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SUMMARY

Subjective reports of American astronauts and their Soviet counterparts suggest that homogeneous, often symmetrical, spacecraft interiors can contribute to motion sickness during the earliest phase of a mission and can also engender boredom. Two studies investigated the functional aspects of Space Station interior aesthetics. One experiment examined differential color brightnesses as body orientation cues; the other involved a large survey of photographs and paintings that might enhance the interior aesthetics of the proposed International Space Station.

Ninety male and female college students reclining on their backs in the dark were disoriented by a rotating platform and inserted under a slowly rotating disk that filled their entire visual field. The entire disk was painted the same color but one half had a brightness value that was about 69% higher than the other. The effects of red, blue, and yellow were examined. Subjects wearing frosted goggles opened their eyes to view the rotating, illuminated disk, which was stopped when they felt that they were right-side up. For all three colors, significant numbers of subjects said they felt right-side up when the brighter side of the disk filled their upper visual field. These results suggest that color brightness could provide Space Station crew members with body orientation cues as they move about.

The study of picture perception was conducted in a high-fidelity mock-up of the proposed International Space Station wardroom in which subjects observed 35-mm slides projected on a simulated flat-screen video monitor. Discriminant analysis of various attributes of 320 pictures revealed one finding of particular relevance to Space Station interior design: subjects preferred photographs and paintings with the greatest apparent depths of field, irrespective of picture topic. This indicates that the opportunity to look outside of a confined environment is a very desirable attribute that can be simulated by spacious photographs and paintings of landscapes.

INTRODUCTION

Recent advances in space technology, which include recoverable vehicles like the NASA Space Shuttle and boosters with heavy lift capacity such as the Soviet Energia, will soon permit the construction of large space facilities that will provide living and working conditions not unlike those found in

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Antarctic stations. The proposed International Space Station Freedom planned by NASA for the mid 1990s will be a modular space facility that can be expanded to enhance the station's research capability. Despite relatively short tours of duty (several months), crew members are likely to experience episodes of boredom because of the homogeneous interior geometry of the station, as well as the need to perform routine maintenance and research. Such episodes of boredom could adversely affect the quality of the crew's performance.

Short-term laboratory deprivation experiments in humans have documented the emergence of visual disturbances, illusions, and restlessness characteristic of reduced environmental variation (Doane et al. 1959; Hauty 1964; Heron, Doane and Scott 1956), although personality factors (Persky et al. 1966; Vernon and McGill 1960), the presence of another participant (Flinn et al. 1961), and expectancies of stress (Zuckerman, Persky, and Link 1969) may buffer the intensity of this effect. Two major findings have emerged from these laboratory studies: (1) "hunger" for new opportunities to organize one's behavior builds up as a function of the duration of restricted experience and (2) individuals may differ in their tolerance to such conditions (for review, see Fraser 1966; Zubeck 1973; Zuckerman 1979).

Under longer conditions of confinement in isolated settings, such as that provided by a 7-month Antarctic winter-over context, station crews are reported to experience serious behavioral disturbances that can include sleep disorders, increased anxiety, irritability accompanied by withdrawal, and reductions in vigilance that can be hazardous (Natani and Shurley 1974; Suedfeld 1980). Weybrew and Noddin (1979) also note that reduction of alertness is a common finding among submarine crews during the monotonous conditions of prolonged submergence.

Soviet research has shown that long-term confinement in their small Salyut-6 Space Station engendered prolonged episodes of boredom (Bluth 1981; Gurovskiy, Kosmolinskiy, and Mel'nikov 1980). To alleviate the stress of boredom, Soviet cosmonauts spent many off-duty hours at the station windows to obtain spectacular views of Earth and colorful aurora borealis (Gurovskiy, Kosmolinskiy, and Mel'nikov 1980). Similar Earth-viewing activity was reported for off-duty Skylab astronauts (Johnson 1974). Cosmonauts Berezevoy and Lebedev reported that looking outside for long periods of time replaced the watching of telecasts of artistic theater and video movies as a form of relaxation (Zubkov 1982). It must be noted here that based on their extensive experience with earlier Salyut crews, the Group for Psychological Support, including habitability researchers, initiated a "psychoprophylactic" program of managing stress and boredom. Salyut cosmonauts were provided with recordings of their favorite radio and television programs, as well as teleconferences with friends, family members, writers, journalists, artists, and athletes (Pishchik 1985). In 1978, Salyut-6 cosmonauts were provided with a video tape player and numerous video tapes of movies. Video tapes depicting natural scenery in the Soviet Union were found to be especially appealing (Gurovskiy, Kosmolinskiy, and Mel'nikov 1980).

Habitability improvements on the subsequent Salyut-7 and MIR Space Stations have been the result, in part, of an evolving process of aesthetic experimentation, application, and evaluation in an attempt to provide familiar Earth-reference cues. For example, the Group for Psychological Support initially recommended soft pastel colors for the Salyut-6 Space Station interior to create a familiar home-like ambiance (Kidger 1979). The Salyut-7 Space Station, on the other hand, was provided with more contrasting colors (Konovalov 1982) in an attempt to provide the cosmonauts with ecologically "natural" spatial orientation cues in the microgravity environment. More specifically, the station was provided with a well-illuminated white ceiling that according to Gurovskiy, Kosmolinskiy, and Mel'nikov (1980), "will seem to imitate the sky." Although such application of spatial and aesthetic Earth-reference cues might ameliorate the working and living conditions in Soviet spacecraft by enhancing the diversity of cosmonaut experiences, we have no evidence that this application was based on empirical research using either flight or simulator experiments. The present research attempts to fill this gap by using simulations to determine whether spatial and aesthetic Earth-reference cues have potential utility in advanced space facilities, such as the proposed 1996 International Space Station and other isolated and confined facilities.

FUNCTIONAL ASPECTS OF SPACE STATION INTERIOR DECOR

Experiment 1: Differential Color Brightness as a Body Orientation Cue

Anecdotal information derived from Skylab and Salyut experience indicates that crew members have tended to establish a top-down orientation during their initial adjustment to the microgravity environment (Gurovskiy, Kosmolinskiy, and Mel'nikov 1980; Johnson 1974; Oman et al. 1986). This effect was especially apparent in the NASA Skylab Space Station, which had a clearly defined floor and ceiling architecture. Video records of Spacelab crew activity in the space shuttle show similar adherence to an upright body orientation as crew members move about.

Other evidence supports the notion (e.g., Gurovskiy, Kosmolinskiy, and Mel'nikov 1980) that differential illumination or color brightness might act as a body orientation cue. Underwater research has found that differential water brightness is used by divers to orient their bodies with respect to the gravitational vertical (Adolfson and Berghage 1974; Ross et al. 1969). In a similar context of obscured spatial reference cues, aircraft pilots report a phenomenon called "leaning toward the Sun" that can occur when they fly through thick cloud cover. During such episodes, the pilot may ignore or dispute the horizon indicator instrument and align the aircraft so that the brightest portion of the cloud appears overhead (Sharp 1978).

In light of the problems of transient spatial disorientation among astronauts and cosmonauts during their first mission week (Graybiel, Miller, and Homick 1975; Oman et al. 1986), the observations that differential brightness can act as a body orientation cue for establishing a subjective vertical prompted further experimental study (Barbour and Coss 1988). We hypothesized that subtle variation in color (hue) and brightness (value) of commercial pigments might provide subjects with sufficient information for establishing a subjective vertical. The findings of this experiment might thus substantiate the Soviet selection of a luminous ceiling for the Salyut-7 Space Station, as well as provide more generality to the lighting and interior decor of other advanced space facilities, such as the proposed 1996 International Space Station.

Ninety men and women college students ranging in age between 19 and 35 years were divided into three groups of equal size and balanced for sex. None of the students claimed to have visual anomalies. To begin the experiment, the subject entered a darkened room with eyes closed and reclined face up on a padded table, a position that disrupted otolith cues for the gravitational vertical (Cohen 1981). Each subject wore frosted goggles that diffused light evenly and occluded peripheral glare. The table was rotated slowly to further disorient the subject. After three rotations, the table supporting the subject was inserted under an apparatus comprising a rotating 76-cm-diam disk mounted approximately 17 cm above the subject's face. The subject's eyes were then centered under the rotating disk, and several seconds later two pairs of cool-white fluorescent lamps positioned on either side of the subject's viewing table were turned on to illuminate the disk; the disk was rotating quietly at 36°/sec. The subject was then asked to open his or her eyes to view the disk, which filled the entire visual field.

To assess color brightness as a body orientation cue, one half of the disk was painted with a brighter value of the same color than the other half. The differential brightnesses of yellow (5Y), blue (5B) and red (5R) were selected for study based on the Munsell Book of Color; for all three colors, the brightest sides of the three disks exhibited a Munsell value of 9, whereas the darker sides had a Munsell value of 7. Spectrophotometry of the three colors revealed that the luminance levels of the brighter halves of the disks averaged 69% higher than those of the darker halves. The commercial pigments used to paint the disks (Universal Color System) exhibited CIE chromaticity coordinates that differed an average of 1.7% from the Munsell matte surface samples.

After opening their eyes, the subjects viewed three rotations of the disk, following which they were asked to say "stop" when what they were looking at was most effective in making them feel as if they were right-side up. Subjects exhibited little difficulty in choosing particular brightness orientation patterns as subjective vertical cues. However, only three disk orientations (brighter side up, darker side up, and brighter and darker sides aligned in parallel with the axis of the subject's head) were selected by subjects as body orientation cues.

Frequency counts of subjects assigned to the three disk color conditions were examined using a log-linear analysis of a $2 \times 3 \times 3$ (gender x disk color x disk orientation) contingency table. Initial statistical analysis revealed that the interaction of sex, disk color, and disk orientation was not significant (Wald chi-square (4) = 5.43, $p = 0.24$). The major effect for disk orientation, however, was significant (Wald chi-square (2) = 33.18, $p = 0.001$). With respect to the three brightness orientation patterns selected, the majority (64.4%) selected the brighter side up to determine their body orientation. Planned comparisons showed that each of the colors engendered significantly different ($p < 0.05$) frequency counts for disk orientation, with the largest percentage of subjects selecting blue as the brighter side up (fig. 1).

The experimental results support previous anecdotes obtained from divers and pilots (e.g., Adolfson and Berghage 1974; Ross et al. 1969; Sharp 1978) that greater brightness in the upper visual field juxtaposed with lesser brightness in the lower visual field can act as a cue for the subjective assessment of a vertical body orientation. More specifically, spectrophotometry of the pigments used in the present study indicates that a luminance difference in which the upper visual field is as little as 42% brighter than the lower visual field is sufficient to produce this effect. Furthermore, the results of this study lend credence to the recommendation of a luminous ceiling for future Soviet spacecraft by Gurovskiy, Kosmolinskiy, and Mel'nikov (1980) that might provide a "light orientation guide for top and bottom," a recommendation that was apparently adopted for the Salyut-7 space station.

The finding that subtle differences in pigment reflectance seen under light-diffusing goggles, which blurred the boundary between the lighter and darker pigment values, suggests that various combinations of lighting levels and colors could create ecologically natural brightness asymmetry which would provide space-station crews with a constant "floor-ceiling" reference (Barbour and Coss 1988). It must be noted that motion sickness is most likely to occur during the first mission week of adaptation to the microgravity environment. This is the time when astronauts and cosmonauts often report the sensation of continuously falling backwards (for review, see Connors, Harrison, and Akins 1985; Oman et al. 1986). Anecdotal reports that crew members sometimes wedge their bodies against equipment racks to maintain their positions (Dalton 1974) could imply that the mild sensation of continuous falling is stressful, especially while facing wall surfaces out of immediate reach.

With disruption of normal otolith cues for the gravitational vertical, sudden turns of the head as crew members move about can cause vomiting. Spatial information is thus heavily relied upon for aligning the body as one moves about. Moreover, transient episodes of disorientation can exacerbate motion sickness during conditions in which crew members move through more symmetrical areas with ambiguous orientation cues. In one anecdote, for example, an astronaut reported that he found himself in an unexpected orientation with an unfamiliar inverted view of equipment racks and other crew members as he emerged from the tunnel connecting the Shuttle mid deck and Spacelab.

The application of interior decor with differential brightness thus appears to have the greatest utility during the earliest phase of a long mission as crew members become familiar with initially novel inverted space-station interior views. Another function of differential brightness could apply to emergency conditions involving rapid egress and ingress requiring the rapid assessment of body orientation relative to emergency control panels. Overall then, variation in lighting and pigment brightness is one of several design strategies (Clearwater 1988) for providing advanced space facilities with ecologically natural perceptual features.

Experiment 2: Aesthetic Enhancement by Decorative Pictures

Another strategy for enhancing the function of Space Station interior decor dealt with providing environmental variation to combat boredom. This involved examination of the potential utility of decorative pictures in enhancing the visual quality of relatively monotonous spacecraft and Space Station interiors. Because aesthetically pleasing pictures would periodically catch the viewer's attention, momentarily enlarging the contextual framework of the viewer to include the properties of other settings, they could increase the diversity of cognitive activity in a way that might make long space missions more bearable. The desire to enlarge this contextual framework has been noted under short-term conditions in which subjects were placed in an isolation chamber and were thus highly motivated to seek changes in the setting. Persky et al. (1966) reported that under these conditions subjects kept a television set on almost continuously except when they were sleeping.

The application of graphical materials to ease the boredom of long space missions is not a new one. Soviet space habitability researchers have adopted the theoretical perspectives of "technical aesthetics," the Soviet equivalent of industrial design in the West. Because of the absence of intrinsic industrial competition in product design, the Soviet form of "artistic design" does not emphasize aesthetics for the sake of selling products. In their view, technical aesthetics can embody an ecological approach to improving the working and living conditions of factories by combining features of the natural environment (Gurovskiy, Kosmolinskiy, and Mel'nikov 1980) with artwork (Mel'nikov 1970). An example is found in the so-called "psychological relief rooms" that provide fatigued factory workers with 10-min simulations of wilderness settings using music and large back-illuminated photographic transparencies from nature (Mel'nikov 1978). Potential adaptation of this concept to Soviet spacecraft interiors includes the use of landscape postcards and projected slides of landscapes and other images on a "special screen that imitates a window" (Gurovskiy, Kosmolinskiy, and Mel'nikov 1980).

The idea that ecologically natural properties of the environment might have restorative qualities is an old one in Western thought and is manifested by the desire of city dwellers to visit wilderness areas and to send children to camp (Tuan 1978). Recent research by Ulrich (1984) using hospital recovery data for gallbladder patients has shown that those with a window view of trees and bushes recovered more quickly than patients who viewed a brick wall. Although there is no experimental evidence to our knowledge that pictures have similar restorative properties, there is some evidence that nature photographs have the potential of lowering physiological arousal that affects a person's well-being. In several studies using pupillary dilation as an index of sympathetic nervous system arousal, Hess (1975a) reports that relative to provocative pictures, landscape pictures engendered very little arousal and were therefore used as experimental controls. Similarly, Ulrich (1981) found in comparing projected slides of nature scenes versus city scenes of similar complexity that nature scenes depicting water engendered the strongest positive ratings, as well as the greatest amount of "wakefully relaxed" cortical activity measured by means of electroencephalographic recordings of alpha wave amplitude.

The present research continues this theme of measuring subjective preferences and physiological arousal, but incorporates the context of viewing pictures in a simulated Space Station interior to determine the most appropriate types of pictures for enhancing the aesthetic appeal of this technical environment. A high-fidelity mock-up of the proposed Space Station wardroom in the Habitat Module was constructed in which subjects could view projected slides and pictures under low ambient lighting (photopic light = 3.1 candelas/m2). The mock-up comprised a 182-cm2, peach-colored wall of high Munsell value (Universal Color System P20 "peach frappe") equipped with cabinets, a control panel, and a flat-screen video monitor simulated by illuminated switches and a 58- by 34-cm screen for projecting 35-mm slides. A darker pigment value (Universal Color System 3-6 "Elegy") was applied to the lower wall section below the simulated video monitor based on the experimental results obtained from the study of body orientation cues. The sides of the mock-up consisted of light-blue padded fabric walls and curtains (Universal Color System 28-6 "Horizon") not unlike those of other NASA Space Station mock-ups (fig. 2). Continuous 76-dB background sound provided by two baffled fans simulated the noisy conditions expected in the actual Space Station interior.

The rationale for selecting the wardroom of the Habitat Module as the contextual backdrop for conducting a large picture survey was based, in part, on the proposed dining, conference, and off-duty entertainment functions of this facility. Because of these proposed functions, the wardroom would be the ideal location for displaying pictures on the large video monitor proposed for showing video movies. With application of emerging flat-screen video technology with concomitant low power requirements, thousands of digitized pictures stored on laser disks could be continuously displayed as still-frame video images either randomly or by programmed selection for different time periods. Because the crews using this facility will be of mixed nationalities and sex, the pictures selected for study should have an international appeal to both men and women. With this in mind, 320 photographic slides were selected for study. Although the primary research objective of this survey was applied, several theoretical issues in experimental aesthetics could be evaluated owing to the large diversity of photographic slides sampled. The following theoretical issues were considered in the selection of photographic slides:

Landscape perception– Several studies indicate that scenes depicting water or moist vegetation are preferred over those that are more arid (Balling and Falk 1982; Lyons 1983; Zube 1974). Strong preferences are given to spacious scenes with greater apparent depths of field (Ulrich 1977; 1983), especially distant mountain ridges with low hills and sparse trees in the foreground (Buhyoff, Wellman, and Daniel 1982; Hull and Buhyoff 1983; Patsfall et al. 1984).

Biologically relevant images– Views of spacious park-like settings (e.g., moist African savannas with widely spaced acacia trees) are thought to afford more pleasant emotional responses than views of dense forests and deserts, this because of the assumed evolutionary persistence of ancient savanna habitat preferences (Balling and Falk 1982; Orians 1980), especially window-like views from protected locations (Appleton 1975). Unlike serene landscape settings (e.g., Hess 1975a; Ulrich 1981), provocative images that are ecologically important to the viewer can elicit strong physiological arousal. Such images include close-up views of facial features that are innately recognized, such as two-facing eyes (Coss 1970,1979; Hess 1975b), and dangerous looking teeth and claw-like shapes ending in sharp points (Coss 1965, 1968). The fact that these images appear often in artifacts indicates that they can exhibit favorable aesthetic qualities in certain decorative contexts (for review, see Coss 1968, 1974). Although these latter images might not be appropriate for enhancing the Space Station interior, they provided important contrast for evaluating any provocative or aesthetically pleasing aspects of the various pictures.

Pattern complexity, novelty, and incongruity– Studies have documented that preference is correlated positively with familiarity (Hammitt 1979; Herzog, Kaplan, and Kaplan 1976; Lyons 1983; Zajonc 1968). Pattern complexity and incongruity are also known to increase physiological arousal (Berlyne et al. 1963; Berlyne and McDonnell 1965), but complex images like some works of modern art do not reliably increase arousal in all subjects (Hess 1975a; but also see Konecni and Sargent-Pollock 1977). Based on this pattern-perception research, landscapes and urban scenes with unstructured, randomly arranged features (e.g., low legibility) were thought to afford more uncertainty in information assessment by the percipient (Kaplan 1972; Wohlwill 1968) and therefore to produce lower aesthetic preferences than more homogeneous settings; however, findings to support this view are mixed. On the other hand, landscape views that are spacious in the foreground and partially occluded in the background offer a sense of "mystery" (Kaplan 1973) that seems to prompt more interest and preference in the viewer (for review, see Ulrich 1983).

Decoration of personal space– A study by Hansen and Altman (1976) indicated that the types of pictures selected to decorate the co[illegible]e dormitory rooms of males varied considerably, but the appearance of some types of pictures increased with the duration of occupancy. Posters with abstract designs, flowers, sports activities, and landscapes were popular. Landscapes and action pictures, such as skiing, were very popular, with technical posters of radios and sports equipment occupying the least wall space. Both landscapes and sports photographs spread over more wall space as the academic quarter progressed. The findings of this study suggested that in addition to landscapes a wide range of picture topics including sports photographs and close-up views of plants and animals needed to be included in the picture survey.

Categories of Pictures Surveyed

Paintings– Ninety-five 16th-20th century paintings were selected to include a diverse range of artists, techniques, and themes. Spacious landscape paintings by Andreas Achenbach, Fortunato Arriola, J. Beaufort, Albert Bierstadt, Alfred Bricher, John Casilaer, Fredrick Church, Thomas Cole, John Constable, Gustave Courbet, El Greco, Regis Gignoux, Meindert Hobbema, John Kensett, Theodore Robinson, Joseph Turner, and Worthington Whittredge were selected to compare with landscape photographs depicting similar themes. Paintings depicting humans and animals in action by Joe Beeler, George Bellows, George Bingham, Ralf Blakelock, Pieter Brueghel, Edgar Degas, Eugene Delacroix, Thomas Eakins, Seth Eastman, Winslow Homer, Kawanabe Kyosai, Frederic Remington, Norman Rockwell, Charles Russell, and Frank Schoonover provided the animate thematic context of sports and recreational outdoor activity.

Impressionist paintings by Paul Cezanne, William Chace, John Enneking, Herman Herzog, Vincent Van Gogh, and Maurice de Viamincle exhibited complex texture and lighting that might promote the viewer's interest. Photorealistic paintings of landscapes and urban scenes by Donald Eddy, Richard Estes, Setsko Karasuda, David Parrish, and Idelle Weber were selected to determine if paintings that appeared real to the observer might be evaluated solely for their content and not their artistic merit. Surrealistic and abstract expressionist paintings by artists such as Salvidor Dali, Frank Holmes, and Franz Marc, complemented by contemporary paintings by D. J. Hall, Neil Welliver, and Joseph Raffael, provided the wide range of thematic diversity and artistic styles needed to round out the survey. As a way of providing contrast to works by the above artists, imaginary landscapes and abstract fantasy illustrations by Don Dixon, H. R. Giger, Syndey Goodman, Albert Ryder, and Patrick Woodroffe provided unfamiliar, incongruous, and biologically important images that might require more cognitive processing and hence engender greater physiological arousal than the other paintings.

Photographs– Two hundred twenty-five photographs were obtained from field photography and books and magazines that emphasized high-quality graphical images. The topics sampled were as diverse as the geographic sites, which included scenes from many different cultures. Landscape scenes with and without buildings, animals in natural settings, and people engaged in athletic and recreational activities made up the largest number of photographs.

With respect to landscapes, 58 of them were spacious views of mountains, savannas, prairies, and deserts; less spacious views of deciduous forests in different seasons and tropical forests provided occluded backgrounds that were expected to promote a quality of "mystery." Eighteen landscape photographs were taken during the evening or at dawn, showing crimson skies and sparkling highlights (e.g., glitter) on water and moist vegetation that could be aesthetically pleasing to the viewer. Another form of glitter appeared in 12 photographs with space themes, including satellite views of Earth and Moon and brightly illuminated views of astronauts performing extravehicular and lunar activities.

Exterior and interior photographs of architecture from different cultures appeared in 27 photographs. Twenty-nine photographs depicted humans engaged in strenuous activities, such as acrobatics, skiing, jogging, and participation in major team sports. Animals such as reptiles, birds, and mammals, the latter emphasizing African fauna, were shown in 54 photographs; several of these animals appeared potentially threatening to the viewer and were expected to elicit physiological arousal. Fourteen photographs dealt with close-up views of flowers, bark, and rocks with various textures. Fifteen photographs dealt with artifacts, such as close-up views of commercial displays and consumer products. Finally, 16 photographs depicted novel and incongruous elements, analogous to those displayed by some of the paintings, providing contrast for evaluating those features that potentially engender positive aesthetic preferences or elicit physiological arousal.

The picture survey was conducted using 16 separate experimental sets, each of which was composed of 20 subjects balanced for sex and 20 different photographic slides. Subjects consisted of students, faculty, and staff from the University of California, Davis, between 18 and 50 years of age. [illegible] of the following types and concomitant ranges were randomly assigned to each experiment: five to [illegible] paintings, three to four landscapes, one to two architectural pictures, three to four animals, one to two sports or recreational themes, two close-up pictures of humans artifacts and natural objects, and at least one picture with novel and incongruous elements. This consistency in picture types within each experiment generated a range of attitude and physiological measurements that could be statistically evaluated to determine if the 16 experiment sets exhibited homogeneous variances for any dependent variable.

During the experiment, subjects were seated in front of the slide projection screen and provided a brief description of the wardroom mock-up and the objectives of the experiment. Physiological arousal during picture perception was measured using an AIM Biosciences pupillometer to monitor changes in pupil size (see Coss 1970). This self-report device is sensitive enough to detect hippus activity (spontaneous oscillations of the pupil). It is worn as a comfortable pair of goggles that occludes one eye, but permits flexible head positions for visually scanning slides (fig. 2).

Pupillary dilation reflects sympathetic nervous system arousal mediated by hypothalamo-cortical activity (Hess 1972). During exposure to provocative pictures, pupillary dilation is detectable about 0.5 sec after the onset of picture presentation, following which it may reach an asymptote in less than 7 sec. Subjects easily read their pupil size shown on an illuminated scale within the device before the arousal of reading activity altered pupil size; however, they were not informed about the meaning of the scale within the device. Since prolonged arousal is accompanied by an increased output of epinephrine that can also elicit pupillary dilation 8-15 sec later by means of the circulatory system (Loewenfeld 1958), slide presentation was restricted to a 5-sec duration before the pupillometer was illuminated, cueing the subjects to read their pupil scores. Spectrophotometry of each slide revealed that covariation of slide luminance and pupil size within subjects was not significant.

Four attitudinal questions employing a seven-point Likert scale examined the following subjective topics: (1) preference, "rate the picture based simply on how well you like it"; (2) interest, "rate the picture based on how interested you are in the topic presented by the picture"; (3) familiarity, "rate the picture based on how familiar you are with the topic presented by the picture"; (4) enhancement, "rate the picture based on its ability to make this setting in here more enjoyable."

Five practice slides were presented to familiarize the subjects with each of four attitude questions, following which they observed 10 or more practice slides to become familiar with the pupillometer. Following this practice phase of using the pupillometer, the subjects reported their pupillary scores during the presentation of the 20 experiment slides. After completing this first exposure to the slides, the subjects removed the pupillometer and were requested to subjectively rate the pictures on the Likert scale. Presentation of slides in all experiments was randomized for the five dependent variables; the order of the four attitudinal questions was also randomized for each subject.

Mixed analyses of variance (ANOVAs) examined sex and slide differences within each experiment and the average scores derived from the 20 subjects were further analyzed by single-factor ANOVAs to determine if the 16 experiment groups differed appreciably. For the four attitude variables, significant sex differences did not appear in any experiment; none of the experiment groups differed significantly as well using average slide data, indicating that the balanced selection of slide topics assigned to each experiment set produced homogeneous variances in attitude across the 16 experiment sets. The experiment sets did differ significantly, however, on the pupillary dilation measure, a result best explained by the presence of strongly arousing slides in several experiments.

The average scores for each slide were further analyzed by multivariate analyses of variance (MANOVAs) and discriminant analyses (Bray and Maxwell 1985), the latter permitting investigation of the global properties of the entire set of 320 slides or selected slide subsets. Slides were grouped according to the theoretical issues discussed above. Only the effects of differences in the apparent depths of field of the various slides (e.g., Ulrich 1983) will be emphasized here owing to the implication that some pictures, especially those of nature, might substitute for windows in the confined setting of the International Space Station.

Slide differences in apparent depths of field were examined by grouping slides as a function of the following estimated distances between the picture plane and the picture's central topic: (1) 0-1 m, 69 slides with the least depth, (2) 1-10 m, 101 slides with intermediate depth; (3) 10 m or more, 150 slides with the greatest apparent depth. ANOVAs on each of the dependent variables (fig. 3) and the concomitant MANOVA revealed that the groups differed significantly as a function of apparent picture depth (Pillai-Bartlett trace = 0.296; multivariate $F = 10.89$, $df = 10, 628$, $p < 0.0005$). Only the first discriminant function was significant ($p < 0.0005$) and examination of the standardized discriminant coefficients and canonical variate correlations (Bray and Maxwell 1985) revealed that interest in the picture's topic, followed successively by preference and interior enhancement, contributed the most to group separation. Finally, the statistical assignment of the slides to their respective groups was relatively robust in that 63.8% of the slides with the least apparent depth and 67.3% of the slides with the greatest apparent depth were correctly classified as members of their respective groups.

The canonical variate correlations permit some interpretation of the underlying processes accounting for group separation on the first discriminant function. It must be noted that physiological arousal was negatively correlated with the first discriminant function, reflecting the general decline in arousal during the visual fixation of the more preferred and interesting slides with the greatest apparent depths of field (compare figs. 3(a)-3(e)). Since the least preferred but most arousing slides tended to be those with the least apparent depths of field, the distribution of slides on the first discriminant function (see factor 1, fig. 4) seems to reflect an index of emotional and cognitive "tranquility." This interpretation is further supported by the results of Pearson product-moment correlations applied to each group. For slides of intermediate depths of field, physiological arousal was positively correlated with slide preference ($r(99) = 0.212$, $p < 0.05$, two-tailed test), in significant contrast with the low negative correlation coefficient of arousal and preference for slides of greatest apparent depth ($Z = 2.29$, $p < 0.025$, two-tailed test).

To further examine which landscape features engendered the highest attitude ratings, spacious photographs and paintings that depicted buildings were compared with those without buildings. ANOVAs revealed that the slide group depicting landscape views without buildings exhibited significantly higher ratings ($p < 0.005$) than those depicting buildings for all the attitude variables, especially interior enhancement of the Space Station mock-up. Further examination of landscape slides revealed that depictions of rivers, lakes, and ocean views (e.g., glittery slides) were rated significantly higher ($p < 0.05$) for all the attitude variables than those in which water was not apparent, again a result that was most notable for interior enhancement of the mock-up (fig. 5).

Pictures Perceived Under Low Light or Inverted Conditions

Two follow-up experiments investigated the general applicability of the picture survey findings to other presentation contexts in which lighting or body orientation might affect picture perception. Unlike the wardroom context in which highly preferred pictures could be displayed as luminous images on the proposed video monitor, pictures could also be displayed in numerous locations in the Space Station as printed images that reflect rather than emit light. Since ambient lighting levels for some locations, such as the crew quarters, are likely to be low (10-30 lux), certain types of pictures might degrade aesthetically when observed under those conditions. For example, landscape pictures depicting forests with closely spaced trees were considered particularly vulnerable to low lighting conditions because thick forests viewed in dim light might cause mild viewer discomfort. In contrast, landscape pictures depicting crimson sunsets were expected to maintain their aesthetically pleasing properties despite low ambient lighting because the low light of the evening sky is an important contextual property of the photograph.

Ten highly preferred landscape slides from the general survey were made into 20- by 22-cm prints that could be mounted at eye level on the wall adjacent to the slide projection screen in the Space Station mock-up (fig. 2). Five prints depicted dense forest vegetation in the background and five prints depicted forests and savannas photographed under sunset and twilight conditions. These pictures were presented randomly to two groups of subjects under two incandescent lighting conditions (1.1 and 9.5 candelas/m2) measured as photopic light reflected from the slide projection screen next to the picture. Each group consisted of 20 subjects balanced by sex. After a 10-min period of dark adaptation using practice slides, the subjects were asked to rate the photographic prints based on the interior enhancement question about how well the picture makes the mock-up setting more enjoyable.

Contrary to our expectations, a mixed ANOVA revealed that the two lighting conditions had very little effect on the aesthetic quality of the prints. Moreover, the prints observed under the two lighting conditions engendered mean ratings that were very similar to those obtained from the projected slides; the prints from both lighting conditions and the projected slides yielded interior enhancement ratings that were also positively intercorrelated ($p < 0.05$, one-tailed tests). The results of this experiment indicate that ambient lighting does not provide an important constraint on the selection of locations for displaying prints of aesthetically pleasing pictures.

Although differences in ambient lighting might not constrain the choice of locations for displaying pictures, some locations in the station might be inappropriate for displaying pictures because crew members moving about in the microgravity environment might frequently see the pictures from oblique or inverted viewing positions. Some types of pictures, notably those with strong orientation cues, might not retain their aesthetically pleasing properties if displayed in areas where the crew frequently rotate their bodies during ingress or egress. To examine this potential constraint, the fourth survey experiment was repeated using the same protocol except that the 20 slides were shown inverted. This experiment was selected for the comparison of upright and inverted slides because it contained seven slides with ambiguous orientation cues. Subjects were not informed why some slides appeared to be inverted until after their ratings were completed.

Data from pupillary dilation and interior enhancement were combined with those of the fourth survey experiment and treated statistically by mixed ANOVAs. Despite the fact that slides were shown upside down, significant group differences did not emerge for either pupillary dilation or interior enhancement. Right-side-up and upside-down slides produced enhancement ratings that were strongly correlated ($p < 0.005$, two-tailed test), a result that further implies that pictures can retain their attractive or unattractive qualities irrespective of the percipient's body orientation. In short, these follow-up experiments indicate that in addition to displaying pictures on the wardroom video monitor, photographic prints can be placed throughout the station with little concern for lighting or viewing angles.

DISCUSSION

Two types of experiments examined the functional aspects of interior decor that could enhance the proposed International Space Station by facilitating an upright body orientation as crew members move about and by providing environmental variation to combat boredom. The first experiment examined the effects of differential color brightness as body orientation cues, revealing that irrespective of the colors sampled, differential brightnesses of the same color seen in the upper and lower visual fields are effective cues for establishing a subjective vertical. Since brightness differences of as little as 42% were sufficient to engender this effect, a wide range of color schemes could be employed throughout the station to aid crew members' identification of floor-ceiling relationships in various settings.

The second experiment was a large survey of 35-mm slides presented on a simulated video monitor in a high-fidelity mock-up of the Space Station wardroom. This survey was aimed at identifying picture topics that are appropriate for enhancing the aesthetic appeal of this technical setting in a way that might make long space missions more bearable. One finding was particularly relevant for assessing the utility of pictures in the Space Station setting: pictures with the greatest apparent depths of field, irrespective of topic, engendered the strongest aesthetic preferences, a finding supportive of previous studies restricted exclusively to evaluating landscape preferences (e.g., Buhyoff et al. 1982; Patsfall et al. 1984; Ulrich 1983). Moreover, such pictures retained their aesthetically pleasing properties when viewed upside down or presented as photographic prints in dim light.

The group of pictures exhibiting the least apparent depth was the least preferred for enhancing the Space Station mock-up, although there were some exceptions among the individual pictures. On the average, pictures in this group were also the most arousing physiologically, a likely by-product of the more complex cognitive activity associated with the perceptual integration of larger picture components produced by close-up views (Kosslyn 1987). Several studies have shown that pupillary dilation occurs with short-term problem-solving and other complex information-processing tasks (Beatty 1982; Beatty and Wagoner 1978; Hess and Polt 1964). A few very arousing pictures in this group were clearly disliked in the context of the Space Station interior whereas other arousing pictures were very appealing.

In support of the view that pupillary dilation reflects cognitive processing activity, it must be noted that the most arousing picture in the entire survey was a painting by H. R. Giger depicting an incongruous close-up view of gruesome baboon-like canines emerging from a cluster of serpentine forms (see painting in Masello 1986, p. 81). Furthermore, this picture was the only one among the series of pictures with incongruous properties that was highly arousing, a finding that does not lend support to previous studies using simple incongruous patterns (Berlyne et al. 1963; Berlyne and McDonnell 1965; Berlyne 1971). In keeping with this general finding, physiological arousal was not elevated during the perception of inverted pictures, which present another type of incongruity. The provocative aspect of the Giger painting, therefore, more likely results from its depiction of ecologically important shapes with sharp points known to elicit pupillary dilation (Coss 1965, 1968) rather than complex cognitive assessment owing to pattern incongruity. On the other hand, complex cognitive processing may account, in part, for the high arousal and strong positive attitudes engendered by close-up views of people engaged in vigorous athletic activities, such as canoeing and sailboarding. Similarly, the cognitive processing of images depicting complex human activity very likely contributed to the moderately high arousal evinced when viewing paintings by William Chase, Thomas Eakins, Seth Eastman, and Winslow Homer. Other examples of pictures that were both aesthetically appealing and arousing were nonthreatening views of active animals, such as an eagle landing, a prairie dog with her pup, and foraging zebras and American pronghorns.

Psychobiological Maintenance Aspects of Picture Perception

Although the entire set of pictures was grouped on the basis of other attributes for statistical comparisons not emphasized herein, group discrimination simply on the basis of apparent depth of field suggests that the opportunity to look outside is a very desirable feature that can be simulated with spacious landscape photographs and paintings. In effect, pictures depicting spacious views can provide some substitution for windows in confined technical environments.

Space Station crew members experiencing long tours of duty are likely to discard progressively the tendency to maintain a vertical body orientation with respect to the floor and ceiling and explore the station interior using novel viewing angles. For example, some Skylab astronauts found themselves unexpectedly rotating as they pushed off surfaces (Dalton 1974). With repeated experience in controlling body orientation, some Skylab and Salyut crew members experimented with unusual body orientations providing unique interior views. Such novel interior views might temporarily delay habituation to the station interior. As the novelty of these viewing angles dissipates during the 4-month missions planned for the International Space Station, pictures that simulate window-like views to the outside, especially those that change frequently, can expand the contextual properties of the setting by fostering the perceptual processing of complex information.

Neurobiological Implications

The question therefore arises in the context of a long space mission whether novel pictures, especially serene views of nature, do indeed exhibit functional qualities beyond that of providing aesthetically pleasing depictions of Earth-associated activities. Neurophysiological research on animals, especially primates, clearly indicates that simple perceptual-motor tasks activate large areas of the brain (cf. John et al. 1986; Moran and Desimone 1985; Ungerleider and Mishkin 1982). Perceptual processing of ecologically important images, such as novel faces, are known to involve large ensembles of cortical and subcortical neurons (Baylis, Rolls, and Leonard 1985; Rolls 1984). From a theoretical perspective, the initial perception of printed pictures very likely involves the activation of unique patterns of neural processes integrated with those previously generated by earlier experiences in similar contexts. With subsequent habituation during repeated viewing, even brief glances at pictures would entail drawing the viewer's attention away from ongoing cognitive activity by "forcing" recall of various associated topics. For example, transient scanning of a familiar picture depicting a downhill skier is congruent with rapid categorical recognition of the picture topic coupled in memory with related issues associated with skiing. Similarly, glances directed at various aspects of a familiar scenic view of nature could provoke associations based on previous experiences, including the emergence of imagery involving a simulated exploration of the setting.

Picture perception could combat specific forms of experiential deprivation inherent in the confined technical setting of the International Space Station by augmenting the diversity of cognitive activity in ways that are similar to that produced by Earth-bound situations. Clearly, work and off-duty activities in the International Space Station will not have the degree of diversity typically experienced by crew members before and during mission training on the ground. It is important to consider that despite Soviet attempts to enhance motivation by providing variation in work and leisure schedules that included frequent contact with family and friends, prolonged deprivation of normal Earth-bound activities is a reasonable explanation for the growing homesickness experienced by cosmonaut Yuri Romanenko during the final weeks of his 326-day mission in the MIR Space Station in 1987. Homesickness, however, was not reported during the 1987-88 one-year mission of Vladimir Titov and Musa Manarov, indicating that chronic stress is not inevitable during long space missions and that personality factors may buffer some individuals from experiencing chronic stress. This and previous Soviet experience with shorter missions (Bluth 1981, 1986) indicates that the potential exists for similar episodes of depression under the much shorter tours of duty anticipated for the International Space Station. The emergence of depression, however, does reflect underlying neurological changes that in the longer time scale might be functionally analogous to the short-term neurological adjustments to reduced innervation made during the first mission week to the disruption of otolith cues for a gravitational vertical (Oman et al. 1986).

Recent neurophysiological research provides some evidence that generalized neural activity (e.g., membrane depolarization) may be paramount for maintaining neurotransmitter levels (Black et al. 1987), inhibition of neurotrophic remodeling of neurons (Thoenen and Edgar 1985), and calcium-dependent enzymatic activity that adjusts membrane and synaptic conductances (Alkon 1984; DeRiemer et al. 1985; Lynch and Baudry 1984). With respect to the latter, extracellular calcium ions are known to enter depolarized dendritic spines (Andrews et al. 1988) and several theoretical studies provide a model in which intracellular calcium ion concentrations modulated by voltage-dependent membrane channels could play an important role in maintaining synaptic efficacy (Bear, Cooper, and Ebner 1987; Coss and Perkel 1985; Gamble and Koch 1987). Picture perception could thus foster neurobiological maintenance by initiating some types of Earth-associated cognitive activity that are very diminished or absent entirely in the Space Station. In light of the above discussion of the use of pictures to "force" activation of less frequently used neural processes in deprived settings, it must be noted that neuroanatomical studies of aged animals have shown that an "enriched environment" can defer some of the neuroanatomical changes that normally accompany the decline of sensory input with aging (Connor, Diamond, and Johnson 1980; Connor et al. 1981). In short, picture perception could initiate patterns of neural activity that might arrest the normal reorganizational processes thought to occur when specific synaptic sites are infrequently activated (Bear et al. 1987).

Arousal as a Constraint on Picture Display

With a few notable exceptions represented by pictures showing crimson sunsets, contrasting cloud formations, and moist glitter that were among the most appealing in the survey, photographs and realistic paintings depicting unobstructed views of mountains in the distance and water in the foreground engendered very little physiological arousal. The low arousal associated with these serene pictures is congruent with previous findings by Hess (1975a) using spacious landscapes as control slides for pupillary measurements and landscape perception research by Ulrich (1981), measuring wakefully relaxed brain wave activity. Since pictures of wilderness tend not to elevate physiological arousal during short-term exposure, it is unlikely that they would augment arousal later as crew members habituate to fixed exhibits of pictures during long space missions. Of course, habituation is not an issue if wilderness pictures are displayed as transient digitized images on the video monitors proposed for both the wardroom and crew quarters.

Long-term habituation, however, might pose a problem if wilderness pictures are the predominant topic displayed as prints throughout the station. Although pupillary dilation appears to reflect short-term and relatively generalized brain activity (Beatty and Wagoner 1978), little is known about whether increased neural activity during attentional shifts evinced by periodic glances at pictures with interesting properties would "protect" these pictures from a general decline in the viewer's interest during a long space mission. Even though on the average they tend to be slightly less preferred than landscape pictures, prints with arousal-enhancing properties, such as action-oriented scenes of humans and animals, might attract the viewer's attention more persistently than landscape pictures and, therefore, might be ideal for fixed exhibits. In addition to landscapes, such action pictures are known to maintain the interest of college students as indicated by their persistent display on dormitory walls (Hansen and Altman 1976).

Research in progress is examining this theoretical issue of whether physiologically arousing pictures are indeed more effective at maintaining the viewer's interest that those that are less arousing. Each crew member wintering over between February and August 1988 at two Australian Antarctic research stations (Davis and Mawson) was provided with a unique set of five pictures for display in work areas and living quarters. Australian crews at Casey acted as controls for the physiological portion of this study. This experimental study using the Antarctic winter-over context as a simulation of a long space mission is expected to provide insight into the utility of fixed picture displays for enhancing the interior of the proposed International Space Station and other advance space facilities.

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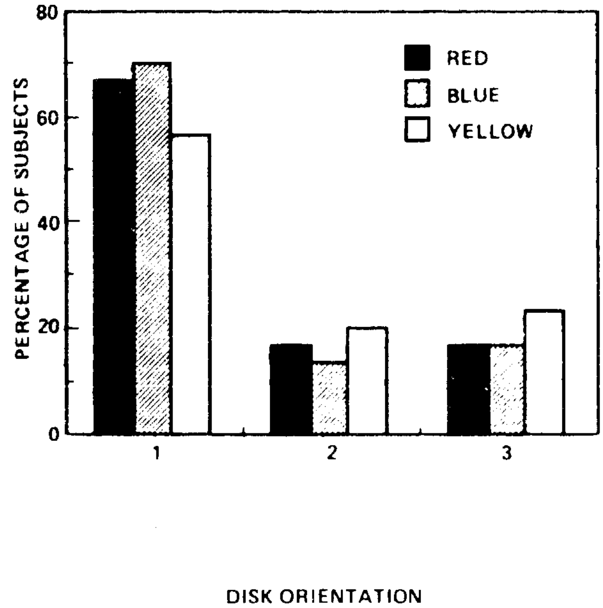

Figure 1.– Percentage of subjects selecting the orientation of differential brightness displayed by one of three disk colors when the slowly rotating pattern of brightness made them feel as if they were right-side up. Each color engendered significantly ($p < 0.05$) different proportions of subjects.

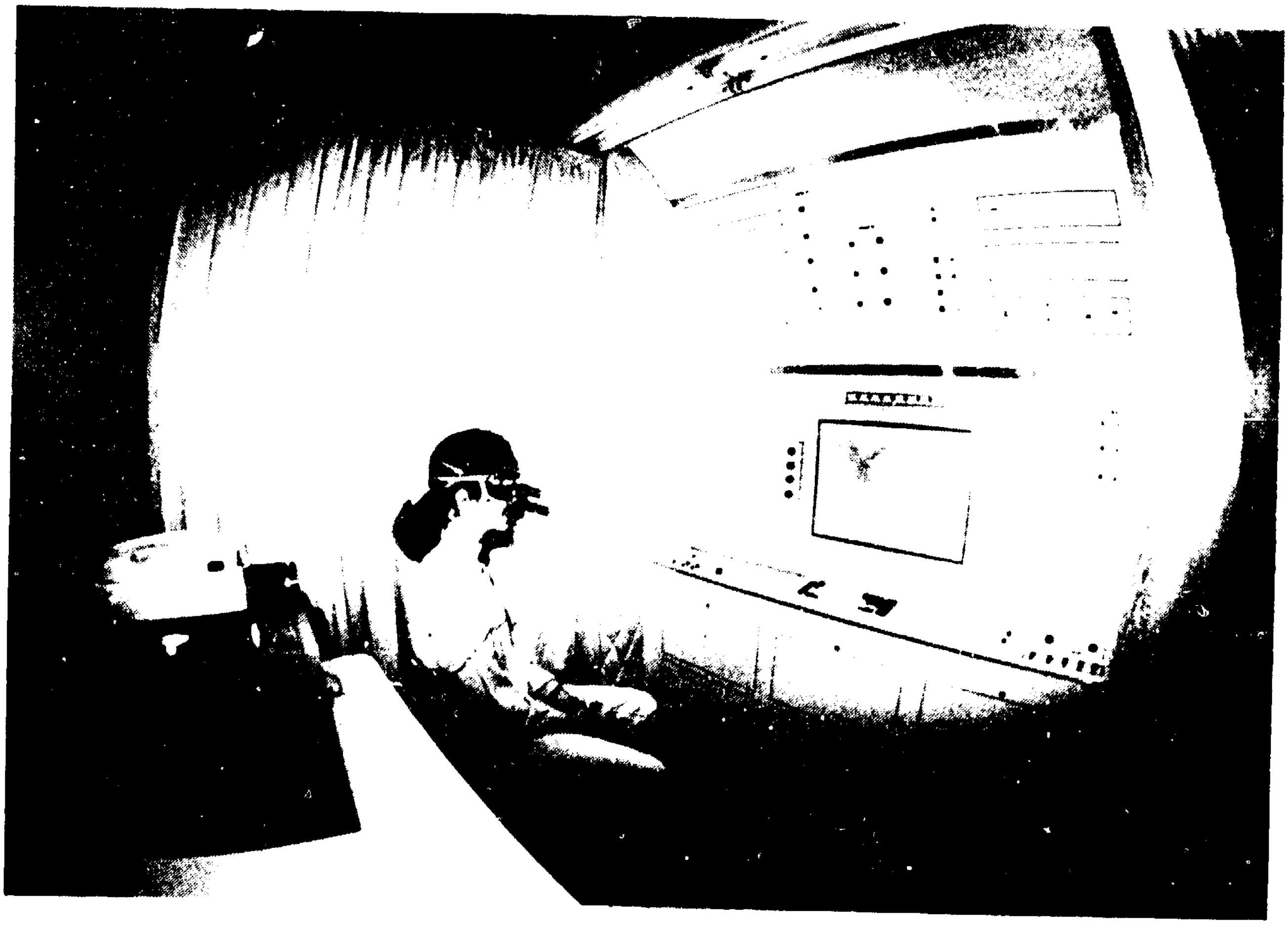

Figure. 2.- Interior view of the high-fidelity mock-up of the proposed International Space Station wardroom showing the experimental setup for viewing 35-mm slides projected on a simulated flat-screen video monitor. The subject shown is wearing a pupillometer to measure sympathetic nervous system arousal during initial picture perception. The panel to the left of the projection screen was used for displaying photographic prints.

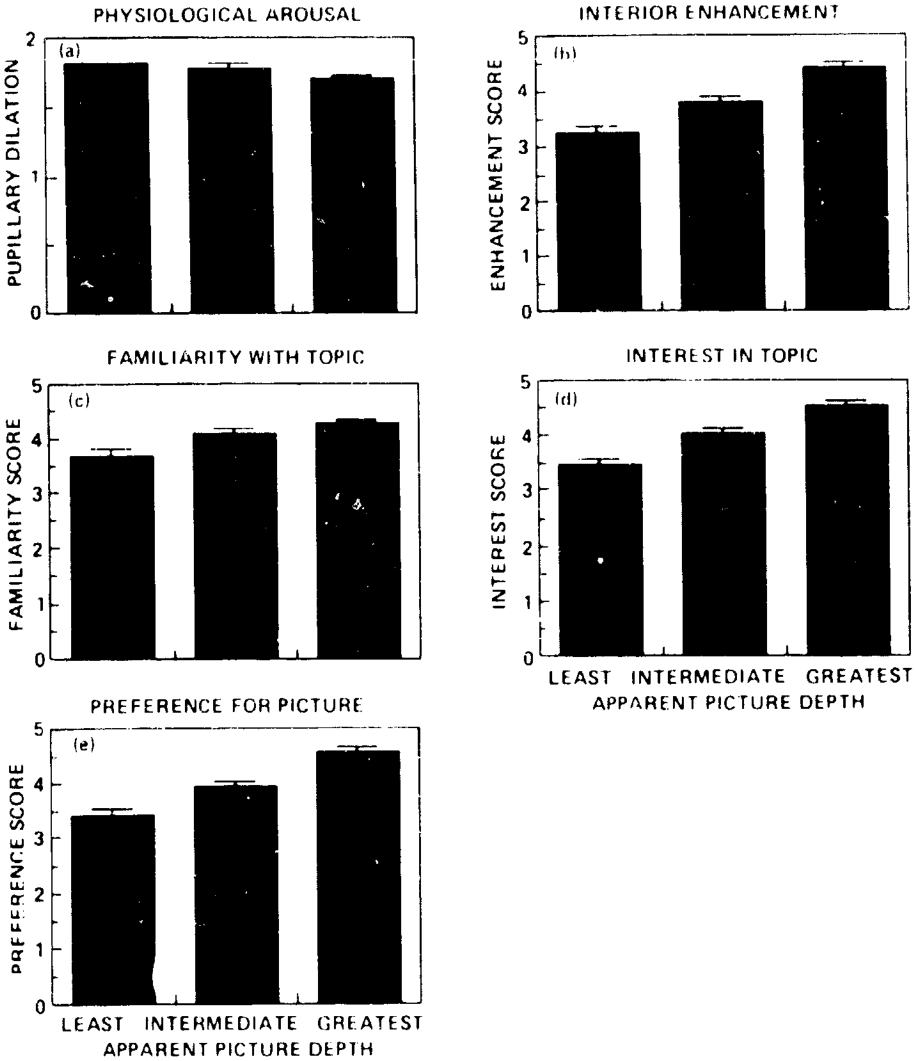

Figure 3.– Comparisons of picture groups based on apparent depths of field. All variables engendered significant ($p < 0.05$) group differences. Mean and standard error values are shown. Note the inverse trend relationships between physiological arousal evinced by pupillary dilation (A) and the four attitude measures (B-E) as a function of increasing apparent depths of field.

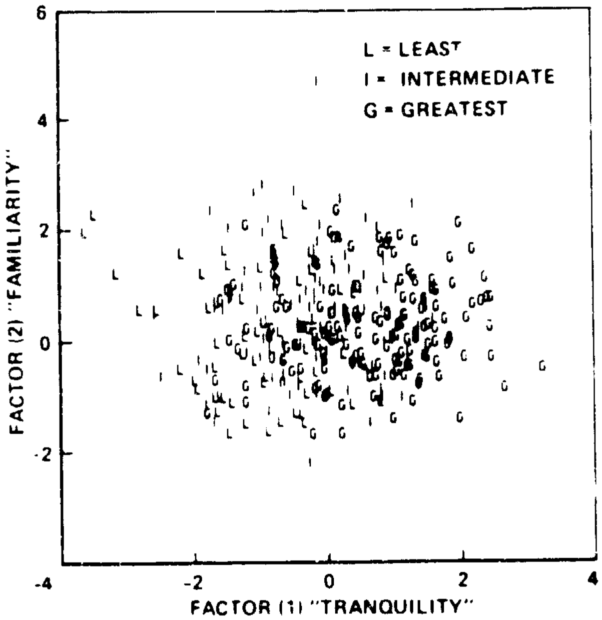

Figure 4.– Discriminant space depicting the distribution of 320 pictures sampled in the general survey as a function of apparent picture depth. The first discriminant function (Factor 1) was significant ($p < 0.0005$) whereas the second function (Factor 2) was not significant ($p = 0.15$).

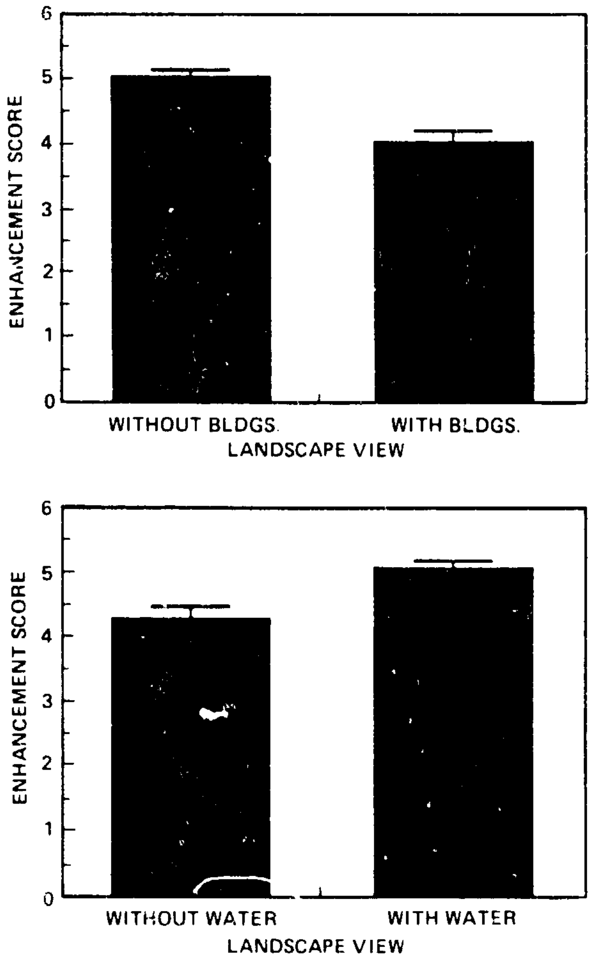

Figure 5.– Comparisons of the effectiveness of groups of landscape pictures in making the experience of being in the Space Station mock-up more enjoyable. Groups depicting (a) wilderness settings without buildings and (b) exhibiting water in the form of lakes, rivers, and streams evinced significantly higher ($p < 0.05$) interior enhancement scores than the respective groups with buildings or without water. Mean and standard error values are shown.

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16. Abstract

Subjective reports of American astronauts and their Soviet counterparts suggest that homogeneous, often symmetrical, spacecraft interiors can contribute to motion sickness during the earliest phase of a mission and can also engender boredom. Two studies investigated the functional aspects of Space Station interior aesthetics. One experiment examined differential color brightnesses as body orientation cues; the other involved a large survey of photographs and paintings that might enhance the interior aesthetics of the proposed International Space Station. Ninety male and female college students reclining on their backs in the dark were disoriented by a rotating platform and inserted under a slowly rotating disk that filled their entire visual field. The entire disk was painted the same color but one half had a brightness value that was about 69% higher than the other. The effects of red, blue, and yellow were examined. Subjects wearing frosted goggles opened their eyes to view the rotating, illuminated disk, which was stopped when they felt that they were right-side up. For all three colors, significant numbers of subjects said they felt right-side up when the brighter side of the disk filled their upper visual field. These results suggest that color brightness could provide Space Station crew members with body orientation cues as they move about. The study of picture perception was conducted in a high-fidelity mock-up of the proposed International Space Station wardroom in which subjects observed 35-mm slides projected on a simulated flat-screen video monitor. Discriminant analysis of various attributes of 320 pictures revealed one finding of particular relevance to Space Station interior design: subjects preferred photographs and paintings with the greatest apparent depths of field, irrespective of picture topic. This indicates that the opportunity to look outside of a confined environment is a very desirable attribute that can be simulated by spacious photographs and paintings of landscapes.

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