AD-A259 597

(2)

WSU/FINAL REPORT/661805

AFOSR-TR- 92 19

# Perception/Action: An Holistic Approach


Prepared by

John M. Flach

Psychology Department
Wright State University
Dayton, OH 45435






October 1992


Contract AFOSR-91-0151


Prepared for

## AFOSR

Air Force Office of Scientific Research
Directorate of Life and Environmental Sciences
Bolling Air Force Base, DC 20332-6448

93-01511

46pt

1 DEC 1992

| REPORT DOCUMENTATION PAGE | 1. REPORT NO. AFOSR-91-1051 | 2. | 3. Recipient's Accession No. |
|---|---|---|---|

**4. Title and Subtitle**
Perception/Action: An Holistic Approach

**5. Report Date** October 1992

**6.**

**7. Author(s)**
John M. Flach

**8. Performing Organization Rept. No.** WSU-FR-661805

**9. Performing Organization Name and Address**
Psychology Dept.
Wright State University
Dayton, Ohio 45435

**10. Project/Task/Work Unit No.** 2313/CS

**11. Contract(C) or Grant(G) No.**
(C) AFOSR-91-0151
(G)

**12. Sponsoring Organization Name and Address**
Air Force Office of Scientific Research
Directorate of Life and Environmental Sciences
Bolling Air Force Base, DC 20332-6448

**13. Type of Report & Period Covered** FINAL 12/15/90 - 8/29/92

**14.**

**15. Supplementary Notes**
John M. Flach (513) 873-2391
AFOSR Technical Monitor Dr. John Tangney (202) 767-5021

**16. Abstract (Limit: 200 words)**

A general systems approach is taken to studying the emergent properties of the human perception/action system. Two task domains, the control of locomotion and the recognition of objects, are used to study human performance. The locomotion task involves the control of altitude. Experiments are described that will manipulate the type of texture, the speed of forward motion, and altitude. A general hypothesis is presented that performance in the altitude control task is a function of the signal-to-noise ratio within the flow field — where signal refers to optical activity resulting from change of altitude and noise refers to optical activity resulting from other sources. An analysis of the flow geometry is presented to illustrate how the motion of the observer and the position of texture elements combine to determine the optical information available to the observer. The object recognition task involves the discrimination of 3-dimensional wire-frame forms using the information available in dynamic occlusion. A key manipulation within this task was the mode of observation. Observers were either active (they could manipulate the object using a joystick to produce dynamic occlusion) or they were passive (they could observe the motions produced by the active observer, but they could not act on the display to produce dynamic occlusions). Three experiments are presented. The most important result was that no differences were found as a function of mode. In all three experiments passive observers performed at least as well as active observers. Experiment 5 showed that performance was significantly better when stereotypic motions were generated by the computer, than when an active observer controlled the motion of the object. A brief review of factors that may effect when active subjects have an advantage over passive subjects is presented.

**17. Document Analysis a. Descriptors**
perception of self-motion
altitude control
object recognition
dynamic occlusion
passive vs active observers

**b. Identifiers/Open-Ended Terms**

Approved for public release;
distribution unlimited.

**c. COSATI Field/Group**

| 18. Availability Statement | 19. Security Class (This Report) | 21. No. of Pages |
|---|---|---|
| unlimited<br>John M. Flach<br>Psychology Dept.<br>Wright State University, Dayton, OH 45435 | Unclassified | 45 |
| | 20. Security Class (This Page) Unclassified | 22. Price |

(See ANSI-Z39.18) See Instructions on Reverse OPTIONAL FORM 272 (4-77)

1 DEC 1992

# Perception/Action: An Holistic Approach

## Contents

# Perception/Action: An Holistic Approach

John M. Flach
Wright State University

## Abstract

A general systems approach is used to study the emergent properties of the human perception/action system. Two task domains, the control of locomotion and the recognition of objects, are used to study human performance. The locomotion task involves the control of altitude. Experiments are described that will manipulate the type of texture, the speed of forward motion, and altitude. A general hypothesis is presented that performance in the altitude control task is a function of the signal-to-noise ratio within the flow field — where signal refers to optical activity resulting from change of altitude and noise refers to optical activity resulting from other sources. An analysis of the flow geometry is presented to illustrate how the motion of the observer and the position of texture elements combine to determine the optical information available to the observer. The object recognition task involves the discrimination of 3-dimensional wire-frame forms using the information available in dynamic occlusion. A key manipulation within this task was the mode of observation. Observers were either active (they could manipulate the object using a joystick to produce dynamic occlusion) or they were passive (they could observe the motions produced by the active observer, but they could not act on the display to produce dynamic occlusions). Three experiments are presented. The most important result was that no differences were found as a function of mode. In all three experiments passive observers performed at least as well as active observers. Experiment 5 showed that performance was significantly better when stereotypic motions were generated by the computer, than when an active observer controlled the motion of the object. A brief review of factors that may effect when active subjects have an advantage over passive subjects is presented.

## List of Figures

# General Overview

A fundamental role of the human component in complex systems (e.g., vehicular control, air traffic control, or process control) is to "close-the-loop." That is, the humans are included in the system because of their unique and adaptive abilities of perception, decision making, and motor control. Although there have been great advances in automated control systems, the adaptability and generality of the human have yet to be matched by automated sensing and control systems. This generality and adaptability of the human controllers that makes them attractive (if not essential in many cases) as components within complex systems poses a great challenge to basic researchers interested in modeling human performance, as well as for system designers who need to be able to integrate across human and electro-mechanical components to predict and evaluate system performance. The general goal of this research program is to develop a framework for studying humans as an adaptive, closed-loop controllers.

Traditionally, psychology has parsed the problem of human performance into problems of perception, cognition, and motor control. Research programs have evolved that focus on one or the other of these components in isolation from the others. For example, those who focus on perception often tightly constrain action (e.g., fixating the head with bite boards, using brief, tachistoscopic stimulus presentations, or using restricted response protocols such as key presses). Those who study motor control go to great lengths (e.g., deafferentation) to isolate motor control from perception. And those who study cognition select problems (e.g., tower of Hanoi, missionaries and cannibals, logic theorems) with minimal perceptual and motor demands.

Such strategies for studying perception and action have been successful in reducing complexity and allowing scientists to make inferences about the elementary cognitive processes that combine to control performance. However, these approaches miss the emergent properties that arise from the coupling of perception and action. Without an understanding of these emergent properties it may <u>not</u> be possible to integrate what we have learned about perception systems and action systems in isolation into a comprehensive and general theory of human performance (a theory capable of guiding decisions about interface design and training for complex systems such as high performance aircraft). Thus, it is important not to ignore these emergent properties of the closed-loop, perception-action system. An *active psychophysics* (Flach, 1990; Warren, 1988; Warren & McMillan, 1984) is needed to compliment the traditional work on passive psychophysics, perception, and motor performance.

A fundamental theme of our research program is that perception must be studied in the context of action. The importance of the coupling of perception and action for development of visually guided behaviors in cats was demonstrated in the classic study of Held and Hein (1963; See also Held, 1965).

In attacking the general problem of active psychophysics, our research has examined two classes of problems: the discrimination of objects using information available in dynamic occlusion and the control of locomotion. The first section of this report will discuss the problem of control of locomotion and the second section will discuss the problem of dynamic occlusion.

## The Control of Locomotion

Locomotion is a classic problem that illustrates the importance of studying perception-action as a closed-loop system. Visual flow fields are widely regarded as a critical source of information for the control of self-motion (Gibson, 1958; Gibson, Olum, and Rosenblatt, 1955; Warren & Wertheim, 1990). The visual flow field is the relative motion of stationary texture (e.g., resulting from objects in the field of view) projected to a moving observation point. This radial streaming of texture is produced in the action of locomoting and in turn feeds back as information specific to the observation point's movements relative to environmental surfaces. Despite the obvious closed-loop nature of this behavior, much of the research on the perception of self-motion has used passive tasks in which observers make judgments about visual flow fields controlled by the experimenter (e.g., Andersen & Braunstein, 1985; Cutting, 1986; Cutting, Springer, Braren, & Johnson, 1992; Larish & Flach, 1990; Owen & R.Warren, 1987; R.Warren, 1976; W.Warren & Hannon, 1988; W.Warren, Mestre, Blackwell & Morris, 1991; W.Warren, Morris & Kalish, 1988). It is not our position, that such approaches are not without merit. However, we believe that it is important to validate the results and conclusions from these studies in the context of active control.

Our current plans are to focus on three dimensions for the control of locomotion: the control of altitude, the control of speed, and the control of heading. Our principle strategy will be to manipulate the information available for control. This will be done through changing surface textures, changing the nature of the event (e.g., speed or altitude), by changing the goals (e.g., maintain constant altitude, speed, or flow rate), or by changing the action coupling with the display (e.g., vehicle slaved display or head and vehicle slaved display). Over the past year we have focused on the problems of control of altitude. In particular, we have been interested in how the information for altitude may be confounded with information for speed.

Altitude and speed are very tightly coupled both in terms of the information in optical flow fields and in terms of the consequences for the actor (e.g., time-to-contact a surface). With respect to the information linkage, Gibson, Olum, and Rosenblatt (1955), note in their mathematical analysis of optic flow that :

> Ground speed and altitude are not . . . independently determined by optical information. A more rapid flow pattern may indicate

> either an increase in speed or a decrease in altitude. Length of time before touching down, however, is given by the optical information in a univocal manner (p. 382).

This description anticipates a more complete analysis by Lee (1976, 1980). Lee's analysis shows that the time-to-contact (tau) with a surface is specified as the inverse of the rate of optical expansion. Lee (1976) discusses the implications of this information for the control of automobiles.

Recently, Flach, Hagen, & Larish (1992) have suggested that conflicting results with regard to the perception of altitude, might be due to variations in the simulated speed of motion across the various studies. Researchers studying the perception of altitude in the context of fixed wing aircraft (Wolpert, 1988; Wolpert, Owen, & R.Warren, 1983) have found that perception and control of altitude is best when subjects are presented displays designed to isolate splay (operationalized as texture parallel to the direction of motion) information as shown in Figure 1(a). On the other hand, researchers studying the perception and control of altitude in the context of rotary wing aircraft (Johnson, Bennett, O'Donnell, & Phatak, 1988; Johnson, Tsang, Bennett, & Phatak, 1989) have found that control is best when subjects are presented with displays designed to isolate optical density (operationalized as texture perpendicular to the direction of motion) as shown in Figure 1(b). In all cases, performance was nominally best (but generally not significantly better) with the information in isolation (either splay or optical density), than for displays that combined the parallel and perpendicular textures as in Figure 1(c). A key difference between the studies for fixed and rotary wing aircraft was the speed of forward motion simulated. The fixed wing simulations used relatively high optical speeds (all greater than 1 eyeheight/sec), whereas the rotary wing simulations used relatively low optical speeds (all less than .25 eyeheights/sec).

Flach, Hagen, and Larish (1992) have suggested that perhaps the key variable is not the kind of texture (splay/parallel or optical density/perpendicular), but rather the amount of optical activity associated with changes in altitude (signal) relative to the amount of activity (noise) associated with other variables (e.g., speed of forward motion). The different ordering of textures in terms of performance found by different laboratories may result from an interaction of texture type with global optical flow rate. At high rates of global optical flow (e.g., as might be experienced in fixed wing aircraft at low altitudes) splay may best isolate the optical effects due to changes in altitude, whereas at low rates of global optical flow (e.g., as might be experienced in rotary wing aircraft at hover) optical density or depression angle may best isolate the optical effects of altitude. This suggests that neither kind of texture is privileged with regard to altitude control. The relative amount of optical activity specific to change of altitude, depends both on the type of texture and on the nature of the event (e.g., forward flight or hover). Our first experiment will assess this hypothesis.

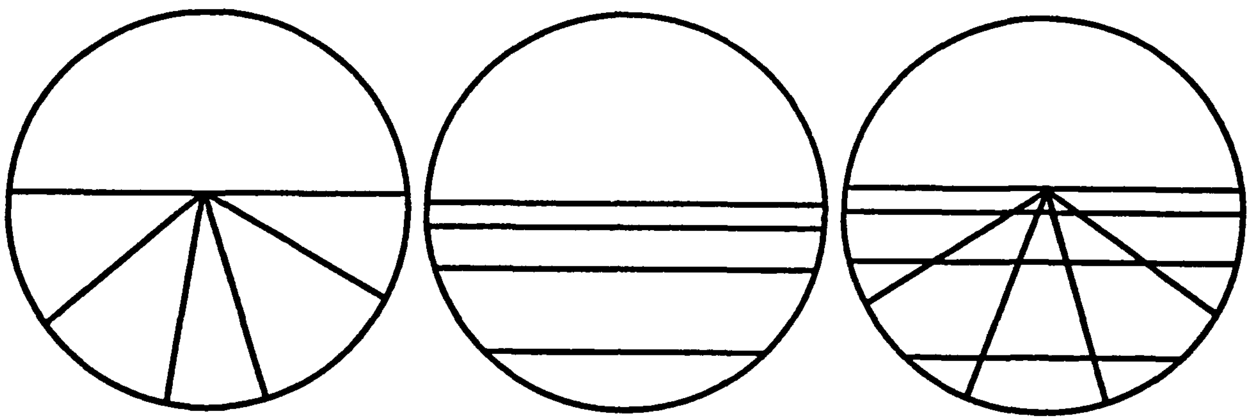



**Figure 1.** Three types of textures that have been used to isolate component sources of information for the control of altitude: (a) splay only (horizontal to the direction of motion); (b) optical density or depression angle only (perpendicular to the direction of motion); and (c) square texture.

**EXPERIMENT 1**

The control of altitude will be examined as a function of texture, speed, and altitude. Texture and speed will be manipulated within subjects. Four textures will be used --- the three textures shown in Figure 1 and a random dot texture. Four speeds will be used (0, .5, 1, & 2 eyeheights/sec). Altitude will be manipulated between subjects. Three altitudes will be used (25 ft., 100 ft., & 200 ft.). Disturbances will be presented on three axes (variable headwind, side-to-side, and altitude). Subjects will only have control, however, over altitude. Dependent measures will include RMSE, root mean square control & control rate, and control power correlated with the altitude disturbances. Our hypothesis is that there will be an interaction such that, for low speeds, control of altitude will be best with the perpendicular texture (optical density, Figure 1(b)), but at high speeds, control will be best with the parallel texture (splay, Figure 1(a)).

Over the past year a general purpose software program has been developed. This program allows specification of texture, vehicle dynamics, disturbances, and procedural details. This software will provide the environment for Experiment 1 and Experiment 2. It is also being used for numerous other experiments at the Armstrong Lab. This includes studies of heading judgments and of the phenomenology of self-motion.

**EXPERIMENT 2**

Experiment 1 was designed to test the general hypothesis that differences in performance in altitude control tasks reflect differences in the signal-to-noise ratio in the visual displays --- where signal refers to optical changes that result from changes in the controlled variable, altitude; and noise refers to optical changes that result from other motions of the observer (side-to-side and fore-aft). In Experiment 1 the signal-to-noise ratio will be manipulated by changing the forward speed of the observer. However, other variables affect the relative amount of optical activity associated with altitude (i.e., the signal-to-noise ratio). These other variables include the position of texture elements and the size of motions on axes other than the altitude axis. Figure 2 from Flach et al. (1992) illustrates the perspective geometry for splay and Equation 1 specifies how the rates of changes for splay angle (S) varies with altitude (Z) and the ground distance to particular texture elements ($Y_g$ & $X_g$). Figure 3, also from Flach et al. (1992) illustrates the perspective geometry for optical depression angle and Equation 2 specifies how optical depression angle ($\delta$) varies with altitude and the ground distance to particular texture elements. Figures 4-7 show change in optical splay and optical depression angle (plotted on the ordinate) as a function of the perpendicular distance to edges in a square texture (plotted on the

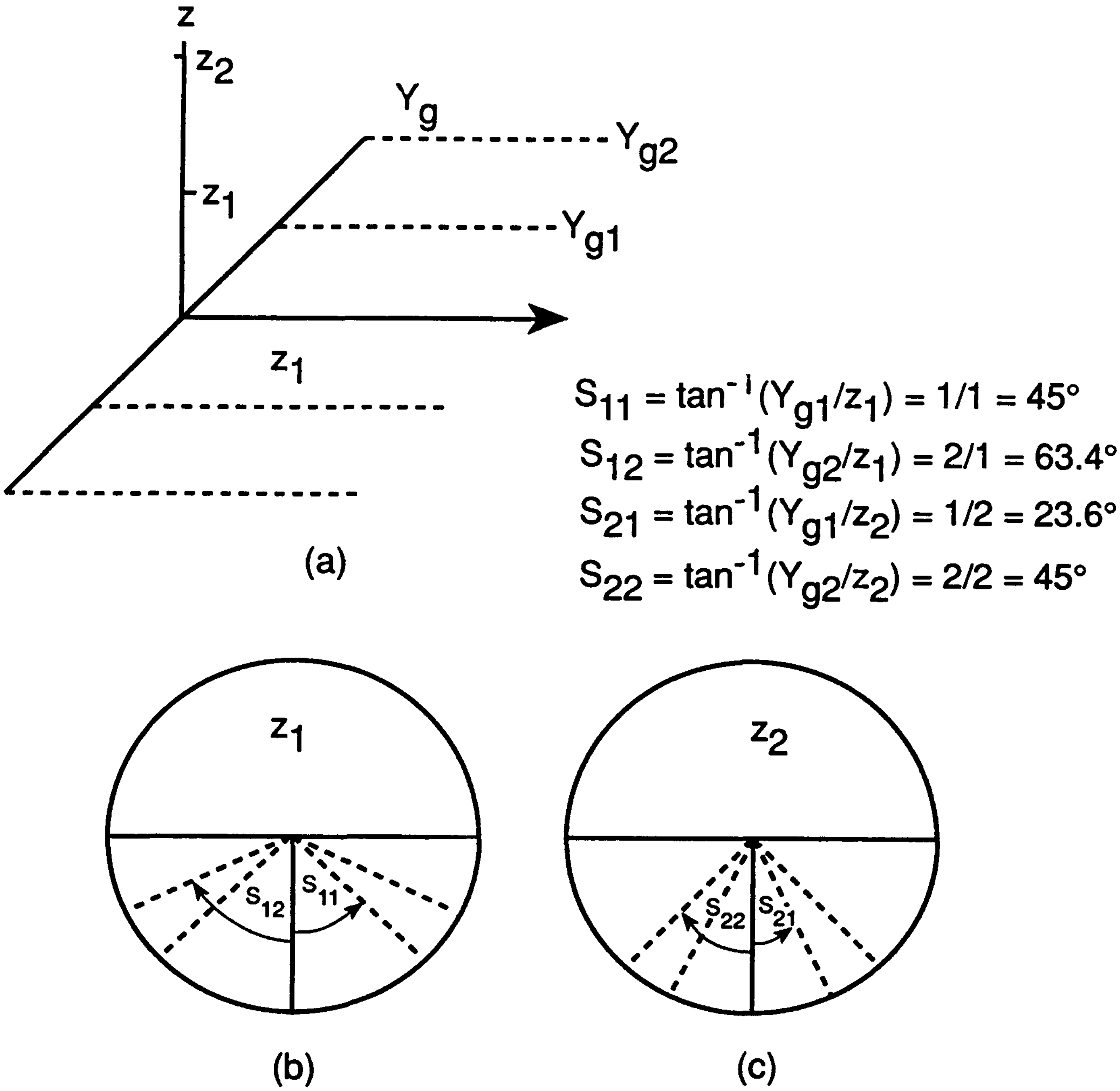



**Figure 2.** Illustration of the perspective geometry for splay: (a) an extrinsic view of the observer's location at $z_1$ or $z_2$; (b) perspective view from $z_1$; and (c) perspective view from $z_2$.

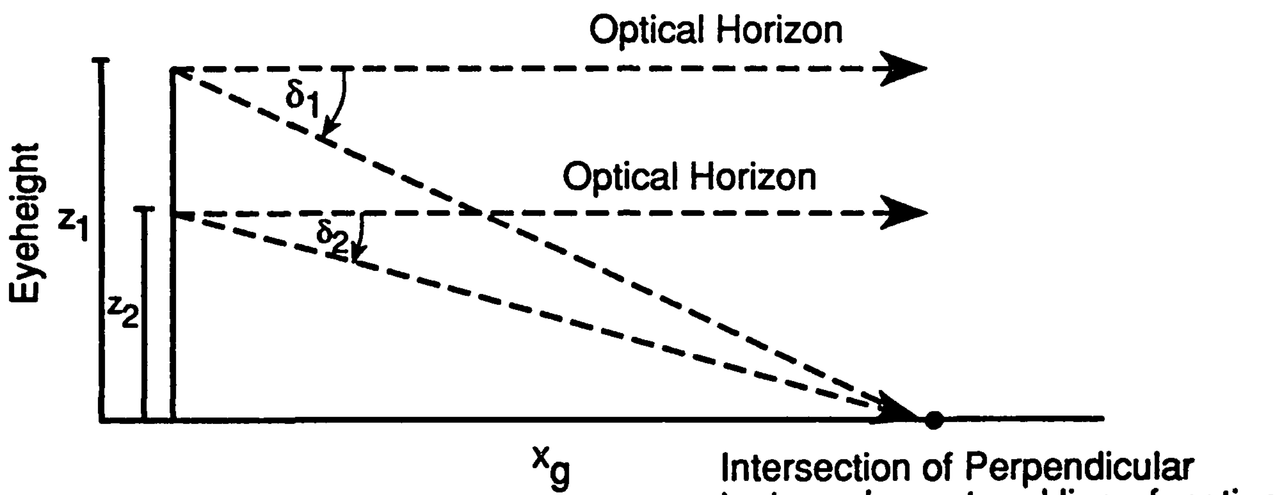



Figure 3. Illustration of how depression angle (delta) changes as a function of change in eyeheight (z).

abscissa), and the change in position (altitude Z, lateral distance $Y_g$, and forward distance $X_g$). Figure 4 illustrates the effects, at an altitude of 200 ft., of a rate of change of altitude of -100 ft./s. Note that altitude has symmetrical effects on the splay and depression angles. Figure 5 illustrates the effects, at an altitude of 200 ft., of a rate of change of forward position of 100 ft./s. Note that forward motion affects depression angle, but has no effect on splay angle. Figure 6 illustrates the effects, at an altitude of 200 ft., of a rate of change of lateral position of 100 ft./s. Note that changes of lateral position affect splay angle, but have no effect on depression angle. Finally, Figure 7 illustrates the effects, at an altitude of 200 ft., of the combination of a 100 ft./s rate of altitude loss, a 100 ft./s forward velocity, and a 100 ft./s lateral movement. It is important to note that every point representing splay angle will be in the normal frontal field of view (e.g. as illustrated in Figures 8 - 10). However, only those depression lines that are at least 2 eyeheights in front of the observer will be visible. The other depression lines will be too low in field of view to be seen or will be behind the observer.

$$\textbf{(1)}\quad \dot{S} = \left(\frac{-\dot{Z}}{Z}\right) COS\,S\ SIN\,S + \left(\frac{\dot{Y}_g}{Z}\right) COS^2 S$$

$$\textbf{(2)}\quad \dot{\delta} = \left(\frac{\dot{Z}}{Z}\right) COS\,\delta\ SIN\,\delta - \left(\frac{\dot{X}_g}{Z}\right) SIN^2\delta$$

Figures 8 & 9 illustrate the relations specified in Equations 1 and 2 in terms of the perspective view. Solid lines represent texture on the ground and the arrow represents the path of motion. The upper left quadrant of Figure 8(a) shows splay angle for texture elements that are one eyeheight to the right and left of the path of motion (45°). The upper right quadrant (8b) shows how the splay angle changes as eyeheight is reduced by one half (63°). The lower left quadrant (8c) shows the effect of moving laterally by .5 eyeheights, without a change in altitude (eyeheight). Finally, the lower left quadrant shows the combined effect of reducing altitude by .5 eyeheights and moving laterally .5 eyeheights. Figure 9 illustrates similar effects for optical depression angle. The upper left quadrant shows the depression angle for a texture element 4 eyeheights in front of the observer. The upper right quadrant shows the optical change when eyeheight is reduced in half. The lower left quadrant shows the optical change associated with moving forward .5 eyeheights. Finally, the lower right quadrant shows the combined effects of moving forward and down by .5 eyeheights. Figure 10 shows how the perspective view for the combination of splay and optical depression angle changes with changes of the point of observation..

Experiment 2 will vary the signal (altitude specific optical information) to noise (optical information independent of altitude) by manipulating texture position ($X_g$ and $Y_g$) and colateral motions ($dX_g$ and $dY_g$) in a hover task in which the observer is to maintain constant altitude. The hypothesis to be evaluated is that performance will vary as a function of signal to noise ratio independent of a specific texture type (splay or depression angle).

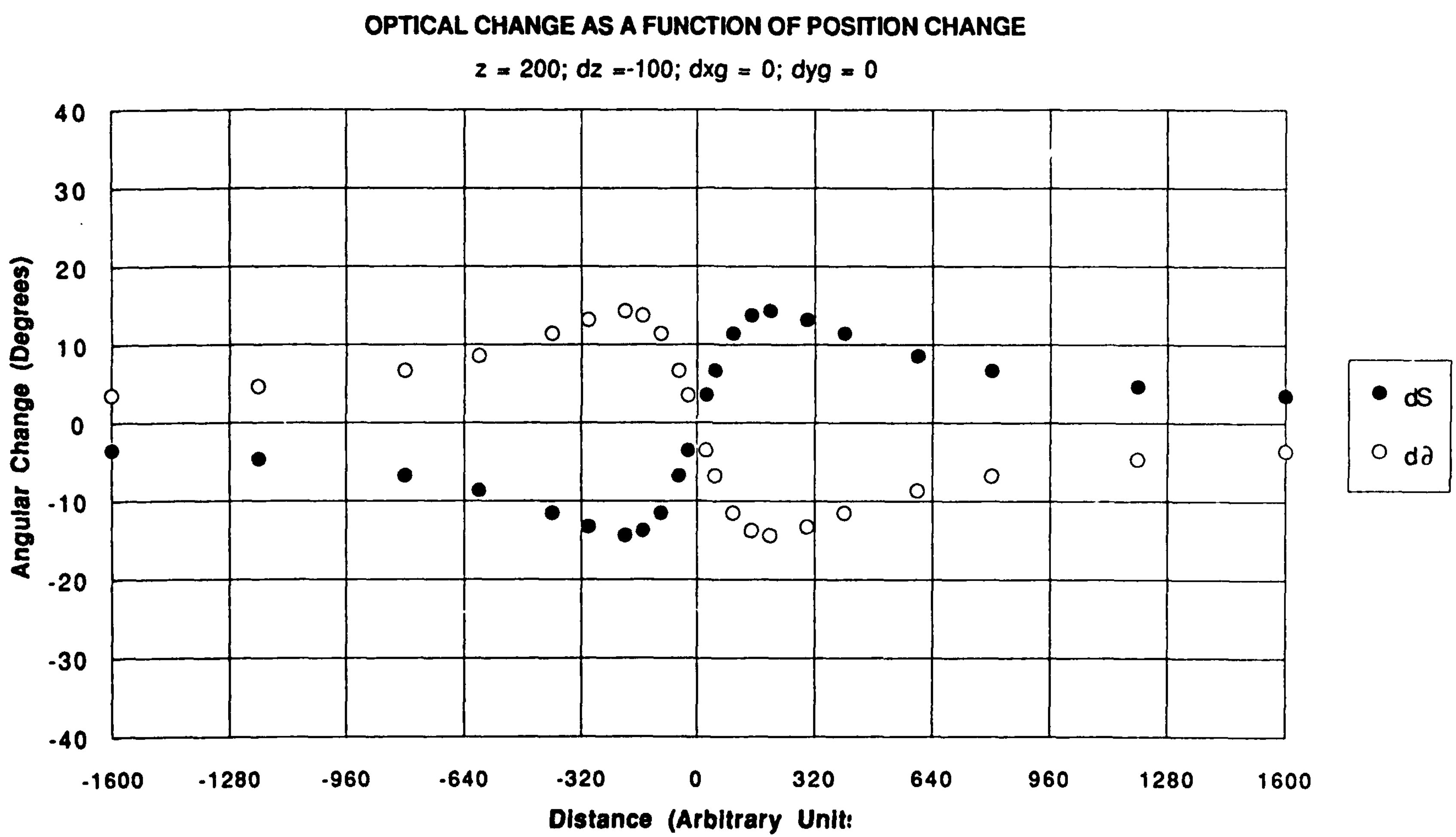



**Figure 4.** Change in optical splay and optical depression angles as a function of the perpendicular distance to edges in a square texture for an altitude of 200 ft. and a rate of change in altitude of 100 ft/s.

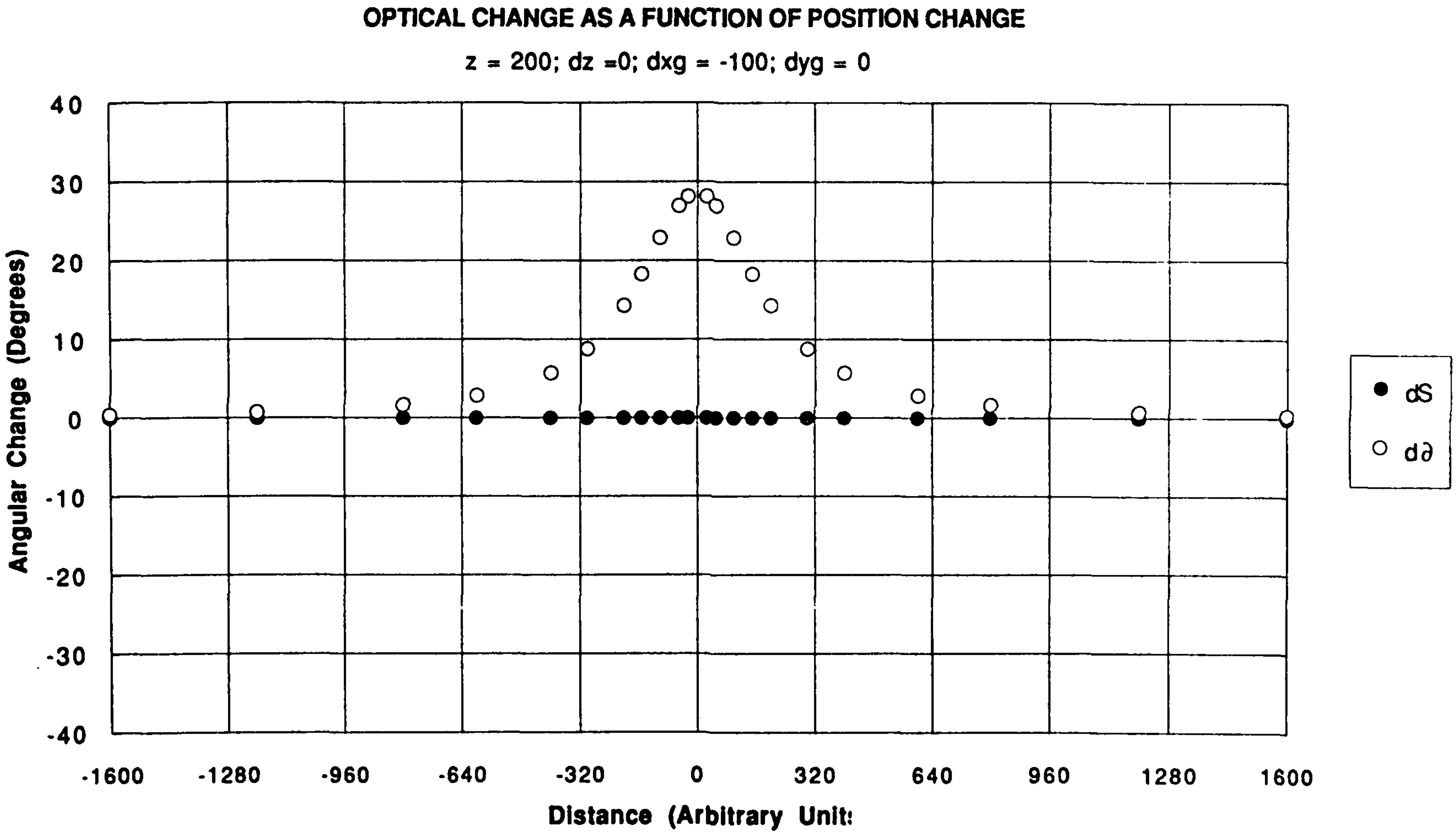



**Figure 5.** Change in optical splay and optical depression angles as a function of perpendicular distance to edges in a square texture for an altitude of 200 ft. and a rate of change in forward position of 100 ft/s.

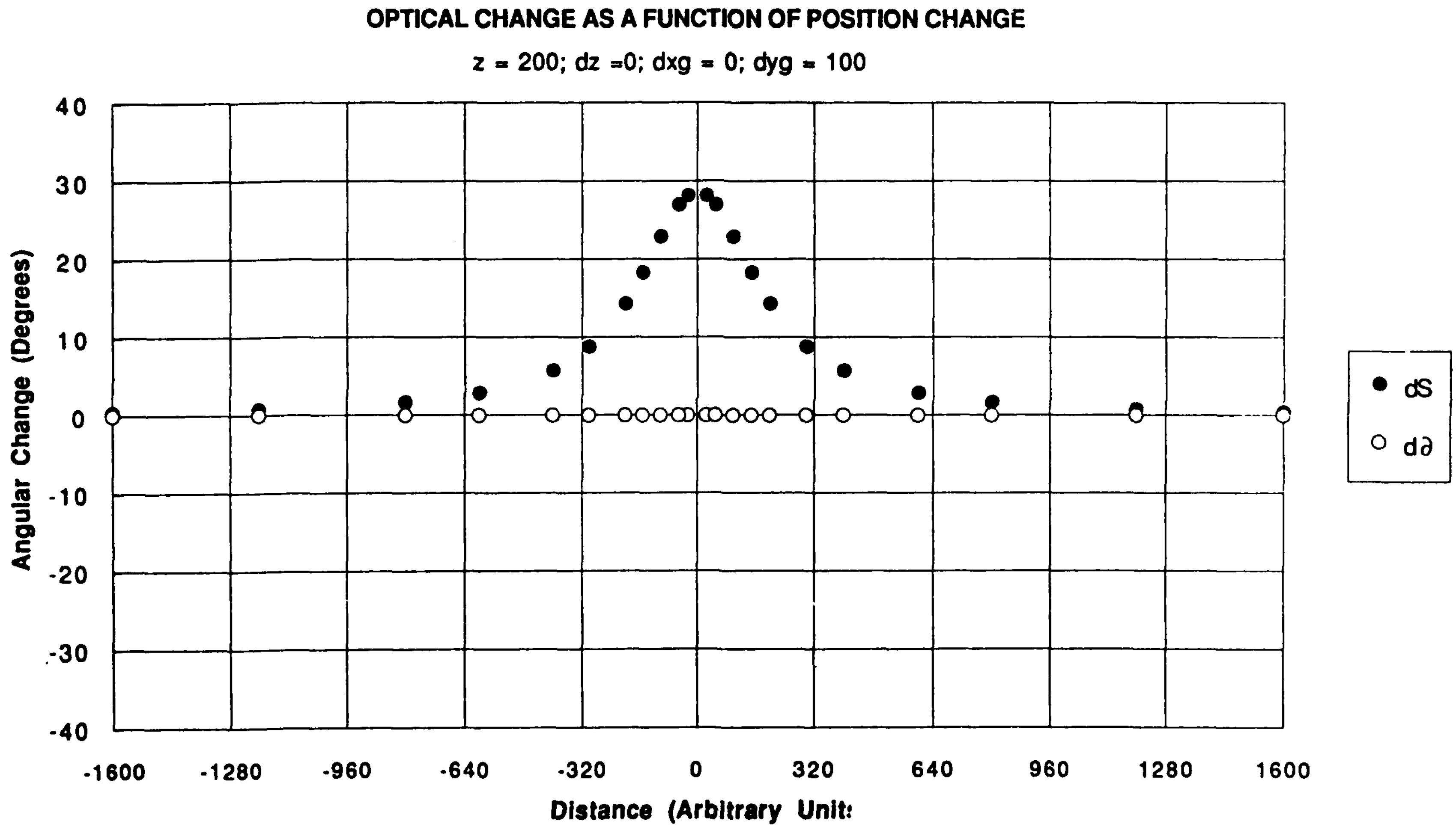



**Figure 6.** Change in optical splay and optical depression angles as a function of perpendicular distance to edges in a square texture for an altitude of 200 ft. and a rate of change in lateral position of 100 ft/s.

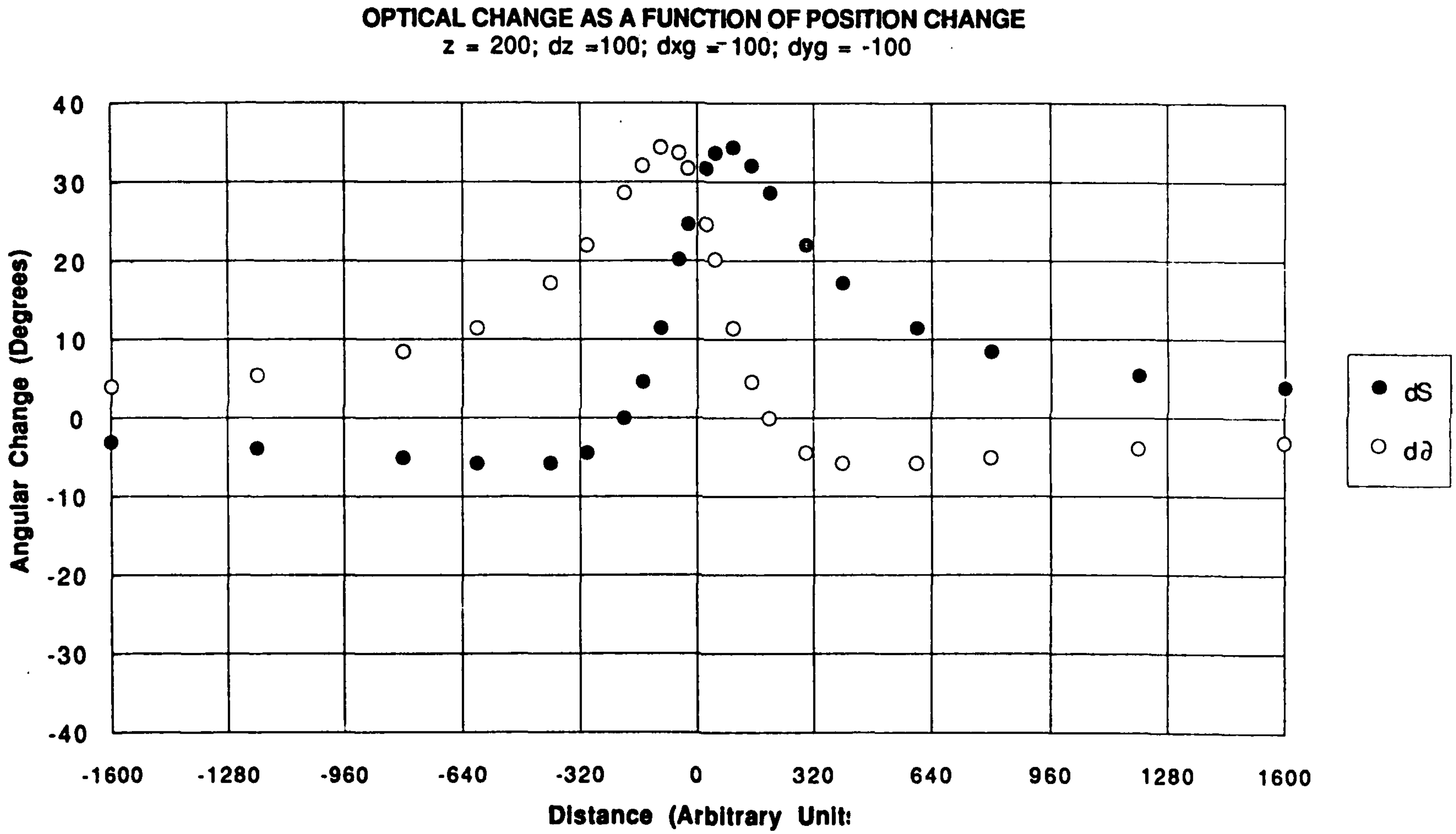



**Figure 7.** Change in optical splay and optical depression angles as a function of perpendicular distance to edges in a square texture for an altitude of 200 ft. and a rate of change in altitude, forward position, and lateral position of 100 ft/s.

(a) (b)

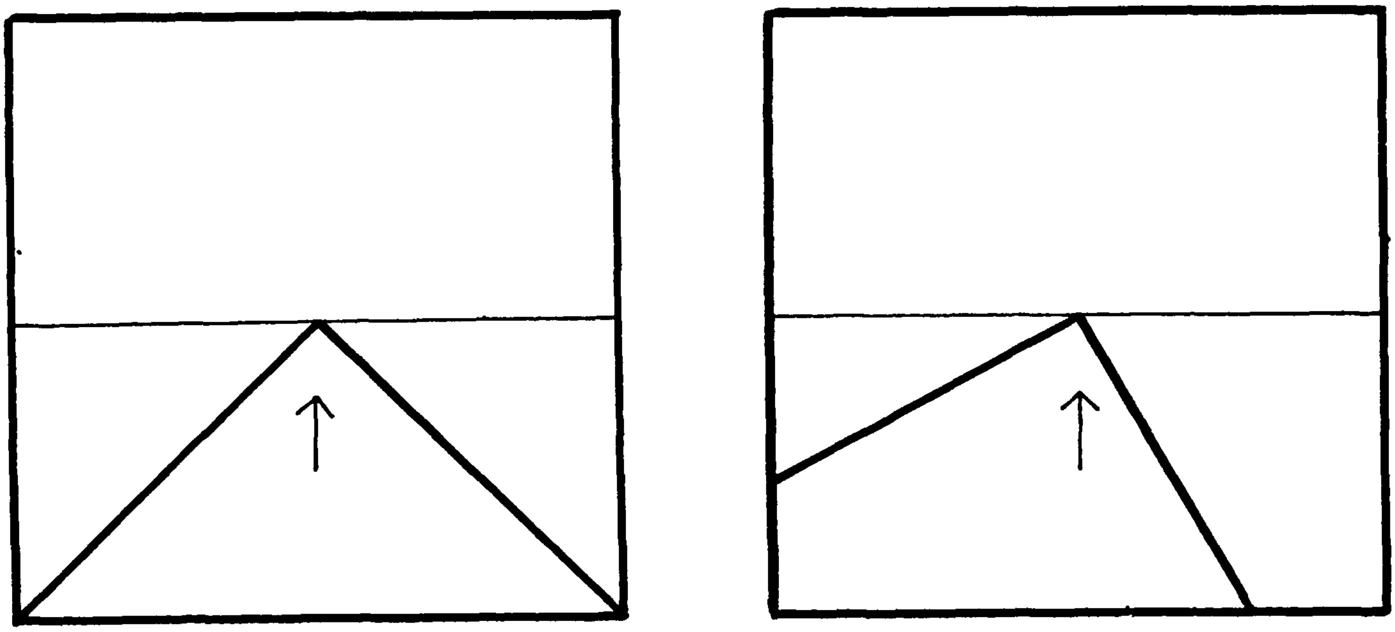
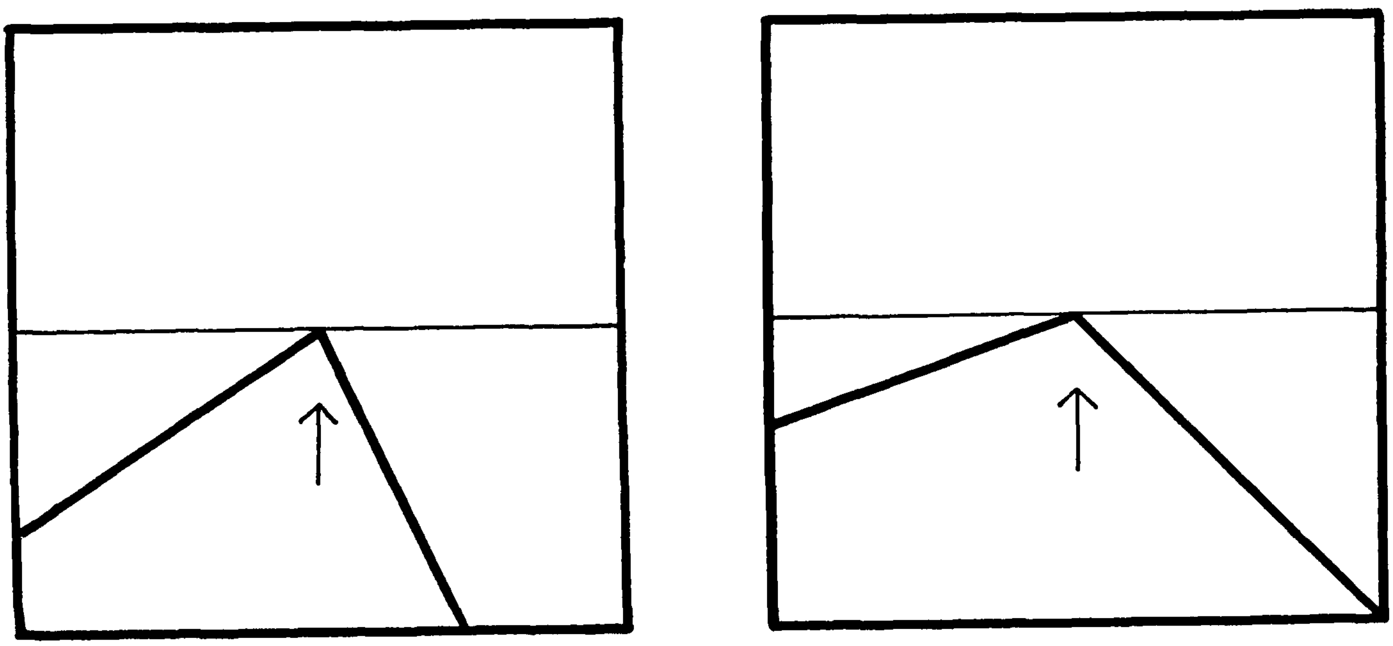


**Figure 8.** Splay angle for texture elements that are (a) one eye-height to the right and left of the motion path (shown as arrow). The effects of reducing the altitude by one half eye-height are shown in (b). The effects of moving the observation point one half eye-height laterally are shown in (c); The combined effects of reducing altitude and moving laterally by one half eye-height are shown in (d).



(c) (d)

(a) (b)

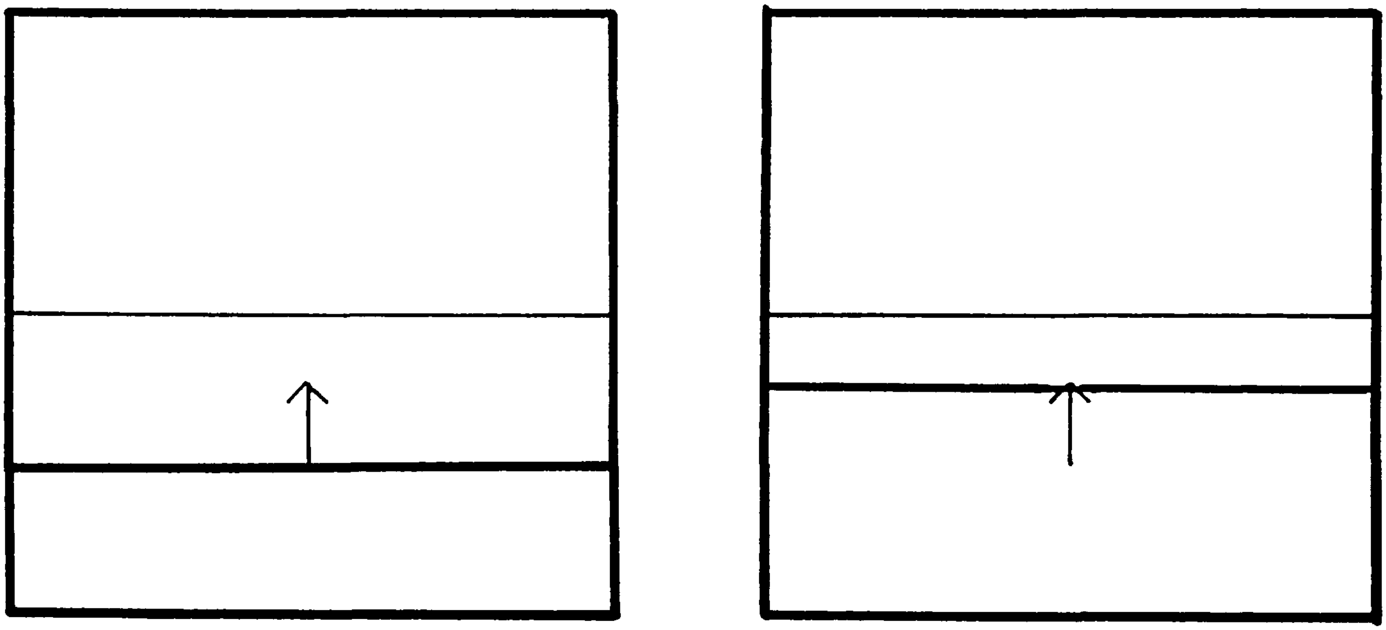
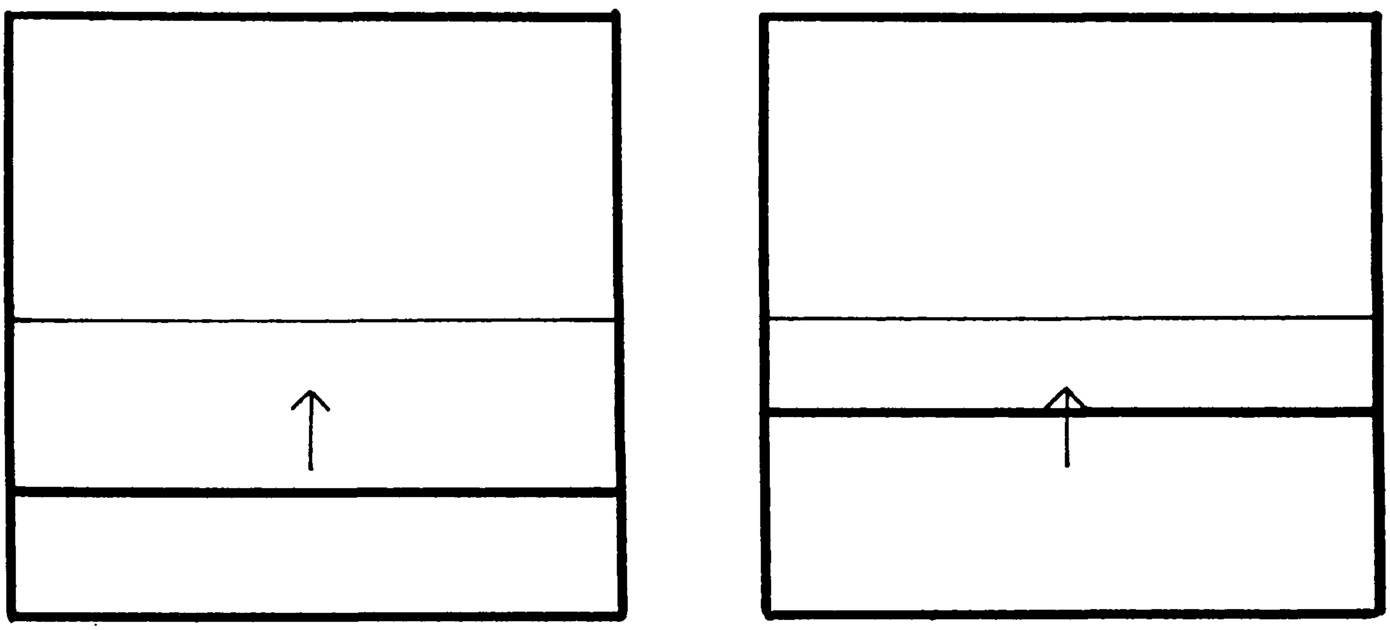


**Figure 9.** Optical depression angle for a texture element four eye-heights in front of the observer (a). The effects of reducing altitude by one half are shown in (b). The effects of moving forward by one half eye-height are shown in (c). The combined effects of reducing altitude and moving forward by one half eye-height are shown in (d).



(c) (d)

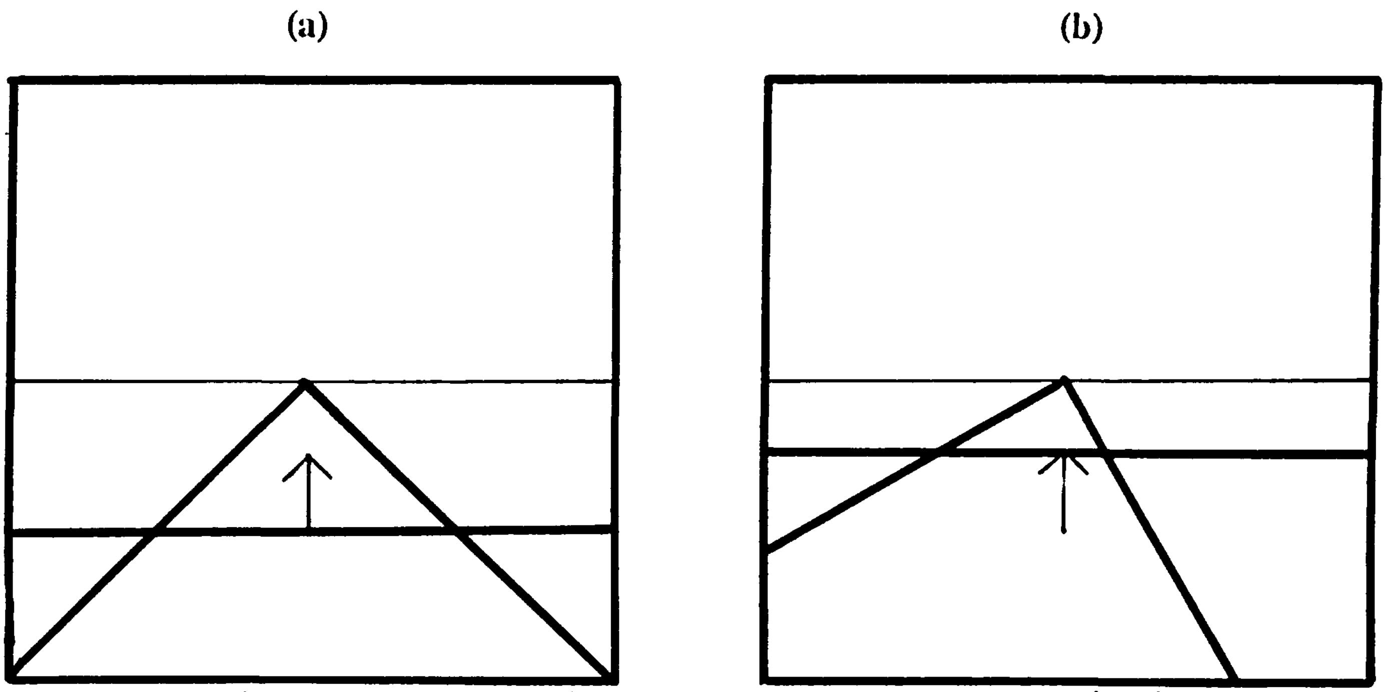
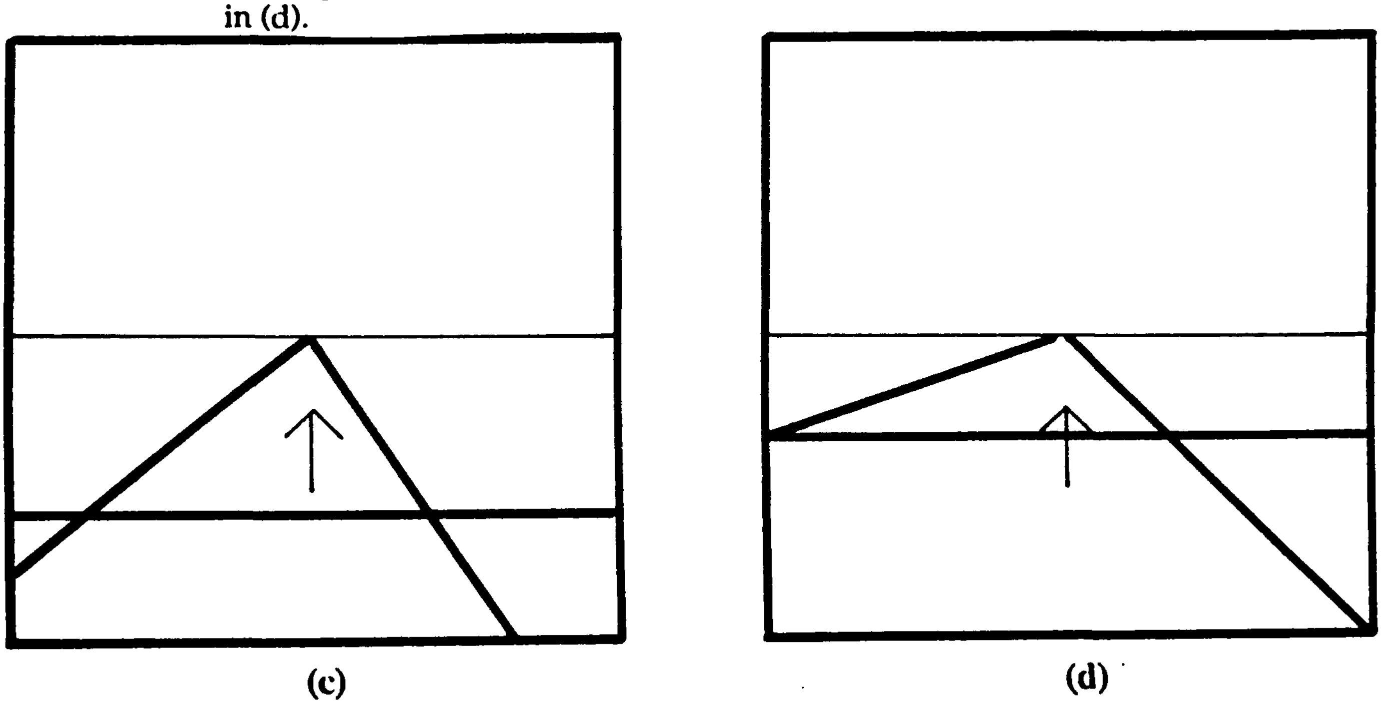



**Figure 10.** Splay angle for texture elements that are one eye-height to the right and left of the motion path (arrow) and optical depression angle for a texture element four eye-heights in front of the observer (a). The effects of reducing altitude by one half are shown in (b). The effects of moving the observation point forward and laterally one half eye-height are shown in (c). The combined effects of reducing altitude, moving forward, and moving laterally by one half eye-height are shown in (d).



## Dynamic Occlusion

> This percept has a subjective component as well as an objective component, i.e. it specifies O's position, movement and direction as much as it specifies the location, slant, and shape of the surface. (Gibson, Olum, & Rosenblatt, 1955, p. 383)

> The changing images resulting from relative motion between an observer and surfaces in the environment constitute an important source of information about the shapes, orientations, and relative distances of these surfaces. The perception of three-dimensional structure from motion is relevant to virtually all tasks involving vision of the environment outside the cockpit.... (Braunstein, 1989; p. 89)

Gibson et al. (1955) were careful to point out that structure produced by movement through the environment points both ways. The structure has a "subjective component" providing information about the moving observer and an "objective component" revealing the structure of the environment. In the previous section we focused on the "subjective components" of motion parallax (altitude (position), speed, and direction). In this section, we turn our attention to the "objective components" of motion parallax --- how movement reveals structure of objects (i.e., structure from motion). Specifically, we are interested in information that specifies the shape of three-dimensional objects.

Gibson (1962) made a distinction between active touch or "touching" and passive touch or "being touched". Gibson argued that active touch is the natural mode which yields experiences that "correspond to the environment instead of to the events at the sensory surface." Experiments involving the recognition of cookie cutter shapes showed that shapes were recognized more reliably when subjects actively explored the cookie cutter than when the cookie cutter was pressed down on the passive palm. Rotating the cookie cutter on the passive palm resulted in improved recognition, but not to the level achieved by active observers.

In comparing vision and touch, Gibson (1962) argued that "vision and touch have nothing in common only when they are conceived as channels for pure and meaningless sensory data. When they are conceived instead as channels for information pickup, having active and exploratory sense organs, they have much in common. In some respects they seem to register the same information and to yield the same phenomenal experiences" (p. 490).

Stappers (1989) recently replicated the cookie cutter experiment for the visual modality. In Stappers' experiment, 2-dimensional forms (analogous to cookie cutter shapes) were drawn in the same color as the background on a CRT that also contained fields of randomly distributed point lights. Thus, when no motion was present the shapes were completely invisible. However, when these shapes were moved across the display they occluded and disoccluded the point lights. Stappers reported that this dynamic occlusion provided sufficient information for the forms to be recognized. He also reported that, as with Gibson's study of active touch, recognition was improved if the movement of the shape was controlled by the subject, rather than by the computer with the human as a passive observer.

## EXPERIMENT 3

A problem with both Gibson's (1962) and Stappers' (1989) experiments is that the mode of interaction (active versus passive) is confounded with the nature of the information. The motions of the cookie cutter on the hand in Gibson's study and of the computer generated objects in Stappers' study were not the same for active and passive subjects. Thus, it is not clear whether differences in recognition reflect the mode of interaction (active vs. passive) or the quality of information generated (i.e., different kinematics - space-time signals). The present study was an extension of the Stappers (1989) study that used a yoked design in an attempt to eliminate this confound. In our experiment six 3-dimensional forms were used as stimuli. These stimuli could be rotated in depth or translated across the screen by an active subject using a joystick control. Subjects were run in yoked pairs with one subject able to actively manipulate the object and a second subject observing the same pattern of occlusion/disocclusion, but with no ability to manipulate the object. Our hypothesis was that performance would be better in the Active Mode, than in the Passive Mode.

### Method

Subjects. Fourteen males and 16 females were recruited from an Introductory Psychology course at Wright State University. Subjects received course credit for participation

Apparatus. Six stimuli were used in this experiment as shown in Figure 11. The stimuli were 3-dimensional wire objects drawn in the same color as the screen background and were completely invisible on a static display. Six fields of point lights were arranged so that three fields were in front of the object and three fields were behind the object as illustrated in Figure 12. Three densities of point lights were used (200, 100, & 64 points per field). When the object was in motion point lights from the 3 fields behind the object were occluded and disoccluded. The result was a display in which a subset of the lights dynamically appeared and disappeared as a function of the position of the 3-dimensional wire object.

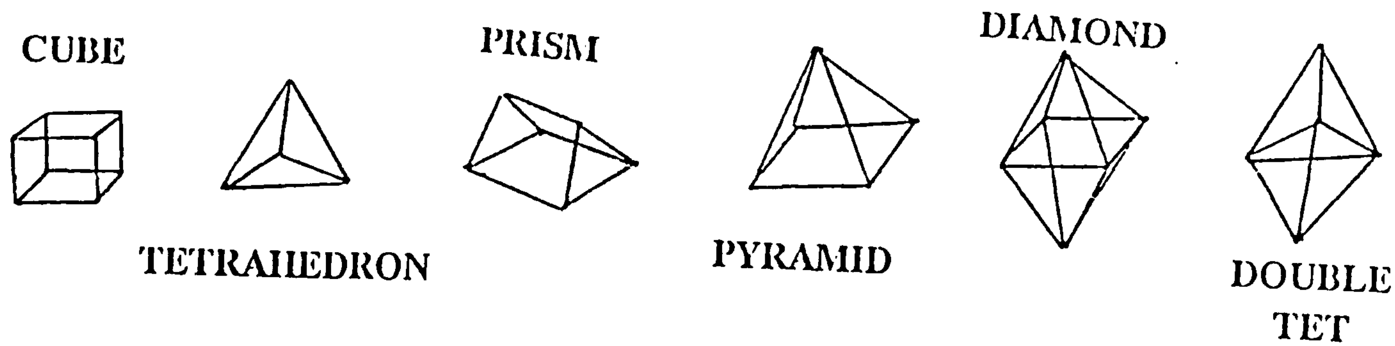



**Figure 11.** Six geometric figures used in the dynamic occlusion task.

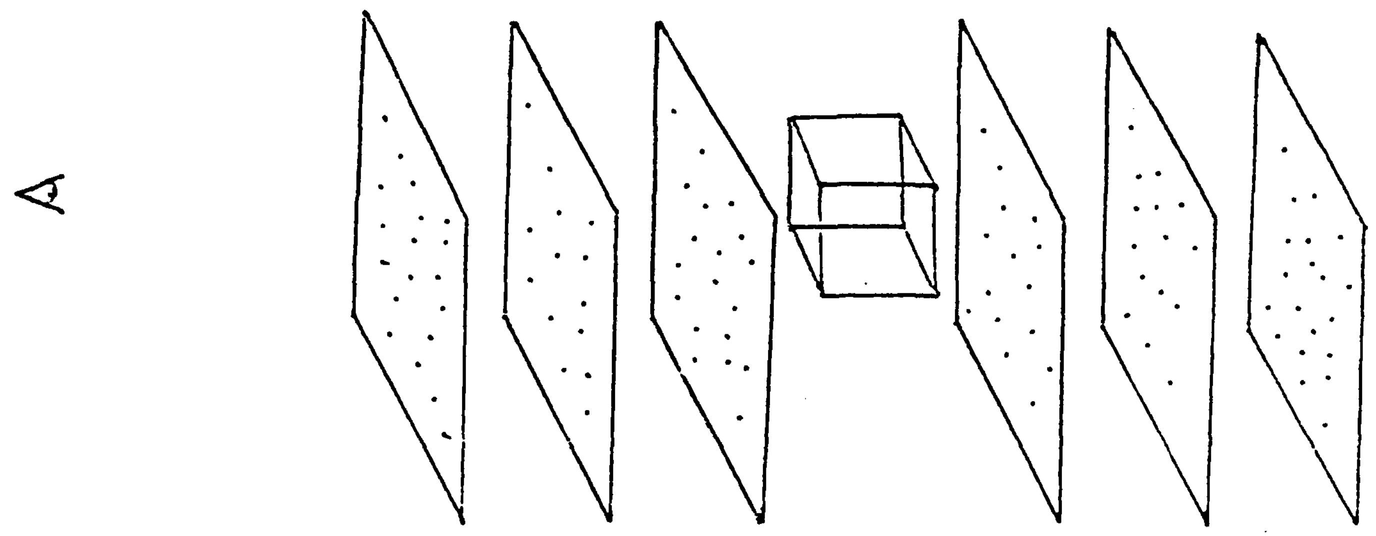


**Figure 12.** A schematic representation of the object within the point light sources used in the dynamic occlusion task. The object was located so that 3 fields of point lights were in front of the object and 3 fields were behind the object. Only points behind the object were occluded when the object moved.

Procedure. Five different pairs of subjects were tested at each level of density. Each pair participated for ten blocks of trials divided between two 1.5 hour experimental sessions. At the beginning of the experiment all subjects were allowed to view and manipulate all six of the objects, which were shown on the computer display drawn in a color different from that of the background. Also, each subject had a response sheet that showed pictures of each of the wire frame objects.

Each block contained ten trials. Subjects alternated between blocks of Active and Passive modes. Thus, subjects received 5 blocks of trials in each mode. Each trial lasted 40 s. During that time, the active subject could manipulate the object using a joystick control. The object could be rotated or translated on the screen producing a pattern of dynamic occlusion. At the end of a trial, each subject recorded their best judgment as to which of the six objects was being displayed on that trial using a paper response form. Subjects received performance feedback in the form of a confusion matrix at the end of each block.

Design. A mixed hierarchical design was used in this experiment. Density (3 levels) was manipulated between pairs of subjects. Pairs were nested within density and subjects were nested within pairs within density. Mode (Active vs. Passive) and Block (1 - 5) were manipulated within subjects. The dependent variable was percent correct identifications.

**Results**

Performance is shown in Figure 13. These results were analyzed using Analysis of Variance with pooled error terms. The use of pooled error terms was required because of the hierarchical design used (See Myers 1972; p. 232-233). This analysis showed a main effect for density ($F(2,27) = 5.10$, $p < .05$). Performance improved as density increased from 64 points per plane (39.8%), to 100 points per plane (57.1%), to 200 points per plane (58.4%). Tukey's HSD post hoc analysis showed that there was a significant difference between the lowest density and the other two densities, but that there was no difference between the two higher densities This pattern is apparent in Figure 13. There was also a main effect for blocks ($F(4,108) = 11.98$, $p < .001$). Performance improved with practice from 39.83% on Block 1 to 60.17% on Block 5. There was, however, no effect for Mode ($F(1,27) = .26$, $p > .25$) and no interaction between Mode and any other factor.

**Discussion**

Gibson (1962) and Stappers (1989) both observed superior discrimination for active observers relative to passive observers. However, in both of these studies the dynamic patterns were different for active and passive observers. In this experiment, active and passive observers were run in yoked pairs so that both observers viewed identical dynamic patterns as generated by the active

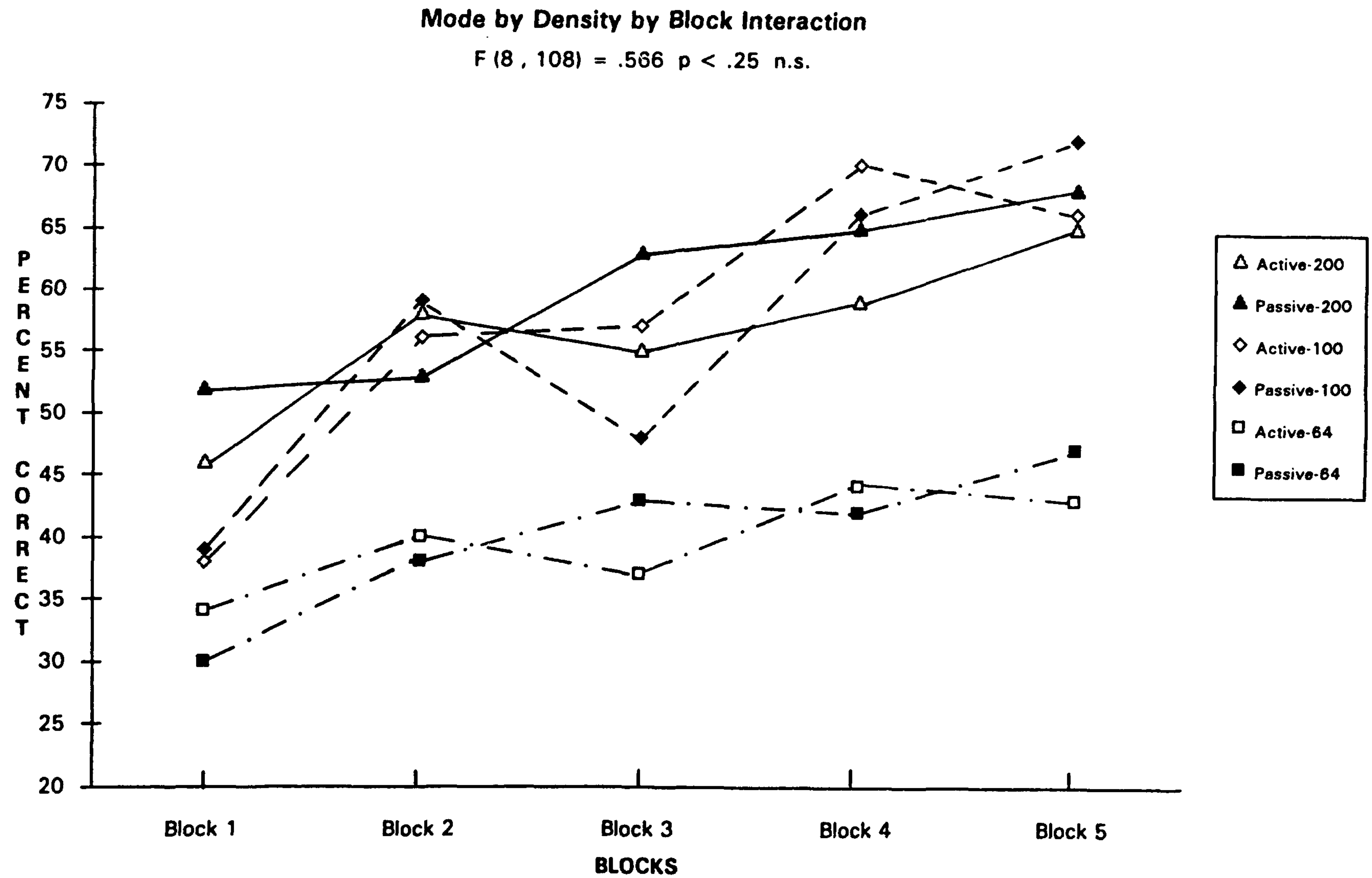



Figure 13. The mean percent correct scores obtained in Experiment 3, plotted in terms of the Mode (Active vs Passive) x Density (64, 100, 200) x Block (1-5) interaction.

subjects. Under these conditions, no advantage was found for active observers. Thus, our hypothesis was not supported.

These results suggest that active coupling, per se, is not important. What may be important is the dynamic pattern of stimulation produced by an active observer. When this dynamic pattern is presented to a passive observer, discrimination performance is at the same level as for the active observer. This suggests that differences in the quality of information are the operative dimension for the previous observations of Gibson and Stappers, not differences in the mode of observation. Further research and analyses are necessary before these conclusions, based as they are on a null result, can be presented with confidence.

## EXPERIMENT 4

In Experiment 3, subjects alternated between Passive and Active Modes of control. Thus, Mode was manipulated as a within subjects variable. One possible explanation for the result that there was no difference between performance in the Passive and Active Modes is that all the subjects had active experience. Performance in the Passive Mode may have benefited from transfer due to learning in the Active Mode. In Experiment 4, the training protocol was changed so that Mode was manipulated within subjects to avoid transfer between modes. Our hypothesis was that with the transfer between Active and Passive Modes eliminated, performance would be better for the Active Mode.

### Method

Subjects. Ten males and 10 females participated in Experiment 4. Subjects were recruited from an Introductory Psychology class at Wright State University and received course credit for participation.

Apparatus. The apparatus and stimuli for Experiment 4 were identical to those used in Experiment 3 with the exception that only two densities were examined in Experiment 4 (100 & 64 points per field).

Procedures. Ten pairs of subjects were tested. Each pair participated for 11 blocks of trials divided between two 1.5 hour experimental sessions. At the beginning of the experiment, subjects in the active condition were allowed to view and manipulate three of the objects (cube, pyramid, and double-tetrahedron), which were shown on the computer display drawn in a color different from that of the background. After the demonstration of the control stick for the active subjects, the passive subject entered the experimental room. Both active and passive subjects were allowed to view all six of the objects, which were drawn in a color different from that of the background. In this demonstration, the motion of the objects was controlled by the computer. On Blocks 1 thru 10, one subject in each pair performed in an active mode and the other subject performed in a Passive Mode. On the eleventh block the roles were reversed. A background density of 100 points per frame was used for Blocks 1 thru 5 and a background density of 64 points per frame was used for Blocks 6 thru 10. Note that practice and density were confounded in this design. This was intentional. We thought that the 64 points per frame might be too difficult for unpracticed subjects.

Each block contained ten trials. Each trial lasted 25 s. During that time, the active subject could manipulate the object using a joystick control. The object could be rotated or translated on the screen producing a pattern of dynamic occlusion. At the end of a trial, each subject recorded a best judgment as to which of the six objects was being displayed using a response menu on the computer display which showed the six objects. Subjects received performance feedback in the form of a confusion matrix at the end of each block.

Design. Blocks 1 to 10 were treated as one experiment and Blocks 10 and 11 were treated as a second experiment. Blocks 1 to 10 were treated as a mixed design with Mode manipulated between subjects and Density and Block manipulated within subjects. Two levels of Mode were used: Active and Passive. Two levels of Density were used (64 and 100 points per frame). Five blocks were included within each level of Density. Blocks 10 and 11 were treated as a mixed design with Training (Active or Passive) as a between subjects variable and Compatibility (Same or Different) manipulated within subjects. Training indicates whether the subject had been active or passive on previous blocks. Compatibity indicates whether the subject was performing the task in the same mode as used in training (Block 10) or a different mode (Block 11). Order is confounded with compatibility. All subjects performed in a compatible mode first (Block 10) and then performed in an incompatible mode on Block 11

**Results**

The percent correct data from Blocks 1 to 10 are shown in Figure 14. These data were analyzed using a mixed design Analysis of Variance. This analysis showed a main effect for Density ($F(1,18) = 10.33, p = .0048$). Performance was superior (57.1%) for the 64 points per frame density, than with the 100 points per frame density (49.7%). This result is in the opposite direction to the effect of Density in Experiment 3. This is likely due to the fact that practice was confounded with density. All subjects performed 5 Blocks with the 100 points per frame density first, then they were given 5 Blocks with the 64 points per frame density. Thus, the significant difference here probably reflects learning. There was also a significant main effect for the 5 Blocks within each density ($F(4,72) = 7.05, p < .0001$). Performance improved from 43.7% in Block 1 to 60.2% in Block 5. As with Experiment 3 there was no significant effect of Mode (Active vs. Passive) ($F(1,18) = .95, p = .3425$). Also, there were no significant interactions.

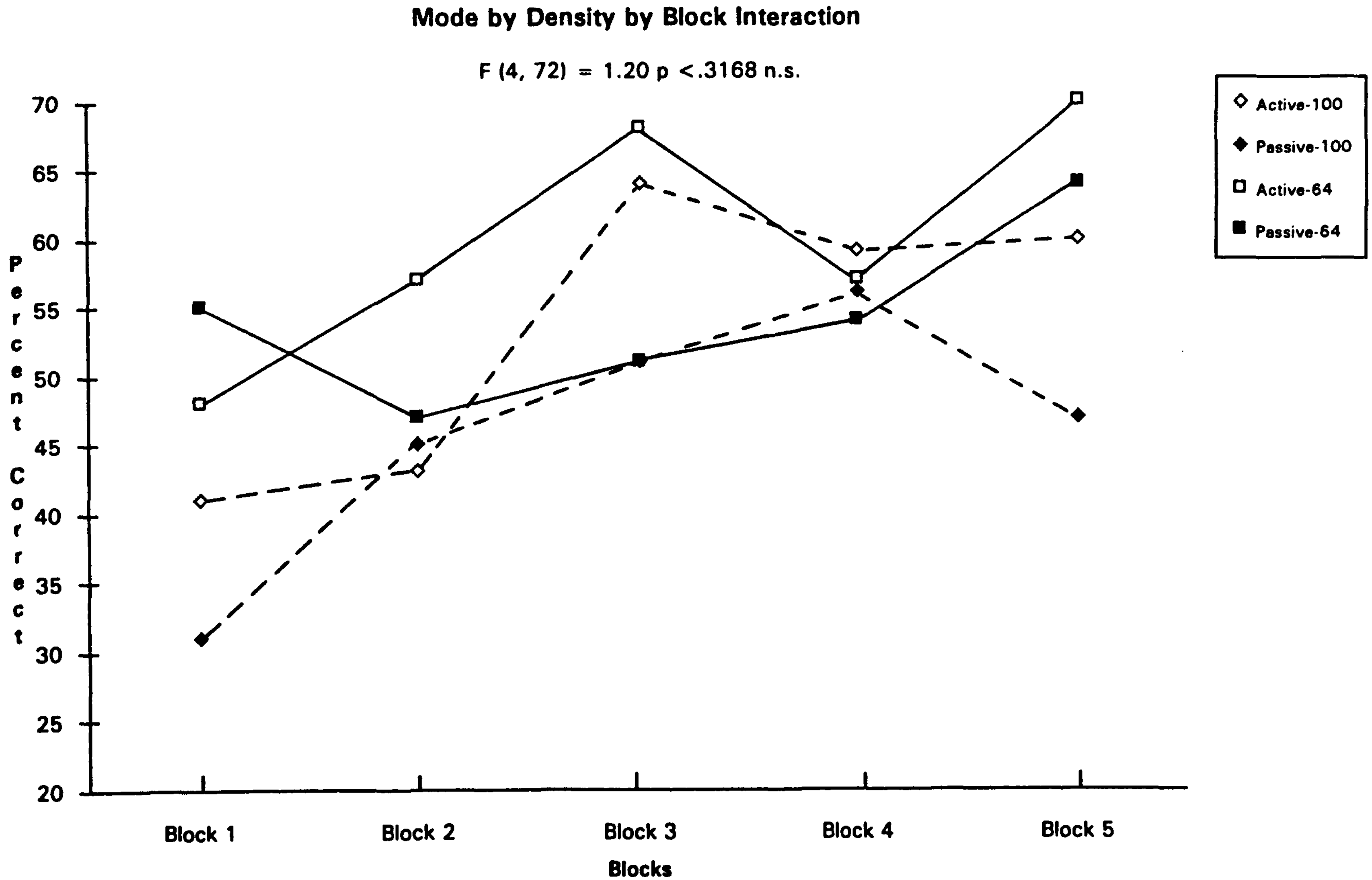



**Figure 14.** The mean percent correct scores obtained for the training phase of Experiment 4, plotted in terms of the Mode (Active vs. Passive) x Density (64, 100) x Block (1-5) interaction.

Percent correct data for Blocks 10 and 11 are shown in Figure 15. This data was analyzed using a mixed design analysis of variance. This analysis found a significant effect for compatibility ($F(1,18) = 10.57$, $p = .0044$). Subjects performed better when the Mode of control was the same as that used in training (67%), than when it was different (50%). There is a hint of an interaction in Figure 15, such that within levels of Compatibility performance was better for the subject in the Active Mode. However, this interaction was not significant $F(1,18) = 1.79$, $p = .1973$).

## Discussion

The principal motive for Experiment 4 was to examine the possibility that the failure to obtain significant effects for Mode in Experiment 3 was due to transfer of training between Active and Passive Modes. In the previous experiment, subjects alternated between modes. In the present experiment, Mode was manipulated between subjects for the first 10 Blocks, so that, passive subjects had no experience in the Active Mode. However, as in Experiment 3, our hypothesis of an advantage for the Active Mode was not supported. There were no significant effects associated with Mode. Again, we must be very cautious in making inferences from a null result. It would be incorrect to say that there was no effect of Mode. In fact, the mean performance was nominally better in the Active Mode (56.7% vs. 50.1%). However, if Mode does effect performance in this task, the effects appear to be very small relative to the differences among individuals and relative to the effects of Density and practice.

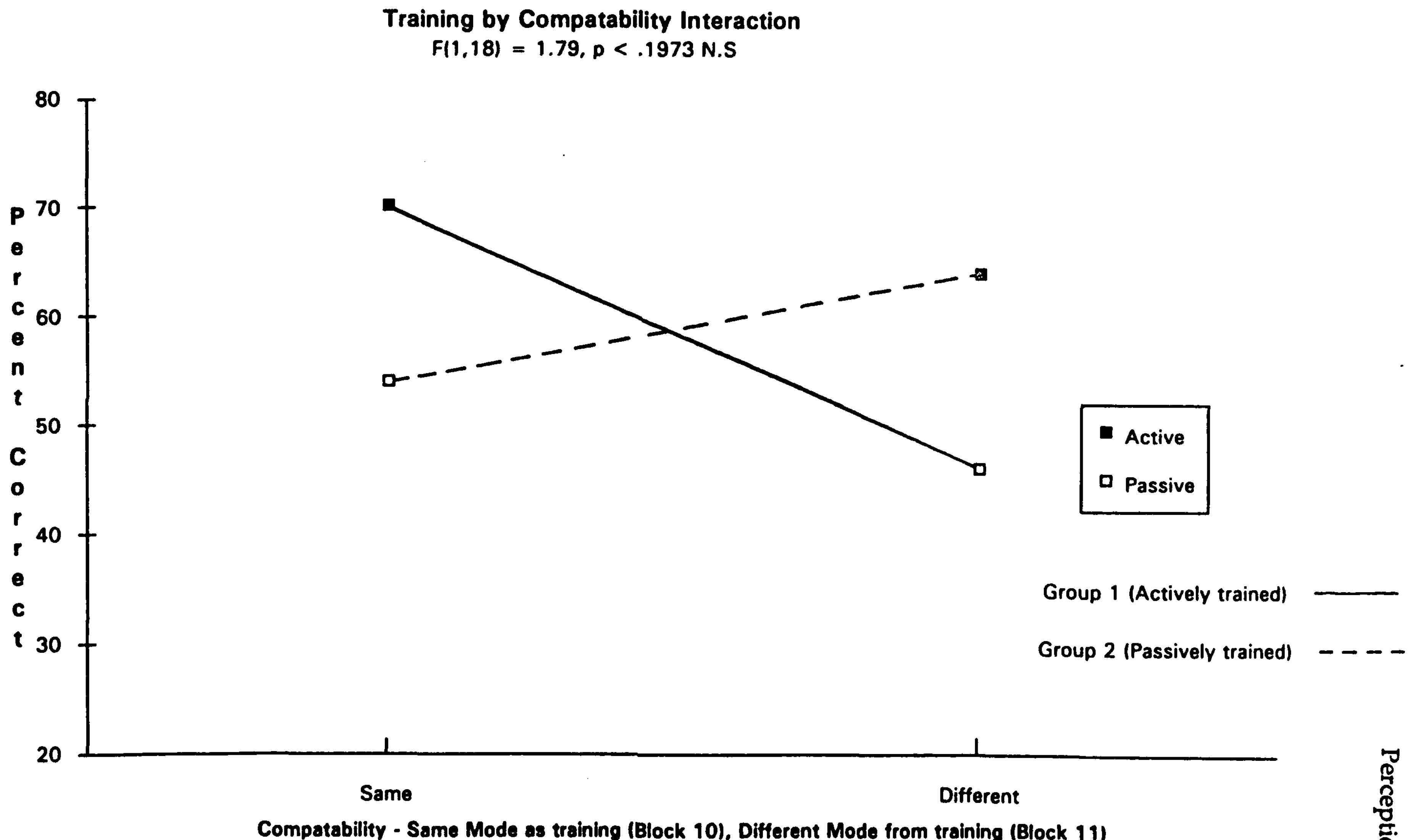



**Figure 15** The interaction between Training (Active vs Passive) and Transfer (Same vs Different) obtained for Blocks 10 and 11 from Experiment 4

**EXPERIMENT 5**

As we have noted above, previous research by Gibson (1962) and Stappers (1989), that has compared performance of active and passive observers, has confounded mode and information. That is, the information available to passive subjects was the consequence of a stereotypic motion pattern. However, the information available to active subjects was the consequence of motion generated by a discriminating observer. We might presume that in the active case the motion is guided by the information that it makes available. Experiments 3 and 4 used yoked pairs of subjects in an attempt to isolate mode from the confounding effects of information. In these experiments, both active and passive subjects observed the same motion pattern. This was a pattern generated by the active observer. The fact, that no significant difference was found for Mode in our experiments, suggests the hypothesis that the pattern of available information may have been the operative factor producing the differences observed by Gibson (1962) and Stappers (1989). In other words, when the pattern of motion (i.e., kinematics or information) is identical, then there is no advantage for the Active Mode.

Experiment 5 was designed to more carefully examine this hypothesis. In Experiment 5 performance using motion patterns generated by active observers was compared to performance using stereotypical motion patterns. Two types of stereotypical motion patterns were examined: rotation and translation. In the rotation condition the object alternately rotated around the vertical and horizontal axes at a constant velocity. In the translation condition the object alternately translated vertically and horizontally. The hypothesis was that performance would be better with kinematic patterns generated by the active observers than with stereotypic, kinematic patterns generated by the computer.

**Method**

Subjects. Thirteen males and 27 females participated in this experiment. Subjects were recruited from the student population at Wright State University. Subjects received either course credit or payment ($5.00/hr.) for participation in the experiment.

Apparatus. The experimental set up was identical to that used for Experiments 3 and 4, except for the automated trials. Two types of automated trials were used. In Rotation conditions, the object alternately rotated around the horizontal and vertical axes at .14 Hz, or 1 cycle every 7 s. In Translation conditions, the object alternately translated along the horizontal and vertical axes at .21 Hz or 1.5 cycles every 7 s..

Procedure. Twenty pairs of subjects were tested. One subject in each pair was the active observer and the other subject was the passive observer. Each pair participated for 2 sessions of 6 blocks each. Blocks alternated between subject generated information blocks in which movement of the object was controlled by the active observer and computer generated information blocks in which movement of the object was controlled by the computer. For half the pairs, the computer generated motion was rotations and for the other half the computer generated motion was translations as described in the Apparatus section. Each block contained ten 28 s trials. At the end of each trial subjects responded using a response menu showing the six possible objects on the computer screen. Subjects received performance feedback in the form of a confusion matrix at the end of each block.

Design. A 2 x 2 x 2 x 2 x 6 mixed design was used for this experiment. Mode (Active vs Passive), Automation (Rotation or Translation), and Density (100 or 64 points per plane) were manipulated between subjects. Information (Subject Generated vs. Computer Generated) and Block (1-6) were manipulated within subjects. Subjects were run in pairs. One member of each pair was active. That is, on nonautomated trials this subject could control the movements of the object. The other member of each pair was passive. This subject could view the same visual display as the active subject, but could not control the object. This subject saw the visual consequences of motions produced by the active subject. Performance was measured alternatively on subject driven or computer driven trials. On computer driven trials the motion of the object was controlled by the computer. Subjects either saw rotations or translations but never both. On subject driven trials the motion of the object was controlled by the active subject. Observers saw either 64 or 100 dot densities.

**Results**

A mixed design Analysis of Variance showed a main effect for Information ($F(1,32)=65.03$, $p<.001$). Performance was better with computer generated motions than with subject generated motions ( 70.5% vs 56.2%). This result directly contradicts our hypothesis. There was also an interaction between Information and Automation (Rotation vs Translation) ($F(1,32) = 5.48$, $p=0.0256$). This interaction is shown in Figure 16. The pattern shown in Figure 16 is somewhat puzzling in that the type of automation showed differential effects on the subject generated information trials, but not on the automated (computer generated) information trials. This suggests that there must have been transfer between the computer generated and subject generated trials. Otherwise, the stimuli on the subject generated trials should not have differed as a function of the type of automation (Rotation or Translation).

There was a main effect of Block ($F(5, 160) = 37.36$, $p<.001$). Performance improved from 43.4% on Block 1 to 72.7% on Block 6. There was also a significant two way interaction between Block and Information ($F(5,160) = 3.68$, $p=0.003$) as shown in Figure 17. The magnitude of difference between Subject and Computer Generated Information conditions decreased from 24.3% on Block 1 to 6.0% on Block 6. The pattern in Figure 17 suggests that the performance advantage for Computer Generated Information diminishes with practice. Early in practice there is a large advantage for Computer Generated Information trials, but with practice performance on both Computer and Subject Generated trials

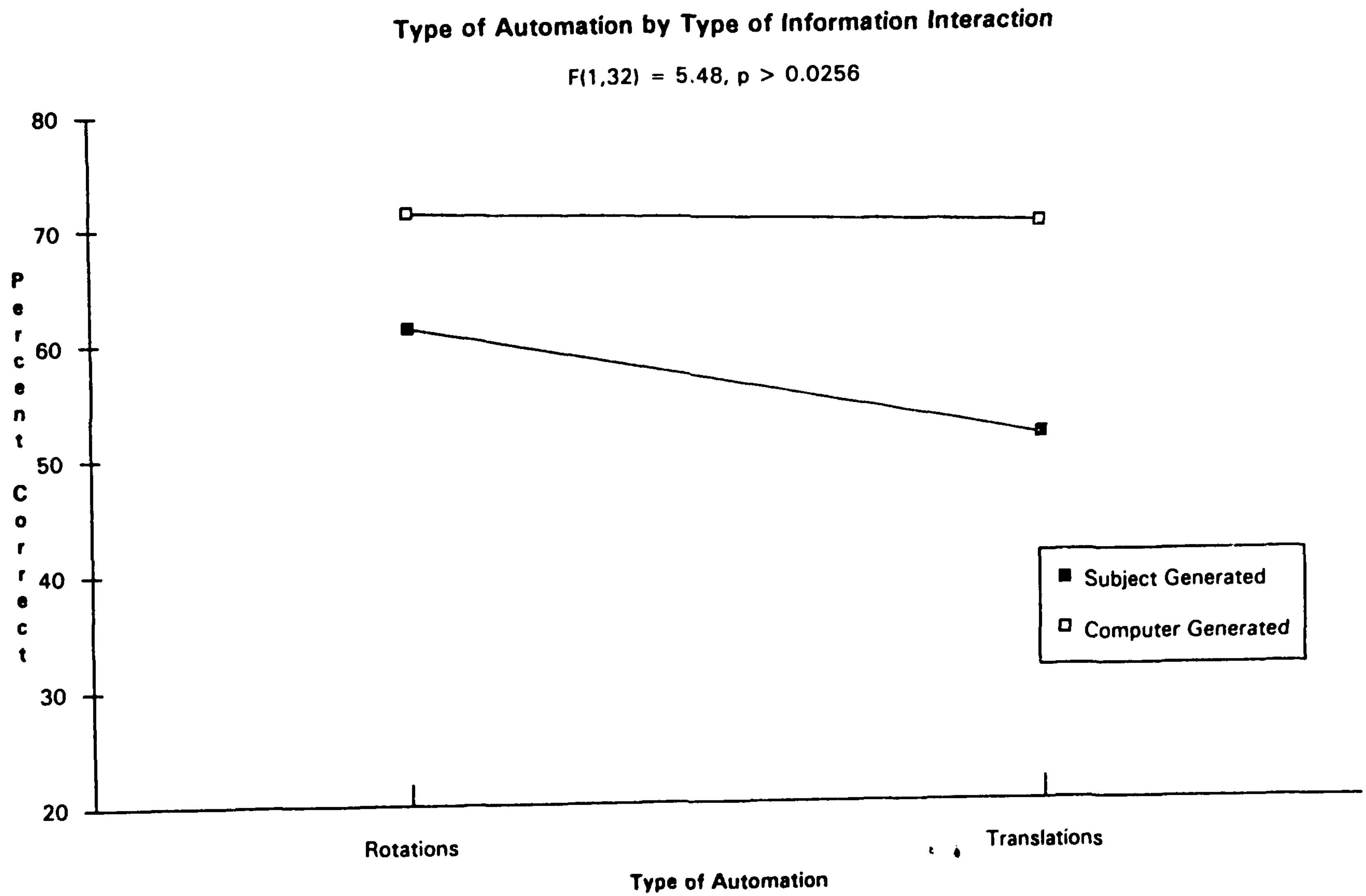



**Figure 16.** The interaction between Information (Computer Generated vs Subject Generated) and type of Automation (Rotations vs Translations) obtained in Experiment 5.

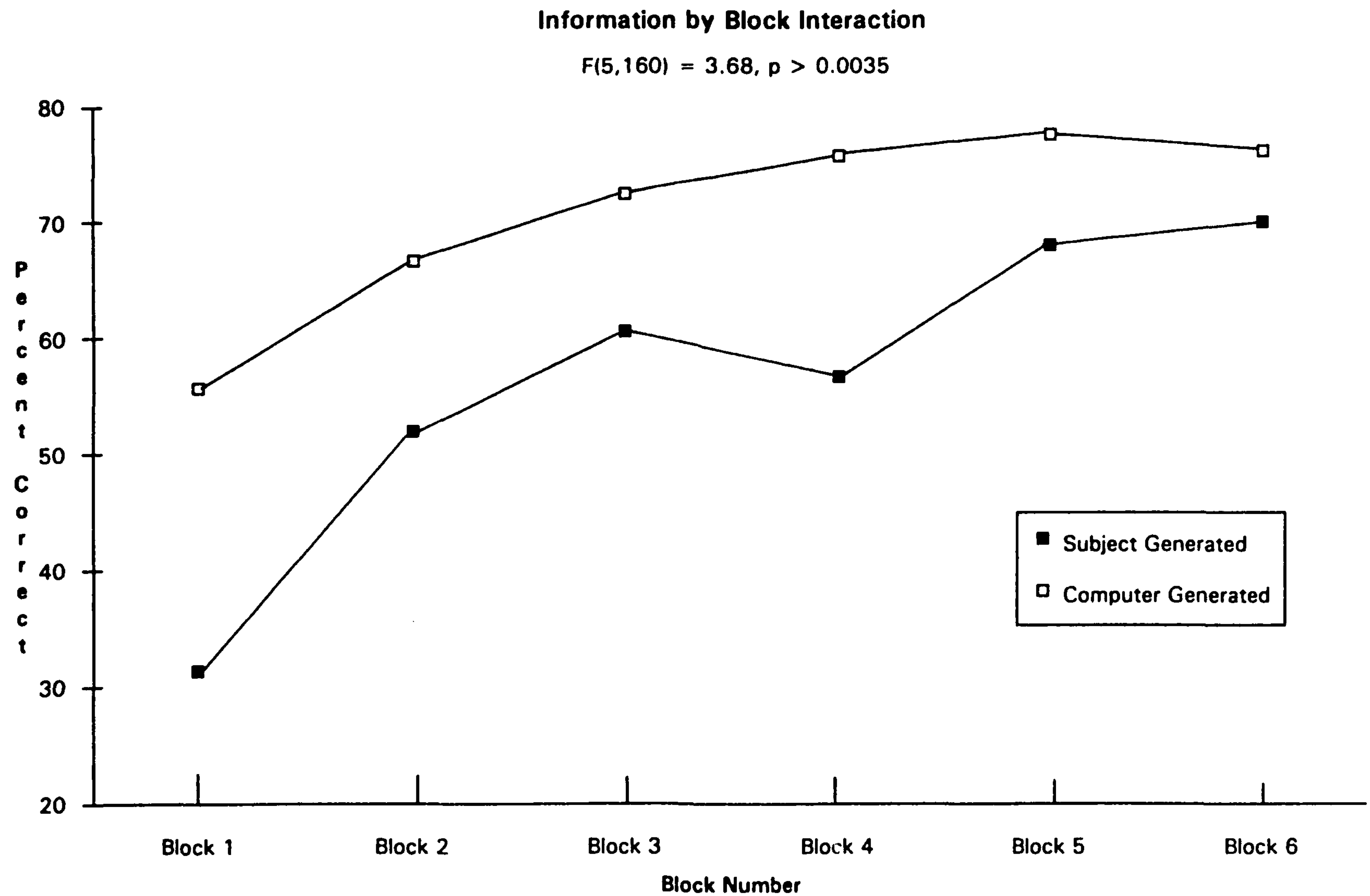



**Figure 17.** The interaction between Information (Computer Generated vs Subject Generated) and Block (1-6) obtained in Experiment 5.

appears to be converging to a common asymptote. Finally, there was a significant 3-way interaction between Block, Automation, and Density ($F(5,160) = 3.08$, $p = 0.011$) as shown in Figure 18. This interaction shows that performance with the 64 dot density displays and with the translation type of automation approaches an asymptote much lower than that approached for the other conditions. The learning curves across blocks for Rotations at Density of 100, Translations at Density 100, and Rotations at Density of 64 appear to be equivalent.

There were no significant main effects for Mode ($F(1,32)=0.37$, $p=.5469$), nor were there any significant interactions between Mode and the other variables. Mean performance for Active subjects was 61.9% and mean performance for Passive subjects was 64.8%.

## Discussion

Again, as in Experiments 3 and 4, there were no significant effects involving the Active/Passive distinction. On two of the four comparisons shown in Table 1 passive observers were superior to active observers. We must remain somewhat cautious because these are all null results, but the fact that this result has been replicated in three experiments, under three different training protocols suggests that there is, in fact, no advantage for the active observer in this task.

**Table 1.** Active vs Passive Observers

| Experiment | Active | Passive |
|---|---|---|
| 1 | 51.2% | 52.3% |
| 2 (Training) | 56.7% | 50.1% |
| 2 (Transfer) | 54.0% | 46.0% |
| 3 | 61.9% | 64.8% |

The significant performance advantage found for the computer generated motions over the subject generated motions contradicted our hypothesis that was based on the assumption that performance with information driven motions would be superior to performance with stereotypic motions. The interaction between Information and Blocks shown in Figure 17, suggests that initially the subject generated condition was more difficult than the computer generated condition. However, the learning curves for subject and computer generated motions seem to be converging to a common asymptote. Thus, it appears the subject must learn how to generate the information effectively, this is in addition to learning how to discriminate between the objects based on the information of dynamic occlusion. Of the two kinds of stereotypic motion, rotations seem to provide information more effectively than translations as seen in Figure 18.

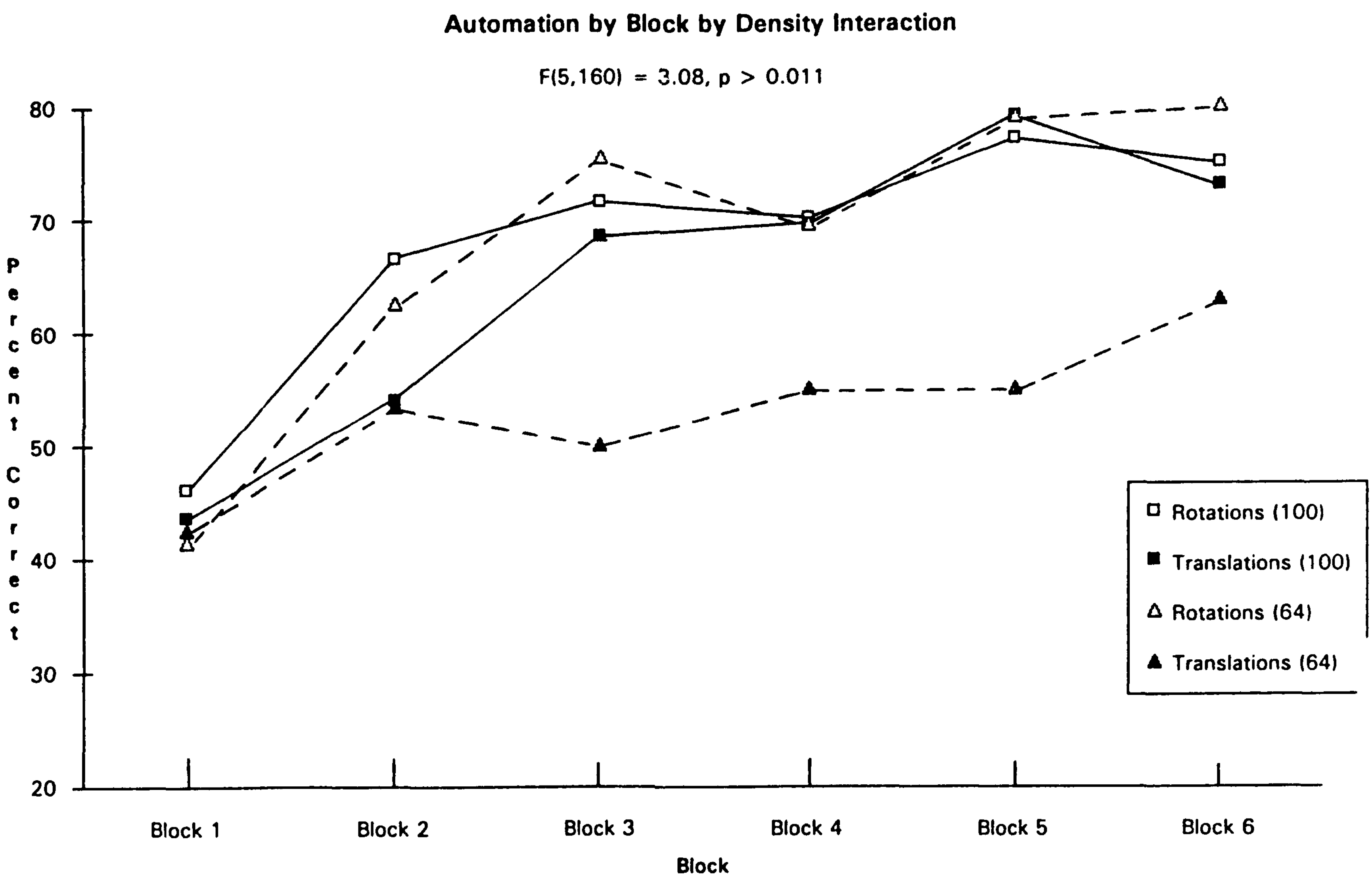



**Figure 18.** The interaction between Automation (Translations vs. Rotations), Density (64, 100), and Block (1-6) obtained in Experiment 5.

So, we are left with a puzzle. How to account for our failure to replicate the previous findings reported by Gibson (1962) and Stappers (1989). There are several obvious differences to consider. One obvious difference is modality. Perhaps active manipulation is more important for the tactile modality as studied by Gibson (1962), than for the visual modality studied in our experiment. Another difference is the dimensionality of the objects used. Stappers (1989) used 2-dimensional shapes, whereas 3-dimensional shapes were used in our experiments.

Other important considerations for evaluating our results include the following:

The *nature of the judgment* that was required. Neisser (1992) has recently made a distinction between "direct" or "situating perception" and "re-cognition" or categorizing perception. Neisser describes situating perception as

> immediate, non-inferential, bottom-up and cognitively impenetrable. It provides us with immediate access to the real facts of our ecological situation. We see directly where things are, how they are shaped, and how we might act upon them. It provides information about ourselves as well as our environment, and thus establishes in each of us a first important sense of who we are - a kind of "ecological self." Perhaps most important, it enables us to see that we live <u>in</u> and act <u>on</u> a real environment - one that exists independently of us even as we interact with it.
>
> Our knowledge of that independently existing environment does not have to be "constructed," as I myself once misleadingly argued; it can simply be perceived. Stationary observers with restricted fields of view may have to guess at what they see, but moving ones pick up information that specifies the layout unambiguously. What's more, because it is not inferential or symbolic, that knowledge cannot be "deconstructed" in the modern philosophical sense of the term. Like the environment itself, it is there no matter what we may think about it. Situating perception is what establishes the "background," so long and justly celebrated by phenomenologists, which undergirds all other, less certain beliefs. (p. 12)

Re-cognition or categorizing perception is the skill by which associations are made between present inputs and pre-existing representations. Neisser explains that "the logical difference between direct perception and recognition is roughly - though not exactly - parallel to the linguistic and philosophical distinction between "seeing" and "seeing as." I can <u>see</u> the car in direct perception, but to see it <u>as</u> a <u>car</u> or as <u>my</u> car requires stored information" (p. 14). It may be that activity is very important for direct perception, but it may not be so important for categorical perception. The categorical discrimination that is required by our task may be tapping re-cognitional processes as opposed to direct perceptual processes.

The *nature of the discrimination* that was required. The discrimination required in our experiments are based on purely kinematic (space - time) properties of the stimulus. It may be that the kinematic properties are equally accessible to passive and active observers. On the other hand, kinetic properties of objects (mass - force) may be differentially available to active and passive observers. For example, a passenger and driver in an automobile may be equally qualified for identifying the current heading of the vehicle (a kinematic task), however, the driver may have an advantage in specifying the minimum stopping distance (a kinetic task).

The *specific objects* that were used. We used regularly shaped, 3-dimensional polygons. The distinctions between these polygons were fairly distinct and well defined. If the shapes were more irregular, or the distinctions were less well defined (for example, no previously learned, distinct labels for the various shapes), then the active subjects may have had an advantage over passive subjects.

The *intentions* of the subjects. In our experiments the intentions for both active and passive observers were clearly specified as identifying the objects. However, in some experiments the task situation may result in intentional differences between the active and passive observers (e.g., Held & Hein, 1963). The intentional differences may cause the active observer to be more attentive to details of the stimulus situation. Thus, differences between active and passive observers may be more likely to appear when the task involves incidental learning.

The *coupling between the active observer and the display*. The joystick is not a natural coupling for action and perception in this task. In natural situations dynamic occlusion would be produced by movements of the observer. The difficulties in learning this unnatural coupling may overwhelm any advantages that active control might provide for this task.

The *reference frame*. In our experiments all motions were centered on the object and the object started out in (and was generally maintained within) the center of the screen. Thus, there was a clearly defined and essentially constant reference frame which provided the background against which to interpret the dynamic occlusions. If the occlusions were produced by the more natural coupling of head movements, then the reference frame would be constantly changing. The active observers may have an advantage in this situation since they have correlary kinesthetic, tactile, and vestibular information to specify the moving reference frame. Without this additional information the passive observer may have difficulty picking-up the information available in the dyamic occlusion.

The nature of the *background point lights* used. In our experiments the background was static. The only changes that occurred were those produced by motions of the object. Thus, there is no ambiguity about the source of variations in the display. If a light is occluded it is due to the object. What if the background was dynamic. That is, what if there were variations in the background (e.g., noise) that were unrelated to the motion of the object. This may create a situation where the active observers may be at an advantage since they can use correlations between variations in the stimulus and their own actions to disambiguate the variations due to occlusion that specify the object (i.e., signal) from variation due to other sources (i.e., noise).

In sum, there are many questions that must be addressed before we can begin to understand the nature of the coupling between action and perception. We feel confident that the dynamic occlusion task provides a rich and interesting context for addressing many of these questions. Our current plans are to continue systematically addressing the questions that have been outlined above using the dynamic occlusion paradigm.

## General Summary

Much of the work over the last year and a half has been devoted to setting up laboratories and developing software. Development has progressed much more quickly on the software for the dynamic occlusion task than on the software for the control of locomotion. However, a powerful software tool is being developed for studying the control of locomotion. This software will support a wide range of experiments that will address numerous aspects of the control of locomotion problem. To date, only pilot data has been collected on the altitude control task. However, a proposal for a Master's Thesis to do Experiment 1 has been accepted. We hope to collect data over the next six months and to have a completed thesis by Spring of 1993.

The dynamic occlusion task has generated far more questions than answers. Contrary to previous research by Gibson (1962) and others we find no effects for mode of observation (i.e., active vs passive). Our results raise interesting questions about the relation between perception and action. Under what circumstances does the capacity for active control of information enhance our ability to perceive? We believe that the dynamic occlusion paradigm provides a rich environment in which to explore questions about the role of activity in perception.

# Publication Activity

**Journal Articles and Book Chapters:**

Flach, J.M., Hancock, P.A., Caird, J.K. & Vicente, K.J. (In press). *The ecology of human-machine systems.I: Global perspectives.* Hillsdale, NJ: Erlbaum.

Flach, J.M., Hancock, P.A., Caird, J.K. & Vicente, K.J. (In press). *The ecology of human-machine systems.II: Local applications.* Hillsdale, NJ: Erlbaum.

Flach, J.M. & Warren, R. (In press). Active psychophysics: The relation between mind and what matters. In J. Flach, P. Hancock, J. Caird, & K. Vicente (Eds.) *The ecology of human-machine systemsI: Global perspectives.* Hillsdale, NJ: Erlbaum.

Flach, J.M. (In press). Active psychophysics: A psychophysical program for closed-loop systems. In E.J. Haug (Ed.). *Concurrent engineering tools and technologies for mechanical system design.* New York: Springer-Verlag.

Bennett, K. & Flach, J.M. (In press). Graphical displays: Implications for divided attention, focussed attention, and problem solving. *Human Factors,* **34**(5),

Flach, J.M., Allen, B.L., Brickman, B.J. & Hutton, R.J.B. (1992). Dynamic occlusion: Active versus passive observers. *INSIGHT: The Visual Performance Technical Group Newsletter,* **14**(2), 5-7.

Flach, J.M., Hagen, B.A., & Larish, J.F. (1992). Sources of information in optic flow for the regulation of altitude. *Perception & Psychophysics.,* **51**(6), 557-568.

**Published Conference Proceedings:**

Flach, J.M. & Bennett, K.B. (1992). Graphical interfaces to complex systems: Separating the wheat from the chaff. *Proceedings of the Human Factors Society 36th Annual Meeting.* Santa Monica, CA: Human Factors Society.

Flach, J.M. & Hancock, P.A. (1992). An ecological approach to human-machine systems. *Proceedings of the Human Factors Society 36th Annual Meeting.* Santa Monica, CA: Human Factors Society.

Flach, J.M. (1991). Manual Control Laboratory. *Proceedings of the Human Factors Society 35th Annual Meeting.* Santa Monica, CA: Human Factors Society.

Flach, J. M., Wilcox, S.B., Rutter, B.G., Wilkin, L., Bennett, K.B., & Hansen, J.P. (1991). Ecological psychology: An alternative perspective for human factors design. *Interface '91.* Dayton, OH. (pp. 248-257).

**Conference Presentations Publication of Abstract Only:**

Flach, J.M. (1992). Skill: Dancing with the environment. *NASPSPA '92*. North American Society for the Psychology of Sport and Physical Activity. Pittsburg, PA. (June).

Flach, J.M. (1992). Active psychophysics: A psychophysical program for closed-loop systems. Haug, E. (Ed.). *NATO Advanced Study Institute: Concurrent Engineering Tools and Technologies for Mechanical System Design*. Iowa City, IA. (May 25 - June 5).

## Participating Professionals

| Graduate Students | RA Support | Proposal Approved | Thesis Completed |
|---|---|---|---|
| Brad Allen | 8-90 - 9-91 | | |
| Bart Brickman | 6-92 - | | |
| Sheila Garness | 9-92 - | | |
| Robert Hutton | 6-92 - | | |
| Leigh Kelly | 9 -91 - 6-92 | 7-92 | |

**Undergraduate Students:** Mark Guisinger

## Interactions

**Presentations:**

Flach, J.M. (1992). Human performance in low altitude flight. Invited lecture *The Tenth Annual International Conference on Aviation Physiology and Training: Human Factors in Aviation Part III*. Southampton, PA: Aeromedical Training Institute (AMTI) A Division of Environmental Tectronics Corporation.

Flach, J.M. (1992). Direct perception and affordances. Invited presentation at the Learning Center, University of Minnesota, Minneapolis, MN. 13 Feb.

Flach, J.M. (1991). Active psychophysics: New problem, new method, or new paradigm? Invited presentation to the Psychology Department, University of Cincinnati, OH, 18 Oct.

Flach, J.M. & Allen, B.L. (1991). Dynamic occlusion: Active versus passive observers. Poster presented at the *Sixth International Conference on Event Perception and Action*. Free University, Amsterdam.

Flach, J.M. & Hagen, B.A. (1991). Regulating altitude: Signal and noise in optic flow. Poster presented at the *Sixth International Conference on Event Perception and Action*. Free University, Amsterdam.

Flach, J.M. (1991). Invited Discussant: Motor Learning/Motor Control Symposium 2: Visual Control of Movement: Real World Applications. Presented at the *North American Society for the Psychology of Sport and Physical Activity Annual Conference,* June 13-16, Asilomar, CA.

Flach, J.M. & Hansen, J.P. (1991). The abstraction hierarchy as interface: A new look for design databases. The Armstrong Laboratory: Wright Patterson AFB, OH. May.

## References

Anderson, G.J. & Braunstein, M. (1985). Induced self motion in central vision. *Journal of Experimental Psychology: Human Perception and Performance*, **11**, 122-132.

Braunstein, M.L. (1989). Structure from motion. In J.I. Elkind, S.K. Card, J. Hochberg, & B.M. Huey (eds.). *Human Performance Models for Computer-Aided Engineering*. Washington, DC: National Academy Press.

Cutting, J. E. (1986). *Perception with an eye for motion*. Cambridge, MA: MIT Press.

Cutting, J.E.,Springer, K., Braren, P.A., & Johnson, S.H. (1992). Wayfinding on foot from information in retinal, not optical, flow. *Journal of Experimental Psychology: General*, **1**, 41-72.

Flach, J.M.(1990). Control with an eye for perception: Precursors to an active psychophysics. *Ecological Psychology*, **2**, 83 -111.

Flach, J.M., Hagen, B.A., & Larish, J.F. (1992). Visual information for the active regulation of altitude. *Perception & Psychophysics*, **51**, 557-568.

Gibson, J.J. (1958). Visually controlled locomotion and visual orientation in animals. *British Journal of Psychology*, **49**, 182-194. Also in E. Reed & R. Jones (Eds.) (1982). Reasons for realism. Hillsdale, NJ: Lawrence Erlbaum Associates. (148- 163).

Gibson, J.J. (1962). Observations on active touch. *Psychological Review*, **69**, 477-491.

Gibson, J.J., Olum, P., & Rosenblatt, F. (1955). Parallax and perspective during aircraft landings. *American Journal of Psychology*, **68**, 372-385.

Held, R. (1965). Plasticity in sensory motor systems. *Scientific American*, **213**, 84-94.

Held, R. & Hein, A. (1963). Movement-produced stimulation in the development of visually guided behavior. *Journal of Comparative and Physiological Psychology*, **56**, 872-876.

Johnson, W.W., Bennett, C.T., O'Donnell, K., & Phatak, A.V. (1988). Optical variables useful in the active control of altitude. *Proceedings of the 23rd Annual Conference on Manual Control*. Cambridge, MA.

Johnson, W.W., Tsang, P.S. Bennett, C.T., & Phatak, A.V. (1989). The visually guided control of simulated altitude. *Aviation, Space, and Environmental Medicine*, **60**, 152-156.

Larish, J.F. & Flach, J.M. (1990). Sources of optical information useful for perception of speed of rectilinear self-motion. *Journal of Experimental Psychology: Human Perception and Performance*, **16**, 295-302.

Lee, D.N. (1976). A theory of visual control of braking based on information about time-to-collision. *Perception*, **5**, 437-459.

Lee, D.N. (1980). The optical flow field: The foundation of vision. *Philosophical transactions of the Royal Society*, London, (B), **290**, 169-178.

Myers, J. L. (1972). *Fundamentals of experimental design*. Boston: Allyn & Bacon.

Neisser, U. (1989). From direct perception to conceptual structure. In U. Neisser (Ed.), *Concepts and conceptual development: Ecological and intellectual factors in categorization.* (pp. 11-24). Cambridge, MA: Cambridge University Press.

Neisser, U. (1992, Unpublished paper). Direct perception and re-cognition: Opposing theories but complimentary perceptual systems.

Owen, D.H. & Warren, R. (1987). Perception and control of self-motion: Implications for visual simulation of vehicular locomotion. In L.S. Mark, J.S. Warm, & R.L. Huston (Eds.) *Ergonomics and human factors: Recent research.* New York: Springer Verlag.

Stappers, P.J. (1989). Forms can be recognized by dynamic occlusion alone. *Perceptual and Motor Skills,* **68**, 243-251.

Warren, R. (1976). The perception of egomotion. *Journal of Experimental Psychology: Human Perception and Performance,* **2**, 448-456.

Warren, R. (1988). Active Psychophysics: Theory and practice. In H.K. Ross (Ed.), *Fechner Day '88* (Proceedings of the 4th Annual Meeting of the International Society for Psychophysics) (pp. 47-52). Stirling, Scotland.

Warren, R. & McMillan, G.R. (1984). Altitude control using action-demanding interactive displays: Toward an active psychophysics. *Proceedings of the 1984 IMAGE III Conference.* (pp. 405 -415). Phoenix, AZ: Air Force Human Resources Laboratory.

Warren, R. & Wertheim, A.H. (1990). *Perception & control of self motion.* Hillsdale, NJ: Erlbaum.

Warren, W.H. & Hannon, D.J. (1988). Direction of self motion is perceived from optical flow. Nature, 336, 162-163.

Warren, W.H., Mestre. D.R., Blackwell, A.W., & Morris, M.W. (1991). Perception of circular heading from optic flow. *Journal of Experimental Psychology: Human Perception and Performance,* **17**, 28-43.

Warren, W.H., Morris, M.W., & Kalish, M. (1988). Perception of translational heading from optical flow. *Journal of Experimental Psychology: Human Perception and Performance,* **14**, 644-660.

Wolpert, L. (1988). The active control of altitude over differing texture. *Proceedings of the 32nd Annual Meeting of the Human Factors Society* (pp. 15-19). Santa Monica, CA: Human Factors Society.

Wolpert, L., Owen, D., & Warren, R. (1983). Eye-height-scaled versus ground-texture-unit-scaled metrics for the detection of loss in altitude. *Proceedings of the 2nd Symposium on Aviation Psychology.* Columbus, OH.