Assessing the Influence of Operational Factors on the Perceived Structure of Real-World Scenes Viewed During Low-Altitude, High-Speed Flight

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Previous research indicates that pilots of most jet-fighter aircraft attend to similar elements of the natural flight environment when flying at low altitudes. However, some evidence suggests that differences may exist for pilots of certain specific types of aircraft. The present experiment examined the influence of operational factors on the perceived structure of real-world scenes viewed during low-altitude flight. Multidimensional scaling analyses with stimuli consisting of videotape segments of low-altitude flight over a variety of real-world terrains revealed differences in perceived environmental structure for pilots assigned to different types of jet-fighter aircraft. These results provide evidence that perceptual learning evolves differently under different operational conditions and suggests that training programs should be designed to reflect those differences.

Recent accounts of perceptual–motor skill have emphasized a process of perceptual attunement to task relevant stimulus information underlying skill acquisition (Flach, Lintern & Larish, 1990; Lintern, 1991). A skilled actor is one who can "tune into task relevant structures and who can tune out task irrelevant structures" (Flach et al., 1990, p. 329). Structure here refers to "patterns in stimulation that carry information regarding the state of the actor, of the system under the actor's control, and/or of the environment" (Flach et al., 1990, p. 328). The important implication of this view for skill training is that learning and transfer of learning will be enhanced to the degree that relevant stimulus structures in the operational environ-

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14. ABSTRACT
Previous research indicates that pilots of most jet-fighter aircraft attend to similar elements of the natural flight environment when flying at low altitudes. However, some evidence suggests that differences may exist for pilots of certain specific types of aircraft. The present experiment examined the influence of operational factors on the perceived structure of real-world scenes viewed during low-altitude flight. Multidimensional scaling analyses with stimuli consisting of videotape segments of low-altitude flight over a variety of real-world terrains revealed differences in perceived environmental structure for pilots assigned to different types of jet-fighter aircraft. These results provide evidence that perceptual learning evolves differently under different operational conditions and suggests that training programs should be designed to reflect those differences.

15. SUBJECT TERMS
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ment can be identified and made the focus of attention during training. The purpose of the present investigation is to identify environmental structure to which pilots of jet-fighter aircraft attend while flying at low altitudes. This knowledge can then be applied to the design of flight simulator visual scenes in which scene elements must be explicitly modeled using computer image generators.

The skill exhibited by expert pilots testifies to their knowledge of environmental structures relevant for the task of visual low-altitude flight. One method that has been used to assess this knowledge is to observe pilots' behavior under controlled conditions in flight simulators, where the influence of various factors on task performance can be assessed (Buckland, Edwards, & Stephens, 1981; DeMaio, Rinalducci, Brooks, & Brunderman, 1983; Kleiss & Hubbard, 1993; Martin & Rinalducci, 1983; McCormick, Smith, Lewandowski, Preskar, & Martin, 1983). What is not known from such experiments, however, is the degree to which simulated scenes may be lacking in relevant structure present in the natural flight environment.

The complexity of the natural environment poses a serious problem for researchers interested in identifying relevant environmental structures. The opinions of subject matter experts compiled in training materials (162d Tactical Fighter Group, 1986; Kellogg & Miller, 1984) are a potentially important source of information as are analyses of crash incidents by vision experts (Haber, 1987). However, this information lacks the direct support of empirical data and may also be insensitive to subtle environmental factors that are unavailable for conscious verbal report.

Kleiss (1990, 1995) sought to examine complex natural scenes using a more formal method, multidimensional scaling (MDS). MDS is a method for revealing the perceived structure in a set of stimuli by mapping stimuli within an n-dimensional spatial configuration. The mapping is derived from observers' judgments of similarity between stimuli such that similar stimuli are positioned close to one another in multidimensional space whereas dissimilar stimuli are positioned farther apart. It is assumed that the ordering of stimuli along each dimensional axis in the spatial configuration reflects variation in a different stimulus property perceived by observers. Subsequent examination of dimensions is informative as to the identity of each stimulus property.

The stimuli in Kleiss's (1990, 1995) investigations were videotape segments depicting low-altitude, high-speed flight over a variety of real-world terrains. Jet-fighter pilots skilled in visual low-altitude flight rated the degree of perceived similarity between terrains with respect to visual cues deemed to be important for the task of visual low-altitude flight. Results from three experiments (Kleiss, 1990, 1995, Experiments 1 and 2) consistently revealed that pilots perceived variation in two fundamental types of environmental structure: (a) terrain shape, exemplified by hills and ridges, and (b) discrete objects, exemplified by large, high-contrast objects. In each experiment, terrain shape was found to be the more important type

of structure in that it explained the largest proportion of variance in similarity ratings for each group.

The MDS algorithm used by Kleiss (1990; see Young, Takane, & Lewyckyj, 1978) also provided individual differences information that revealed an interesting pattern. Two pilots in the experiment of Kleiss (1990) showed a reverse pattern in which the dimension related to objects was found to be disproportionately more important than the dimension related to terrain shape. These 2 pilots were also unique in one other potentially important way as they were the only pilots in the sample assigned to the A–10 aircraft at the time of the investigation. Remaining pilots in the experiment of Kleiss (1990) as well as all pilots examined in the two experiments of Kleiss (1995) were assigned to either the A–7, F–4, F–5 or F–16 aircraft. Of these 46 pilots, only 1 showed a pattern in which objects were disproportionately more important than terrain shape. Hence, the pattern appears to be comparatively rare among pilots of other fighter-type aircraft.

The apparent difference for the two A–10 pilots is pertinent because it implies that the operational environment in which A–10 pilots fly is one in which a different hierarchy of scene structures is learned. Hence, learning in the A–10 aircraft might be enhanced by designing training programs that emphasize a different hierarchy of scene structures than would be emphasized for other fighter-type aircraft. Operational factors for the A–10 aircraft do differ in potentially important ways from those for other jet-fighter aircraft. For example, the A–10 flies at comparatively slow speeds (250 to 300 kt) compared to other jet-fighter aircraft (400 kt or above), which are well suited to its mission of visually locating, identifying, and attacking ground targets. Missions for other jet-fighter aircraft typically involve a more lengthy approach to a designated target followed by an attack and then an egress from the target area. The difference between speed and time spent traversing terrain on the one hand versus searching for targets on the other could well motivate a different visual strategy for A–10 pilots and a consequent shift in the perceived importance of various types of environmental structure.

It is imprudent to generalize based on data from only two participants, so it was deemed important to replicate the difference using a larger sample of A–10 pilots. The specific objective of this study is to demonstrate a disproportionate emphasis on objects compared to terrain shape for an entire sample of A–10 pilots. In light of the consistency with which the reverse pattern has been obtained for pilots of other fighter-type aircraft, such a difference would provide strong support that the difference is real. In consequence, one would hypothesize a training benefit for emphasizing objects as opposed to terrain shape.

For comparison, a group of F–16 pilots who are representative of the general class of fighter pilots investigated previously were examined. A group of F–111 pilots were also examined because this aircraft type had not previously been investigated. The F–111 aircraft has speed and mission characteristics that are generally similar to those of the F–16. However, the F–111 is large by jet-fighter

standards and has a unique side-by-side crew-seating arrangement that occludes the pilot's right-side view out of the cockpit. A large nose section also partially occludes the forward view out of the aircraft, and these restrictions could reasonably impact visual performance. Two control groups were also examined. A group of nonpilot participants provided a basis for assessing the degree of perceptual learning specific to flying jet-fighter aircraft. A group of Air Force pilots with little or no formal low-altitude training were also examined to provide a basis for comparing learning specific to the task of visual low-altitude flight versus general piloting skills. Differences among groups were reflected in the type and relative importance of dimensions derived by MDS analyses.

METHOD

Participants

F–16.   Seventeen mission-qualified F–16 pilots from the 10th, 313th, and 496th Tactical Fighter Squadrons (TFS), Hahn and Ramstein Air Bases, Germany, participated in the study. Pilots averaged 1,323 hr total flying time ($SD = 735$, R = 400 to 3,000) with 276 hr in the F–16 ($SD = 161$, R = 100 to 700).

A–10.   Nineteen mission-qualified A–10 instructor pilots (IPs) from the 333rd, 357th, and 358th Tactical Fighter Training Squadrons (TFTS), Davis-Monthan Air Force Base, Tucson, Arizona, participated in the study. Pilots averaged 1,680 hr total flying time ($SD = 659$, R = 1,050 to 3,300) with 1,178 hr in the A–10 ($SD = 325$, R = 600 to 1,800).

F–111.   Eighteen mission-qualified F–111 pilots and IPs from the 522nd and 523rd TFSs and the 358th TFTS, Cannon Air Force Base, New Mexico, participated in the study. Pilots averaged 1,397 hr total flying time ($SD = 1,083$, R = 325 to 4,500) with 772 hr in the F–111 ($SD = 578$, R = 90 to 2,000). Hours in the F–111 are based on data from only 17 pilots as 1 pilot had previous experience in a variant of the F–111, the FB-111, but did not report those hours.

Typical missions for all of the aforementioned pilots include flying at or below 152 m (500 ft) above ground level (AGL). A one-way analysis of variance (ANOVA) using total hours flying time as the dependent variable revealed no differences among these three groups, $F(2, 51) < 1$. A one-way ANOVA using hours in present aircraft type as the dependent variable was significant, $F(2, 50) = 23.83$, $p < .001$. Pairwise comparisons using Scheffé's method revealed that all three means differed significantly from one another beyond the $p = .05$ level of

confidence. Hence, whereas these three groups do not differ with respect to overall experience, the F–111 and A–10 groups each had increasingly more experience in their particular aircraft. It is not anticipated that this should be a factor because the two A–10 pilots in the experiment of Kleiss (1990) had the least experience in comparison to other pilots in that sample.

Inexperienced.   Twelve U.S. Air Force pilots who had little or no operational low-altitude flight training participated in the study. Eight were IPs in the T–37 or T–38 aircraft from the 96th, 97th, 98th, and 99th Flying Training Squadrons, Williams Air Force Base, Arizona. They averaged 1,151 hr total flying time ($SD = 407$, R = 280 to 1,530) and had no formal training at altitudes below 152 m. Four pilots were recent graduates of undergraduate pilot training and averaged 280 hr total flying time ($SD = 54$, $R = 200$ to 320). Three of these were students in either the A–10 or F–111 aircraft with fewer than 80 hr in those aircraft and minimal low-altitude experience. The 4th had not yet been assigned to an aircraft. It must be emphasized that the term *inexperienced* refers specifically to formal low-altitude training and not to piloting skills in general.

Nonpilot.   This group consisted of 24 undergraduate students enrolled in a psychology course at Arizona State University. None had previous piloting experience.

Minimum visual requirements for Air Force pilots on flying status are 20/200 visual acuity corrected to 20/20, +3.5 to –2.5 diopters refractive error, 2.0 diopters or less astigmatism, and no color deficit. Nonpilots had normal or corrected-to-normal vision.

Stimuli

The stimuli were identical to those used by Kleiss (1995, Experiment 2). The stimulus set comprised seventeen, 5-sec videotape segments depicting low-altitude, high-speed flight over a variety of real-world terrains. All except one (the forested mountain scene, which was donated by Fred Previc from Air Force files) were photographed from a T–33 jet aircraft using a 16 mm color motion picture camera with a 12.5 mm lens mounted in the nose section of the aircraft. A radar altimeter was used to monitor altitude during filming. Each segment was filmed during straight-and-level flight at an altitude of 38 m (125 ft) AGL and an airspeed of 350 kt, as closely as conditions would allow. Altitude was relative to the tops of hills. Motion picture film was transferred to videotape and video speed was increased to produce the appearance of 420 kt. The altitude is typical of that flown during combat

missions. The speed is somewhat faster than that flown by the A–10 aircraft. Because initial filming occurred at a relatively high speed, the increase in videotape speed produced little apparent exaggeration of motion due to wind buffeting and minor positional adjustments. Descriptions of the 17 scenes are as follows:

1. Airport: flat terrain with hangars, runway, and parked aircraft; mountains occluding the horizon.
2. Desert: flat terrain with small, dense bushes; mountains occluding the horizon.
3. Dry Lake: flat terrain with no vegetation; mountains occluding the horizon.
4. Ridges: multiple ridges perpendicular to the flight path; little vegetation.
5. Trees/Pasture: flat terrain with groups of large trees; mountains occluding the horizon.
6. Dense Trees: flat terrain with large, closely spaced trees and intermittent clearings; mountains on sides and occluding the horizon.
7. Valley: river valley with surrounding mountains, trees and bushes, ridges, and large rocks.
8. Forested Mountain: sharply contoured terrain with a dense canopy of trees.
9. Hills w/Trees: highly undulating terrain with a high density of individual trees.
10. Barren Hills: highly undulating terrain with sparse grassy vegetation and occasional roads.
11. Sand Dunes: large sand dunes with no objects or vegetation.
12. Desert w/Trees: gently rolling terrain with small desert trees and bushes; mountains occluding the horizon.
13. Ocean: smooth water with no objects or land visible.
14. Coastline: flight path over water parallel to coastline.
15. Agricultural: flat terrain with small, dense vegetation and clearly delineated field boundaries.
16. Grassland: flat terrain with grass and scattered bushes; mountains occluding the horizon.
17. Shore Approach: flight path over water approaching shore; mountains occluding the horizon.

Figure 1 shows the Trees/Pasture, Hills w/Trees, and Ocean scenes that exemplified dimensions in the experiments of Kleiss (1995).

Design

Seventeen stimuli yield a total of 136 unique stimulus pairings, which Kruskal and Wish (1986) suggested is sufficient to reveal up to four dimensions if that level of
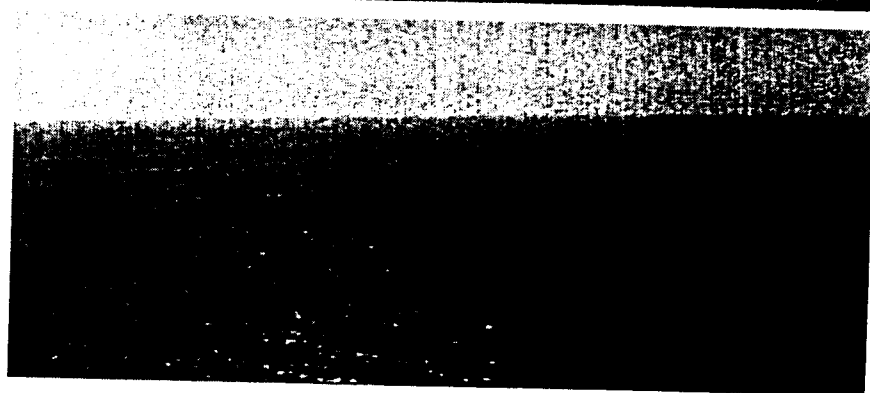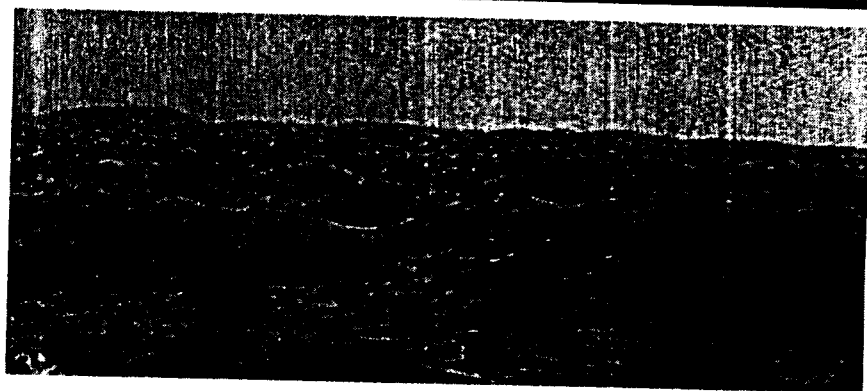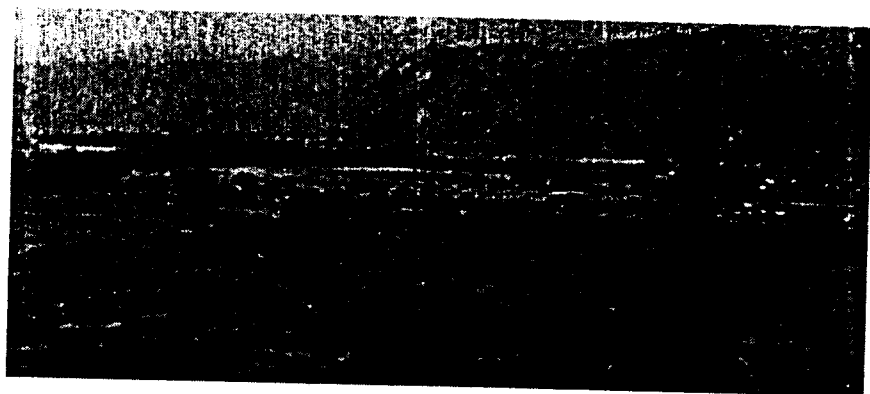
FIGURE 1   Trees/Pasture, Hills w/Trees, and Ocean scenes (top to bottom).

structure is present in the data. Because it was impossible to present this many stimuli within the 1 hr allotted for data collection, an incomplete data design was used in which each participant viewed only half (68) of the pairs (Schiffman, Reynolds, & Young, 1981). MacCallum (1978) provides evidence that structure can be successfully recovered from data with as many as 60% missing observations provided that sample size is 10 or larger and different observations are missing across participants. Stimulus pairs were randomly assigned to one of two subsets (68 pairs each) with the constraints that (a) individual scenes appeared approximately equally often in each subset and (b) no specific scene appeared in consecutive pairs. Two additional subsets were constructed in a similar fashion except that the order of scenes within each pair was reversed.

Rating Scales

Following Schiffman et al. (1981), similarity judgments were recorded on 120-mm, ungraduated lines anchored at the left with "exact same" and at the right with "completely different." Rating scales were arranged in a booklet with four scales per page, each numbered in sequence. An instruction page appeared at the front of the booklet and described the purpose of the experiment as well as the rating procedure.

To aid dimensional interpretation, a second type of data was also collected. Each scene was rated on eight bipolar attribute scales which were included at the end of the booklet. These scales were 120-mm lines anchored at each end with dichotomous labels corresponding to scene attributes of potential importance for low-altitude flight based upon Air Force instructional materials, pilot interviews, and demonstrated importance in flight simulation research. Attribute labels and the rationale for choosing them are as follows:

1. "Prefer" versus "Not prefer": The degree of preference for scene properties, which was assumed to reflect the quality of information depicted in scenes.
2. "Hilly/mountainous" versus "Flat": The degree of terrain vertical development.
3. "Objects" versus "No objects": A high density of vertical objects has been found to be an important factor affecting performance in flight simulators (Kleiss & Hubbard, 1993; Martin & Rinalducci, 1983).
4. "Known size references" versus "No known size references": The apparent size of familiar features is used by pilots as a cue for distance (162d Tactical Fighter Group, 1986).
5. "Texture/detail" versus "No texture/detail": Apparent detail is used by pilots as a cue for distance (162d Tactical Fighter Group, 1986).

6. "Complex" versus "Simple": Intended as a measure of global scene complexity.
7. "Regular" versus "Random": Intended to reflect the orderliness or predictability in the positioning of scene elements.
8. "High contrast" versus "Low contrast": The degree to which scene elements stand out against the background.

Attributes were selected to capture a range of potentially relevant scene properties without regard for possible correlations among attributes.

Procedure

Data were collected in small groups of 2 to 4 participants. Approximately equal numbers of participants viewed each subset of stimuli. Participants first read the cover sheet, and then major aspects of the procedure were emphasized verbally with opportunities for questions. Particular emphasis was placed on the fact that ratings should be based upon scene properties perceived to be important for the task of visual low-altitude flight. If the two scenes in a pair looked the same, participants were instructed to place a mark at the extreme left end of the rating scale. If the two scenes looked different, they were instructed to place a mark somewhere along the scale indicating how different. It was also emphasized that ratings should be based upon a general impression of similarity rather than an element-by-element comparison of scenes. Participants were encouraged to use the entire range available on the rating scales.

To familiarize participants with the range of stimuli used in the experiment, scenes were first shown individually before presentation of stimulus pairs. A number preceded each stimulus pair on the videotape to indicate its position within the sequence (1 through 68). A 1-sec blank separated each segment within a pair and a 3-sec blank separated each pair to provide time to enter responses. There were no apparent problems due to the fast pace of videotape presentation. Videotapes were displayed with a cathode ray tube projector that provided a projected image measuring approximately 31° horizontally by 23° vertically viewed from a distance of 3.66 m.

After participants completed similarity ratings, each scene was again presented individually and participants rated the scene on each of the eight bipolar attribute scales. Participants were first familiarized with the anchor labels so that questions regarding their meanings could be addressed. Each scale was marked at a location that corresponded to the perceived amount of the given attribute. The entire session took approximately 1 hr.

RESULTS

Data for all analyses were distances in millimeters measured from the left end of each scale to the point at which the participant marked the scale. Values ranged from 0 to 120. For pairwise ratings, larger values indicated greater dissimilarity.

Multidimensional Scaling

Pairwise ratings were submitted to MDS analyses using ALSCAL for PCs (Alternating Least squares SCALing, Young et al., 1978). A weighted (individual differences), nonmetric approach was used that not only yields the most robust and reliable results but provides spatial configurations that are fixed (i.e., not rotatable) in relation to dimensional axes and, therefore, directly interpretable (Schiffman et al., 1981). The weighted approach also furnishes subject weights that indicate the relative importance of each dimension for individual participants. Ratings were assumed to be continuous. Missing stimulus pairs were treated as missing values.

Three measures describe the discrepancy between dissimilarities derived from raw rating data and interstimulus distances in MDS spatial configurations of various dimensionalities: *Stress* (Kruskal & Wish, 1986), which is based on MDS distances; *S-Stress* (Takane, Young, & de Leeuw, 1977), which is based on squared MDS distances; and *1–RSQ*, which is the proportion of variance in dissimilarities not accounted for by a regression of dissimilarities onto MDS distances. Smaller values indicate better fit for all three measures. A commonly accepted criterion for identifying correct dimensionality (i.e., the dimensionality that affords maximum structure) is to plot measures of fit as a function of increasing dimensionality and then look for an "elbow" in the plot indicating the point at which increasing dimensionality produces a diminishing improvement in fit (Kruskal & Wish, 1986). Isaac and Poor (1974) also suggested comparing stress for experimental data and stress for random data (i.e., data with 100% error). The dimensionality with maximum structure is taken to be that at which the difference between experimental and random stress is largest.

Figure 2 shows S-Stress, 1-RSQ, Stress, and stress for random data as a function of increasing dimensionality for each of the five groups. Stress values for random data were taken from Spence and Ogilvie (1973) and are estimates derived from Monte Carlo studies by Young (1968) using a stimulus set size equal to 17. Values were only published for dimensions one through five. ALSCAL does not compute a one-dimensional solution with the individual differences approach.

Examination of Figure 2 reveals no strong evidence of an elbow for any of the three measures of fit. The difference between stress for experimental data and stress for random data is largest at dimensionality equal to two for each group. Two-di-
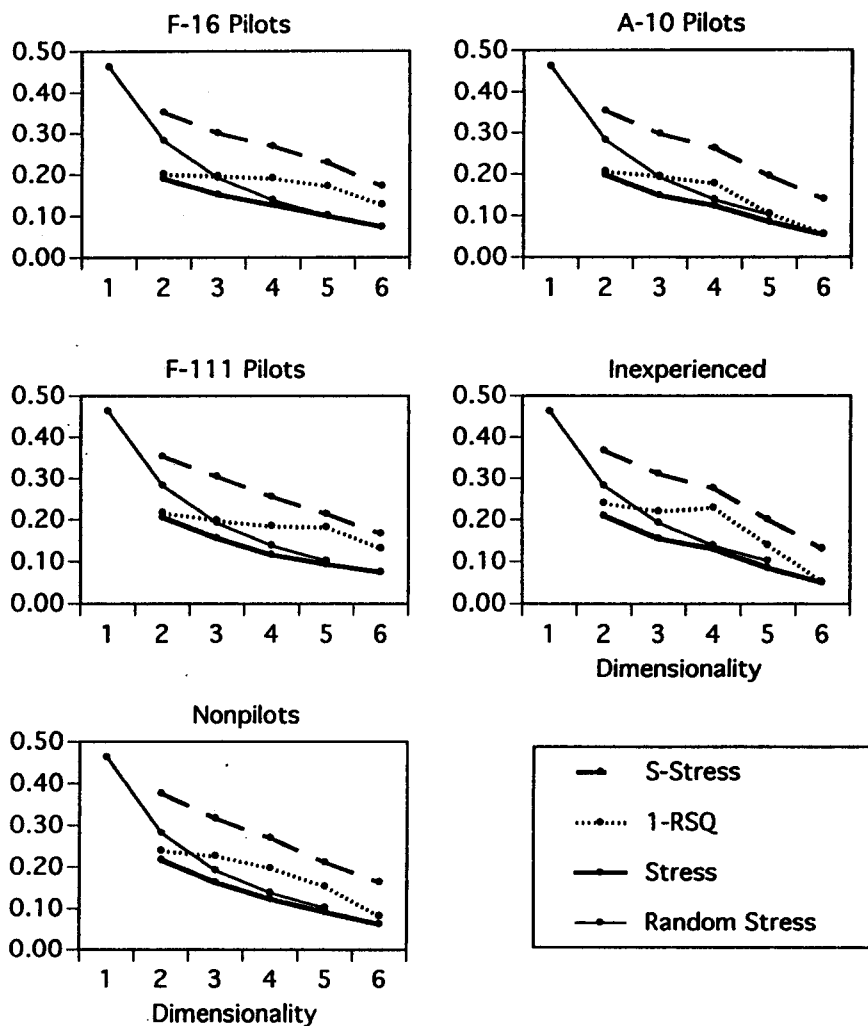
FIGURE 2   S-Stress, 1-RSQ, stress, and stress for random data as a function of dimensionality for each group.

mensional solutions are consistent with previous results (Kleiss, 1990, 1995) and will be considered.

ALSCAL also provides estimates of the variance in similarity ratings explained by each dimension that index the relative importance of dimensions. These are shown in Table 1 for each group; it can be seen that there is a fairly large difference

TABLE 1
Average Squared Subject Weights for Dimensions 1 and 2 in Each Group

Group	Dimension 1	Dimension 2
F-16 pilots	.581	.218
A-10 pilots	.462	.342
F-111 pilots	.430	.354
Inexperienced pilots	.408	.353
Nonpilots	.602	.159

favoring Dimension 1 for both the nonpilot and F–16 groups. Smaller differences favoring Dimension 1 are apparent for each of the A–10, F–111, and inexperienced groups, indicating a more equal weighing between dimensions.

The degree to which an individual participant's weighing of dimensions is proportionate to the group average is indexed by "weirdness." It was this value that revealed the difference for the two A–10 pilots in the experiment of Kleiss (1990). A weirdness value of zero indicates that an individual's weighing of dimensions is exactly proportional to the group average, whereas a weirdness value approaching one indicates that an individual has one large weight and the other(s) small. Only 3 participants, 1 in each the F–16, A–10, and F–111 groups, showed a disproportionate emphasis on Dimension 2 compared to Dimension 1. Participants were therefore highly consistent in their ratings within groups.

Bipolar Attribute Ratings

Bipolar attribute ratings were analyzed using a multiple regression approach described by Kruskal and Wish (1986). Bipolar attribute ratings for each scene were averaged across participants within each group. For each of the bipolar attributes, mean ratings were regressed on dimensional coordinates derived from the two-dimensional ALSCAL solutions. Kruskal and Wish suggested that a bipolar attribute may provide a satisfactory interpretation of a dimension if: (a) the multiple correlation for the scale is large and statistically reliable (multiple correlations of .90 or larger are considered good, but .80s and .70s may suffice) and (b) the regression weight for a given dimension is large in comparison to others. Kruskal and Wish recommended converting regression weights to direction cosines by normalizing so that they sum to 1.00 when squared. Regression weights normalized in this fashion describe property vectors that indicate the direction in multidimensional space that best fits rated increase in a given attribute. A regression weight of 1.00 for a given dimension indicates perfect alignment of the property vector with the dimensional axis. A criterion value of 0.940 or larger was chosen for regression weights in the present experiment, which corresponds to a deviation from the dimensional axis of 20° or less.

Table 2 shows the dimensions that met the aforementioned criteria for each bipolar attribute within each group. The pattern for the F–16 group is essentially identical to that revealed in previous research (Kleiss, 1995) for pilots of a variety of fighter-type aircraft viewing similar stimuli. Scenes ordered along the Dimension 1 axis are associated with the attributes of being hilly/mountainous and random in appearance. Scenes ordered along the Dimension 2 axis are associated with the attributes of being preferred as well as containing objects, elements of known size, texture, and high-contrast edges. A very similar pattern is evident for the nonpilot group, which differs from the F–16 group only in absence of an association of Dimension 1 with the attributes of preference and objects. The similarity between these two groups implies similar dimensional structures. The pattern for the A–10 group is noteworthy because it is essentially the reverse of that for the F–16 group. Dimension 1 for the A–10 group is associated with attributes that for the F–16 group are associated with Dimension 2, and vice versa. Discrepancies for the A–10 group include the fact that Dimension 1 is associated with the attribute of complexity but not high contrast. Also, Dimension 2 is not associated with the attribute of being random. Results for the A–10 group suggest that dimensions reflect similar scene structure to that for the F–16 group but that dimensions are reversed in their relative importance. Results for the F–111 and inexperienced groups are characterized by a general lack of association of dimensions with attributes. For both groups, Dimension 1 is associated with the attribute of complexity. In addition, Dimension 1 in the inexperienced group is associated with the attribute of preference. These patterns suggest notably different dimensional structures for these two groups compared to the previous three.

Spatial Configurations

Figures 3 through 7 show the two-dimensional spatial configurations based on ALSCAL dimensional coordinates for the F–16, nonpilot, A–10, F–111, and

TABLE 2
Results of Multiple Regression Analyses on Bipolar Attribute Ratings in Each Group

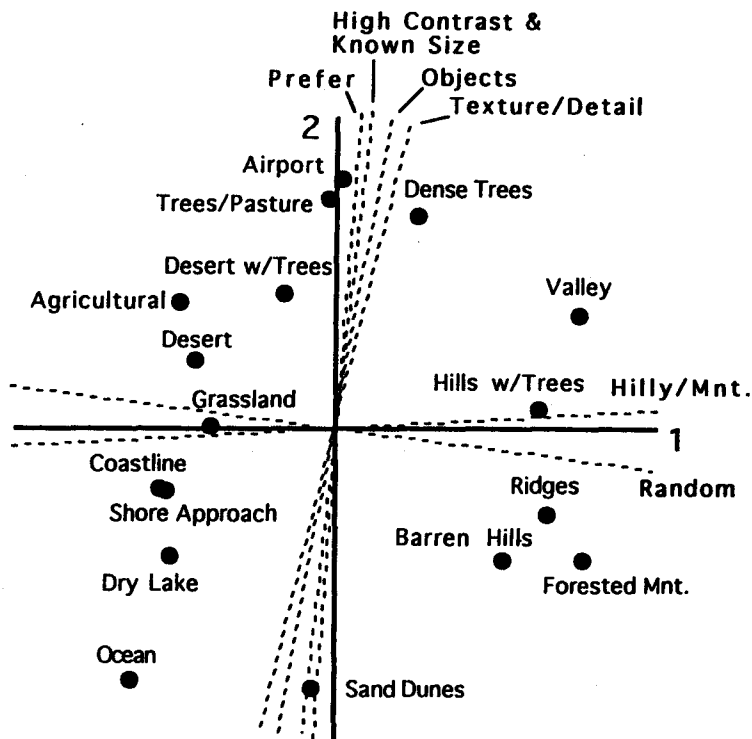| Group	Prefer		Hilly/ Mountainous		Objects		Known Size		Texture		Complex		Random		Hi- Contra	
	D1	D2	D1	D2	D1	D2	D1	D2	D1	D2	D1	D2	D1	D2	D1	D
F-16		×	×			×		×		×			×			×
A-10	×			×	×		×		×		×				×	
F-111											×					
Inexperienced		×										×		×		
Nonpilot			×					×		×			×			×

FIGURE 3   Two-dimensional spatial configuration and property vectors for the F–16 group.

inexperienced groups respectively. Dotted lines are property vectors that indicate the direction through multidimensional space that best fits rated increase in bipolar attributes in Table 2. The degree to which each property vector is aligned with its corresponding dimensional axis reflects the degree of relation between that attribute and the ordering of scenes along the dimensional axis.

The spatial configuration for the F–16 group (Figure 3) is essentially identical to those reported previously by Kleiss (1995) for pilots of a variety of fighter-type aircraft viewing similar stimuli. Scenes positioned at the extreme right pole of the Dimension 1 axis contain hills or ridges and are associated with the attributes of being hilly/mountainous and random in appearance. Scenes positioned at the extreme left pole of Dimension 1 are flat in the vicinity of the eyepoint. However, some scenes positioned at the left pole of Dimension 1 (e.g., Dry Lake and Shore Approach) contain large mountains obstructing the horizon, whereas some scenes positioned at the right pole of Dimension 1 contain no large vertical obstructions

(e.g., Hills w/Trees and Barren Hills). Therefore, the important property related to Dimension 1 is vertical relief in the terrain surface over which the aircraft is flying rather than presence of large vertical obstructions. Large buildings and localized regions of dense vegetation would appear to exhibit some degree of vertical relief because the Trees/Pasture, Dense Trees, and Airport scenes are positioned near the middle of the Dimension 1 axis despite the presence of flat terrain in the near vicinity of the eyepoint. These observations support an interpretation of Dimension 1 consistent with presence or absence of terrain vertical relief.

Scenes positioned at the extreme upper pole of the Dimension 2 axis contain large objects such as buildings or localized regions of dense vegetation that are associated with the attributes of being preferred, high in contrast, as well as containing elements of known size, objects, and texture/detail. Scenes positioned at the bottom pole of the Dimension 2 axis lack notable objects or vegetation, supporting a general interpretation of this dimension consistent with presence or absence of discrete objects. The Dense Trees and Trees/Pasture scenes at the top of
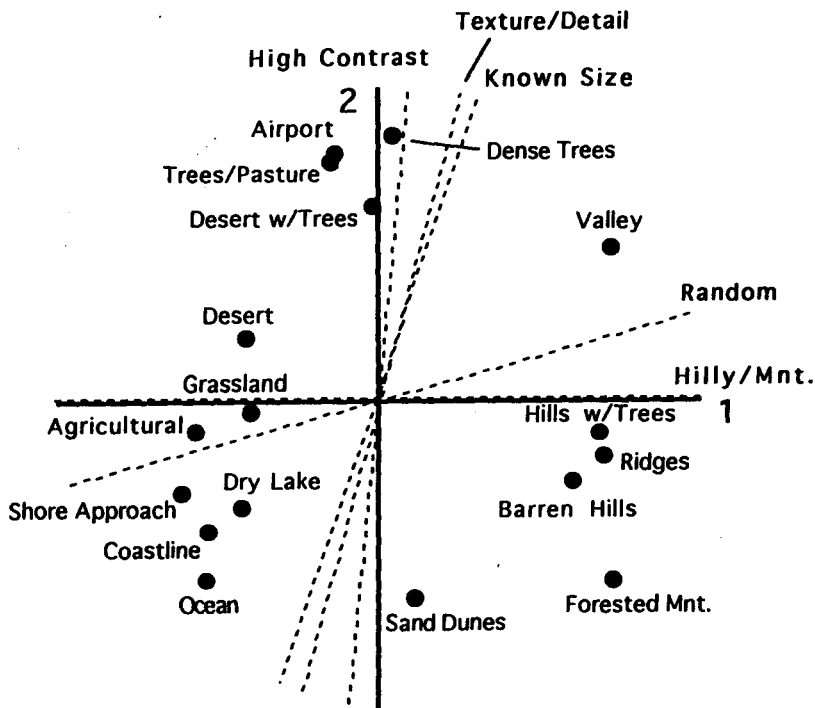

FIGURE 4 Two-dimensional spatial configuration and property vectors for the nonpilot group.
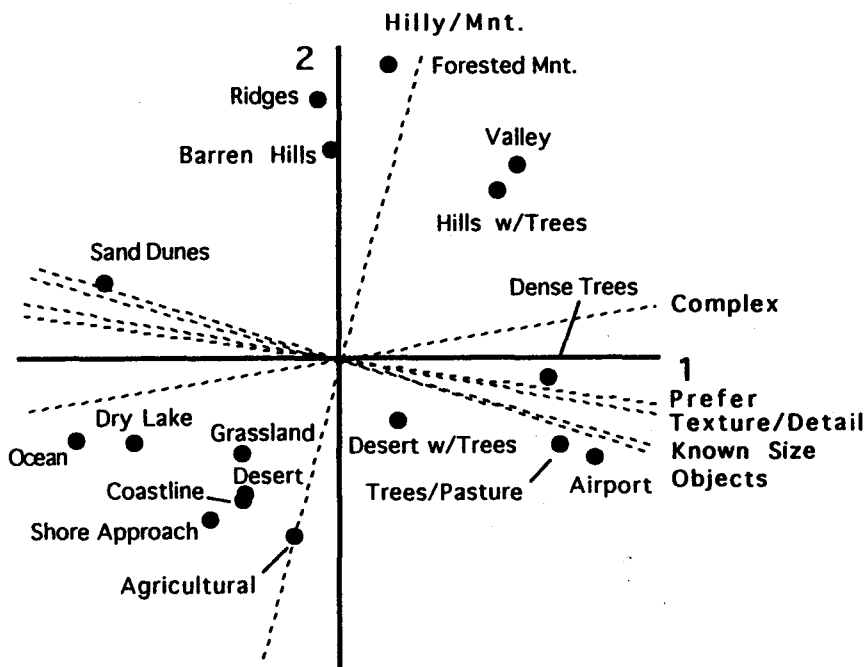
FIGURE 5   Two-dimensional spatial configuration and property vectors for the A–10 group.

the dimension differ from other scenes containing larger elements of vegetation (e.g., Desert w/Trees, Valley, and Hills w/Trees) in that vegetation is clustered into groups. The close positioning of the Dense Trees and Trees/Pasture scenes to the Airport scene with its large buildings suggests that localized regions of dense vegetation are perceived as a single large object rather than a collection of smaller objects. Hence, object size is a factor. Vertical extent has been shown to be an important property of objects in flight simulator visual scenes (Kleiss & Hubbard, 1993; Martin & Rinalducci, 1983). Present results suggest that horizontal extent is also an important property of objects. Scenes exhibiting the features that exemplify these dimensions can be seen in Figure 1.

Figure 4 shows the two-dimensional spatial configuration for the nonpilot group. Analyses of bipolar attribute ratings in Table 2 suggest that this spatial configuration should be similar to that for the F–16 group (Figure 3). Examination of Figure 4 confirms this expectation. Minor differences worth noting for the nonpilot group are the positioning of the Desert w/Trees and Valley scenes somewhat nearer the upper pole of Dimension 2 and the positioning of remaining scenes somewhat

nearer the bottom pole. This pattern suggests that compared to F–16 pilots, nonpilots are somewhat more sensitive to isolated trees and bushes in scenes but somewhat less sensitive to a homogeneous distribution of small vegetation. Large objects remain the dominant exemplars of Dimension 2, although this dimension is not associated with the property of containing objects. Although nonpilots perceive essentially the same items in scenes, they do not appear to conceptualize those items to be object-like in the same way F–16 pilots do.

Figure 5 shows the two-dimensional spatial configuration for the A–10 group. Analyses of bipolar attribute ratings summarized in Table 2 suggest that this spatial configuration is similar to that for the F–16 group with the dimensions reversed. Examination of Figure 5 confirms this expectation. Scenes with large objects are positioned at the extreme right pole of Dimension 1, whereas scenes with hills or ridges are positioned at the extreme upper pole of Dimension 2. A subtle difference in the relative positioning of scenes along the Dimension 1 axis suggests that A–10 pilots attend to a somewhat different property of objects than do F–16 pilots. The five scenes containing hills or ridges are, on average, positioned nearer the scenes with large objects along the Dimension 1 axis, suggesting that they are perceived
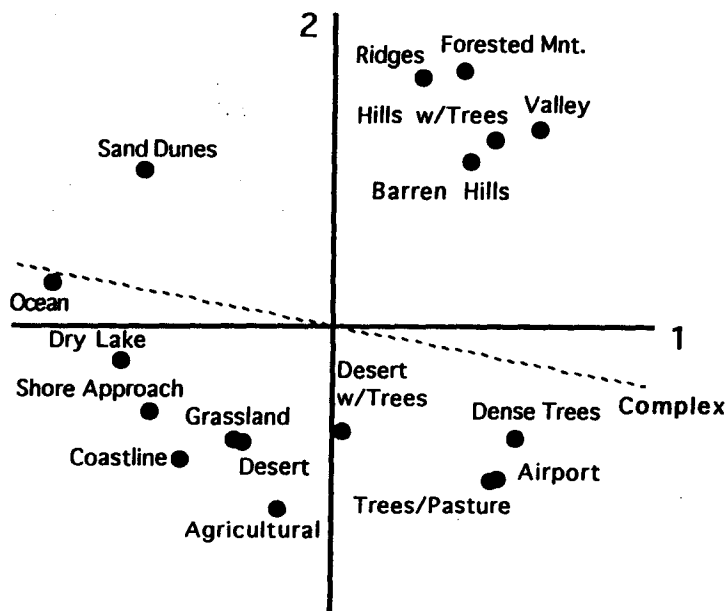

FIGURE 6   Two-dimensional spatial configuration and property vectors for the F–111 group.
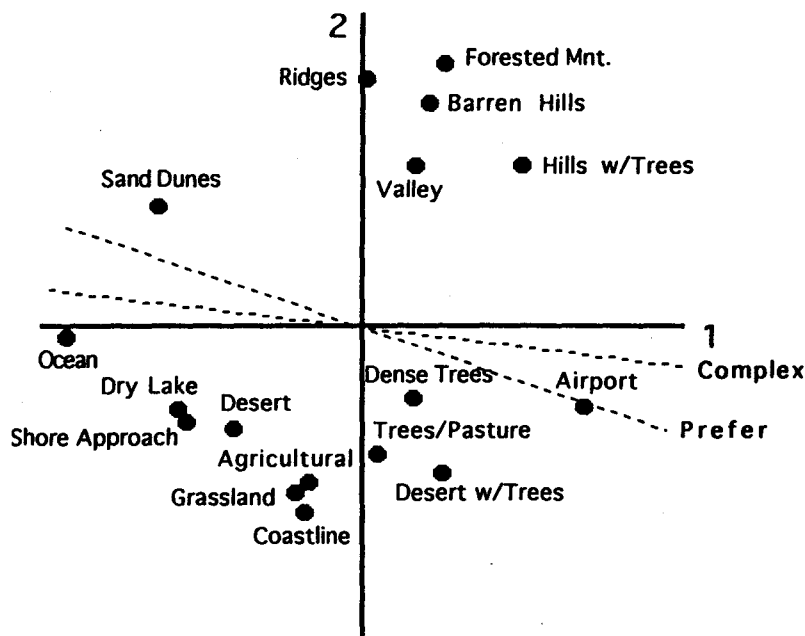
FIGURE 7   Two-dimensional spatial configuration and property vectors for the inexperienced group.

to be more similar to large objects. The Hills w/Trees and Valley scenes, in particular, are positioned very near the upper pole of the dimension. These two scenes contain isolated trees and large bushes, which are consistent with an interpretation of this dimension related to vertical objects. However, the Ridges, Barren Hills, and Forested Mountain scenes lack discernible objects (large trees in the Forested Mountain scene are spaced so closely that they form a homogeneous canopy). The positioning of these scenes nearer the scenes with objects suggests attention to some property other than discrete contrast boundaries. Individual hills and ridges exhibit properties of three-dimensional shape such as vertically slanted surfaces, apparent curvature, or apparent volume, which could be relevant. Evidence of decreased attention to contrast boundaries for the A–10 group is also provided by the fact that Dimension 1 in Figure 5 is not associated with the attribute of high contrast.

Figure 6 shows the two-dimensional spatial configuration for the F–111 group. Analyses of bipolar attribute ratings summarized in Table 2 suggest that this spatial configuration differs notably from those described previously. However, examination of the spatial configuration in Figure 6 reveals many similarities to the

aforementioned spatial configurations. In particular, it appears similar to what would be obtained by rotating the spatial configuration for the A–10 group clockwise in relation to dimensional axes. Scenes with hills or ridges are clustered in the upper-right quadrant of the spatial configuration, whereas scenes with large objects are clustered in the lower-right quadrant. Spatial configurations derived by ALSCAL with the individual differences option are assumed to be fixed in relation to dimensional axes (Schiffman et al., 1981). The apparent rotation may therefore be taken to indicate a meaningful difference in stimulus properties to which F–111 pilots attend.

The positioning of scenes with hills or ridges near the scenes with large objects at the extreme right pole of Dimension 1 (Figure 6) indicates that these scenes are perceived to share some property in common. The positioning of scenes with no objects or vegetation at the extreme left pole of the Dimension 1 argues for an interpretation of this dimension consistent with presence or absence of large scene elements. The absence of high contrast edges defining hills or ridges indicates that large scene elements are defined by three-dimensional properties such as vertically slanted surfaces, apparent curvature, or apparent volume.

Scenes with hills or ridges are positioned at the extreme upper pole of Dimension 2 (Figure 6), whereas scenes with large objects are positioned at the extreme bottom pole among scenes with smaller vegetation distributed evenly on flat terrain. Isolation of scenes with hills or ridges at the upper pole of Dimension 2 argues for an interpretation of this dimension consistent with some property of terrain shape. It is noteworthy that the scenes with the flattest and most barren terrain (Ocean and Dry Lake) are positioned near the middle of the Dimension 2 axis, suggesting a point of demarcation between two types of terrain. Scenes at the bottom pole of the dimension are not defined simply by the absence of hills or ridges but the presence of a continuous gradient of objects and/or vegetation on flat terrain. This pattern argues for an interpretation of Dimension 2 consistent with a distinction between two types of terrain shape information, vertical relief versus a continuous horizontal gradient indicating flatness.

Figure 7 shows the two-dimensional spatial configuration for the inexperienced group. This spatial configuration appears similar to that for the F–111 group (Figure 6) except that the Airport scene is somewhat more isolated at the extreme right pole of the Dimension 1 axis, whereas the Dense Trees and Trees/Pasture scenes are positioned nearer the middle of the dimension. This suggests that the inexperienced group is somewhat more attuned to cultural objects as exemplars of large scene elements. Similar to the F–111 group (Figure 6), Dimension 2 reflects a distinction between two types of terrain shape information, vertical relief versus a continuous horizontal gradient indicating flatness.

Table 3 summarizes interpretations of dimensions based upon examination of spatial configurations for each group.

TABLE 3
Interpretations of Dimensions Based on Examination of Spatial Configurations

Group	Dimension 1	Dimension 2
F-16 pilots	Presence/absence of terrain vertical relief	Large, high-contrast objects
Nonpilots	Presence/absence of terrain vertical relief	Large, high-contrast elements
A-10 pilots	Vertical elements	Presence/absence of terrain vertical relief
F-111 pilots	Large three-dimensional elements	Terrain vertical relief versus a horizontal gradient
Inexperienced pilots	Large three-dimensional elements exemplified by buildings	Terrain vertical relief versus a horizontal gradient

DISCUSSION

Results for the F–16 group replicate in detail those obtained previously with pilots of a variety of fighter-type aircraft (Kleiss, 1995) and provide strong support for the generality of this dimensional structure. The high degree of similarity between results for the F–16 group and results for the nonpilot group suggests that attention to terrain vertical relief (Dimension 1) and large, high-contrast objects (Dimension 2) is not the result of perceptual learning specific to the task of low-altitude flight in jet-fighter aircraft. This is not to suggest that nonpilots are equivalent to pilots with respect to visual skill at low-altitude flight. Present data are based upon similarity ratings rather than skill at tasks involving perception and/or control of altitude. Results of several experiments indicate that pilots outperform nonpilots on a variety of tasks involving perception of altitude (e.g., Kleiss & Hubbard, 1991; Rinalducci, Patterson, & DeMaio, 1984; Rinalducci, Patterson, Forren, & Andes, 1985). Present results do suggest that the environmental structure to which pilots attend while flying is, in general, similar to that used for the more general task of moving and navigating within the natural environment.

The consistency with which results similar to those described have been obtained with both pilots and nonpilots highlights the differences for the A–10, F–111, and inexperienced groups. The difference for the A–10 group is particularly noteworthy because it replicates a reversal in the relative importance of dimensions for two A–10 pilots reported by Kleiss (1990). Present results, therefore, provide strong evidence that operational factors unique to these aircraft result in a process of perceptual attunement to different environmental structures than those to which most pilots attend.

Given the similarity between the F–16 group and the nonpilot group, one would anticipate a similar pattern of results for the inexperienced group, who had received

little or no formal low-altitude training. The difference for this group suggests that the training environment within which these pilots fly poses unique visual demands that require attention to unique environmental structure. In this light it is interesting to note that the prototypical exemplar of Dimension 1 for the inexperienced group (Figure 7, Dimension 1) is the scene bearing closest resemblance to the training environment—that is, the Airport scene. Because this group had received no formal low-altitude training, however, the difference is probably of little practical importance for teaching low-altitude flight skills. The fact that F–16 pilots had been exposed to this environment early in their careers and showed the typical pattern of results indicates that pilots readapt when operational conditions change.

Design Implications and Future Research

The assumption underlying this research is that flight training effectiveness will be improved to the degree that relevant environmental structure can be identified and made the focus of attention during training. Previous research suggests that performance and learning of low-altitude flight tasks improves when relevant visual information is presented in isolation so that distractions are reduced (Flach, Hagen, & Larish, 1992; Warren & Riccio, 1985). One advantage of the present multidimensional conceptualization of environmental structure is that it provides a basis for isolating specific types of environmental structure for specialized training. This issue is of particular relevance in the context of flight training simulators in which environmental elements are explicitly modeled using computer image generators.

The reversal in the relative importance of dimensions for the A–10 group suggests that these pilots might benefit from specialized training in which vertical objects are emphasized more than terrain vertical relief. A problem arises, however, when one attempts to isolate relevant environmental structures for the F–111 group, because hills and ridges and large objects each served a dual role in scenes defining properties related to each of the two dimensions. Hence, presenting either of these types of scene elements in isolation would not serve to isolate relevant information related to each dimension. Indeed, even results for the F–16 and A–10 groups indicate attention to multiple properties of the same scene elements. For example, F–16 pilots perceived large objects to be somewhat similar to hills and ridges in Dimension 1 (Figure 3), whereas A–10 pilots perceived hills and ridges to be somewhat similar to large objects in Dimension 1 (Figure 5). These results imply that relevant environmental structures are not defined at the level of distinct scene elements such as hills, ridges, or large objects but at some more abstract level. This conclusion is supported by laboratory research indicating that perception of change in speed and altitude is based upon geometric transformations in fairly abstract stimulus elements such as grid lines (Flach et al., 1992; Johnson, Tsang, Bennett, & Phatak, 1989; Wolpert, 1988; Wolpert, Owen, & Warren, 1983).

Present results are useful in isolating the specific environmental elements that are the bearers of relevant structure, but they are only suggestive as to the identity of that structure. It remains for future research to identify the various types of structure provided by hills/ridges and large objects. Questions of particular concern are:

1. The difference between contrast edges defining large objects for F–16 pilots versus vertical relief that is shared by hills/ridges.
2. The difference between verticality shared by large objects and hills/ridges for A–10 and F–111 pilots versus terrain vertical relief that is unique to hills/ridges.
3. The property of large objects shared by smaller objects and vegetation on flat terrain which is contrasted with hills/ridges for F–111 pilots.

In order to generalize to aircraft types not included in this investigation it would be useful to know what specific operational factors account for the present differences. Potentially important factors such as speed, mission type, and out-of-the cockpit visibility were mentioned previously. However, present results are not diagnostic with regard to which specific factors mediated these differences. Because the A–10 and F–111 aircraft differ as much from one another as they do from the F–16, the differences cannot be traced to any single factor. It is important to note that each group viewed the exact same stimuli. Hence, if physical factors such as speed or limited visibility are important, their influence is mediated by perceptual learning, which is evidenced even in the absence these factors. A careful analysis of the operational environments in which A–10 and F–111 pilots fly would be useful in identifying specific differences for these aircraft. However, by identifying the specific stimulus structure to which pilots attend, it may also be possible to draw inferences about the unique visual behavior associated with that structure.

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