study of observing responses[7] in an attempt to isolate the relevant variables that affect pilot vigilance in collision avoidance. Since one well-researched factor is target visibility (or conspicuity), it was decided at the outset to exclude visibility as a factor in the current study and to concentrate instead on those factors other than conspicuity which might influence pilot vigilance. Target frequency was selected as a variable for investigation because it seems obvious from Holland's work[8] that observing responses, when considered as simple operants, are reinforced by the appearance of the target. The second variable, the frequency of Air Traffic Control (ATC) traffic warnings, was selected because, in the operant model, ATC traffic warnings may be considered as positive discriminative stimuli (S^D) for the performance of the observing response, the degree of stimulus control exerted by these warnings being a function of the frequency of their validity; i.e., if observable traffic were always preceded by traffic warnings, traffic warnings would represent a perfectly reliable S^D. When traffic appears in the absence of an ATC traffic warning or when the warning precedes traffic that cannot be seen, traffic warnings should become less effective as an S^D for the observing response. Finally, because pilots do not spend all their time searching for possible conflicting traffic, the frequency of behaviors that would compete with the observing response was systematically varied. This competitive behavior was generated by including ATC clearance procedures as a variable. Each variable had two values (high and low) in the current study.

II. Method.

A. *Subjects.* The subjects were 18 instrument- and multi-engine-rated male and female pilots who were either FAA personnel selected from the available pilot population at the FAA Aeronautical Center, or volunteer members of the Oklahoma City aviation community. Those subjects who were FAA personnel received their regular salary for participation. Non-FAA personnel were paid an hourly wage for participation.

B. *Apparatus.* The equipment used consisted of a fixed-base Convair–340 simulator (Curtis-Wright) in which a microswitch was installed on the right side of the left control wheel. The switch was connected to an input module of a panel of solid-state logic modules (Lehigh Valley Electronics) used for session timing, response recording, and control of experimental contingencies. A pulse from one output module was used to gate a General Radio Model 1538–A Strobotac to produce a 0.6–sec burst of flashes to serve as the target. The Strobotac was mounted directly in front of the simulator and directed towards the windshield. When presented, flashes from the Strobotac were always visible through the translucent windshield of the simulator, no matter where the pilot was looking.

C. *Procedure.* Each subject was assigned at random to one of two groups of subjects, each group receiving stimulus protocols that were counterbalanced over time and that were complements of the protocols used by the other group; i.e., since there were three 2-valued variables (clearances, traffic, and traffic warnings, each of high and low frequency), the sessions were divided into eight periods with one value of each variable assigned to periods in counterbalanced order in such a way that each unique combination of values occurred once during a session, but the orders of unique combinations were reversed for subjects assigned to the second group.

After being briefed about the aircraft, each subject was given a flight plan (Figure 1) and told to maintain as closely as possible the indicated headings and airspeeds. Each subject was told to report passing over each checkpoint (ALPHA through NOVEMBER in Figure 1). After the briefing, the following instructions were read to the subject:

"This is a study of the see-and-be-seen concept of collision avoidance. You will be flying an IFR mission under VFR conditions. Your flight plan will take you through regions of varying traffic density. Although Air Traffic Control will endeavor to warn you of possible traffic, it is still your primary responsibility to look for possible traffic.

"Every time you wish to look for traffic, press the button on the control wheel; if traffic is not visible, nothing will happen. However, if traffic is present, you will see it when you press the button. Press it now and you will observe traffic." (At this point the experimenter waited until the subject had pressed the switch and observed the flashes at least once.) "If traffic is present, it will always appear as you have just

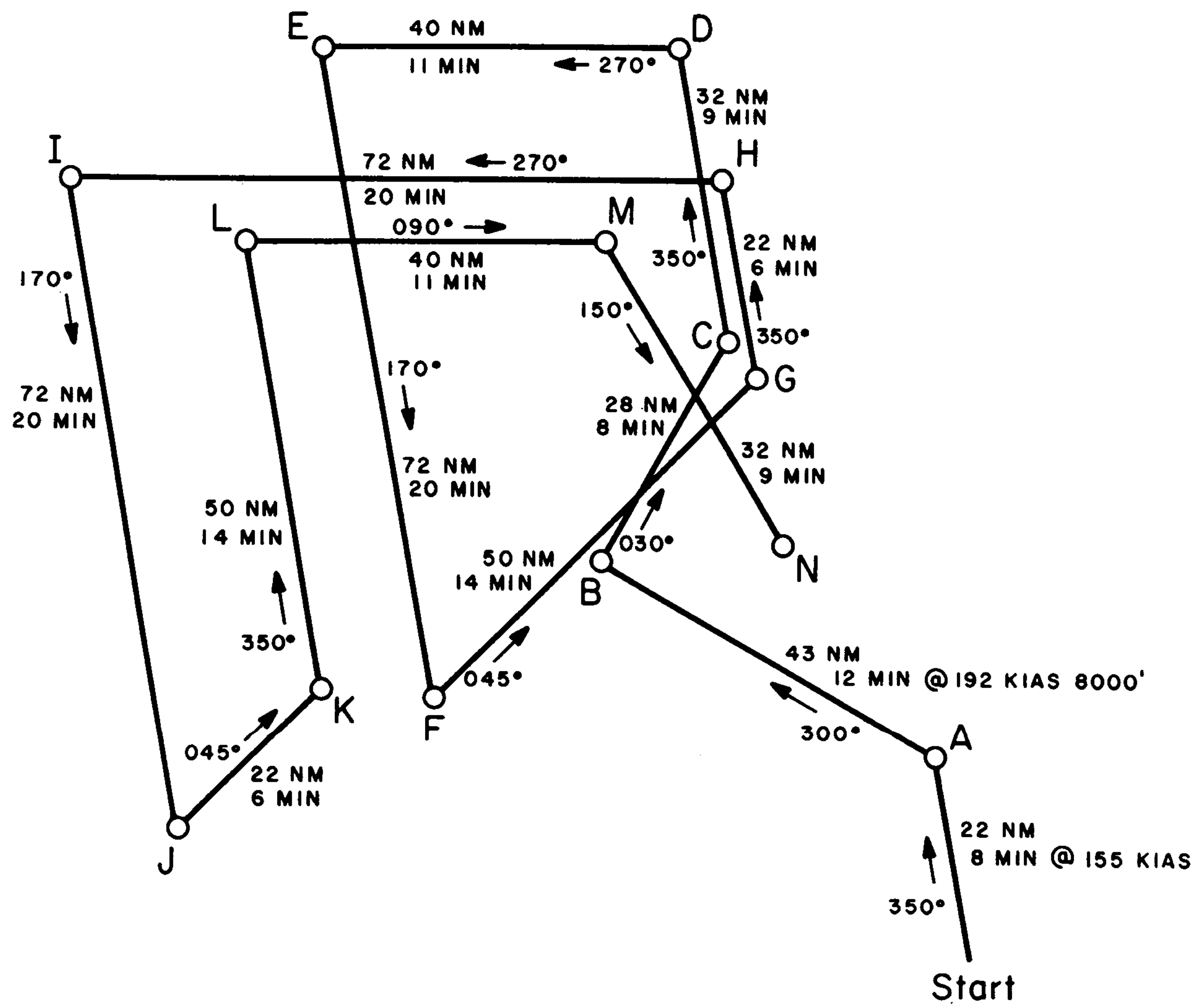

FIGURE 1. Flight plan used by participating pilots. The experimental protocol began when each pilot reported over point ALPHA and ended two hours and 40 minutes later, before each pilot had reached point NOVEMBER.

seen it. You must press the button each time you wish to look for traffic. Pressing it and holding it down will not work. If you report all traffic you encounter to ATC, you need not take evasive action and you will enjoy a safe flight.

"You will not encounter any traffic until after you report over point ALPHA. Before reaching point ALPHA, you may press the button for practice, but you will not see any traffic. Please contact the Oklahoma City Tower on 118.3 when you are ready to take off."

As indicated in Figure 1, the subject had approximately eight min available for practice (with no feedback) after take-off. During these eight min, the pilot was expected to reach his assigned altitude of 8000 feet. As soon as the subject reported passing over point ALPHA, the automated experimental protocol was started. The session consisted of eight 20-min segments, during each of which the predetermined order of frequencies for each variable was programmed.

Traffic warnings and traffic were both generated by feeding the same timebase (25 sec) into two independent sets of probability gates. For high frequency traffic warnings, the probability gate selected had a value of 0.85, while the low frequency gate was set at 0.15. High frequency traffic was determined with an independent probability gate of 0.85, while the low traffic gate was set at a probability of 0.15. High frequency clearances were determined by a timebase of 60 sec feeding through a probability gate of 0.75, while low frequency clearances depended on a 360-sec timebase via a 0.5 probability gate. Clearances consisted of instructions from ATC to change altitude, to change radio frequencies, to alter transponder settings, and in those cases where the pilot was proceeding too quickly through the flight plan, to reduce airspeed.

A response produced traffic (flash burst) if the response occurred within seven sec of a scheduled traffic event; i.e., each event (clearances, warnings, and traffic) may be described as occurring on Random Interval (RI) schedules of reinforcement, where only traffic required a response and had a limited hold of seven sec. The traffic timebase incorporated a delay of three sec from the warning timebase, so that in the event of simultaneous warning and traffic, the warning could be delivered before onset of the traffic limited hold.

III. Results.

A repeated measures analysis of variance with one between-subjects factor and three within-subjects factors (the equivalent of a split-plot factorial—2.222 analysis of variance[9]) indicated that the effect of order of presentation of treatments (the between-subjects factor) was nonsignificant ($F<1.00$). Therefore, the number of observing responses for each treatment combination was combined across order of presentation and a 2^3 repeated measures design, where all factors were within-subjects factors, was used to complete the analysis. The cell means for all treatment combinations are presented in Table 1.

The analysis revealed significant main effects from frequency of clearances ($F=4.85$; $df=1,17$; $p<.05$) and from frequency of traffic warnings ($F=7.95$; $df=1,17$; $p<.05$). Significant interactions were obtained for clearances x traffic warnings ($F=7.17$; $df=1,17$; $p<.05$) and traffic x traffic warnings ($F=7.83$; $df=1,17$; $p<.05$). To qualify the statements concerning the significant main effects of clearances and traffic warnings, tests of simple main effects were computed. The following main effects were significant: clearances at the low frequency level of traffic warning ($F=11.18$; $df=1,34$; $p<.005$), traffic warnings at the high frequency level of clearances ($F=11.83$; $df=1,34$; $p<.005$), and traffic warnings at the low frequency level of traffic ($F=14.10$; $df=1,34$; $p<.001$).

Individual comparisons with Tukey's HSD[9] test indicated that there was a significant difference ($p<.01$) between the mean number of observing responses in each of the following situations: (1) When clearances occurred at a high frequency, more observing responses were made when traffic warning frequency was high

TABLE 1. Mean number of observing responses.

	Clearances (Low)		*Clearances (High)*	
	Traffic (Low)	*Traffic (High)*	*Traffic (Low)*	*Traffic (High)*
Traffic Warning (Low)	158.00	165.78	99.28	147.39
Traffic Warning (High)	247.78	173.83	206.72	209.06

than when traffic warning frequency was low; (2) When traffic warning frequency was low, more observing responses occurred when clearance frequency was low than when clearance frequency was high; (3) When traffic frequency was low, more observing responses were made under conditions of high frequency of traffic warnings than when the frequency of traffic warnings was low.

IV. Discussion.

Under ideal circumstances, a solo pilot flying under VFR conditions makes a number of observing responses sufficient to detect all visible and possibly conflicting traffic. The current study indicates that, in fact, the observing response rate is affected by the frequency with which the pilot receives traffic warnings and the amount of competing behavior the flying task imposes on his work load. That these variables interact with each other and with traffic density surely is no surprise; the results suggest that when competing behavior is prepotent and traffic density is low, the consequent decrease in traffic warnings yields a diminution in vigilance that might well result in disaster. The current study indicates a simple method for evaluating these factors and additional research is clearly indicated. Because only two values were assigned to each variable, and because the exposure of each subject to each combination of variables was restricted to a relatively short duration, the reader is cautioned not to draw overly general conclusions from the data presented.

What is definitely indicated is the need for a full parametric study of the variables selected for study in this paper, in addition to studies introducing variation in crew size and in the placement and visibility of the target (by mentioning visibility, it is implied also that target size and hue are factors to be introduced in the course of future research).

That traffic density was not in itself a significant main effect may, at first, seem surprising. However, the subjects worked on what may be described as a mixed RI RI schedule of reinforcement with relatively short periods for each component schedule. Consequently, it is quite reasonable for their behavior to reflect a single RI schedule, the mean interval of which is an average of the component schedules. Thus, the proposed parametric study should include variation in exposure time to each combination of variables, a procedure that might well indicate if fatigue (a factor excluded from the current study) affects vigilance.

Finally, mention should be made of the comments made by a number of our subjects to the effect that pressing the button was not at all like visually scanning for traffic. Obviously the responses are not the same. However, there is clear laboratory evidence that the rates for a simple operant observing response are comparable with eye movement data, when similar contingencies are in effect.[10]

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