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EFFECT OF TWO TYPES OF SCENE DETAIL ON DETECTION OF ALTITUDE CHANGE IN A FLIGHT SIMULATOR

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The effect of two types of simulator scene detail on detection of change in altitude was evaluated. The first type was the density of three-dimensional objects in scenes, which ranged from 11 objects per square mile to 175 objects per square mile. The second was the detail/realism of three-dimensional objects, which ranged from simple, untextured tetrahedrons (i.e., three-sided pyramids) to a mix of highly detailed and realistic appearing oak trees, pine trees, and bushes. A group of pilots and a group of non-pilots viewed short segments of flight over simulated terrains and responded by pushing one of three buttons to indicate whether they were descending, remaining level at 150 ft above ground level or ascending. Results of Experiment 1 showed that accuracy and reaction times for both groups improved significantly with increases in object density. However, a significant effect of object type was obtained only for the non-pilot group with the accuracy dependent measures. Interestingly, the advantage favored tetrahedrons over realistic objects. In Experiment 2, these effects persisted even after four sessions of practice. These results suggest that available computer-image generator processing capacity may be used most effectively by maximizing object density rather than object realism.

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PREFACE

This effort was conducted in support of the current Armstrong Laboratory (AL) Research and Technology Plan, one objective of which is training research and development to maintain air combat readiness and, specifically, the Visual Scene and Display Requirements goal.

This work was performed in support of Work Unit No. 1123-32-03, Tactical Scene Content Requirements, Principal Investigator, Dr. Elizabeth L. Martin, and 2743-25-17, ACME Flying Training Research Support, for Contract No. F33615-90-C-0005, Contract Monitor, Capt Claire A. Fitzpatrick. One of the objectives of these work units is to identify flight simulator visual scene content factors that contribute to training effectiveness for low-altitude flight.

We also gratefully acknowledge the assistance of Ms. Marge Keslin.

EFFECT OF TWO TYPES OF SCENE DETAIL ON DETECTION OF ALTITUDE CHANGE IN A FLIGHT SIMULATOR

SUMMARY

Increasing the level of detail in flight simulator visual scenes produces performance improvements with a number of tasks involving flight near the terrain surface. Not all types of detail affect performance equally, however, so an important question is which types of detail are most important.

In the present investigation, the effect of two types of flight simulator visual scene detail, the density of three-dimensional objects and the detail/realism of individual objects, was evaluated using a descent/ascent detection task. Object densities ranged from 11 objects per square mile to 175 objects per square mile. The objects were either tetrahedrons (three-sided pyramids turned upside down so that the bases faced upward) or realistic-appearing trees and bushes. Results of Experiment 1 showed that object density had a larger effect on performance than object realism. Results of Experiment 2 showed that this pattern persisted even after four sessions of practice. These results suggest that computer-image generator processing capacity may be used most effectively by increasing the density of objects in simulator scenes rather than enhancing the realistic appearance of objects.

INTRODUCTION

A major concern of designers of flight simulators is to provide sufficient levels of scene detail to support such tasks as low-level flight. Performance of a variety of tasks involving flight near the terrain surface improves as scene detail (i.e., the number of lines, surfaces, objects, etc.) increases. Examples include dive bombing (Lintern et al., 1987), estimation of impact point on approach to a runway (Barfield et al., 1989), landing (Buckland et al., 1981), and altitude control in low-level flight (Engle, 1980; Martin & Rinalducci, 1983). However, not all types of scene detail are equally effective. For example, estimation of impact point on final approach to a runway is more accurate with a grid pattern on the runway than with dots (Reardon, 1988); altitude control is better with lines running parallel to the flight path than perpendicular to it (Wolpert, 1988); and altitude control is better with three-dimensional objects than with two-dimensional scene elements lying flat on the terrain surface (Buckland et al., 1981; Martin & Rinalducci, 1983; McCormick et al., 1983). The issue, therefore, is not simply a matter of the quantity of detail per se, but rather, the type(s) of detail that affect performance most.

Kleiss et al. (1989) compared the effects of three-dimensional object density and the detail/realism of individual objects on perception of change in altitude in a flight simulator. Pilot training texts (Academic Text: Low Altitude Training, 1986) and basic laboratory research (Fitzpatrick et al., 1982; Higashiyama, 1984), suggest that the apparent size of familiar objects is a useful cue for distance and altitude. Kleiss et al. (1989) found that both detection accuracy and reaction time improved with increases in object density. However, there was no advantage for realistic trees and bushes compared to simple inverted tetrahedrons (three-sided pyramids).

Given the somewhat surprising nature of this result, an attempted replication was deemed appropriate with slight modification. Kleiss et al. (1989) used a task in which altitude was varied in discrete increments. Given that continuous motion typifies actual flight, a task was chosen for the present investigation which required detection of continuous change in altitude. Shorter trial durations provided a larger number of trials per session, thus allowing both object type (which was varied between groups by Kleiss et al., 1989) and object density to be varied within subjects. A fourth type of object, inverted tetrahedrons without textured surfaces, was added to the three previous object types (i.e., textured tetrahedrons, pine trees, and a mixture of trees and bushes) in order to assess possible differences due to the presence of complex texture irrespective of the realistic appearance of objects. Lastly, a group of non-pilots was included as a control group.

EXPERIMENT 1

Method

Subjects

The Pilot group consisted of 12 U.S. Air Force male pilots. Eleven subjects were instructor pilots (IPs) in the T-37 and T-38 aircraft; and one was a graduate of pilot training and currently a student in the F-111 aircraft. The pilots averaged 26.25 years of age (SD = .87) and 938 h mean total flying time (SD = 241.33). The IPs had no previous tactical experience and little low-level experience below the altitude of 1,000 ft above ground level (AGL). However, they do many runway approaches and takeoffs during the course of their assignment as flight instructors and are familiar with the optical transformations that accompany changes in altitude near the terrain surface.

The Non-Pilot group consisted of 8 male and 4 female staff members at the Air Force Human Resources Laboratory*, Aircrew Training Research Division, Williams Air Force Base, Arizona. Mean age was 37.08 years (SD = 9.70). None of the Non-Pilots had experience flying aircraft.

Experimental Design and Stimuli

Three factors were varied within subjects: (1) Descent/Ascent Rate, (2) Object Density, and (3) Object Type. There were 5 levels of Descent/Ascent Rate: 0 ft/minute (level flight), +/-400 ft/minute, +/-800 ft/minute. These values were chosen after interviews with pilots indicated that 400- and 800-ft/minute rates would encompass a range from just noticeable change in altitude to easily detectable change in altitude. Evidence suggests (e.g., Owen et al., 1982) that the functional variable for detecting change in altitude is fractional (i.e., percent) change rather than change measured in absolute ground units such as feet. The 400 ft/minute rates correspond to an initial (at 150 AGL) fractional rate of 4.44%/s and the 800 ft/minute rates correspond to an initial fractional rate of 8.88%/s. These values are nearly identical to a range defined by Hettinger and Owen (1985) for an "easy" training condition (4.0%/s to 9.0%/s). They note that values less than 3.0%/s typically result in high error rates.

There were 3 levels of Object Density: (1) 11 objects/square mile, (2) 45 objects/square mile, and (3) 175 objects/square mile. These densities are the 3 highest densities used by Kleiss et al. (1989) which represented equal log intervals between zero and the highest feasible density for the available image generation system. The lowest level of 3 objects/square mile was excluded in the present investigation because of its clear inferiority in the Kleiss et al. (1989) investigation. Inter-object spacings were 1,600, 800, and 400 ft between objects respectively.

There were 4 levels of Object Type: (1) textured Tetrahedrons that were 5, 15, and 35 ft in height and contained a mottled green texture pattern on surfaces; (2) untextured Tetrahedrons of the same size and shape as Textured Tetrahedrons with uniform green surfaces; (3) cell-textured Pine Trees that were 5, 15, and 35 ft in height; and (4) a Mix consisting of 5-ft bushes, 15-ft pine trees, and 35-ft oak trees. The Mix was included in an attempt to replicate the finding of McCormick et al. (1983) that performance

*AFHRL has been redesignated Human Resources Directorate, Armstrong Laboratory.

of a simulated low-altitude flight task was better with a mixture of different types of objects than with a single type of object alone. The 3 sizes of objects in each condition were mixed in equal proportions. All objects appeared on a flat, uniform green terrain surface (Fig. 1). An Untextured Tetrahedron is not shown as it was identical to the Textured Tetrahedron except for the presence of the texture pattern. Luminances and contrasts are shown in Table 1.

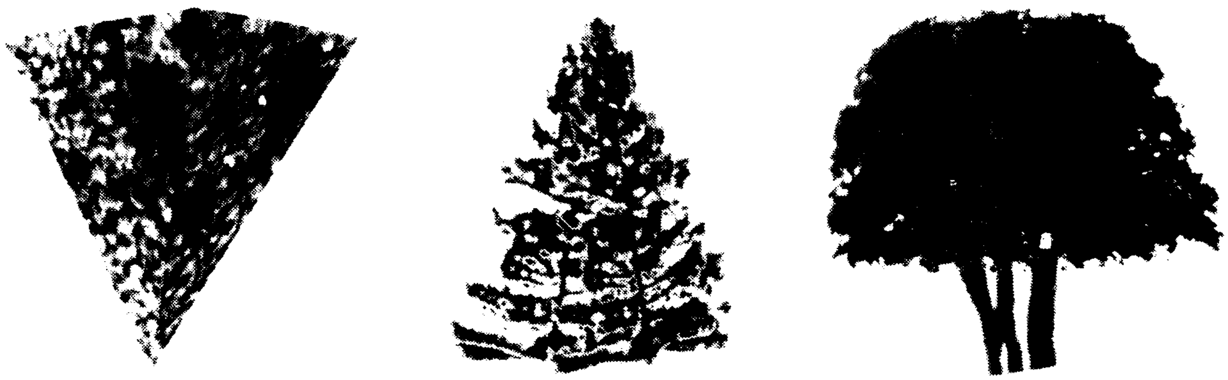

Figure 1. Three-Dimensional Objects. Pictured are a Textured Tetrahedron, a Pine, and an Oak Tree from the Mix condition. Note: Objects were photographed on a 1,000 line high-resolution monitor.

Table 1. Luminance Values and Contrasts

Object Type	Luminance (Foot-lamberts)	Contrast
Textured Tetrahedron	.59	64.5%
Untextured Tetrahedron	.59	64.5%
Pine Tree	.53	68.4%
Oak tree	.55	67.4%
Terrain Surface	2.83	

Note: Contrasts are based on the formula: [(max. luminance - min. luminance)/(max. luminance + min. luminance)] X 100.

Apparatus

Imagery was displayed on a 10-ft diameter domed surface. Total field of view was 110 degrees horizontal by 85 degrees vertical. Addressable resolution was 985 lines by 1,000 elements per line (Eibeck & Petrie, 1988).

A chair was positioned in front of the dome such that eye point was located approximately at the focal point of the dome. Responses were entered by means of a 3-button response box. The buttons were positioned on an inclined surface with the button indicating ascent in the highest position, the button indicating level flight in the middle, and the button indicating descent in the lowest position.

Visual imagery was generated by the Advanced Visual Technology System (AVTS, Eibeck & Petrie, 1988). Among its capabilities is cell texturing, a technique by which a complex digitized texture pattern can be stored in memory and replicated on surfaces by modulating the lightness and darkness of the surface.

Procedure

Subjects received an initial briefing on the general purpose of the experiment and a description of the task. Subjects were familiarized with the appearance of simulator scenes with photographs of actual simulator imagery. Photographs showed the 4 types of objects and 3 levels of density at a variety of altitudes corresponding to the terminal altitudes attained after 10 s of flight at each of the 5 Descent/Ascent Rates.

Each trial began with a 1-s gray display field, which served to alert the subject to the onset of the trial, followed immediately by the onset of dynamic imagery. Initial altitude was fixed at 150 ft AGL and, ground speed was constant throughout the trial at 450 kts. These values are within a range typical of low-level training missions for a variety of fighter-type aircraft. Further, the range of 100-200 ft AGL is one in which pilots have proven to be efficient at controlling altitude in previous simulator investigations (Martin & Rinalducci, 1983). Immediately after display onset, motion proceeded according to 1 of the 5 levels of Descent/Ascent Rate. Subjects were instructed to respond by pushing the appropriate button on the response box to indicate whether they were descending, level, or ascending. They were encouraged to respond quickly, but to maintain accuracy as high as possible. They were not required to discriminate between the 400 and 800 ft/minute rates. Maximum trial duration was 10 s. If the subject responded in less than 10 s the screen was immediately blanked for three s, after which the alerting signal automatically reappeared followed by the onset of the next trial. If the subject did not respond within 10 s, the screen was blanked until a response was entered. The altitudes attained after the maximum

10-s trial duration were as follows: 17 ft AGL at -800 ft/minute; 83 ft AGL at -400 ft/minute; 150 ft AGL at zero feet/minute; 217 ft AGL at +400 ft/minute; and 283 ft AGL at +800 ft/minute. Verbal accuracy feedback consisting of the words "correct" or "incorrect" was provided after each trial.

A session consisted of three blocks of 60 trials, one presentation of each of the 60 possible combinations of Object Type, Object Density, and Descent/Ascent Rate. The order of presentation of all treatment combinations was random within a block. Subjects were given a short break between blocks and the entire experiment took approximately 1 h.

Results and Discussion

There were 2 measured responses: (1) Percent Correct, the percentage of correct responses in each treatment condition, and (2) Reaction Time (RT), the time to detect the direction of change in altitude on correct trials only. A log base 2 transformation was performed on raw RT scores after adding 1.0 to each value to ensure that transformed values would be positive.

There were some missing RT data because some subjects had no correct trials in some treatment conditions. These missing data were handled using Searle's approach for unbalanced data with missing cells (Searle, 1987). The data for Pilots and Non-Pilots were analyzed separately because the VAX 11/780 computer used for data analyses lacked sufficient memory to perform the analysis treating pilots and non-pilots as levels of a grouping factor. Analysis of variance (ANOVA) summary tables are shown in Appendix A.

Object Density, Descent/Ascent Rate and Interactions

Figures 2 and 3 show Percent Correct and RT for Descent/Ascent Rate as a function of Object Density for Pilots. Figures 4 and 5 show Percent Correct and RT for Descent/Ascent Rate as a function of Object Density for Non-Pilots. The pattern of results is similar between groups except for the relatively poorer accuracy for Non-Pilots during descent at -400 ft/minute rate. Increases in Object Density produced corresponding increases in Percent Correct and decreases in RT for both groups (main effect of D, Tables A1 through A4). Post hoc comparisons using the Bonferroni method ($p < .05$) revealed that the improvement in performance between 11 and 45 objects per square mile was significant for both dependent measures and subject groups. Only for RT (Figs. 3 & 5) was there improvement between 45 and 175 objects per square mile.

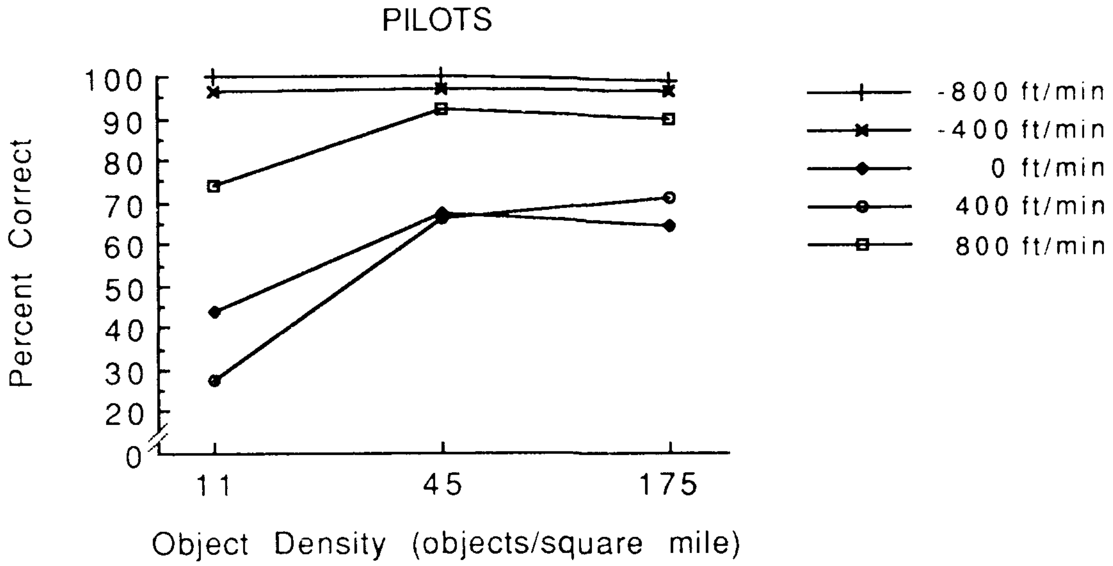

Figure 2. Percent Correct for Descent/Ascent Rate as a Function of Object Density for Pilots.

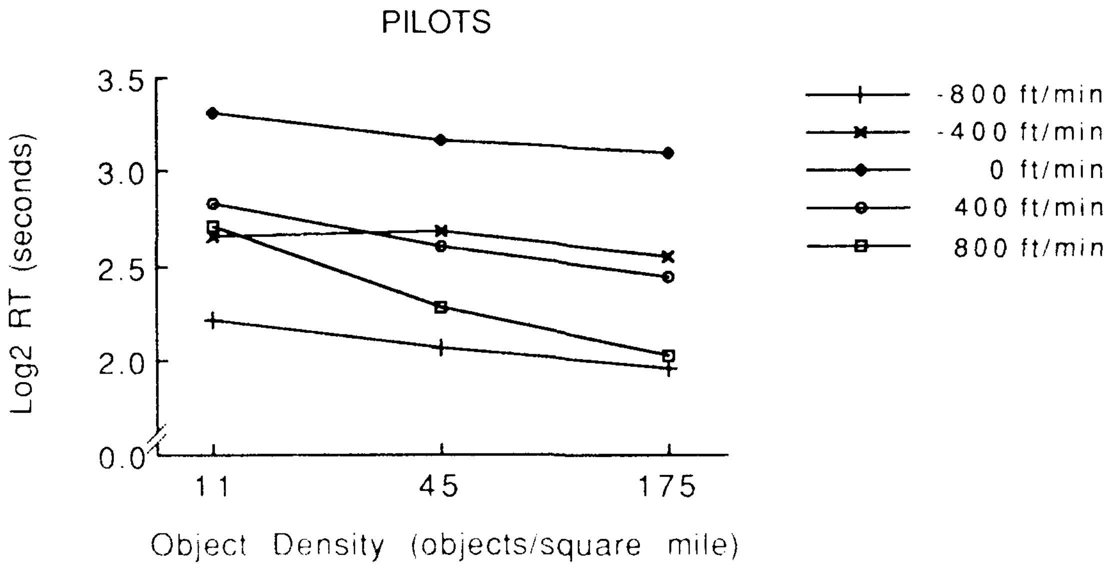

Figure 3. Log2 RT for Descent/Ascent Rate as a Function of Object Density for Pilots.

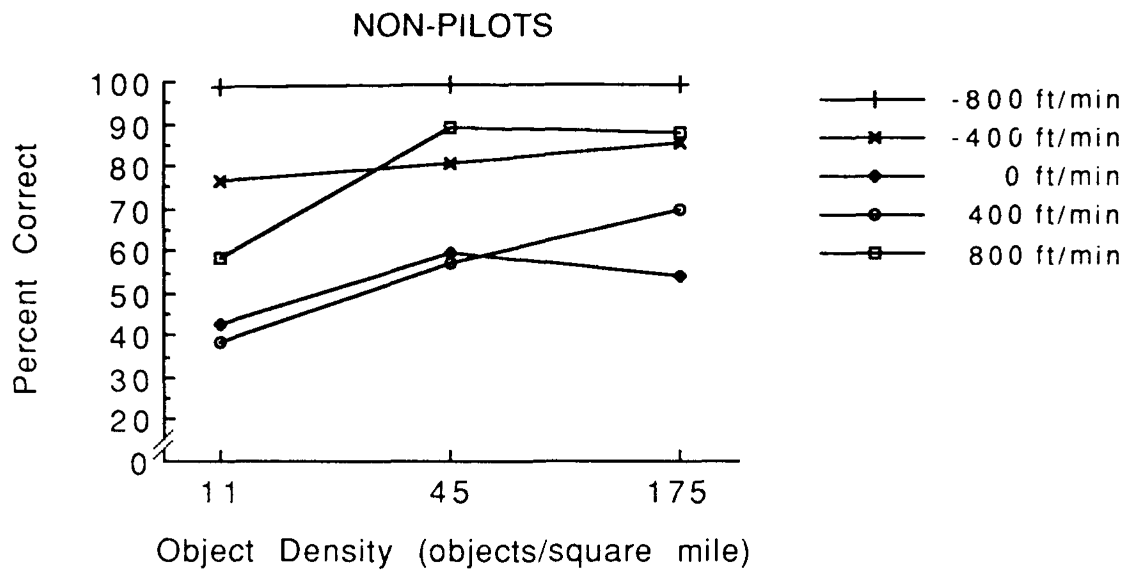

Figure 4. Percent Correct for Descent/Ascent Rate as a Function of Objec+ Density for Non-Pilots.

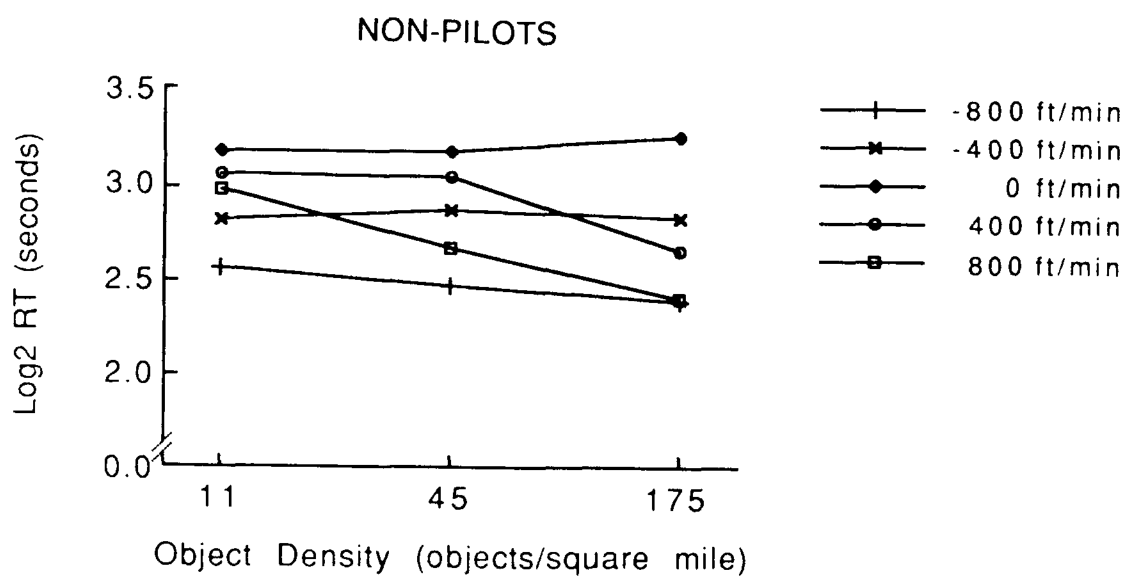

Figure 5. Log2 RT for Descent/Ascent Rate as a Function of Object Density for Non-Pilots.

The improvement in Percent Correct and RT that accompanied increases in Object Density was largest for ascending trials and essentially nonexistent for descending trials (D x R interaction, Tables A1 through A4). Percent Correct on descending trials was high even at the lowest density of 11 objects per square mile, precluding substantial further improvement (Figs. 2 & 4). However, increases in Object Density also produced larger improvements in RT (Figs. 3 & 5) on ascending trials as well. High object density appears to be of particular advantage for detecting ascent.

The change in an optical variable such as optical flow rate per unit change in altitude is smaller for upward than for downward changes in altitude. Detecting ascent should, therefore, take longer and/or be less accurate than detecting descent. Interestingly, at the highest density of 175 objects per square mile, RT (Figs. 3 & 5) for rapid ascent (+800 ft/minute) equaled rapid descent (-800 ft/minute) and Percent Correct (Figs. 2 & 4) for rapid ascent nearly equaled rapid descent. With high object density, therefore, subjects appeared to detect rapid ascent better than would be expected on the basis change in a given optical variable alone. This finding further emphasizes the importance of high levels of object density, particularly for detecting ascent. However, the question remains as to why performance in this condition was so good.

Speed and accuracy of detecting a change in altitude improves as initial fractional rate of change in altitude increases (e.g., Hettinger & Owen, 1985). Both Percent Correct (Figs. 2 & 4) and RT (Figs. 3 & 5) were better for higher than for lower rates of descent and ascent in the present investigation (main effect of R, Tables A1 through A4). These facts are consistent with the view that in actual flight, slow descent is hazardous because it is often not detected before corrective action can be taken. Table 2 shows values for magnitude of change in altitude measured in feet (raw reaction time multiplied by rate of change in altitude in feet per second) for each rate of descent and ascent. Note that despite quicker RTs, change in altitude was actually <u>larger</u> for the highest rates of descent and ascent. In this sense, gradual descent was the safer condition.

There are several differences between the present task and actual flight that could account for this apparent discrepancy. First, in actual flight, changes in altitude are accompanied by changes in pitch and, therefore, changes in the relative position of the horizon. The horizon was held constant in the present experiment in order to control for this cue which was not of primary interest. In actual flight, a large displacement of the horizon may be the dominant cue for rapid change in altitude. Second, in the present investigation there were no kinesthetic cues to signal rapid changes in altitude. Third, pilots in actual flight continuously perform multiple tasks creating a high-workload

Table 2. Change in Altitude at Time of Responding for each Descent/Ascent Rate

Group	Descent/Ascent Rate	Change (ft)
Pilots	-800	-45.46
	-400	-37.29
	400	39.85
	800	63.76
Non-Pilots	-800	-65.12
	-400	-43.58
	400	47.93
	800	80.53

environment. Detection of gradual descent may be much more difficult under conditions of high workload and task saturation.

Owen and Freeman (1987) found that increases in the density of lines in a two-dimensional grid produced a larger improvement in RT and perceptual sensitivity (A_g) to discriminate descent from level flight with lower fractional rates of descent. Increases in Object Density also tend to produce larger increases in Percent Correct (Figs. 2 & 4) for lower rates of change, particularly ascent for Pilots. However, this is not true of the RT data (Figs. 3 & 5). Indeed, the effect of Object Density on RT tends to be smaller for lower rates of change, again most evident for Pilots. The present results obtained with three-dimensional objects do not, therefore, strongly support those of Owen and Freeman (1987). Not only did Owen and Freeman (1987) use a two-dimensional grid, but fractional rates of change in altitude were also smaller than in the present investigation (1.23%/s to 5.0%/s) which could account for the discrepancy. The present values for fractional change in altitude were selected based on appropriateness for jet aircraft and probably represent the more-valid parameters.

Object Type and Interactions

The only significant main effect for Object Type was Percent Correct for Non-Pilots (effect of O, Table A3). Table 3 shows Percent Correct for each Object Type for Non-Pilots. Interestingly, performance was best for the Tetrahedrons and worst for the Mix. Planned comparisons revealed that the average of the 2 Tetrahedrons was superior to the average of the 2 conditions with trees and/or bushes, [$F(1,649) = 7.40$, $p = .007$]. Comparisons between Textured and Untextured Tetrahedrons, and between the Pines and the Mix were not significant.

Table 3. Percent Correct for Object Type for Non-Pilots: Experiment 1

Object Type	Percent Correct
Textured Tetrahedrons	76.30
Untextured Tetrahedrons	75.00
Pine Trees	71.20
Mix	69.63

An advantage for realistic objects was predicted for Pilots on the grounds that change in the apparent size of familiar objects would provide additional information regarding change in altitude. Although this added information would not be expected to be as important a factor for Non-Pilots, one would not predict poorer performance with realistic objects than with Tetrahedrons. One possibility is the triangular bases of the tetrahedrons (which faced upward) provided additional motion cues, such as parallax, that were especially useful to the inexperienced Non-Pilots.

Despite the relative absence of main effects of Object Type, there were several statistically significant higher-order interactions involving this variable. Figure 6 shows RT for Object Type as a function of Object Density for Pilots (O x D interaction, Table A2). Relatively large differences among objects are evident

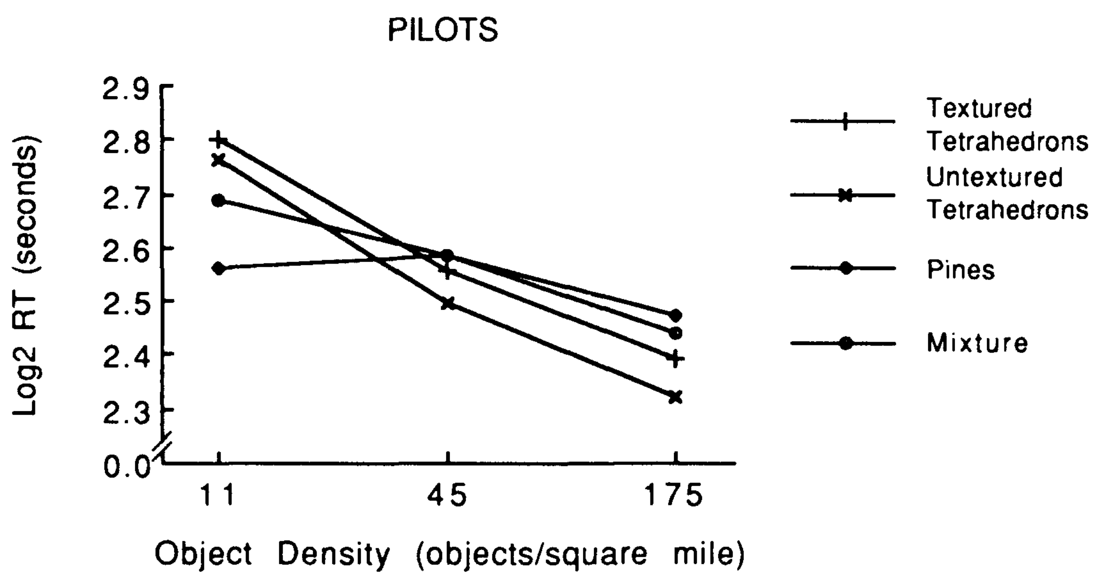

Figure 6. Log2 RT for Object Type as a Function of Object Density for Pilots.

at the lowest density where performance is best for Pines and poorest for the tetrahedrons. As density increases, RTs improve more rapidly for other objects, particularly tetrahedrons, than for Pines such that the reverse pattern is evident at the highest density of 175 objects per square mile. These data provide some evidence of an advantage for realistic objects (at least Pines) under conditions of low object density.

Figures 7 and 8 show RT for Object Type as a function of Descent/Ascent Rate for Pilots and Non-Pilots respectively (O x R interactions, Tables A2 & A4). The one consistent pattern in these data is that RTs for the Mix tend to be relatively quick on descending trial whereas they are slower than other objects on ascending trials.

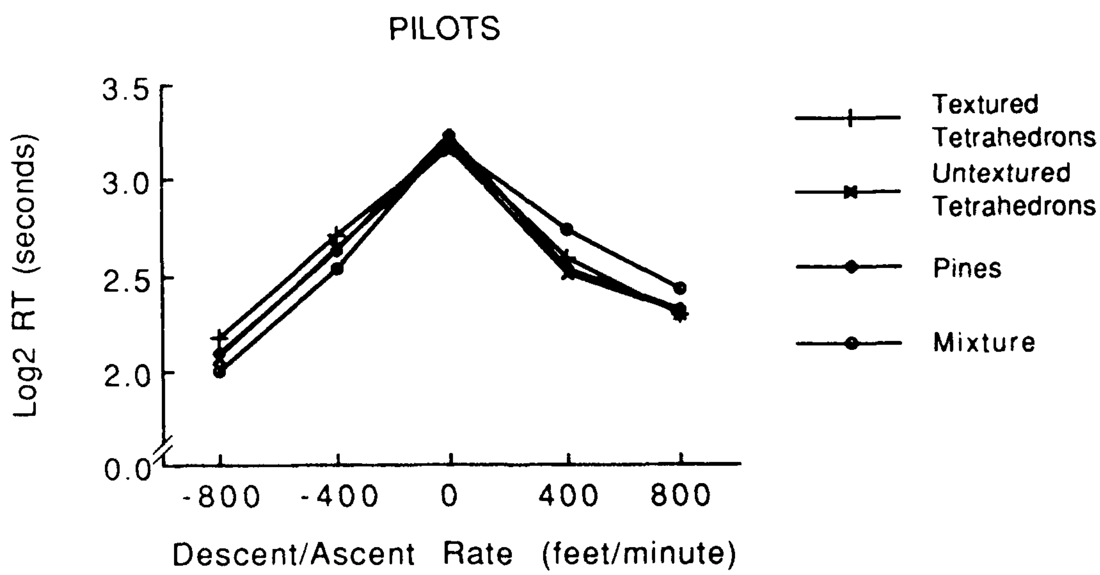

Figure 7. Log2 RT for Object Type as a Function of Descent/Ascent Rate for Pilots.

Additional insight regarding the interactions depicted in Figures 6 and 7 for Pilots is available in Figure 9, above which shows RT for Object Density as a function of Descent/Ascent Rate for each Object Type. Differences in these two-way interactions are the source of the significant three-way interaction of Object Type by Object Density by Descent/Ascent Rate (O x D x R interaction, Table A2). Two features stand out. First, RTs for

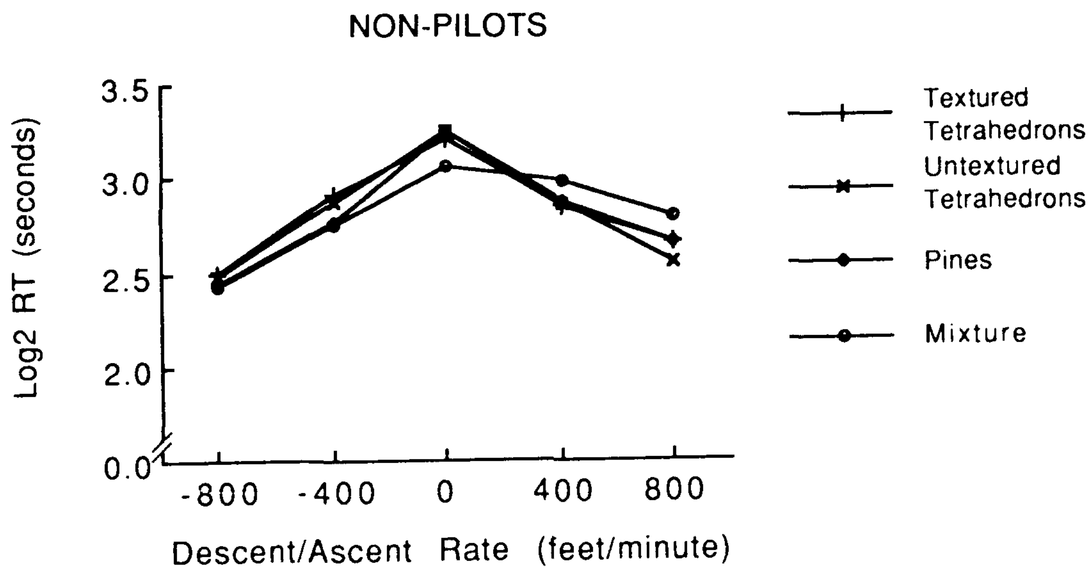

Figure 8. Log2 RT for Object Type as a Function of Descent/Ascent Rate for Non-Pilots.

Pines at the lowest density are notably quicker than other objects only on ascending trials. The quick RT for Pines at the lowest density in Figure 6 can, therefore, be attributed primarily to ascending trials. Second, RTs for the Mix are quicker than other objects on descending trials and slower than other objects on ascending trials primarily at the lowest level of Object Density. Therefore, the poor performance for the Mix on ascending trials in Figure 7 can also be traced primarily to the lowest level of Object Density.

EXPERIMENT 2

During the course of a simulator training program, pilots would almost certainly be exposed to more than a single session of practice in a flight simulator. Despite this fact, there are few investigations that have explored how the effects of variables such as those explored in Experiment 1 change with repeated exposure to the task.

One concern is that effects, or absence of effects, may be short-lived due to temporary unfamiliarity with the simulator environment. For instance, although the trees and bushes used in the present investigation were intended to look like objects that

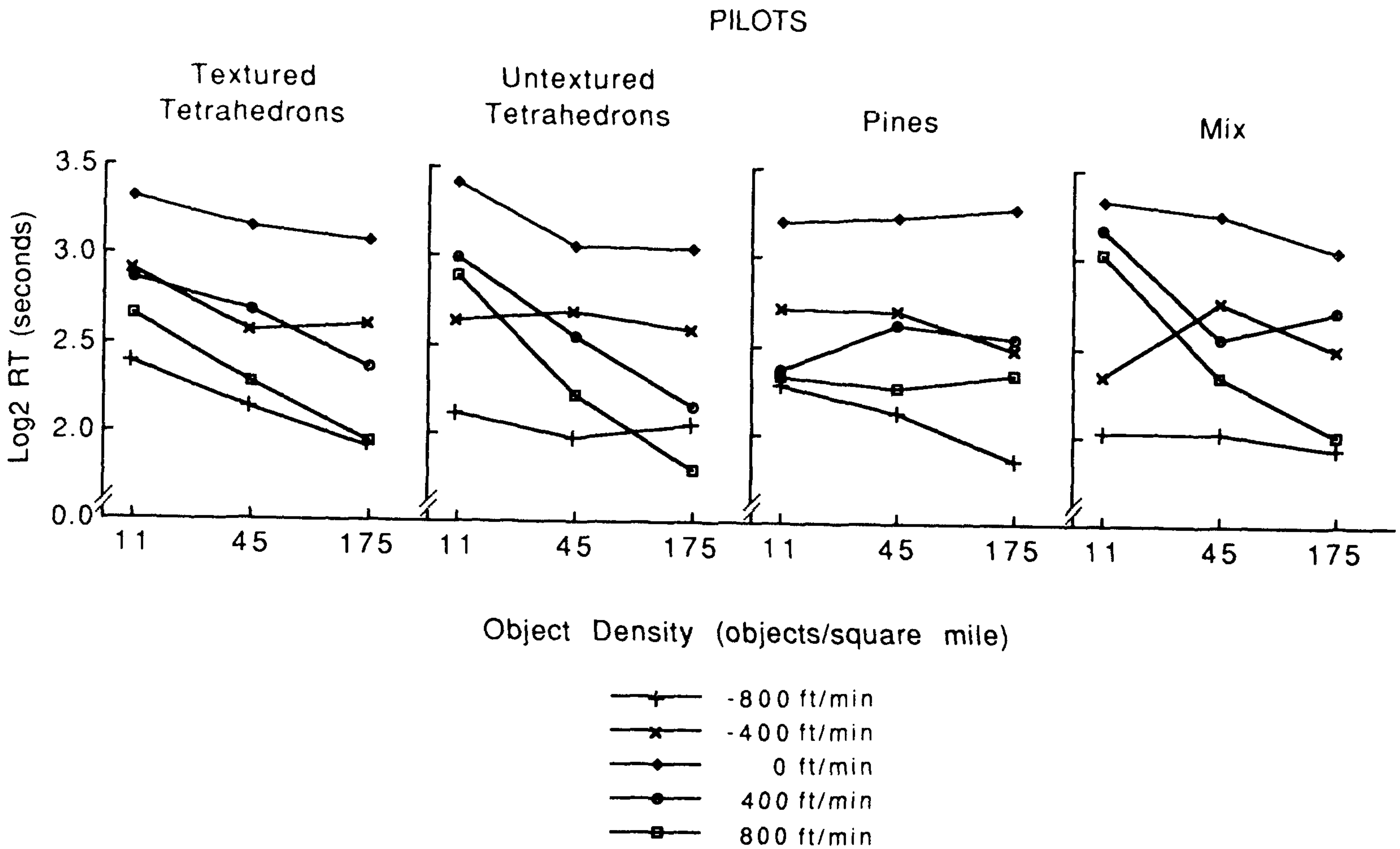

Figure 9. Log2 RT for Descent/Ascent Rate as a Function of Object Density for Each Object Type for Pilots.

are familiar to pilots, their appearance in simulator scenes may have been sufficiently foreign to require a certain period of acclimation. An advantage for realistic objects might, therefore, emerge after additional sessions of practice.

A second concern is whether there are differences in the rate of learning between cue-rich (i.e., high-object density) and reduced-cue (i.e., low-object density) environments. Warren and Riccio (1985) reported faster learning of a simulated altitude control task when one of two qualitatively different types of cues (i.e., either an outline roadway the width of which varied with changes in altitude, or a pattern of dots on the terrain surface which provided optical flow information) was removed from the simulated scene. They concluded that learning might actually be better with less information in simulator scenes. Owen and Wolpert (1987) gave subjects 4 sessions of practice with a task that involved detecting and canceling (through joystick inputs) simulated ascent and descent. They varied the density of lines in a two-dimensional grid and reported no difference in the rate of learning for lower densities compared to higher densities. This density manipulation more closely approximates the object density manipulation in the present investigation. Possible differences between two-dimensional grids and three-dimensional objects caution against generalizing this null result to the present context.

Hettinger and Owen (1985) gave subjects 4 sessions of practice with a task that involved discriminating descent from level flight. Initial learning was fastest when discriminations were easiest (i.e., with higher rates of descent), but the magnitude of improvement was largest when discriminations were difficult (i.e., with lower rates of descent). Although Hettinger and Owen concluded that learning was better with difficult discriminations, error rate in the easy condition was nearly at zero early in practice and could not have improved substantially thereafter. There were no differences in rate of learning among easy and difficult conditions with respect to RT measures. To explore possible differences in rate of learning between easy and difficult discriminations, the different levels of Descent/Ascent Rate were retained in Experiment 2.

Method

Subjects

There were 4 subjects in the Pilot group. One was a civilian flight instructor with 5,900 h flying time (age 49), and 3 were United States Air Force (USAF) pilots who participated in Experiment 1 (mean age = 26.67, SD = .58). Two subjects were T-38 IPs with 1,000 h total flying time each, and 1 had completed undergraduate pilot training in the USAF and, was a student in the F-111 aircraft with 300 h total flying time.

There were 5 subjects in the Non-Pilot group, 2 of which participated in Experiment 1. One Non-Pilot had 71 h flying time as a student pilot in the USAF, but was no longer in pilot training. Mean age was 33.80 years (SD = 8.79).

Experimental Design and Stimuli

Design and stimuli were identical to Experiment 1 except that subjects participated in a total of 4 experimental sessions. Data from Experiment 1 were taken as the first session of practice when available.

Apparatus

Apparatus was identical to Experiment 1.

Procedure

The procedure was identical to Experiment 1 except that 4 sessions of data were collected from each subject. There was only 1 data collection session for each subject per day and an attempt was made to minimize the number of days between practice sessions. Pilots averaged 2.29 days between consecutive sessions (SD = .79). Non-Pilots averaged 3.53 days between consecutive sessions (SD = 2.61).

Results and Discussion

There were 2 measured responses: (1) Percent Correct, the percentage of correct responses in each treatment condition, and (2) Reaction Time (RT), the time to detect the direction of change in altitude on correct trials only. A log base 2 transformation was performed on raw RT scores after adding 1.0 to each value to ensure that transformed values would be positive.

Missing data were handled using Searle's approach for unbalanced data with missing cells (Searle, 1987). The data for Pilots and Non-Pilots were analyzed separately. Results of ANOVAs are shown for each subject group and dependent measure in Appendix B. Only the linear component of the Practice Session variable was used. Only statistically significant ($p < .05$) three-way and higher order interactions are shown.

Practice Session and Interactions

Pilots. Figures 10 and 11 show Percent Correct and RT for Descent/Ascent Rate as a function of Practice Session for Pilots. Although mean Percent Correct (Fig. 10) did not improve with practice (effect of P, Table B1), accuracy did change as a function of practice for some Descent/Ascent Rates (P x R interaction, Table B1). A sizable improvement is evident for the +400 rate of change

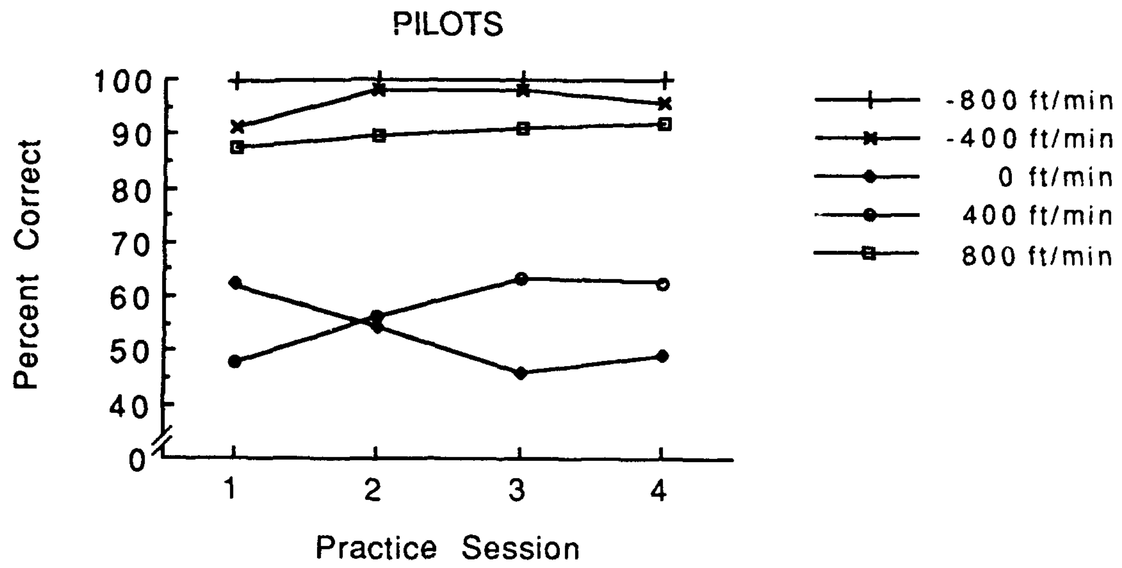

Figure 10. Percent Correct for Descent/Ascent Rate as a Function of Practice Session for Pilots.

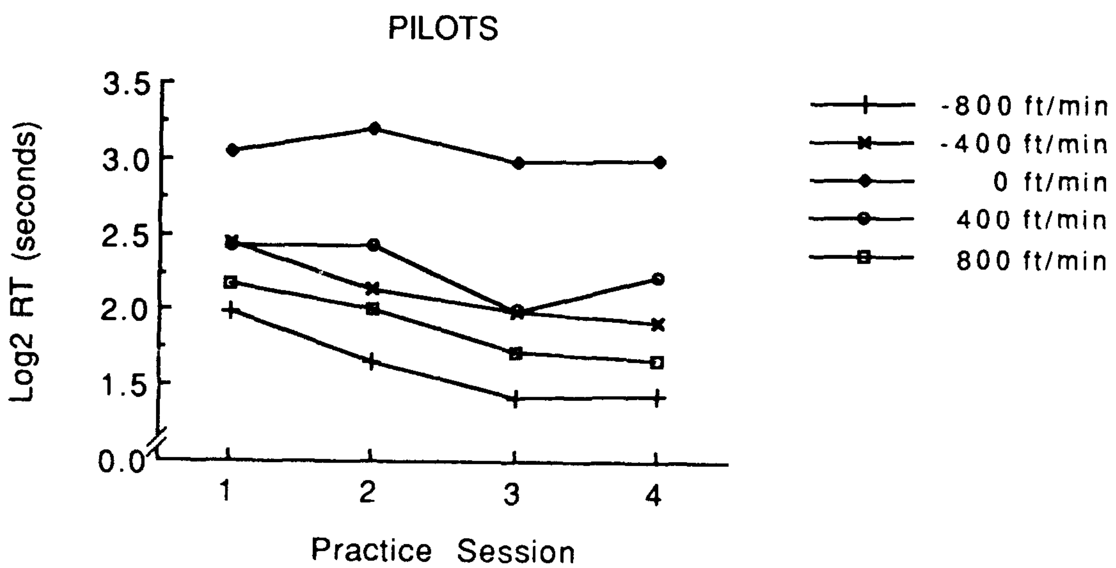

Figure 11. Log2 RT for Descent/Ascent Rate as a Function of Practice Session for Pilots.

whereas accuracy declined for the zero rate. High initial accuracy for the -800, -400, and +800 rates of change probably precluded much further improvement in these conditions.

The pattern for the zero and +400 rates is consistent with a shift in response criterion over Practice Sessions. The poor overall accuracy in these 2 conditions indicates that they were the most difficult. A tendency to respond "no change" in the absence of strong evidence of a change in altitude would result in poor accuracy for +400 due to a high proportion of "misses." However, "hit" rate for the zero rate of change would be inflated, thereby improving accuracy in that condition. A shift toward "ascent" responses would improve accuracy for the +400 rate while reducing accuracy for the zero rate. Consistent with this interpretation, accuracy in Session 1 is poorer for the +400 rate of change than for the zero rate of change whereas a reversal occurs in Sessions 2 through 4. Therefore, the improvement for the +400 rate should probably not be taken as evidence of perceptual learning in that condition.

Reaction Time for Pilots (Fig. 11) decreased significantly with practice (main effect of P, Table B2). The decrease was largest for the -800, 800, and 400 rates of change whereas there was essentially no change for the zero rate (P x R interaction, Table B2). Reaction Time for the -800 ft/minute rate appears to have reached asymptote at Practice Session 3.

Non-Pilots. Figures 12 and 13 show mean Percent Correct and RT for Descent/Ascent Rate as a function of Practice Session for Non-Pilots. Mean Percent Correct (Fig. 12) improved significantly as a function of practice (main effect of P, Table B3) and the improvement was largest for the zero and +400 rates of change (P x R interaction, Table B3). High initial accuracy for the 3 other rates of change precluded substantial further improvement.

Reaction Times (Fig. 13) increased significantly as a function of practice (main effect of P, Table B4). The increase was limited primarily to the zero and +400 rates of change (P x R interaction, Table B4). The large improvement in accuracy in these 2 conditions (Fig. 12), therefore, appears to have been due in part to Non-Pilots becoming less hasty in responding rather than to increased perceptual sensitivity, per se.

Object Density, Descent/Ascent Rate, and Interactions

Figures 14 through 17 show Percent Correct and RT for Descent/Ascent Rate as a function of Object Density for Pilots and Non-Pilots respectively. The pattern of results closely parallels those of Experiment 1 and all statistical effects were identical (Tables B1 through B4). These results will, therefore, not be discussed further.

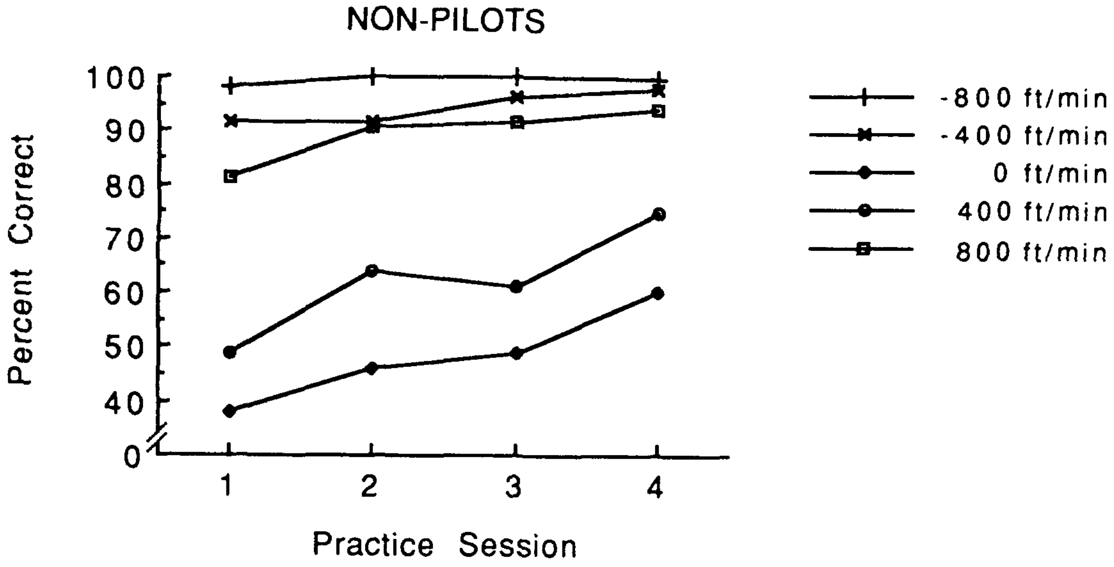

Figure 12. Percent Correct for Descent/Ascent Rate as a Function of Practice Session for Non-Pilots.

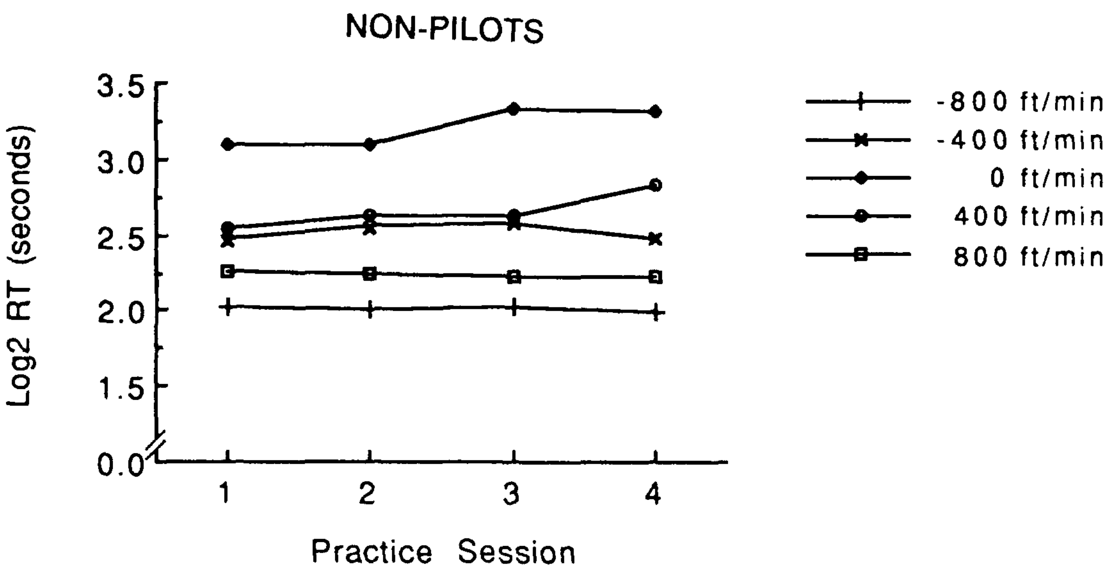

Figure 13. Log2 RT for Descent/Ascent Rate as a Function of Practice Session for Non-Pilots.

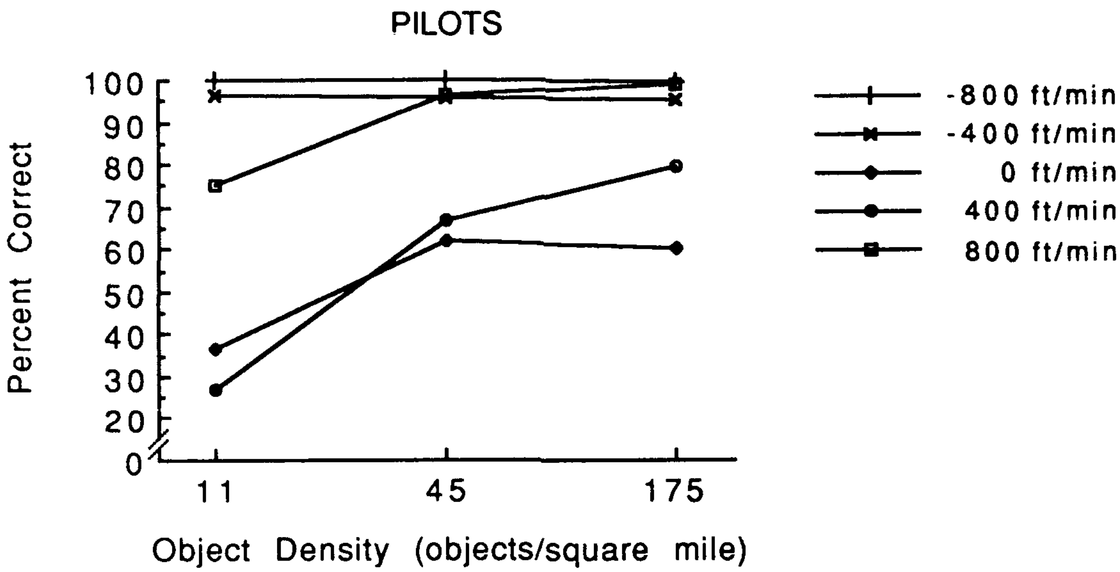

Figure 14. Percent Correct for Descent/Ascent Rate as a Function of Object Density for Pilots.

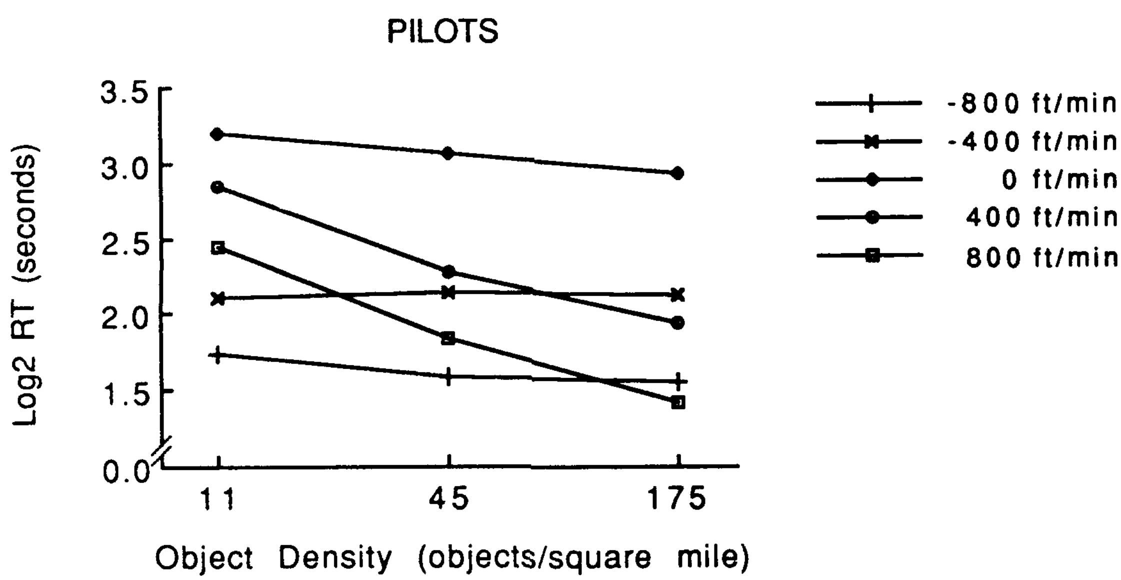

Figure 15. Log2 RT for Descent/Ascent Rate as a Function of Object Density for Pilots.

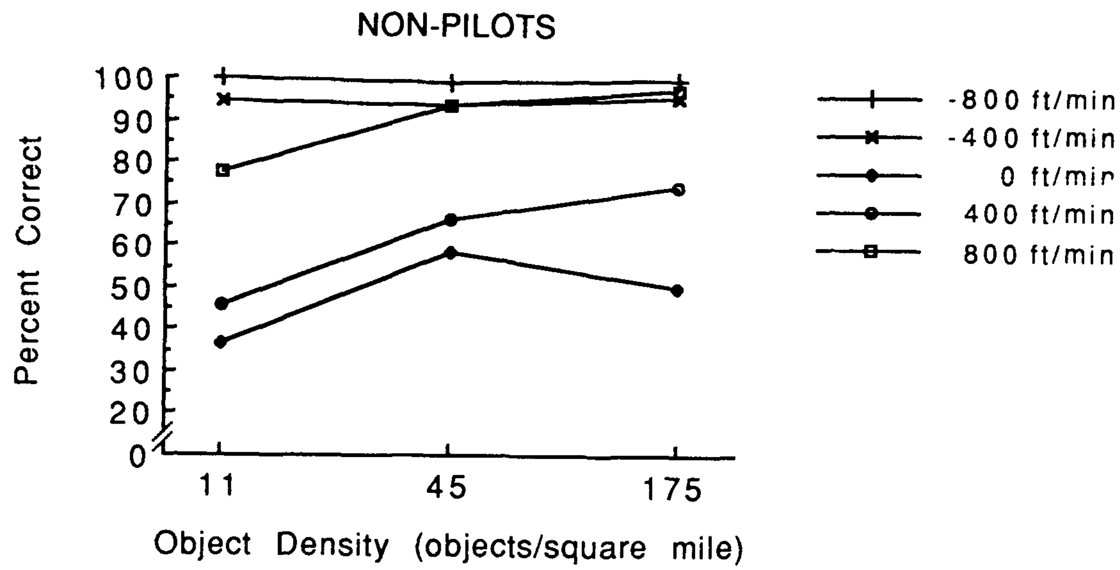

Figure 16. Percent Correct for Ascent/Descent Rate as a Function of Object Density for Non-Pilots.

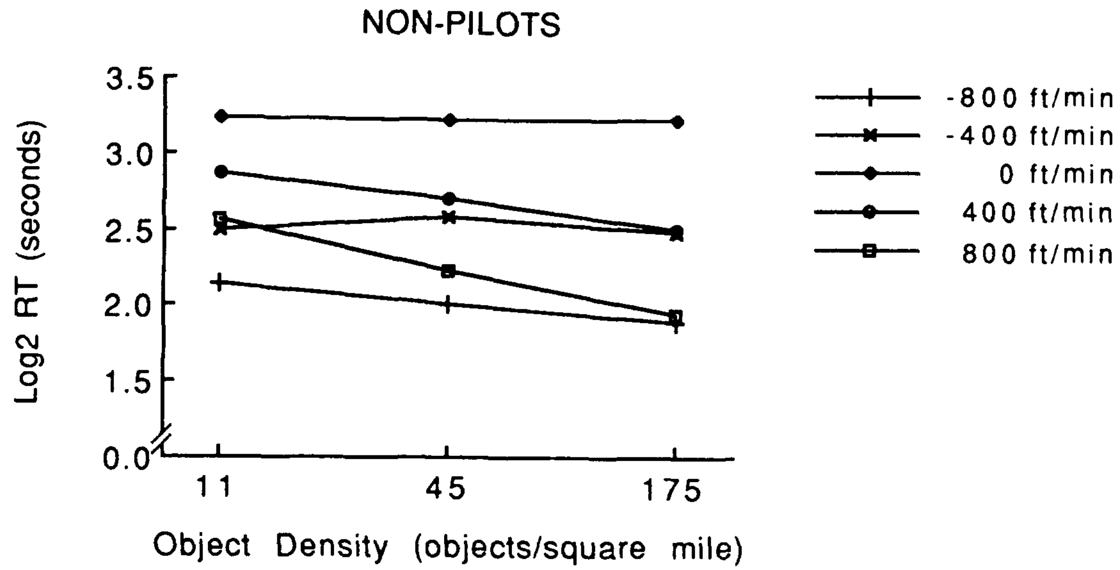

Figure 17. Log2 RT for Ascent/Descent Rate as a Function of Object Density for Non-Pilots.

The only significant main effect of Object Type was, again, Percent Correct for Non-Pilots (main effect of O, Table B3). Means are shown in Table 4. Planned comparisons revealed that the average of the 2 tetrahedrons was significantly better than the average of the 2 realistic objects [$F(1, 1100) = 7.61$, $p = .006$]. Neither the 2 tetrahedrons nor the 2 types of realistic objects differed from one another.

Table 4. Percent Correct for Object Type for Non-Pilots

Object Type	Percent Correct
Textured Tetrahedrons	79.89
Untextured Tetrahedrons	81.00
Pine Trees	75.50
Mixture	78.22

Figure 18 shows Percent Correct for Object Type as a function of Object Density for Non-Pilots (O x D interaction, Table B3). There is a larger increase in Percent Correct between 11 and 45 objects per square mile for the Mix and Untextured Tetrahedrons. Percent Correct increases between 45 and 175 objects per square mile only for Textured Tetrahedrons. It should be noted that Percent Correct for the Mix is low relative to other objects only at the lowest density. Therefore, the low mean Percent Correct in Table 4 can be attributed to the lowest density condition.

Figure 19 shows RT for Object Type as a function of Object Density for Pilots (O x D interaction, Table B2). Unlike Experiment 1 (Fig. 6), there is no advantage for Pines at the lowest density of 11 objects per square mile. Reaction Time is slowest for the Mix at the lowest density, improves sharply at 45 objects per square mile and is again slowest at the highest density. More-consistent improvement is evident for other object types.

Figures 20 and 21 show Percent Correct for Object Type as a function of Descent/Ascent Rate for Pilots and Non-Pilots (O x R interactions, Tables B1 & B3, respectively). Differences among objects are essentially nonexistent on descending trials. For Pilots, Percent Correct for the Mix is highest among objects at the 0 ft/minute rate whereas it is lowest among objects for both rates of ascent. For Non-Pilots, Percent Correct for Pines is lowest among objects at the zero and +400 ft/minute rates of change

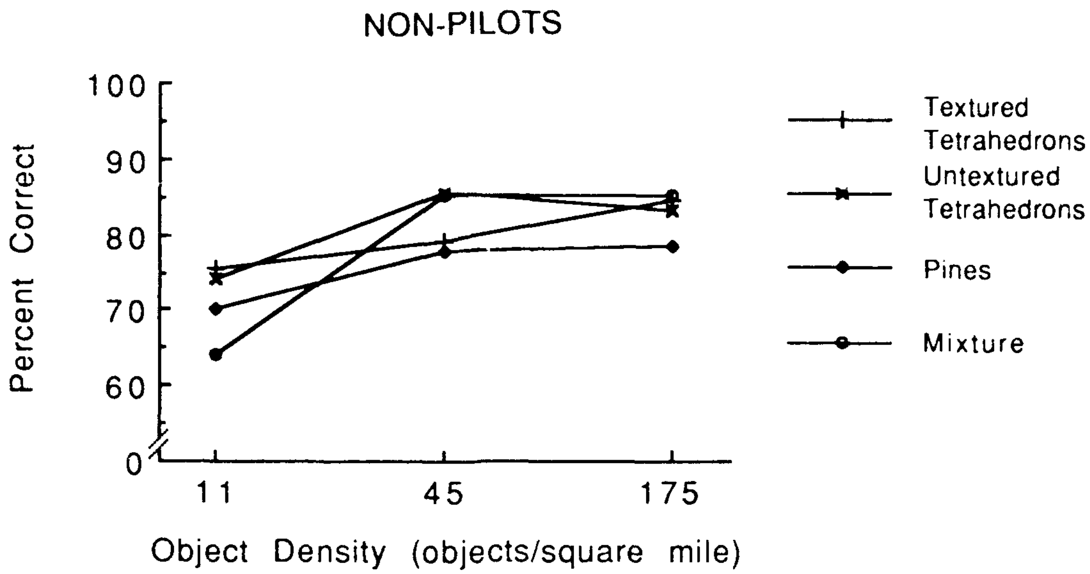

Figure 18. Percent Correct for Object Type as a Function of Object Density for Non-Pilots.

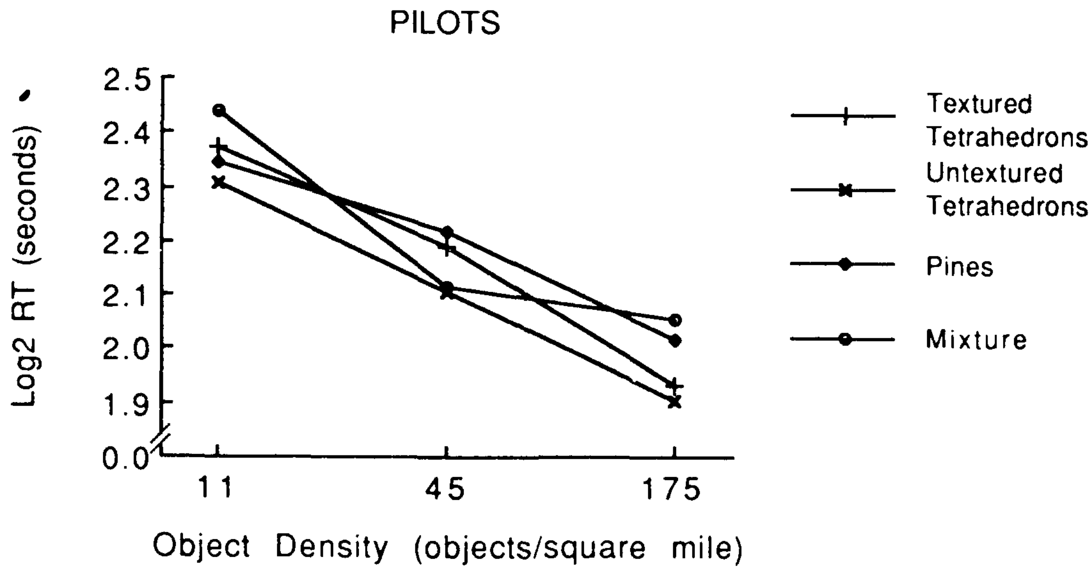

Figure 19. Log2 RT for Object Type as a Function of Object Density for Pilots.

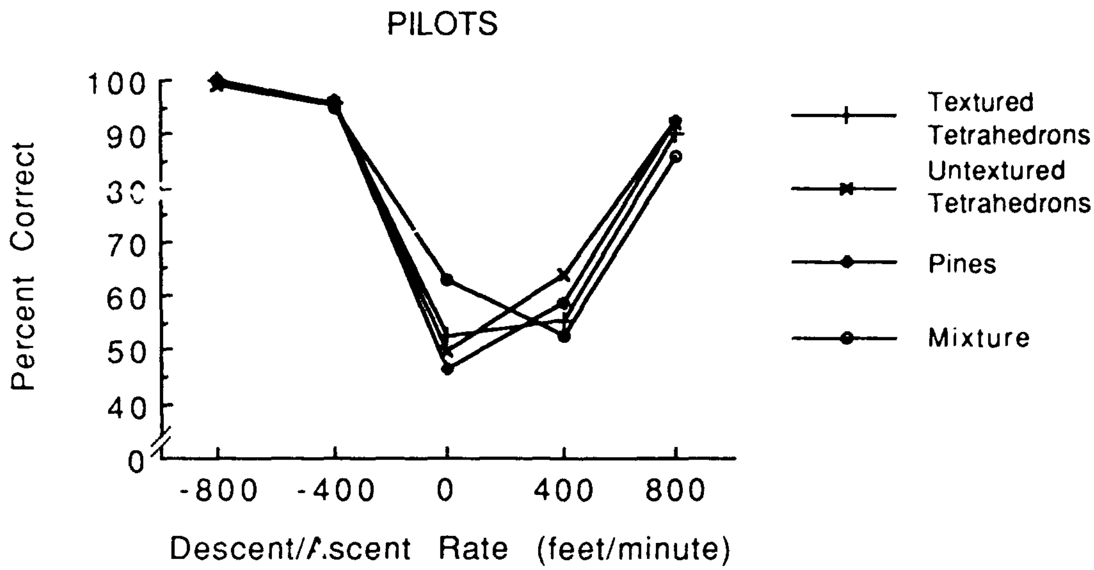

Figure 20. Percent Correct for Object Type as a Function of Descent/Ascent Rate for Pilots.

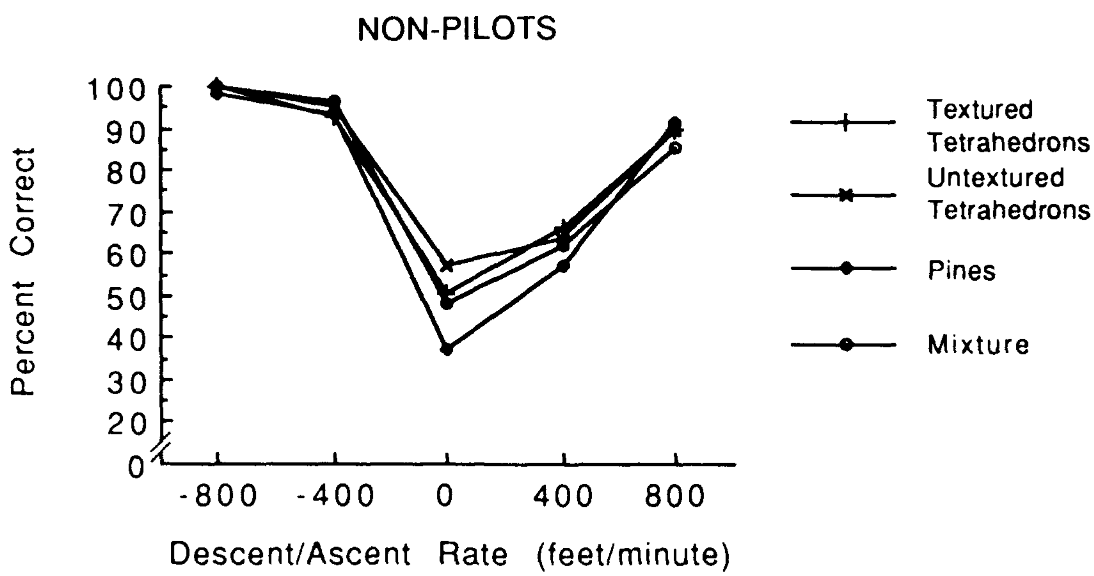

Figure 21. Percent Correct for Object Type as a Function of Descent/Ascent Rate for Non-Pilots.

appear to provide much in the way of meaningful information regarding possible advantages for one type of object over another.

Figure 22 shows RT for Object Type as a function of Descent/ Ascent Rate for Non-Pilots (O x R interaction, Table B4). Reaction Times for Textured Tetrahedrons tend to be slower than other objects on descending trials whereas they are as quick as other objects on ascending trials.

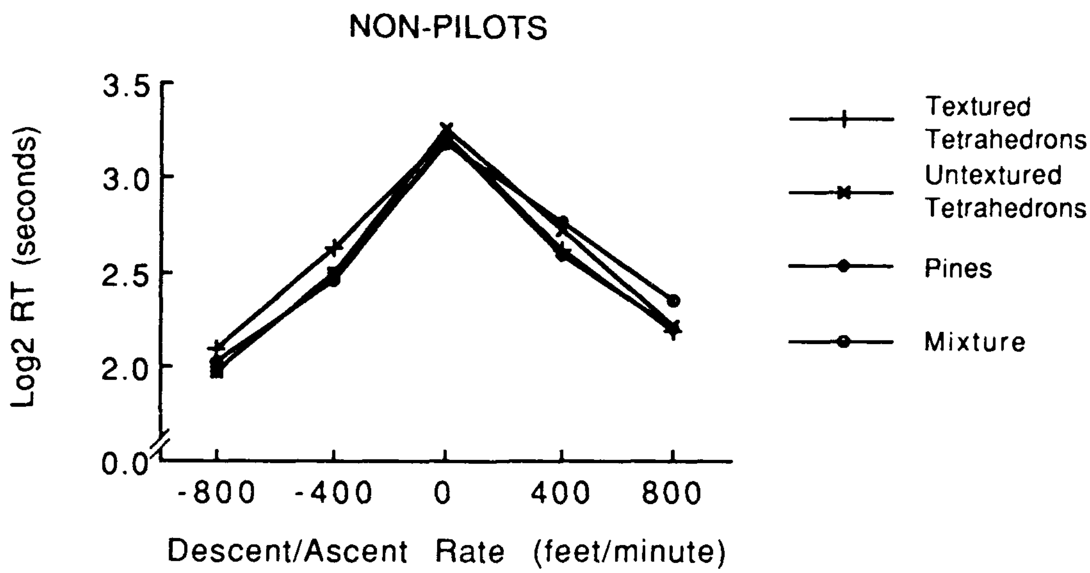

Figure 22. Log2 RT for Object Type as a Function of Descent/Ascent Rate for Non-Pilots.

Figures 23 and 24 show RT for Descent/Ascent Rate as a function of Object Density for each Object Type, for Pilots and Non-Pilots respectively (O x D x R interactions, Tables B2 & B4). For both Pilots (Fig. 23) and Non-Pilots (Fig. 24), RTs for Untextured Tetrahedrons and the Mix are particularly slow at the lowest density on ascending trials.

GENERAL DISCUSSION AND CONCLUSIONS

The most consistent finding across experiments, subject groups, and dependent measures was the poor performance for the lowest density level of 11 objects per square mile. In all cases,

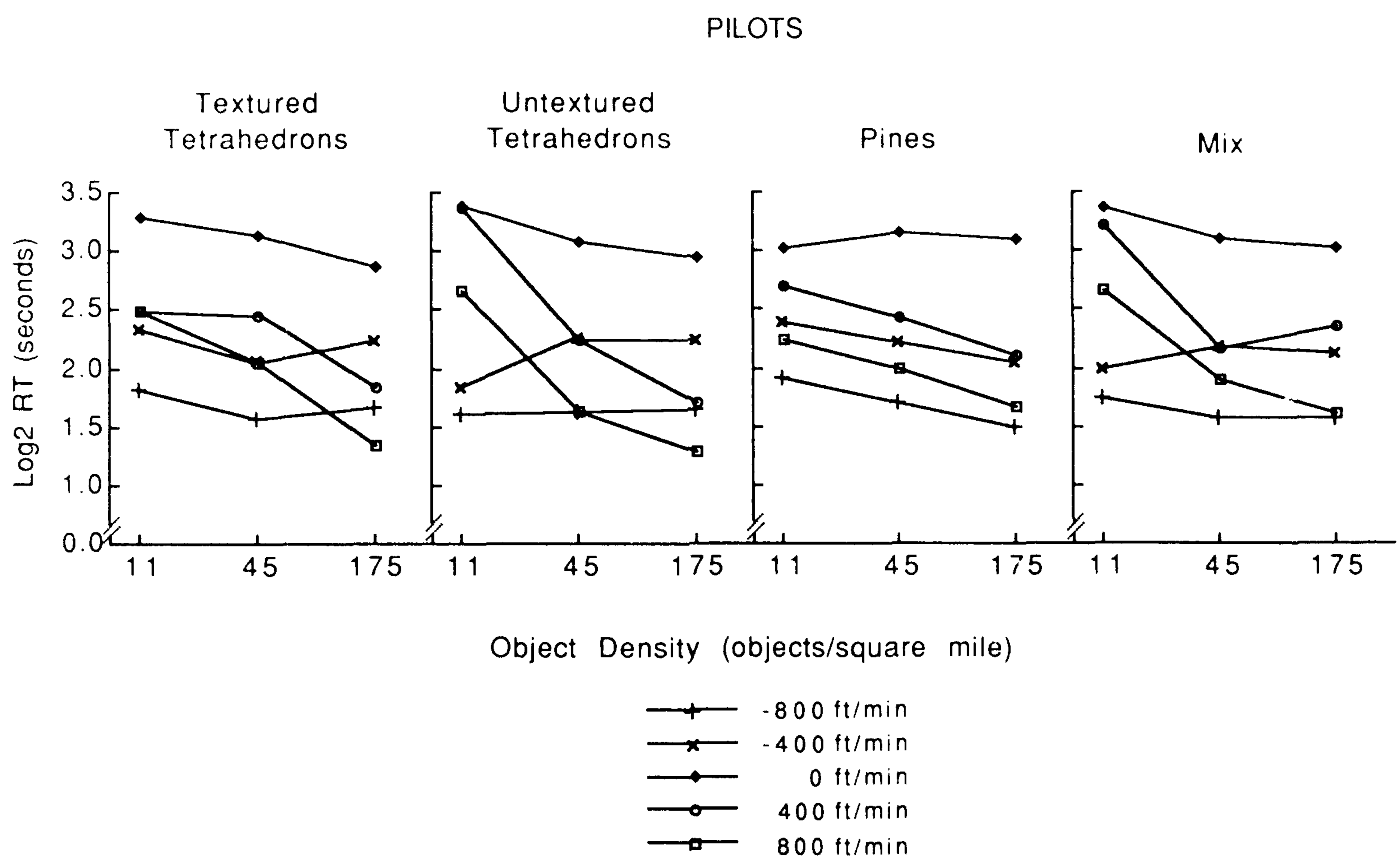

Figure 23. Log2 RT for Descent/Ascent Rate as a Function of Object Density for Each Object Type for Pilots.

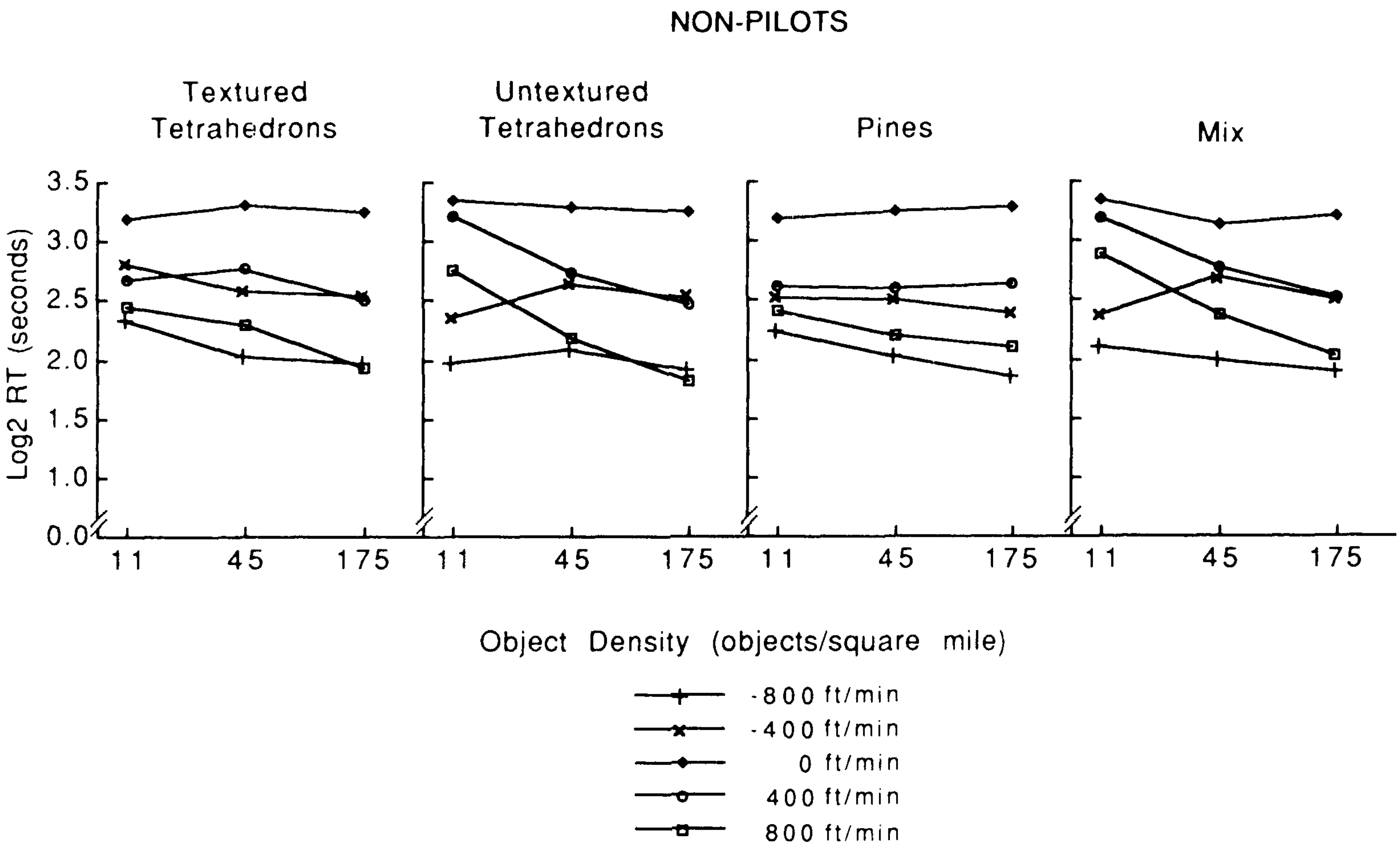

Figure 24. Log2 RT for Descent/Ascent Rate as a Function of Object Density for Each Object Type for Non-Pilots.

a significant advantage was obtained for increases up to 45 objects per square mile. In the case of RT, a further advantage was obtained for the highest density of 175 objects per square mile. These findings replicate the results of Kleiss, et al. (1989) using a different task and provide further support that maximum cuing effectiveness requires densities at least as high as 45 objects per square mile (average spacing of 800 ft between objects) and possibly as high as 175 objects per square mile (average spacing of 400 ft between objects) when the time to detect changes in altitude is of concern.

Also consistent with Kleiss, et al. (1989) was the lack of evidence favoring the more detailed and realistic objects over simple tetrahedrons. The absence of an advantage for realistic objects was unexpected in light of evidence that the apparent size of familiar objects is used by pilots as a cue for altitude. One possibility is that it is not the realistic appearance of objects, per se, that is important, but rather knowledge of the size of objects. Similar to Kleiss et al. (1989), subjects in the present experiment were informed as to the sizes of objects prior to beginning and this information may have been sufficient to nullify whatever advantage would have existed for realistic objects. Because Object Type did not interact with practice, these null results cannot be attributed to transient factors such as temporary unfamiliarity with the display device.

The numerous two-way and three-way interactions involving Object Type testify to the fact that differences among objects can affect performance. However, none of these pointed to a clear advantage for one type of object over another. Further, most interactions could be traced to differences at the lowest level of Object Density, a level that is clearly inferior. The significant higher order interactions involving Object Type are, therefore, probably of little practical importance.

The finding that detection of change in altitude was affected more by object density than by the detail/realism of individual objects suggests that available CIG processing capacity may be used more effectively by maximizing object density rather than the detail/realism of individual objects. The relationship between object density and CIG processing capacity is not straightforward, however. Computer-image generator processing capacity is typically measured in terms of the number of polygons (i.e., planar surfaces, often triangular in shape) a system can process in a given period of time. Quoted specifications sometimes assume that polygons are connected such as when forming a continuous terrain surface. Polygons used to construct individual objects and other cultural features are treated differently. For example, AVTS (Eibeck & Petrie, 1988) is capable of displaying 4,000 visible surfaces at an update rate of 60 cps from which roughly 1,000 tetrahedrons could, theoretically, be constructed. However, AVTS computes and displays a maximum 256 three dimensional objects regardless of the number of polygons used to construct those objects. As the pine trees in the present investigation required 12 polygons each, one could as easily construct 256 pine trees as 256 tetrahedrons with AVTS and there would be no advantage to using the simpler tetrahedrons. A CIG which processed all available polygons equally would need only a capacity in the vicinity of 1,024 independent surfaces to equal this density with tetrahedrons alone. A severe penalty would be incurred if more-detailed and realistic objects were to be used in this case.

Warren and Riccio (1985) found that learning of a simulated altitude control task was faster when multiple redundant cues were removed from the simulator scene. There was no strong evidence that the rate of learning was different for different levels of Object Density in the present investigation. The quantitative manipulation of Object Density in the present experiment more closely approximates the manipulation of line density in a two-dimensional grid by Owen and Wolpert (1987) who reported no difference in the rate of learning of an altitude control task for different levels of density. Therefore, quantitative reductions in cue density may not serve the same purpose as reductions in qualitatively different types of cues such as reported by Warren and Riccio (1985).

The effect of practice for Non-Pilots was similar to that reported by Hettinger and Owen (1985) who used a descent detection task with Non-Pilot subjects. Learning was evidenced primarily in improvements in accuracy and tended to be larger for the more difficult Descent/Ascent Rates (i.e., those with poorest initial accuracy). The pattern was different for Pilots as learning was evidenced primarily in improvements in RT and was larger for the easier (i.e., quicker) Descent/Ascent Rates. There was little indication that the trend in RTs for Non-Pilots was beginning to take on the pattern observed for Pilots even after four sessions of practice. Therefore, the results for Pilots do not appear to reflect a simple matter of proficiency at this particular task. Because these apparent differences were not tested statistically, the question of their generality remains open.

The present results provide additional evidence that certain types of simulator visual scene detail are more effective than others across a range of piloting experience and practice at a particular task. Interestingly, the realistic appearance of objects was not a major factor suggesting that realism, per se, should not be embraced as an important design goal in and of itself. Future research should seek to define the relevant dimensions of scene detail that contribute most to performance of simulated low-altitude flight tasks.

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APPENDIX A
ANOVA TABLES FOR EXPERIMENT 1

Table A1. ANOVA of Percent Correct for Pilots

Source	SS	df	MS	F	p
O	2486.111	3	828.704	1.978	0.116
D	40148.150	2	20074.075	47.914	0.000
R	256120.367	4	64030.092	152.832	0.000
OxD	3481.482	6	580.247	1.385	0.218
OxR	4373.456	12	364.455	00.870	0.517
DxR	38370.374	8	4796.297	11.448	0.000
OxDxR	9913.582	24	413.066	0.986	0.483
E	271902.789	649	418.957	-	-

Key: Object Type; D=Density; R=Descent/Ascent Rate; E=Error.

Table A2. ANOVA of Log2 Correct RT for Pilots

Source	SS	df	MS	F	p
O	0.554	3	0.185	1.716	0.162
D	11.552	2	5.776	53.632	0.000
R	89.960	4	22.490	208.833	0.000
OxD	2.456	6	0.409	3.801	0.001
OxR	3.240	12	0.270	2.507	0.003
DxR	5.509	8	0.689	6.395	0.000
OxDxR	8.821	24	0.368	3.413	0.000
E	65.370	607	0.108	-	-

Key: O=Object Type; D=Density; R=Descent/Ascent Rate; E=Error.

Table A3. ANOVA of Percent Correct for Non-Pilots

Source	SS	df	MS	F	p
O	5300.540	3	1766.847	2.653	0.048
D	38486.886	2	19243.443	28.897	0.000
R	222121.913	4	55530.478	83.387	0.000
OxD	6142.747	6	1023.791	1.537	0.163
OxR	6742.285	12	561.875	0.844	0.605
DxR	24167.440	8	3020.930	4.536	0.000
OxDxR	18764.662	24	781.861	1.174	0.258
E	432194.865	649	665.940	-	-

Key: O=Object Type; D=Density; R=Descent/Ascent Rate; E=Error.

Table A4. ANOVA of Log2 Correct RT for Non-Pilots

Source	SS	df	MS	F	*p*
O	0.185	3	0.062	0.755	0.520
D	4.678	2	2.339	28.672	0.000
R	36.319	4	9.079	111.298	0.000
OxD	0.705	6	0.117	1.440	0.197
OxR	2.232	12	0.186	2.281	0.008
DxR	6.690	8	0.836	10.251	0.000
OxDxR	2.700	24	0.112	1.379	0.108
E	48.290	592	0.082	-	-

Key: O=Object Type; D=Density; R=Descent/Ascent Rate; E=Error.

APPENDIX B
ANOVA TABLES FOR EXPERIMENT 2

Table B1. ANOVA of Percent Correct for Pilots

Source	SS	df	MS	F	*p*
P	531.132	1	531.132	1.201	0.273
O	225.617	3	75.206	0.170	0.917
D	68526.549	2	34263.274	77.484	0.000
R	353949.386	4	88487.347	200.108	0.000
PxO	144.690	3	48.230	0.109	0.955
PxD	129.488	2	64.744	0.146	0.864
PxR	12239.056	4	3059.764	6.919	0.000
OxD	4532.717	6	755.453	1.708	0.116
OxR	10685.433	12	905.453	2.048	0.018
DxR	66532.105	8	8316.513	18.807	0.000
E	354210.034	801	442.199	-	-

Key: P=Practice Session; O=Object Type; D=Density; R=Descent/Ascent Rate; E=Error.

Note: Only the linear component of the Practice Session variable was used. Only three-way and four-way interactions that are significant at the .05 level are reported.

Table B2. ANOVA of Log2 Correct RT for Pilots

Source	SS	df	MS	F	*p*
P	18.165	1	18.165	122.394	0.000
O	0.585	3	0.195	.315	0.268
D	28.189	2	14.095	94.967	0.000
R	176.863	4	44.216	297.919	0.000
PxO	0.070	3	0.023	0.157	0.925
PxD	0.387	2	0.193	1.303	0.272
PxR	3.366	4	0.842	5.670	0.000
OxD	1.852	6	0.309	2.080	0.053
OxR	2.808	12	0.234	1.577	0.093
DxR	24.794	8	3.099	20.882	0.000
OxDxR	14.315	24	0.596	4.019	0.000
E	109.086	735	0.148	-	-

Key: P=Practice Session; O=Object Type; D=Density; R=Descent/Ascent Rate; E=Error.

Note: Only the linear component of the Practice Session variable was used. Only three-way and four-way interactions that are significant at the .05 level are reported.

Table B3. ANOVA of Percent Correct for Non-Pilots

Source	SS	df	MS	F	*p*
P	26111.158	1	26111.158	51.570	0.000
O	5148.843	3	1716.281	3.390	0.018
D	36092.132	2	18046.066	35.641	0.000
R	478883.326	4	119720.832	236.449	0.000
PxO	1607.546	3	535.849	1.058	0.366
PxD	318.426	2	159.213	0.314	0.730
PxR	10869.631	4	2717.408	5.367	0.000
OxD	10539.352	6	1756.559	3.469	0.002
OxR	11738.891	12	978.241	1.932	0.027
DxR	33933.335	8	4241.667	8.377	0.000
E	556961.142	1100	506.328	-	-

Key: P=Practice Session; O=Object Type; D=Density; R=Descent/Ascent Rate; E=Error.

Note: Only the linear component of the Practice Session variable was used. Only three-way and four-way interactions that are significant at the .05 level are reported.

Table B4. ANOVA of Log2 Correct RT for Non-Pilots

Source	SS	df	MS	F	*p*
P	1.043	1	1.043	5.775	0.016
O	1.064	3	0.355	1.964	0.118
D	14.306	2	7.153	39.590	0.000
R	171.445	4	42.861	237.224	0.000
PxO	0.310	3	0.103	0.523	0.633
PxD	0.126	2	0.063	0.348	0.706
PxR	2.358	4	0.589	3.263	0.011
OxD	0.879	6	0.146	0.811	0.562
OxR	3.813	12	0.318	1.758	0.051
DxR	10.127	8	1.266	7.006	0.000
OxDxR	9.548	24	0.398	2.202	0.001
E	181.762	1006	0.181	-	-

Key: P=Practice Session; O=Object Type; D=Density; R=Descent/Ascent Rate; E=Error.

Note: Only the linear component of the Practice Session variable was used. Only three-way and four-way interactions that are significant at the .05 level are reported.

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