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THE EFFECT OF CONTEXT ON PERCEIVED DEPTH

Robert Patterson, Arthur Menendez, and Robert Fox

Department of Psychology
Vanderbilt University
Nashville, Tennessee 37240

July 1982

Technical Report

Prepared for:

Engineering Psychology Programs
Office of Naval Research
800 North Quincy Street, Code 455
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Much of the research on stereopsis, which refers to the perception of relative depth, has been devoted to the testting of hypotheses derived from the geometrical relationships intrinsic to stereoscopic depth perception. Factors not given directly by geometric consider-ations, yet which may affect stereoscopic depth relationships, have received less attention. This report concerns one such factor, namely

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the effect of context on the perceived depth positions of stereoscopic forms. Data do exist that suggest the perceived depth position of one stimulus can be influenced by the apparent depth positions of other stimuli. But such an effect has been obtained only under viewing conditions in which many of the cues to distance and depth are absent. In the present study, however, the effect of a large enveloping form on the perceived depth position of a smaller surrounded (test) form was examined when all cues for veridical distance and depth were present. The forms, which were contours formed from dynamic random-element stereograms, were combined factorially in 36 experimental conditions: four levels of context, three viewing distances, and three levels of disparity value. Perceived depth did vary as a function of viewing distance and disparity value in accord with the geometry of stereoscopic space, but not as a function of context. This result suggests that when multiple sources of distance and depth information are available, such as would be the case during the operation of a three-dimensional display, perceived depth is not influenced by higher-order context effects.

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The Effect of Context On Perceived Depth

The perception of relative depth through the operation of steropsis has been the focus of a sustained inquiry ever since the critical stimulus conditions necessary for its occurrence, retinal disparity, were described by Wheatstone in 1838. Much of the considerable literature that has accrued deals with the evaluation of hypotheses derived from the geometrical relationships intrinsic to stereoscopic depth perception. Such concepts as the horopter, crossed and uncrossed disparity directions, and Panum's fusional area are products of these efforts. Much less attention has been directed to factors that may influence stereoscopic depth perception yet which are not given directly by geometrical considerations. One such factor, and the topic of this report, is the effect of context on the perceived depth positions of stereoscopic forms. Specifically, does the depth position of a form, when seen in isolation, change when it is embedded in a context of forms located at different depth positions.

There are data that provide a positive answer to that question, at least under certain conditions. For example, Gogel (e.g., Gogel, 1977), in his efforts to develop a general theory of three-dimensional space perception, has uncovered several characteristics of the perceptual system that act to alter the perceived depth relationships among objects in visual space. These characteristics, which Gogel calls tendencies, are imposed upon perceived visual space by the perceptual system and, as such, are not derived from the physical conditions of stimulation. One characteristic, called the equidistance tendency, refers to the tendency to perceive objects in different depth planes as lying in a single common depth plane. A second characteristic, called the adjacency principle, refers to the fact that interaction among objects in depth (e.g., the equidistance tendency) is an inverse function of the distance between them in three-dimensional space. A third characteristic, called the specific distance tendency, refers to the perceived distance of objects when all physical cues to distance are eliminated. Evidence garnered in spport of these characteristics demonstrates that the visual system does not deal passively with a replica of physical space, but rather can act to impose its own organization on that space. Further, the work of John Foley, who has investigated the geometrical relationships that follow from the Luneburg model of visual space (e.g., Foley, 1969, 1976; Luneburg, 1947), also shows that the perceived depth position of one stimulus can be influenced by the apparent depth position of other stimuli.

Yet it should be noted that, in general, theoretical considerations have made it necessary for both Gogel and Foley to employ deliberately simplified stimulus conditions in which many of the cues for depth and distance that would be present under normal viewing conditions are absent, and those that are present are often manipulated so as to be in perceptual conflict. But in many real-life situations, depth cues are typically not in conflict and are of sufficient number to provi e redundant sources of veridical information about depth and distance. Under these conditions, it is not known whether context effects among objects in depth can alter their perceived depth positions. To that end, the objective of the inquiry described in this report was to determine the extent to which the perceived depth position of a stereoscopic form could be modified by the context provided by other forms when a full set of complementary depth cues were operative. These are the conditions under which a three-dimensional display would normally be viewed.

METHOD

Apparatus

Only a brief overview of the dynamic random-element stereogram system used in the present study will be given here. For more complete descriptions of this system, consult Fox and Patterson (1981), Lehmkuhle and Fox (1980), and Shetty, Brodersen, and Fox (1979). The system used in this study is composed of three components: the display, the stereogram generation unit, and the optical programmer.

The display is a modified color television receiver upon which random-dot matrices composed of red and dots are displayed. Stereoscopic viewing is achieved via the anaglyph method, in which appropriately matched chromatic filters are worn by the observer.

The stereogram generation unit is a hard-wired device, constructed from high-speed integrated circuits, that performs three functions: (1) It specifies the X/Y coordinates of the stereoscopic form to be displayed. (2) It produces the retinal disparity essential for the induction of stereopsis by introducing a slight delay in the output of one or the other electron guns of the television receiver. This delay results in a difference in spatial position between the red and green dots. (3) It generates random dots, without disparity, that camouflages the gap produced by the delay. The output of this system results in the production of stereoscopic forms that can be seen without the presence of monocular cues. All dots are dynamically replaced in both matrices at either the field rate (60 Hz) or the frame rate (30 Hz) of the video receiver. Apparent motion of the dots produced by their replacement does not impair the visibility of the stereoscopic forms.

The third unit of this system, the optical programmer, is synchronized with the scan of the video receiver. With this device it is possible to present virtually any stimulus configuration as a stereoscopic form. Together with the stereogram generation unit, the programming device controls the X/Y position of the stereoscopic forms. In the present study, only one optical programmer was employed. It scanned an achromatic two-dimensional image of one of the two stimuli used in this study, the context form; the stereogram generation unit generated the other stimulus used in this study, the test form (configured as a rectangle). See Figure 1 for the configuration and dimensions of these stimuli.

Observers

Five persons (two male and three female) served as observers in this study. All possessed normal or corrected-to-normal visual acuity, and had experience in perceiving stereoscopic contours formed from dynamic random-element stereograms. Four were naive with regard to the hypotheses under test.

Design

The purpose of this experiment was to investigate the influence of viewing distance, disparity, and context on the perceived depth position of the test form. Three viewing distances (70 cm, 140 cm, 210 cm), three disparity values (small, medium, large), and four context conditions (no-context, context-equal, context-front, context-back) were combined factorially to yield 36 experimental conditions. Although the apparent size of the two stimuli co-varied with viewing distance in this experiment, previous work in this laboratory has shown that variations in the size of stereoscopic forms does not affect their perceived depth position. See Table 1 for the dimensions of the stimuli employed under the three viewing distances.

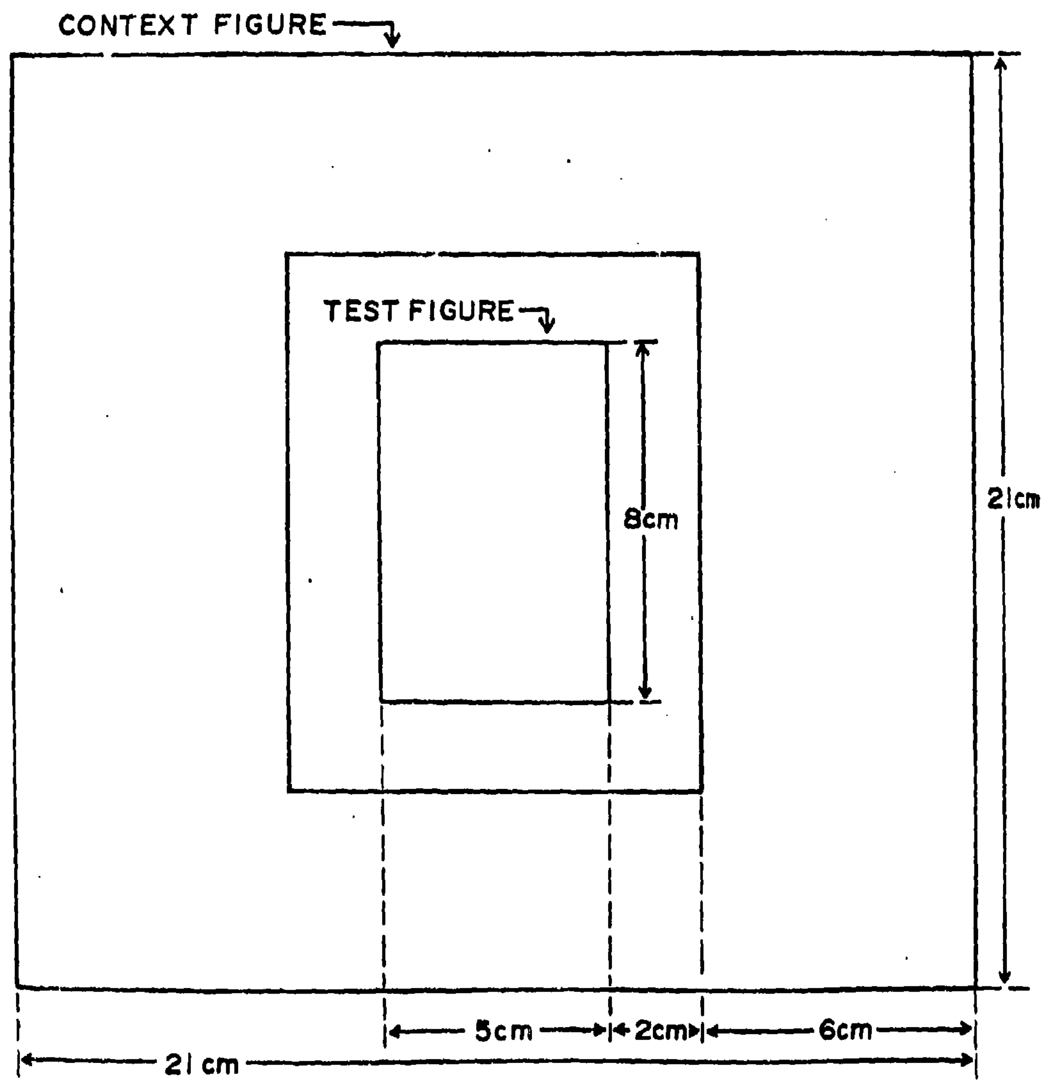

Figure 1. The configuration and dimensions of the context and test forms.

TABLE 1

DIMENSIONS OF CONTEXT AND TEST FORM
FOR THREE VIEWING DISTANCES

	VIEWING DISTANCE		
	70 cm	140 cm	210 cm
Test Form	4°5'34" X6°32'55"	2°2'47" X3°16'27"	1°21'51" X2°10'58"
Context Form—Outer Dimensions	17°11'24"^{2}	8°35'42"^{2}	5°43'48"^{2}
Context Form—Thickness	4°54'41"	2°27'20"	1°38'14"
Lateration Separation Between Context and Test Forms	1°38'14"	49'7"	32'45"

For each of the three viewing distances, the test form was presented at three values of disparity under each of the four context conditions. In the no-context condition, both the context and test forms were presented at the same depth position. In the context-front and context-back conditions, respectively, the context form was presented at a depth position slightly in front of and slightly behind that of the test form. See Table 2 for the precise values of disparity employed for each of three viewing distances. Under all conditions all disparities were crossed, and the stereoscopic stimuli appeared in depth in front of the background elements.

Procedure

The data for each observer were collected in one experimental session. On each trial, the observer indicated the perceived depth position of the test form by aligning a probe stimulus so that it was located in the same depth position. Three trials were run under each of the 36 experimental conditions, with the order of presentation of the conditions determined randomly for each observer.

RESULTS

The data for the five observers were analyzed by a 3 X 3 X 4 (viewing distance x disparity value x context condition) three-way analysis of variance for repeated measures. The analysis revealed that the effects on perceived depth of both viewing distance ($F(2,8) = 583.4$, $p<.001$) and disparity value ($F(2,8) = 764.9$, $p<.001$) are significant, but that the effect of context is not ($F<1.0$). Further, the analysis also revealed that the interaction between viewing distance and disparity value is significant, ($F(4, 16) = 93.2$, $p<.001$); all other interactions are insignificant (see Table 3).

Multiple comparisons were calculated for viewing distance and disparity

TABLE 2

DISPARITY VALUES EMPLOYED FOR THREE VIEWING DISTANCES

	VIEWING DISTANCE								
	70 cm			140 cm			120 cm		
	DISPARITY VALUES								
	Small	Medium	Large	Small	Medium	Large	Small	Medium	Large
Test Form	29'28"	58'56"	1°28'24"	14'44"	29'28"	44'12"	9'49"	19'38"	29'28"
Context Form - Equal Depth	29'28"	58'56"	1°28'24"	14'44"	29'28"	44'12"	9'49"	19'38"	29'28"
Context Form - Front Depth	44'12"	1°13'40"	1°43'8"	22'6"	36'50"	51'34"	14'44"	24'33"	34'23"
Context Form - Back Depth	14'44"	44'12"	1°13'40"	7'22"	22'6"	36'50"	4'55"	14'44"	24'33"

TABLE 3

THREE-WAY ANALYSIS OF VARIANCE SUMMARY TABLE

Source	Sum of Squares	df	Mean Square	F-Ratio
Between Error	495.7	4	123.9	
Viewing Distance	16646.5	2	8323.2	583.4*
Within Error 1	114.1	8	14.3	
Context Condition	2.3	3	0.8	
Within Error 2	12.9	12	1.1	
Distance X Context	2.8	6	0.5	
Within Error 3	23.1	24	1.0	
Disparity Value	10110.1	2	5055.0	764.9*
Within Error 4	52.9	8	6.6	
Distance X Disparity	1376.3	4	344.1	93.2*
Within Error 5	59.1	16	3.7	
Context X Disparity	2.5	6	0.42	
Within Error 6	13.0	24	0.54	
Distance X Context X Disparity	5.0	12	0.42	
Within Error 7	23.2	48	0.48	
TOTAL	28939.4	179	161.673	

*$p < .001$

value using Duncan's multiple range test. With respect to viewing distance, Duncan's test found the following differences to be significant: the 70 cm distance vs the 140 cm and 210 cm distances, and the 140 cm distance vs the 210 cm distance (all $p<.01$). With respect to disparity value, Duncan's test found the following differences to be significant: the low disparity value vs. the medium disparity and high disparity values, and the medium disparity value vs. the high disparity value (all $p<.01$).

To better illustrate the relationships among perceived depth, viewing distance, and disparity, the data were collapsed across the variable context condition (which was statistically insignificant) and are shown in Figure 2. Also shown in Figure 2 are predictions for perceived depth based on the assumption of complete depth constancy (indicated by broken lines; see Discussion).

DISCUSSION

For discussion of the results it would be helpful to proceed by considering, in turn, the effect of each of the three major variables, disparity, viewing distance, and context on perceived depth. Consider first disparity. As can be clearly seen in Figure 2, increases in disparity for any given viewing distance produced an orderly monotonic increase in perceived depth. Further, as the analyses revealed, these increases are statistically reliable. Such a relationship, of course, is not surprising since it is one of the first aspects of stereopsis to receive systematic scrutiny and it is readily incorporated within the geometry of stereoscopic space (Julesz, 1971; Ogle, 1962). Disparity in the present study serves more as a baseline control variable rather than as a subject of major experimental interest. Nevertheless, the presence of the expected disparity-perceived depth relationship does serve to validate the integrity of the experimental methods.

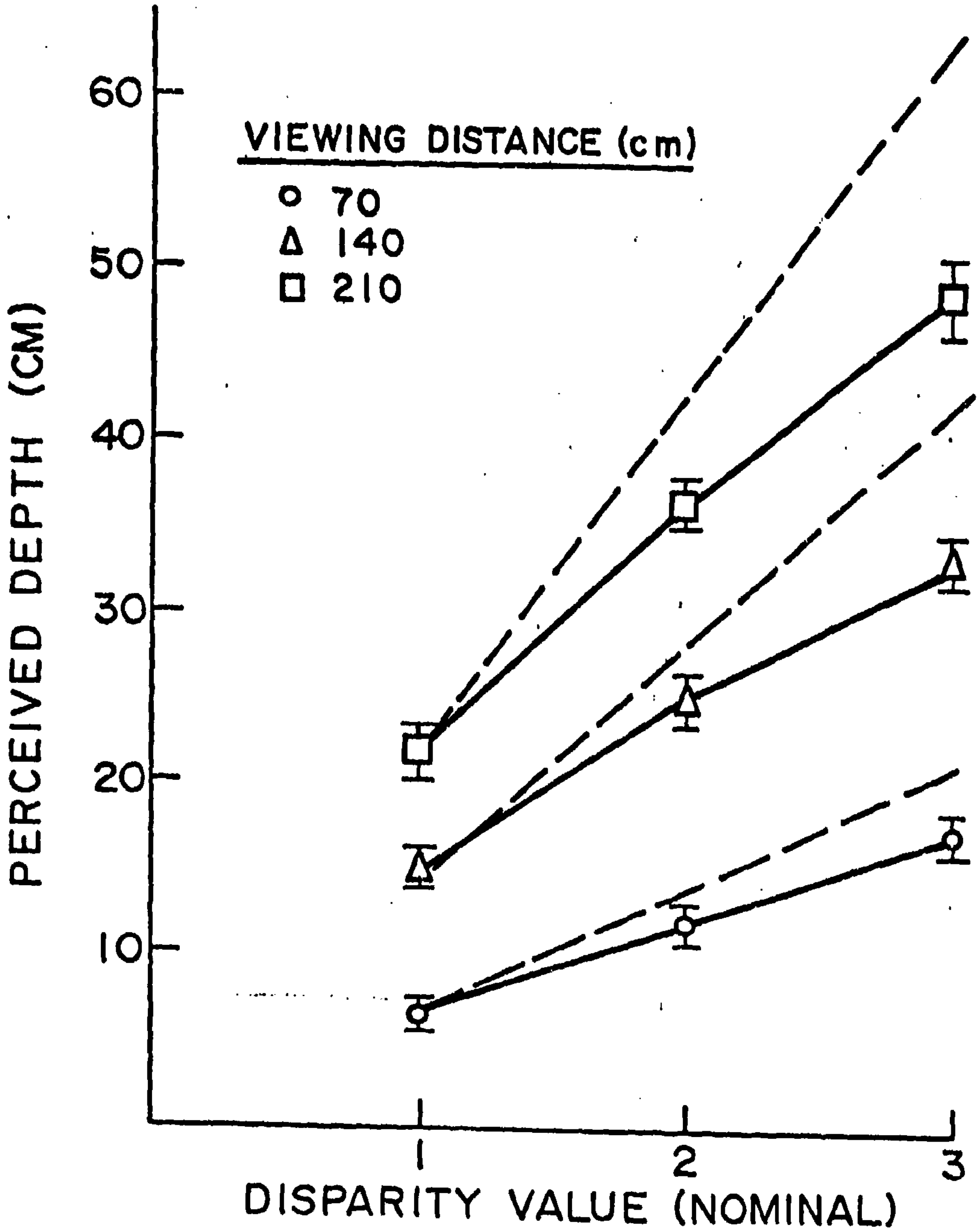

Figure 2. Mean perceived depth judgments for three levels of disparity and three viewing distances. Error brackets equal ± one standard error. Broken lines indicate predicted values on the assumption of complete depth constancy.

But disparity alone does not serve to determine perceived depth. Rather, it operates jointly with the second variable examined in this experiment, viewing distance. The role of perceived distance in determining perceived depth is not widely known, perhaps because of the great emphasis that has been placed upon disparity and the conditions that give rise to it. Yet the crucial role played by perceived distance follows directly from the geometry of stereopsis. Consider below the following formula for the computation of disparity, which although an approximation, works well when the depth interval and the disparity are relatively small compared to the viewing distance (Graham, 1965):

(1) $$e = \frac{p\ d}{D^2} \quad \text{(rads)}$$

where p = interpupillary distance,
d = depth interval
D = viewing distance
e = disparity

Equation 1 shows that, for a constant depth interval, disparity is inversely proportional to the square of the viewing distance. By rearranging terms, the solution for the depth interval may be obtained as given below:

(2) $$d = \frac{D^2 e}{p} \quad \text{(rads)}$$

It can be seen that when disparity is held constant, the depth interval is directly proportional to the square of the viewing distance. The change in perceived depth with variation in viewing distance (Equation 2) means that, for veridical perception of stereoscopic depth to occur, the visual system must somehow process information about viewing distance.

The predicted relationship between perceived depth and viewing distance specified by Equation 2 has been tested and confirmed by Cormack (1982), who used a novel afterimage method to hold disparity constant. It was found that up to the largest distance tested, perceived depth co-varied with viewing distance in accord with the relationship. This result demonstrates that a depth constancy mechanism is operative that calibrates disparity information for different viewing distances. Constancy enables a given physical depth interval to appear the same despite changes in disparity produced by variations in viewing distance. This stabilization of depth is analogous to the stabilization of size that occurs in size constancy. Indeed, in the case of stereoscopic afterimages discussed above, there is a close analogy with Emmert's law (a phenomenon of size constancy in which the apparent size of an afterimage changes as a function of apparent distance). In Emmert's law, size is approximately proportional to distance when retinal image size is constant. Similarly, perceived depth co-varies with distance when disparity is held constant by the afterimage technique.

The operation of depth constancy can also be demonstrated with stereograms. In stereograms, disparity decreases as a linear function of increases in viewing distance because it is represented as a spatial separation in the frontal parallel plane, whereas in physical depth situations, disparity decreases as the square of the distance because it is an angular measure brought about by differences in the Z-axis extent seen by each eye. Since the constancy mechanism is set for compensation of disparity in the physical world where the distance squared rule applies, overcompensation occurs when stereograms are viewed, resulting in the perceived depth interval growing linearly with increases in distance. This expectation was tested and confirmed by Wallach and Zuckerman (1963). Additional confirmatory evidence is also discussed in Ono and Comerford (1977).

The manipulation of viewing distance in the present experiment also serves as an additional test of the depth constancy relationship anticipated from stereograms. In Figure 2 the empirical relationship between viewing distance and perceived depth is given. It can be seen that perceived depth increases with viewing distance and the statistical analysis indicates that these increases are significant. The broken lines in Figure 2 are the expected values for perceived depth based on the assumption of complete or perfect depth constancy. Note that for the first disparity value, value 1, there is very close agreement between the obtained and predicted values of perceived depth. Some departure occurs, however, for disparity values 2 and 3, in the direction of underconstancy. Such departures have been observed before (see Ono & Comerford, 1977) and are probably attributable to a variety of secondary factors. Nevertheless, to a first approximation, the obtained values of perceived depth are in good agreement with those anticipated from depth constancy and, accordingly, from the geometry of stereopsis.

Although the variables of disparity and distance were both effective, the third variable, context, was not. As the statistical analysis makes clear, the context form exerted no influence on the test form under any experimental conditions. It is noteworthy that the large size of the context form and its enveloping configuration were selected to maximize its influence. Stimulus variables of this kind have been effective in those studies in which evidence for a context effect has been found. Yet, as noted in the Introduction, in such studies the bulk of the cues for depth that would be present under ordinary conditions are eliminated. In the present experiment however, the opposite situation prevailed. All cues were present and they could combine to yield stable and correct registration of the distance between the observer and display. This distance information apparently outweighed any influence of the context form. The present results support the conclusion that veridical estimates of depth can be obtained from a 3-D display where forms at different depths are present simultaneously, when the display is viewed under the full cue conditions that prevail during ordinary viewing.

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NAVMAT 0722, Rm. 508
800 North Quincy Street
Arligton, VA 22217

Commander
Naval Air Systems Command
Human Factors Programs
NAVAIR 340F
Washington, D.C. 20361

Commander
Naval Air Systems Command
Crew Station Design
NAVAIR 5313
Washington, D.C. 20361

Mr. Philip Andrews
Naval Sea Systems Command
NAVSEA 0341
Washington, D.C. 20362

Department of the Navy

Commander
Naval Electronics Systems Command
Human Factors Engineering Branch
Code 81323
Washington, D.C. 20360

CDR Robert Biersner
Naval Medical R&D Command
Code 44
Naval Medical Center
Bethesda, MD 20014

Dr. George Moeller
Human Factors Engineering Branch
Submarine Medical Research Lab
Naval Submarine Base
Groton, CT 06340

Head
Aerospace Psychology Department
Code L5
Naval Aerospace Medical Research Lab
Pensacola, FL 32508

Dr. James McGrath
CINCLANT FLT HQS
Code 04E1
Norfolk, VA 23511

Dr. Robert Blanchard
Navy Personnel Research and
Development Center
Command and Support Systems
San Diego, CA 92152

Dr. Julie Hopson
Human Factors Engineering Division
Naval Air Development Center
Warminster, PA 18974

Mr. Jeffrey Grossman
Human Factors Branch
Code 3152
Naval Weapons Center
China Lake, CA 93555

Human Factors Engineering Branch
Code 1226
Pacific Missile Test Center
Point Mugu, CA 93042

Department of the Navy

Mr. J. Williams
Department of Enviornmental
Sciences
U. S. Naval Academy
Annapolis, MD 21402

Dean of the Academic Departments
U. S. Naval Academy
Annapolis, MD 21402

Human Factors Section
Systems Engineering Test
Directorate
U. S. Naval Air Test Center
Patuxent River, MD 20670

CDR W. Moroney
Code 55MP
Naval Postgraduate School
Monterey, CA 93940

Department of the Army

Mr. J. Barber
HQS, Department of the Army
DAPE-MBR
Washington, D.C. 20310

Technical Director
U. S. Army Research Institute
5001 Eisenhower Avenue
Alexandria, VA 22333

Director, Organizations and
Systems Research Laboratory
U. S. Army Research Institute
5001 Eisenhower Avenue
Alexandria, VA 22333

Technical Director
U. S. Army Human Engineering Labs
Aberdeen Proving Ground, MD 21005

ARI Field Unit-USAREUR
ATTN: Library
C/O ODCSPER
HQ USAREUR & 7th Army
APO New York 09403

Department of the Air Force

U. S. Air Force Office of Scientific
Research
Life Sciences Directorate, NL
Bolling Air Force Base
Washington, D.C. 20332

Chief, Systems Engineering Branch
Human Engineering Division
USAF AMRL/HES
Wright-Patterson AFB, OH 45433

Dr. Earl Alluisi
Chief Scientist
AFHRL/CCN
Brooks AFB, TX 78235

Foreign Addresses

Director, Human Factors Wing
Defense & Civil Institute of
Environmental Medicine
P.O. Box 2000
Downsview, Ontario M3M 3B9
CANADA

Dr. A. D. Baddeley
Director, Applied Psychology Unit
Medical Research Council
15 Chaucer Road
Cambridge, CB2 2EF
ENGLAND

Other Government Agencies

Defense Technical Information Center
Cameron Station, Bldg. 5
Alexandria, VA 22314 (12 cys)

Dr. Craig Fields
Director, System Sciences Office
Defense Advanced Research Projects
Agency
1400 Wilson Blvd.
Arlington, VA 22209

Dr. Lloyd Hitchcock
Federal Aviation Administration
ACT 200
Atlantic City Airport, NJ 08405

Other Government Agencies

Dr. M. Montemerlo
Human Factors & Simulation
Technology, RTE-6
NASA HQS
Washington, D.C. 20546

Other Organizations

Dr. Jesse Orlansky
Institute for Defense Analyses
400 Army-Navy Drive
Arlington, VA 22202

Dr. T. B. Sheridan
Department of Mechanical Engineering
Massachusetts Institute of Technology
Cambridge, MA 02139

Dr. Harry Snyder
Department of Industrial Engineering
Virginia Polytechnic Institute and
State University
Blacksburg, VA 24061

Dr. Robert T. Hennessy
NAS - National Research Council
(COHF)
2101 Constitution Ave., N.W.
Washington, D.C. 20418

Dr. Robert Williges
Human Factors Laboratory
Virginia Polytechnic Institute
and State University
130 Whittemore Hall
Blacksburg, VA 24061

Dr. Christopher Wickens
University of Illinois
Department of Psychology
Urbana, Il 61801

Dr. Edward R. Jones
Chief, Human Factors Engineering
McDonnell-Douglas Astronautics
Company
St. Louis Division
Box 516
St. Louis, MO 63166

Dr. Richard W. Pew
Information Sciences Division
Bolt Beranek & Newman, Inc.
50 Moulton Street
Cambridge, MA 02238

Other Organizations

Dr. David J. Getty
Bolt Beranek & Newman, Inc.
50 Moulton Street
Cambridge, MA 02238

Dr. Douglas Towne
University of Southern California
Behavioral Technology Laboratory
3716 S. Hope Street
Los Angeles, CA 90007

Dr. Stanley N. Roscoe
New Mexico State University
Box 5095
Las Cruces, NM 88003

Dr. William R. Uttal
Institute for Social Research
University of Michigan
Ann Arbor, MI 48109