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PSYCHOLOGICAL CONSIDERATIONS IN THE DESIGN OF  
HELMET-MOUNTED DISPLAYS AND SIGHTS: OVERVIEW AND  
ANNOTATED BIBLIOGRAPHY

AEROSPACE MEDICAL RESEARCH LABORATORY

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11. ABSTRACT An overview of the history and the known and potential psychological problems of helmet-mounted displays is followed by an extensive annotated bibliography of relevant material arranged by topics: eye dominance, brightness disparity, helmet-mounted displays/helmet-mounted sights, retinal rivalry, and the AMD visually-coupled systems symposium (of 1972). The bibliography annotations, which vary in length from one sentence to one-half of a page, describe the contents of the articles but do not evaluate them. Most of the bibliographic entries are not listed in previously published articles on helmet-mounted displays and/or sights.	

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## FOREWORD

The research covered herein was initiated by the Performance Requirements Branch, Human Engineering Division of the Aerospace Medical Research Laboratory. The research was performed in partial fulfillment of Project Order AMD/RDOP-9. Richard L. Hughes was the principal investigator for the United States Air Force Academy. Herschel C. Self, PhD, was the technical monitor for the Aerospace Medical Research Laboratory.

This technical report has been reviewed and is approved.

JULIEN M. CHRISTENSEN, PhD  
Director  
Human Engineering Division  
Aerospace Medical Research Laboratory

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## OVERVIEW

A number of converging factors make helmet-mounted displays (HMD) and helmet-mounted sights (HMS) operationally desirable, if not operational necessities. Space limitation in an already crowded cockpit environment is such that if additional information is to be presented to pilots, it must be through the use of either heads-up displays or helmet-mounted displays (Strother & Upton, 1971). Recent advances in technology make it possible to slave aircraft weapon systems to the pilot's line of sight. Furthermore, pilots' preference for a heads-up rather than a heads-down attitude in flight is well known.

Miller (1969) traced interest in helmet-mounted displays and reviewed potential problems concerning their use. These problems include switching from a daylight system to a night system, retinal rivalry, problems with mirrors and reflectance of light, weight considerations, and pilot acceptance. A more in-depth review of perceptual processes and HMD design concepts was conducted by Shontz & Trumm (1969). One of their conclusions was that "a great deal more" human factors research is needed. For instance, there is no evidence that the visual system can simultaneously process two independent channels of visual information. Since those conclusions were written the technology of helmet-mounted displays and sights has been receiving considerable attention. It is imperative that every effort be made to insure that these advanced systems are made usable for man, and

represent the state-of-the-art in human engineering as well as in machine engineering.

Helmet-mounted displays may involve any of several quite different techniques for display presentation. These techniques range from holographic visor displays to cathode ray tube displays. There are unique perceptual problems associated with each. Most currently operational HMDs use a miniature cathode ray tube display presented directly to the pilot's eye(s) through an optical system attached to his helmet. The actual size of the display is small, but its apparent size can be quite large due to its proximity to the eye. Unless otherwise stated, this paper shall be concerned with helmet-mounted displays of the cathode ray tube variety.

Shontz and Trumm (1969) categorize current approaches to HMD design in three ways: one-eye, occluded systems; one-eye, see-through systems; and two-eye, see-through systems. With one-eye, occluded systems the pilot is presented a monocular view of both the real world and the display, one eye seeing only the display and the other seeing only the real world. Perceptual problems with this design which must be investigated are size/distance judgements, reaction time, brightness disparity, retinal rivalry, detection capability, limited field of view, and possible eye strain.

The second HMD concept, the one-eye, see-through design, provides the pilot with a binocular view of the real world while also providing a monocular view of display imagery. With this design some of the



problems associated with the one-eye, occluded concept are diminished. Retinal rivalry, display contrast, and differential dark adaptation in the two eyes (which may induce the Pulfrich phenomenon) are still major problems, however.

The final design concept is the two-eye, see-through system. It provides a binocular view of the real world and the potential of two simultaneous, independent, monocular display presentations. As presently conceived, this design creates such a serious problem of information processing and so restricts the field of view that it would be almost impossible to use (Shontz & Trumm, 1969).

A helmet-mounted sight differs from a helmet-mounted display in several respects. Whereas the imagery of an HMD may be anything which can be displayed on a cathode ray tube, an HMS is simply a sophisticated gunsight. Its imagery is usually some type of tracking gate or reticle. Furthermore, while an HMD can be used in such applications as area search and target detection and recognition, an HMS gives no additional flight information (Linton, 1971).

Both the Army and Navy have operational helmet-mounted sights. Although the Army employs a purely mechanical slaving system which bears little resemblance to the Air Force electro-optical system, the Navy uses a version developed by Air Force HMS programs (Klass, 1972).

Perceptual problems, such as the ideal shape and color of the reticle, associated with the use of currently employed helmet-mounted sights appear to be minimal. Both because of the nature of the equipment used and tasks involved, the perceptual processes associated with the

use of helmet-mounted displays are more complex and pose the greater and more immediate human factors problems. In particular, further experimental research needs to be conducted on the processes of retinal rivalry, brightness disparity, and eye dominance. Several other perceptual processes also require expanded systematic investigation. Each of these will be discussed below and specific recommendations for further research will be made.

#### Retinal Rivalry

When differing visual fields are presented to the two eyes separately, several different perceptions may result. The two fields may fuse. This will happen when the differences between the fields are small. In fact, this is the case in normal binocular vision because the visual fields presented to the two eyes are always, necessarily, somewhat different in perspective. When the differences between the fields are greater, they may be seen as superimposed. Sometimes the superimposition is partial so that only parts of the two fields will be seen at one time. Sometimes both can be seen, but one with much greater clarity than the other. Sometimes one of the fields may dominate. This may be expected if one eye is dominant or has much greater visual acuity than the other (Horowitz, 1949). Finally, the two fields may alternate; first one will be seen and then the other. This alternation is called retinal rivalry (also binocular rivalry). Technically, retinal rivalry is normally defined as the irregular alternation of colors or figures when the two eyes gaze upon different fields that cannot be given unitary interpretation.

Horowitz (1949) points out that when the binocular combination of dissimilar fields does occur, the results are often unexpected. For instance, if a black field is presented to one eye and a white field to the other, the resulting perception is one of lustre. The resulting perception is nothing like that accompanying presentation of the intermediate gray to both eyes. With such varying and unpredictable possibilities accompanying the presentation of dissimilar visual fields to the two eyes, it is understandable that retinal rivalry is considered a major problem in the design of helmet-mounted displays.

Most of the research on retinal rivalry has been directed toward determining those factors which either affect the frequency of alternation or influence the temporal dominance of one field over the other. The various independent variables which have been related to these measures may be conceptualized into three classes: (1) physical characteristics of the stimulus fields, (2) cognitive-affective characteristics of the stimulus fields, or (3) the effects of practice or special instructions. Each of these classes will be briefly reviewed below.

Among the physical variables that have been related to retinal rivalry are contrast, brightness, contour, continuity, illumination, interest, movement, and color of the opposing fields. Alexander (1951) and Whittle (1965) demonstrated that the field containing the greater figure-ground contrast will be the more dominant. Other researchers (Alexander & Bricker, 1952; Mull, Armstrong, & Telfer, 1956) have been unable to demonstrate a relationship between contrast and dominance.

It has been widely demonstrated that the brighter of two fields in a retinal rivalry situation will dominate (Breese, 1909; Horowitz, 1949; Kaplan & Mettay, 1964; Bokander, 1965, 1966).

Horowitz (1949) stated the principle that contours will dominate over plain fields. Further, Alexander (1951) showed that figures with continuous contours will dominate over figures with broken contours. Both Kaplan & Mettay (1964) and Mull, Armstrong, & Telfer (1956) demonstrated that as the illumination of both fields is increased, alternation rate also increases. Horowitz (1949) stated that the geometrically more interesting of two fields will dominate. Woodworth and Schlosberg (1954) report that a moving figure will dominate a stationary one. Finally, Pickford (1947) showed that in binocular color combination complementary colors are difficult to combine and light colors are difficult to combine with dark colors.

The two competing fields in a retinal rivalry situation can differ in more than just physical characteristics. They can also differ in terms of their cognitive-affective content. A considerable body of data indicates that the past experience of the observer is an important factor in retinal rivalry. For instance, there is a greater tendency to see pictures specific to one's own culture, religion, or race when they are presented stereoscopically with pictures of other cultures, religions, or races (Bagby, 1957; Lo Scioto & Harley, 1963; Pettigrew, Allport & Barnett, 1958). When upright and inverted photographs of male faces are presented stereoscopically, the upright photograph dominates (Engel, 1956). Kakizaki (1950) demonstrated that

pre-exposure to geometric figures influences retinal rivalry when they are later presented stereoscopically. Clearly the learning history of an individual can be a relevant factor in a retinal rivalry situation. The result of this learning need not be purely cognitive, however. In many instances there might also be an affective component. For example, Lo Scioto and Hartley demonstrated that Catholics and Jews more readily identify symbols relevant to their own religion when these symbols are presented stereoscopically with those of the other religion. This effect could be due to greater cognitive experience with their own symbols or to the fact that their own symbols are more important (affectively) to them. The cognitive and affective components cannot be separated in this case. In fact, little work has been done on the influence of purely affective factors in retinal rivalry. This would seem to be an area of importance in helmet-mounted displays when one considers the stressful situations which a pilot might encounter.

The third major class of variables which have been related to retinal rivalry has to do with the effects of practice or special instructions. Several researchers have shown that alternation rate in retinal rivalry can be influenced with appropriate instructions (Meredith & Meredith, 1962; Lack, 1969, 1971). It is possible for an observer to change the rate of alternation when instructed to do so (e.g., "Make the fields alternate as rapidly as possible."). It may also be possible to use instructions which will affect the rate indirectly. For instance, it has been shown that rate of alternation in retinal rivalry varies with the duration of target fixation (Aafjes, Hueting, & Visser, 1966).

Instructions which require varying periods of target fixation should affect alternation frequency. Collyer & Nevan (1970) demonstrated that a degree of voluntary control in retinal rivalry applies not only to the rate of alternation but also to which field at any moment would be the dominant one. In other words, an observer can control to some extent which field he sees. Lastly, knowledge of results and distribution of practice are important independent variables which seem to have additive effects in the control of rivalry rate.

The extent of voluntary control over aspects of retinal rivalry should not be overestimated, however. In no instance has it ever been demonstrated that by using any set of instructions, any special procedures, or any amount of practice can an individual develop total control over the alternation of differing visual fields presented stereoscopically.

It is at this point that some serious questions must be raised about the relevance of existing research on retinal rivalry to the design and use of helmet-mounted sights and displays. That differing visual fields presented separately to the two eyes may produce a number of unpredictable perceptions is a well documented fact. If the term retinal rivalry means the alternate perception of one and then the other of these fields, then it is only one of many possible results of the situation described. That being so, questions about the rate of alternation or temporal dominance of the fields do not seem sufficiently to the point of our present purpose. A more relevant question is, "How much is the information-receiving and

processing capability of the observer diminished when different monocular fields are simultaneously presented, each containing significant but transient information?" How fast the two fields alternate or what visual stimuli tend to be dominant in a rivalry situation may be secondary considerations. One of far greater significance is posed in the question that when they alternate or when one of the fields is dominant, how much does the observer not see? Little of the existing literature on retinal rivalry has been directed at this question. Much of the evidence that does exist on this matter indicates a significant decrement in information processing when independent channels of visual information are presented to the two eyes.

For instance, Fox & Check (1966) demonstrated poorer form recognition in the suppressed field during rivalry. In another experiment (Fox & Check, 1968), they found it took significantly more time to detect movement in the suppressed field during rivalry. When different visual fields are presented to the two eyes tachistoscopically, the observer sees substantially more in one field than in the other (Kephart & Reevesman, 1953). In some cases, the inhibition during rivalry may even suppress the normal pupillary reflex to a bright flash (Bokander, 1967).

On the other hand, Jacobs, Triggs, & Aldrich (1970) summarize an experiment conducted at Hughes Aircraft, Culver City: "Although each eye of the subject received different visual inputs, it was demonstrated that this did not prohibit perception of both sets of information."

Unfortunately, neither the procedure nor statistical data of this experiment are presented. The significance of their conclusion depends upon such factors as whether the different visual inputs were static or dynamic and could not be meaningfully interpreted without such information. For example, if the differing inputs were static and the observer were given sufficient time, it is entirely reasonable that all of the information in each field could be perceived. But this situation is very unlike the actual use of an HMD in flight and in combat. There, both sets of inputs may be changing rapidly and continuously and unlimited decision time will not be available. And, of course, the more rapid the rate of change of information over each channel, the more difficult the task of monitoring both.

Another experiment conducted at Hughes Aircraft (Technical Proposal, Report No. TP70-129) used the Electrocular, an early prototype HMD. Subjects monitored radar using either the Electrocular or a conventional display. It was reported that subjects using the Electrocular experienced little visual fatigue and that the display was seen as "distinct and separate from the surrounding environment, not occluding other visual tasks or displays in the subject's line of vision." Again, however, neither specific procedures nor statistical data were presented.

Two other phenomena have been reported which bear some resemblance to retinal rivalry and may be of some relevance in the design and use of helmet-mounted displays. Springbett (1961) reported that contours or surfaces presented to one eye may be erased when a moving contour



is presented to the other. Levelt (1965) argued that the occasional disappearance of a target when it is presented to one eye and a homogeneous field is presented to the other is the result of spontaneous fading and cannot be due to retinal rivalry. This phenomenon is called Troxler's effect. Goldstein (1967), however, presented evidence which suggests that Troxler's effect and retinal rivalry are at least strongly related.

#### Brightness Disparity

The special instance of retinal rivalry involving differing brightnesses of the two fields is called brightness disparity. Its implications for helmet-mounted displays merit special consideration. It will be seen, however, that the adverse perceptual effects resulting from differing monocular brightnesses are not limited to the production of retinal rivalry.

One of the major human factors problems in the development of HMDs has been that of differing monocular brightnesses between the occluded and the nonoccluded eye. In daylight, the outside world may register, on the average, 3,000-5,000 foot-lamberts with peaks as high as 10,000 foot-lamberts, whereas the brightness of a cathode ray tube display is typically less than 100 foot-lamberts. The practical extent of this problem is underscored in a flight test report on a one-eye occluded HMD by Hughes Aircraft (Jacobs, Triggs, & Aldrich, 1970). Test subjects found great difficulty in using the HMD on the right eye when the left eye was exposed to the high ambient brightness of daylight.

"Retinal rivalry effects were marked under these conditions. In fact, most flying was done with an eyepatch covering the left eye." The report went on to note that rivalry effects were reduced and satisfactory information was obtained from the HMD when a one percent transmission neutral density filter was placed over the open eye. This is not an ideal solution, however. Even overlooking the vagueness of the phrase "satisfactory information," the use of a filter over the nonoccluded eye is objectionable because of the additional restriction it would impose upon vision. In addition, Gassowski (1941) demonstrated that the discrimination of information presented monocularly is reduced if the other eye views a surface of different brightness.

To some extent, this problem is reduced because the two eyes dark adapt somewhat independently. But even with different dark adapted states, a transient bright stimulus in the field of the open eye will cause some consensual pupillary constriction in the eye viewing the HMD. Helmet visors with variable transmittance capability have been investigated as one means to overcome this problem.

The associated need for a variable reflectance optical mirror poses greater problems. The HMD see-through device must have a reflectance as high as 90% for daylight use to maintain sufficient image contrast. During night operation, however, the low resulting transmittance would negate any effective see-through capability.

Using a one-eye, see-through HMD is similar to viewing the world binocularly, but with a filter over one eye. When the world is so

viewed, abnormalities in depth perception result. For example, a swinging pendulum viewed binocularly, but with a reducing filter over one eye, is perceived as following an elliptical path in depth rather than the linear path the pendulum truly describes. This is called the Pulfrich phenomenon. Lit (1949) investigated the functional relation between the apparent displacement of the oscillating pendulum and the difference in retinal brightnesses. Rock & Fox (1949) demonstrated that the Pulfrich effect could be produced using differently dark-adapted eyes rather than a monocular filter. Diamond (1958) discovered a perceived displacement opposite to the Pulfrich effect when an inducing field was placed in the periphery of one eye. The abnormalities of depth perception induced by these methods suggest that the use of HMDs could pose serious problems in flight where the accuracy of a pilot's depth perception is essential.

#### Eye Dominance

Most existing prototypes for a one-eye HMD rely upon a right-eye display; although some are capable of relocation to the left side. It is possible that a left-eye display would be a more optimal design for some individuals just as some individuals are more adept at certain tasks with their left hand than with their right. This preference for one eye over the other in certain tasks, such as sighting, is called eye dominance or ocular dominance.

Eye dominance cannot easily be accounted for strictly on the basis of cerebral dominance since both eyes project to both cerebral

hemispheres. Nor is eye dominance related to handedness (Gates & Bard, 1936; Jasper, 1937; Hamburger, 1948) or visual acuity (Snyder & Snyder, 1928; Gates & Bard, 1936; Drenkbahn, 1937). It is better to consider eye dominance a product of the conjugal movement of primate eyes. Since the eyes act together, it would seem more efficient for one to initiate the motor adjustments involved in fixation and accommodation. Further, it would seem reasonable for this leading or dominant eye to be more efficient in this role than the nondominant eye (Foley & Ross, 1963).

Several estimates have been made of the distribution of right and left eye dominance. Snyder & Snyder (1928) tested subjects for eye preference. Approximately 15% had no eye preferences, 64% had a right monocular preference, and 21% had a left monocular preference. Jasper (1937) also found a strong preference for the right eye. Using a test for eye dominance based upon the Phi phenomenon, he found that 86% of his subjects were right-eye dominant, 12% were left-eye dominant and 2% were indeterminate.

The differences in distribution of eye dominance found in these two samples can be accounted for at least in part by the different tests used. In fact, many tests of eye dominance are available (Miles, 1930). Buxton & Crosland (1937) determined the statistical reliabilities of four tests of eye dominance and then investigated the relationship between them. While the test-retest reliabilities of the four tests averaged  $+0.92$ , the correlations among them were not high, in one case as low as  $+0.44$ . With such substantial disagreement among the tests,

it may be that eye dominance, like hand dominance, is better defined in terms of specific activities for which an eye is used (Buxton & Crosland, 1937). Warren & Clark (1938) argued that eye dominance does not exist as a unitary factor. Laterality is so determined by situationally specific factors that they even questioned continued use of the term ocular dominance.

Even if eye dominance is a situationally specific variable, however, it may still be a relevant factor for HMD. This conclusion is based on the fact that there is contradictory evidence regarding its importance in those kinds of tasks which are related to monitoring a display.

One such task is monocular visual tracking. Gilinsky & Brown (1952) found that tracking performance was a function of whether the dominant or nondominant eye was used. This relationship was not corroborated by Shontz (1970), however. He concluded that, "at least for the two-dimensional, monocular presentation of target and sighting reference, the display can be placed before either eye without concern for the effects of eye dominance."

Controversy also exists regarding temporal characteristics of information processing in the dominant and nondominant eyes. Minucci & Connors (1964) reported that reaction times for the dominant eye were faster at all intensity levels than those for the nondominant eye. In questioning the validity of another study, however, Foley & Ross (1963) showed that differences in the speed of information processing between the dominant and nondominant eye disappear when fixation points are supplied.

In other studies, Miles (1933) discovered an anomaly of depth perception based upon eye dominance, and Mefferd & Wieland (1969) found differences in size estimation between the dominant and the nondominant eye.

#### Other Relevant Variables

In addition to retinal rivalry, brightness disparity, and eye dominance, several other perceptual variables should be considered in the design of HMDs.

The engineering compromises which must be made between exit pupil, field of view, and helmet weight can potentially result in so small an exit pupil that the display image would disappear if the helmet shifted even slightly on the head. Because of the eccentric weight of the helmet when an HMD is added, helmet shifting would be very likely to occur under heavy g-loads. In addition, stresses upon the face mask under g-loads cause helmet shifting. Such stresses would be common during air-to-air combat. Thus, the display information could be lost at those times when it would be most critical.

There has been little investigation of the effects a side-mounted display would have upon peripheral vision. Flight test reports (Jacobs et al., 1970) suggest that some problems do exist in this area. For example, subjects reported the impression of "looking into a tunnel" while using an HMD. Research is now being conducted at the U. S. Air Force Academy to determine whether various HMD parameters do restrict peripheral vision. If any do, it has been suggested that the

restriction could be easily overcome by increased head movements (personal communication at Hughes Aircraft, Culver City, 1972). However, the possibility that this could be fatiguing, especially on long flights, needs study.

Accommodation to near targets (such as panel displays) while simultaneously viewing a display collimated at infinity may be difficult. A Hughes Aircraft study (OOLHMD), however, reports that "the operator soon learns to rapidly accommodate in shifting his vision from the near-at-hand view to the far away CRT scene."

The process of shifting attention is a central question with HMD and takes at least three forms: (1) the shifting of focus from near to far field in accommodation, (2) the shifting of attention from an occluded display to the field of the open eye, and (3) the shifts of attention between the superimposed fields in a see-through display. In all of these cases the observer's attention must be divided between different fields. If the information in each is critical and changes rapidly, attention shifts can be expected to be at a high rate. This may induce fatigue and poor performance. In a relevant study, Vallerie (1966) demonstrated that tracking performance deteriorates as switching increases.

A final variable of importance in HMD design is frame of reference. HMD information may be misinterpreted when the pilot's head is turned to the left or right resulting in a mistaken spatial orientation. For instance, a roll error could be interpreted and responded to as a pitch error (Jacobs et al., 1970).

### Summary of Research Questions

The previous overview was written as an introduction to the psychological considerations in the design of helmet-mounted sights and displays. It was not intended to be a comprehensive discussion of this complex area, but simply to serve as a guide to the literature outlined in the annotated bibliography.

There are many viable research questions associated with the interface of man and helmet-mounted sights and displays. The following list is a brief outline of the most critical questions at this point of development from the viewpoint of the authors:

1. To what extent is a pilot's performance impeded by shifts of attention?
2. Can independent channels of continuously changing visual information presented separately to the two eyes be simultaneously monitored? Among the relevant independent variables are: rate of information change, whether the rates of change for the two eyes are equal, contrast within the fields, brightness differences between the fields, content, and spatial location of figures within fields (corresponding or noncorresponding parts of the two retinae).
3. Does stress affect retinal rivalry?
4. What restriction to peripheral vision occurs in the use of devices which are mounted within the fields of view? What additional restriction to vision is imposed if a neutral density filter is worn over the real-world eye to reduce brightness difference between the eyes when an occluding HMD is worn?



5. What is the effect on real-world vision in the use of neutral density filtering of both eyes in a see-through HMD?

6. Does a one-eye (occluding) HMD induce the Pulfrich effect and if so, to what extent will it seriously impede the pilot's depth perception?

7. What is the effect on performance associated with the low transmission levels of ambient light required in visor displays to produce satisfactory contrast ratios for HMDs?

8. How frequently, as a function of signal strength and duration, can a brief signal to the suppressed eye during retinal rivalry go completely unnoticed?

9. Physiologically, how much additional workload is imposed on the pilot by head movements (with a heavier helmet) which compensate for restricted peripheral vision?

10. How much does an eccentrically weighted helmet shift as a function of g-loading?

11. How much, if any, spatial disorientation can be expected when the head is tilted while viewing an HMD?

12. What are the critical factors associated with pilot acceptance of HMDs and HMSs?

### Conclusions

Industry has achieved remarkable technological success in the development of head-worn information displays for flight. Much of the credit for leadership in these significant achievements must be

given to the Performance Requirements Branch, Human Engineering Division, 6570th Aerospace Medical Research Laboratory.

The project objectives are to develop and demonstrate prototype helmet-mounted sight and display subsystems applicable to Air Force missions, including: (1) air-to-ground weapon delivery; (2) air-to-air combat; (3) real-time reconnaissance; and (4) FAC operations. The advantages associated with the use of an HMS include wide off-boresight weapon aiming; quick reaction time; hands-free/head-up tracking; and natural head-tracking of targets. The HMD offers a display similar to a large screen television picture, seen at optical infinity, projected as an overlay of the real world (as desired), and continuously available regardless of head positions. Such advantages are certainly worthwhile objectives considered against the tremendous demands made upon pilots in the high performance environment of present and future flight operations.

The development of these complex systems demands concentrated and cooperative efforts on the part of the military and industry. Such efforts are underway, and increasing at a rapid rate. This was demonstrated clearly during the Symposium on Visually Coupled Systems Development and Application held at Brooks AFB on 8-10 November 1972. Abstracts of the presentations are included as a final section to the annotated bibliography. A few abstracts were not available. Questions on these should be directed to the authors.

## ANNOTATED BIBLIOGRAPHY

### EYE DOMINANCE

- Bakker, D. J. Eye-asymmetry in a simple RT task with children. Perceptual and Motor Skills, 1969, 28(1), 328.

Presented 120 boys and girls (6-11 years old) with flashes of white light, generated by an RT apparatus. Each S was tested under 3 conditions: both eyes, right eye, and left eye. Left eye dominance was found with girls of 9 years and older, but not at all with boys. RTs with binocular stimulation were shorter than RTs with monocular stimulation. However, the difference appeared to be greater with girls than with boys.

- Baneojee, M. N. Monocular estimation of short distances. Indian Journal of Psychology, 1929, 4, 104-113.

Reports a class laboratory experiment in estimation of distances monocularly. With distances of 5 cm and 10 cm more accurate estimations are made with the right eye, whereas the distance of 25 cm is better judged with the left eye.

- Bokander, I. 1965. (See Retinal Rivalry)

- Bokander, I. 1966. (See Retinal Rivalry)

- Buxton, C. E., and Crosland, H. R. The concept of eye preference. American Journal of Psychology, 1937, 49, 458-461.

The purposes of the research were to determine (1) the statistical reliability of single performance tests of eye preference, and (2) the degree of relationship between such tests. The tests used were (1) manoscope, (2) hole in card, (3) ring sighting, and (4) aiming. Handedness was controlled in the first three tests. The reliabilities of the four tests ranged from .87 to .96; the pooled scores for all four tests was .92. Correlations between the four tests, however, did not suggest a unitary trait of eye preference, since they varied between .44 (manoscope-sighting) and .71 (sighting-aiming). It was suggested that possibly eye preference, like hand preference, may be better defined in terms of the number of activities for which an eye is preferred.

- Crider, B. A battery of tests for the dominant eye. Journal of General Psychology, 1944, 31, 179-190.

A battery of tests for determining eye dominance is reported.

Crovitz, H. F., & Lipscomb, D. B. Dominance of the temporal visual fields at a short duration of stimulation. American Journal of Psychology, 1963, 76(4), 631-637.

The background question was the unsolved problem of how the binocular field is related to monocular fields which underlie it. A mirror stachistoscope was used for presenting the stimuli. Two stimulus conditions were designed to present different colors to corresponding areas of the two eyes. The most common percept corresponded to the colors which stimulated the nasal retinas. The data suggested that the binocular field develops over time from monocular fields with the crossed over fiber system showing early dominance.

Culver, C. M., Tanley, J. C., & Eason, R. G. Evoked cortical potentials: Relation to hand dominance and eye dominance. Perceptual & Motor Skills, 1970, 30(2), 407-414.

Studied the amplitude and symmetry of right- and left-occipital lobe evoked potentials (EPs) to right and left visual-field stimulation as a function of hand and eye dominance in 24 female undergraduates. For all Ss, right-lobe EP amplitudes were greater than left-lobe during left visual-field, but not right visual-field, stimulation. Left-eyed Ss had significantly greater EP amplitudes than right-eyed Ss. Comparing this study with previous ones suggests a sex difference in the relationship of handedness to right lobe-left lobe asymmetry.

Drenkbahn. The dominating eye (Das dominierende auge). Deutsche Militararzt (Berlin), 1937, 2, 212.

Investigations of left- and right-eyed soldiers showed that it is not the better but the dominating eye which is used in sighting. Evidently, visual acuity is not a determinant of eye dominance, but the latter is determined by a certain cortical function which gives one, probably the near-sighted eye, greater preference than the other.

Duke, J. D. Lateral eye movement behavior. Journal of General Psychology, 1968, 78(2), 189-195.

Confirmed some of M. E. Day's observations on lateral eye movements: (1) after complex or reflective questions, an undergraduate S momentarily broke his gaze upon the E; (2) he laterally turned his eyes to the right or left before responding; (3) simple questions seldom elicited eye movement behavior; (4) the direction chosen was characteristic for individuals, but not for the group; (5) males more consistently than females turned in 1 direction only; (6) eye

dominance was independent of the phenomenon; and (7) gazing interactions are replete with research potential for interested investigators.

Foley, P. J., & Ross, P. Binocular interaction and serial addition. Australian Journal of Psychology, 1963, 15(1), 12-14.

Study reported that when fixation points are supplied, the differences between the dominant and nondominant eye, at brief exposure times, disappear. This study questioned the validity of a study by Sampson where Sampson concluded that information from the nondominant eye is integrated more slowly than that from the dominant eye.

Gates, A. I., & Hard, G. L. Relation of handedness, eye sighting and acuity dominance to reading. Journal of Educational Psychology, 1936, 27, 450-456.

Tests of handedness, eye dominance and visual acuity were given to children in four groups: (1) 65 retarded readers with a mean age of 8.61 years, (2) a control group of 65 normal readers equivalent in other aspects to the first group, (3) a group of 55 first-grade pupils studied repeatedly during the year, and (4) a group of 57 first-grade pupils studied during the first half of the year. The data obtained from the first-grade pupils, older normal readers, and older reading problem cases showed no consistent tendency for eye dominance, single eye superiority in acuity, hand dominance, or any combination of these to be related to achievement in reading, word pronunciation, reversal errors, or visual perception of various items.

Gilinsky, A. S., & Brown, J. L. Eye dominance and tracking performance. Wright Air Development Center, Wright-Patterson Air Force Base, Ohio. Technical Report WADC 52-15, April 1952.

Found differences in tracking performance as a function of dominant versus nondominant eye when subjects performed a compensatory tracking task using eye/hand coordination.

Gronwall, D. M., & Sampson, H. Ocular dominance: A test of two hypotheses. British Journal of Psychology, 1971, 62(2), 175-185.

Administered a battery of eye dominance tests to 50 17-22 year old undergraduates to determine (1) whether there are 5 types (J. Lederer) or 2 types (G. Walls) of ocular dominance, and the relation between these tests and handedness. There was no evidence in support of either classification, or of any correlation between the preferred eye and the preferred hand. An alternative hypothesis to those formulated by Lederer and by Walls was presented to account for the results.

Hamburger, F. A. Monocular dominance in binocular vision. Klinische Monatsblätter Für Augenheilkunde und Für Augenärztliche Fortbildung, 1943, 109, 1.

Individuals were tested for eye dominance before and after training in range finding. They showed a loss of eye dominance after the training in binocular vision in range finding. There appeared to be no connection between handedness and eye dominance.

Hirata, Ken-Johi, & Osaka, Ryoji. Tachistoscopic recognition of Japanese letter materials in left and right visual fields. Psychologia: An International Journal of Psychology in the Orient, 1967, 10(1), 7-18.

Under successive and simultaneous conditions, perception in the right visual field was better. However, with single letter and nonletter materials, no difference was shown. Eye dominance in the Ss was discussed as a possible explanation.

Humphiss, D. (See Retinal Rivalry).

Jasper, H. H., & Raney, E. T. The phi test of lateral dominance. American Journal of Psychology, 1937, 49, 45-457.

The investigation determined the dominance of the eyes in the visual projection area and compared the results with other tests of dominance. This was done by determining the asymmetry in the perception of direction of movement in the phi phenomenon. Ss were tested twice, 4 weeks apart, with a battery of tests including the phi test, a questionnaire on manual habit preferences, the manoptoscope and paper sighting tests, and the Van Riper critical angle board test. The results showed that 86% of the Ss were right dominant, 12% left dominant, and 2% indeterminate on the phi test, and these results were more closely in agreement with the questionnaire than with any other test used. The agreements between the phi and paper sighting tests and between handedness and eyedness were only a little better than chance. Only chance agreement was found between eyedness and laterality according to the critical angle board.

Jordan, S. Autokinesis and felt eye-position. American Journal of Psychology, 1968, 81(4), 497-512.

Investigated the relationship between perceived eye-position and autokinesis in a series of experiments with 38 undergraduates. Systematic changes in the felt position of the eyes were found to accompany autokinesis. Specifically it was found that an S asked to look straight ahead tended to look in a direction opposite to the direction of autokinetic movement. Since this shift in felt eye-position was found not only during and after but prior to auto-

kinesis, it was concluded that a shift in felt eye-position was a sufficient condition for the perception of autokinetic movement. A theory was proposed on the basic assumption that the eye-position felt to be straight ahead coincides with the center of incoming or afferent stimulation, impinging on the eye. In the darkness, internal sources of asymmetrical stimulation, such as those due to eye-dominance, were assumed sufficient to shift the egocentric coordinates of visual space, resulting in the apparent displacement of a geographically fixed light.

Kaufer & Reiss. (See Retinal Rivalry).

Linton, P. M. (See Helmet-mounted Displays).

McAndrews. Ocular dominance. Archives of Ophthalmology, 1935, 13, 449-455.

Reviews literature, theories of origin (e.g., hereditary) and the possibility of shifting as a result of training.

Mefferd, R. B., Jr., & Wieland, B. A. Influence of eye dominance on the apparent centers of simple horizontal lines. Perceptual & Motor Skills, 1969, 28(3), 847-850.

Ss with right-eye dominance overestimated with either or both eyes the left segment of horizontal lines, regardless of where they fixated the line as they bisected it. The converse occurred with left-dominant Ss, except when these Ss fixated the right end of the line as they bisected it. It was hypothesized that this might be due to the formation of a sharper more accurate representation in the dominant than the nondominant cortex, with a consequent overestimation of the more diffuse representation relative to the sharper one.

Miles, P. W. An analysis of depth factors in anisopia and anisodominance. American Journal of Ophthalmology, 1934, 37, 98-106.

Anomalies of depth perception in which the retinal image of one eye is different in intensity or focus, or in which ocular dominance or unilateral defects in retinal image intensity affect depth perception, are defined.

Miles, P. W. Anomalous binocular depth perception due to unequal image brightness. AMA Archives of Ophthalmology, 1953, 50, 475-478.

A new anomaly of binocular depth perception due to unequal brightness is described and named "anisodominance." It is of general functional significance because with other distance CUES being equal, a right-eyed person will see the right of two objects nearer and vice-versa for left-eyed.

Miles, W. R. Ocular dominance in human adults. Journal of General Psychology, 1930, 3, 412-430.

Eye dominance appears generally demonstrable as a habit. As a rule, special tests must be used to detect dominance. The right hand and right eye are favored in the ordinary alignment test. Several tests of eye dominance are described. Special habits derived from training, as with the use of a microscope, do not determine eye dominance. In about 50% of the cases, adults with average and above average IQ knew which was their leading or dominant eye.

Minucci, P., & Connors, M. Reaction time under three viewing conditions: binocular, dominant eye, and nondominant eye. Journal of Experimental Psychology, 1964, 67, 268-275.

Reaction times of observers were measured for differing photopic intensity levels under binocular, dominant eye, and nondominant eye viewing conditions. Reaction time has been found to be a negatively accelerated, decreasing function of increased light intensity. There was a constant relationship between the binocular reaction time and the average monocular reaction time for each observer. Equivalent brightnesses under each viewing condition were calculated on the basis of speed of reaction. The resulting curves suggest that binocular reaction times are faster than would be expected from the data of the dominant and nondominant eye, even assuming complete summation. Binocular RTs are faster than dominant eye RTs, which in turn are consistently faster than the nondominant eye RTs at all intensity levels.

Nadien, M., Schaeffer, D. S., & Schmeidler, G. R. Mood as a confounding variable in eye dominance, field dependence and reading. Perceptual & Motor Skills, 1969, 29(1), 277-278.

Fast reading was related to strong eye dominance and good comprehension for 14 undergraduates in a good mood (but not for other Ss). Field dependence was related to weak eye dominance and poor comprehension for 21 Ss not in a good mood. Mood seems to interact with habitual tendencies to affect response.

Oltman, P. K., & Capobianco, F. Field dependence and eye dominance. Perceptual & Motor Skills, 1967, 25(2), 645-646.

21 Ss with incompletely established eye dominance were found to be significantly more field dependent (hidden-figures test) than 58 with established eye dominance.



Pateu, J. The 'good eye' and ocular dominance in the building trade training (Coup d'oeil et dominance oculaire dans l'apprentissage des metiers du natement.) Bulletin du Centre d'Etudes et Recherches Psychotechniques, 1958, 7, 211-219.

A good eye is important in the trades due to the importance of visual aim. An analysis of work and learning helped develop a test of visual aim, the results of which are further improved by taking predominance into account.

Sampson & Horrocks. (See Retinal Rivalry)

Sampson, H., & Spong, P. Binocular fixation and immediate memory. British Journal of Psychology, 1961, 52, 239-248.

10 right-handed, right eye-dominant Ss memorized conventional digits projected successively in pairs, 1 digit to each eye. Each worked under 5 different binocular viewing conditions. Performance was analyzed in terms of speed and accuracy of recall of digits projected to each eye. Results suggest a central integrating mechanism of limited capacity in recall, and that temporal grouping of responses is symptomatic of this limited capacity when the mechanism is taxed.

Sampson, H., & Spong, P. Handedness, eye-dominance, and immediate memory. Quarterly Journal of Experimental Psychology, 1961, 13, 173-180.

Subjects varying in handedness and eye dominance recalled conventional and unconventional digits under two conditions: (1) when the same type digit was projected simultaneously to each eye. Right eye-dominant groups, particularly a right-handed and right eye-dominant group, were superior in both accuracy of recall and speed of response to left eye-dominant groups. Least able to recall were left-handed, left eye-dominant subjects. Superiority of right eye-dominant groups was especially marked when a different type of digit was projected to each eye.

Scherdemann, N. V. A simple test for ocular dominance. American Journal of Psychology, 1931, 43, 126.

By tearing a bit (1/2 inch in diameter) out of a sheet of paper and by having the S look at the bit of torn out paper through the hole at a distance of about 15 or 20 inches from the face, S's ocular dominance can be tested. After locating the bit of paper through the hole, S closes the right eye. If he still sees the scrap of paper he is left-eyed; if he is no longer able to see it he is right-eyed. The advantage of the test is its simplicity and the ease with which it can be used.

Shontz, W. D. The effects of eye dominance on target acquisition and tracking performance with a helmet-mounted sight/display. Honeywell Document No. 14327-TRZ, December 1970.

The purpose of this experiment was to determine if motor ocular dominance could be used to predict performance on a target acquisition and tracking task using the Honeywell helmet-mounted sight/display system. Eye dominance in this study was defined in terms of a S's performance on a series of sighting tests. No comparison could be made of left-eye versus right-eye dominant Ss, but the effects of eye dominance per se were evaluated. Performance on a target acquisition and tracking task was evaluated as a function of the eye used and target speed. No relationship existed between eye dominance and the time taken to acquire targets. Tracking error increased as target speed increased.

Smith, L. Eye dominance in a monkey. Perceptual & Motor Skills, 1970, 31(2), 657-658.

Developed a technique of examining eye dominance in a rhesus monkey. One S was tested in binocular viewing conditions which were conflicting due to the method of previous training. Left-eye dominance was demonstrated in this S, who also preferred to use its left hand when working a lever.

Snyder, A. M., & Snyder, M. A. Eye preference tendencies. Journal of Education Psychology, 1928, 19, 431-433

About 15% of Ss tested had no eye preferences, i.e., were ambocular. 64% had a right monocular preference and 21% a left monocular preference. Eye preference does not seem to be correlated with hand preference, nor does it seem caused by the inferiority or superiority of one eye. In many cases, the preferred eye was weaker.

Stoddard, K. B., & Morgan, M. W. Monocular accommodation. American Journal of Optometry, 1942, 19, 460-465.

Although averaged results confirm the view that monocular accommodation does not appreciably exceed .12 diopter, differences of as much as .50 diopter were found for individual observers. A haploscope was used, first to balance accurately the refractive corrections of the two eyes, and then to determine the change in the refractive state of each eye while the eyes fixated binocularly an object at 40 cm and while lenses of powers from .25 to 1.00 diopter were inserted before one eye. Three curves presented indicated the great variety in individual responses to each stimulus situations. Differences were also noted for single observers according to whether the stimulus lens was placed before

the right or left eye. No significant correlation was found between this sort of variation and eye dominance.

Toch, H. H. Can eye dominance be trained? Perceptual & Motor Skills, 1960, 11, 31-34.

An attempt was made to temporarily modify eye dominance through training. A series of 10 stereograms was developed in which one of the two monocular fields strongly predominated over the other. Training consisted of consecutive stereoscopic presentations of these slides, with the dominant field always to the left eye. Total viewing time was 10 minutes. A control group was presented with stereograms which produced composite images. Eye dominance was measured before and after viewing in both groups. The pre-tests showed a tendency toward right eye dominance. This tendency was not present in the post-tests, but neither was there a detectable difference between the two groups. The article discussed alternative explanations. Eye dominance might be viewed as a complex functional relationship or it may be too efficient for any training.

Walls, G. L. A theory of ocular dominance. AMA Archives of Ophthalmology, 1951, 45, 387-412.

"Sighting dominance" is motor in character. It is hypothesized that motor ocular dominance consists in the use of innervating patterns transmitted to the rotary muscles of one eye only for the determination of visually perceived egocentric direction of objects.

Warren, W., & Clark, B. A consideration of the use of the term ocular dominance. Psychological Bulletin, 1938, 35, 298-304.

Eye dominance as a single unitary factor does not exist. Laterality of eye functioning is specifically determined by the situation in which the measurement is made. The relationships between the eyes in such specific measurements are not an indication of any cerebral dominance. Sensory neural organization indicates that the problem of central functioning involves determining the relationships of the two values of the retina rather than the two eyes as a whole. The motor functions of the two eyes are controlled by both hemispheres and cannot be sources from the point of view of cerebral dominance. In view of these facts it should be argued that in the use of the term "ocular dominance" the specific method of measurement be included in the statement of laterality. From this point of view, even the unqualified use of the term "sighting eye" is questionable, since the situation frequently determines the eye used in sighting.

Whittle, P. (See Retinal Rivalry)

Wold, R. M. Dominance--fact or fantasy: Its significance in learning disabilities. Journal of the American Optometric Association, 1968, 39(10), 908-916.

Designed a test battery to study the relationship between various eye dominance tests in a learning disability population of children. A relationship between crossed or mixed eye-hand dominance and learning disabilities was noted. "When the controlling eye for reading is utilized instead of the traditional peripheral or sighting eye (acuity) test the relationship becomes more apparent." Lack of a control group and sex differentiation is noted.

## BRIGHTNESS DISPARITY

Bartley, S. H. Some parallels between pupillary 'reflexes' and brightness discrimination. Journal of Experimental Psychology, 1943, 32, 110-122.

Pupils of two eyes were measured by infrared photography during response to independent stimulation by discs of various sizes and intensities. When stimulation on one eye was very small, or entirely absent, the pupil followed the other pupil precisely.

Bokander, 1966. (See Retinal Rivalry)

Bradshaw, 1970. (See Retinal Rivalry)

Cobb, P. W., & Moss, F. K. Lighting and contrast. Transactions of the Illuminating Engineering Society, 1927, 22, 195-204.

Studied three conditions: (1) contrast between object and immediate background, (2) contrast and adaptation effects of working back and forth between fields differing in brightness, and (3) contrast between working area and outlying areas within field of vision. Tests were used for (1) speed of vision, (2) rate of comparison of pairs of letters for similarity, and (3) threshold of discrimination of black dots in case of large working area and precision of setting a moveable pointer in case of smaller working area.

De Silva, H. R., & Bartley, S. H. Summation and subtraction of brightness in binocular perception. British Journal of Psychology, 1930, 20, 241-250.

Tried to prove a measureable change in the binocular brightness observed when the illumination of one eye was altered. Examination was made of Sherrington's earlier work on the problem. The present results, in opposition to those obtained by him, show that the two eyes function integratively as regards brightness. The findings of F. Allen upon induced effects upon one retina resulting from stimulation of the other retina with dark adaptation or with colored lights were corroborated.

Diamond, A. L. Simultaneous brightness contrast and the pulfrich phenomenon. Journal of the Optometry Society of America, 1958, 48, 887-890.

The investigation concerned whether the Pulfrich phenomenon would occur if the brightness of the moving object were reduced (in one eye) not by a filter, but an inducing field. When a filter

was placed in front of the observer's left eye, this produced a displacement of the moving object away from the observer. This was the Pulfrich effect. When an inducing field was presented slightly peripherally to the observer's left eye, this produced a displacement of the moving object toward the observer, or in the opposite direction of the Pulfrich phenomenon. Displacement was directly proportional to inducing luminance. From these results, it can be assumed that the physiological mechanism for brightness reduction by an inducing field is different in whole or in part than that mechanism for brightness reduction by filter.

Dzidzichvili, H. H. On the intensity of the excitation of one eye upon the sensitivity of the other. Problemy Fiziologicheskoi Optiki (Moscow), 1941, 1, 43-46.

The differential sensitivity of one eye for a constant illumination of 2,000 lux is determined with or without excitation of the other eye varying between 3,000 and 65,000 lux. The differential sensitivity lowers rapidly in proportion as the intensity of the accessory stimulus augments, to establish itself in the neighborhood of 70% of that measured without it.

Forbes, L. M., & Mote, F. A. A comparison of the variability of binocular and monocular threshold measurements during dark adaptation in the human eye. Journal of Comparative Physiological Psychology, 1956, 49, 431-436.

This experiment was designed primarily to allow a comparison of the variability of human dark-adaptation thresholds versus the variability for each eye singly. On the whole the analyses of threshold variabilities seems to warrant the conclusion that there was no overall difference in the scatter of binocular and monocular thresholds as measured by the method used in this experiment. However, the frequency with which the binocular mean threshold lay below those for both monocular mean thresholds was highly significant and pointed to some sort of summative effect.

Gassowski, L. N. Illumination of the retina of the nonutilized eye during work at monocular visual apparatuses. Problemy Fiziologicheskoi Optiki, 1941, 1, 33-42.

Subjects were to count black dots on a white field through a monocular eyeglass. The other eye was presented either a white screen, an illuminated surface of equal brightness to the background of the dots, or a surface of twice the brightness of the dots' background. When the brightness was equal, the discrimination of the dots was better.

Graham, C. H., & Mafe, J. P. Human intensity discrimination with the Watson-Yerkes apparatus. Journal of Genetic Psychology, 1930, 37, 220-231.

The fact that in none of the experiments on brightness disparity or discrimination employing the Yerkes-Watson or similar apparatus has any animal ever shown a high degree of discrimination led to the query whether this might not be due to the character of the apparatus. It was employed with human subjects for comparison with the Konig-Brodhum curve. The obtained results showed that human brightness discrimination as measured by this apparatus is exceedingly gross as compared with the standard curve of brightness discrimination for human beings. There is some discussion as to the disadvantage of the Watson-Yerkes apparatus, with the implication that some more refined method of measuring should be used whenever possible.

Harker, G. S., & O'Neal, O. L. Some observations and measurements of the Pulfrich Phenomenon. USAMRL Report Number 728.

The Pulfrich Pendulum was evaluated as a potential screening device for the detection of anomalies of binocular vision. For this purpose, a booth was set up at the Kentucky State Fair (1964) and the general public invited to observe the pendulum and record their responses with the equipment provided. The obtained results indicate that a clear dichotomy can be achieved between those who have binocular vision and those who do not. However, graduations of binocular vision from poor to good cannot be achieved with the pendulum as presently understood. Contrary to explanatory theory, the characteristically seen shape of the seen pendulum path was asymmetrical following the rule that the path was displaced away from the observer on the side of the filtered eye.

Hartmann, G. W. The increase of visual acuity in one eye through the illumination of the other. Journal of Experimental Psychology, 1933, 16, 383-392.

In opposition to previous findings by the Russian physiologist, Kravkov, this study indicates an increase in the visual acuity of the right eye for both black objects on a white ground and white figures on a black field when the left retina is simultaneously strongly illuminated. A brain theory based upon summation of stimuli is developed to account for these findings.

Jacobs, Triggs, & Aldrich. (See Helmet Mounted Displays)

Johannsen, D. E., & Crook, M. N. Differential adaptation of the two sides of the retina. Journal of General Psychology, 1930, 3, 307-313.

The results of an experiment with four subjects suggest that adaptation is more rapid on the nasal than on the temporal side of each retina. The most experienced subject showed the most reliable differences. The possibility of differential eye movements was eliminated.

Kahn, R. Über den stereoeffekt von Pulfrich. Pfluegers Archiv Fuer Die Gesamte Physiologie des Menschen und des Tiese, 1931, 228, 213-224.

A series of experiments concerning the stereo-effect discovered by Pulfrich are discussed. This effect is described in the following manner: if a moving object is fixated binocularly and is seen in a frontoparallel plane, a partial diminution of the intensity of the light rays from the object will cause the object to be seen as moving in a different plane. Kahn has performed experiments using various objects and intensities in order to discover under what circumstances this effect is diminished or increased.

Kaplan & Mettay. (See Retinal Rivalry)

Katz, M. S., & Schwartz, I. New observation of the Pulfrich Effect. Optical Society of America Journal, 1955, 45, 523-524.

The Pulfrich effect is a perception of depth produced by image disparity when the stimulus to one eye is less bright than the stimulus to the other. A method has been devised which permits ostensible binocular vision, but gives a monocular stimulus to each eye in succession, so that no portion of the pathway of the oscillating stimulus is visible to both eyes at the same time. Under this condition the perception of depth is still reported, thus damaging the latency hypothesis based on binocular vision as an explanation of the phenomenon. All Ss reported that under all conditions of presentation the stimulus light appeared to move in the third dimension, either in front of, or behind its objective linear path. The greatest depth was reached at the middle of the path which took on the shape of an ellipse or a circle in perspective. Binocular disparity is a potent factor in producing the perception of depth, but other depth cues may function in conjunction with or independent of it. Demonstrated effectiveness of monocular factors for giving tridimensionality.

Kravkov, S. V. Changes of visual acuity in one eye under the influence of illumination of the other or acoustic stimuli. Journal of Experimental Psychology, 1934, 17, 805-812.



The author presents evidence which he contends fully establishes the fact of opposite action of indirect stimulation in the case of a black object on a white background and a white object on a black one.

Levelt, W. J. Some demonstrations of the complementary functioning of the eyes. Perception and Psychophysics, 1966, 1, 39-40.

The eyes have complementary shares in the production of binocular brightness. Artificial increase of the contribution of one eye automatically leads to an equal decrease of the contribution of the second eye. The responsible mechanism for an increase and decrease of shares is called "contour mechanism". Its functioning is explained by means of 2 stereoscopic patterns.

Linton, P. M. (See Helmet-mounted Display)

Lit, A. The magnitude of the Pulfrich stereophenomenon as a function of binocular differences of intensity at various levels of illumination. American Journal of Psychology, 1949, 62, 159-181.

With unequal illuminations in the two eyes, the bob of an oscillating plane-pendulum appears to rotate out of its plane of oscillation. This stereophenomenon was first described and analyzed by Pulfrich. This experiment was designed to answer the question of the functional relation between the apparent displacement of the oscillating target and the difference in retinal brightness, and the effect on these relations of a systematic change in the general level of illumination. The results obtained may be accounted for on the assumption that the absolute visual latent-period and the logarithm of the stimulus-intensity are inversely related. Integration with the laws of space-perception is indicated.

Miles, P. W. 1934. (See Eye Dominance)

Miles, P. W. 1953. (See Eye Dominance)

Mitchell, R. T., & Liaudansky, L. H. Effect of differential adaptation of the eyes upon threshold sensitivity. Optical Society of America Journal, 1955, 45, 831-834.

Experimentally determined effect of intense light adaptation of one eye upon the dark adapted threshold of the other eye. Three subjects showed a slight increase in sensitivity and one showed no change. The change was not significant for the group. The findings are consistent with the accepted view that states of adaptation of the two eyes are independent and in contradiction to studies which found an averaging effect. It was concluded that adapting one eye to a very high luminance level does not decrease

the immediately subsequent light sensitivity of the other dark-adapted eye. Therefore, it is unnecessary to hypothesize a central adaptation process.

Nony, C., & Pieron, H. A contribution to the differentiation of retinal and cortical processes in binocular vision. Année Psychologique (Paris), 1940, 34, 318-226.

Evidence is presented to show that stimuli applied to corresponding points on the two retinas are projected independently at the cortical level without fusion of afferent impulses. Stereoscopic observation of a rotating disk was used to check flicker phenomenon which remained the same for both eyes. It was also found that simultaneous contrast does not transfer from one eye to the other

Pugh, M. Brightness perception and binocular adaptation. British Journal of Ophthalmology, 1951, 35, 134-142.

A patient can have a diminished sense of brightness in one eye which has normal visual acuity equal to that of the other eye. A marked loss of adaptability to differences of binocular light balance can be present in one eye in a patient with normal equal visual acuity in each eye.

Rock, M. L., & Fox, B. H. Two aspects of the Pulfrich phenomenon. American Journal of Psychology, 1949, 62, 279-284.

Two of the variables known to influence the Pulfrich phenomenon were systematically investigated. These were (1) the elliptical motion as a function of filter-density (over one eye but scanning with two), and (2) the changes in "stereo effect" seen with one dark adapted eye as this eye loses its dark-adaptation. The results indicate that the stereo effect is a compound logarithmic function of the filter-density and the effect declines as monocular dark-adaptation is reduced. The possible practical and theoretical applications are briefly indicated.

Ronchi, L., & Conticelli, M. Contrast sensitivity and speed of reading under differential binocular adaptation. A TTI Della Fondazione Giorgi Ronchi, 1964, 19(1), 69-83.

Two experiments are reported which show that differential binocular adaptation in some cases is advantageous, with respect to the case where the eyes are adapted to the same level, in other cases it is not. More precisely, when the dynamic aspect of the process of adaptation is taken into account, visual performance is better in the case where the two eyes are simultaneously adapting to light than in the case where they are adapting one after the other. When the static aspect of adaptation is taken into account (and the observer is presented with an

empty field, in order to render the adaptational state as constant as possible), the greater performance is reported when the two eyes are adapted to the same level. The nature of the mechanism subserving the reported effect is discussed.

Self, H. C., A quantitative study of colored shadows. University Microfilms, Ann Arbor, Michigan, 1959, (Library of Congress Card No. MIC 59-4743).

The history of the binocular septum technique is reviewed in detail. The review of the literature shows the applicability of the technique to research in vision, and thus to research in HMD and HMS development. The evidence shows that the errors in saturation matches are small, while errors in hue matching are very small and probably insignificant. The errors in lightness matching are moderate and significant. In practice, effects of ocular dominance appear to be of negligible importance. The presence of after-images appears to be insignificant. Simultaneous contrast enhancement is reviewed and research needs discussed.

Teller, D. Y., & Galanter, E. Brightness, luminances, and Fechner's Paradox. Perception and Psychophysics, 1967, 2(7), 297-300.

When monocular brightnesses were varied without varying monocular luminances, binocular brightness was shown to change with the former, but not the latter. Monocular brightness and luminance were varied by means of simultaneous contrast and changes in the level of adaptation.

Wallace, S. R., Jr. Studies in binocular interdependence: II Some qualitative phenomena. Journal of General Psychology, 1938, 19, 169-177.

Macular light adaptation for 10 seconds in one eye, followed by stimulation of the dark-adapted macula of the other eye, leads to the report of greater brightness for the second stimulation than for the first. The subjects continued observation of the two fields until equality in their brightnesses was reached. Two subjects reported that the less bright field increased abruptly in brightness, while a third held the change to be the result of a sudden loss in brightness of the brighter field.

## HELMET MOUNTED DISPLAYS/HELMET MOUNTED SIGHTS

Abbott, B. A. A head-mounted night vision display system for helicopter operation. Technical Report 299-099-385, U. S. Army Electronics Command Night Vision Laboratories, Fort Belvoir, Va.

Study reports on final development of a small head-mounted (eyeglass) television display and a head controller device which utilized an electro-optical principle. These would be used to aim a turret. Discussed head motion pickoff mechanism and related the details of a breadboard electro-optical head tracker. Also covered results from tests of performance of head-tracker and the effect of the eyeglass on visual skills. Concluded that the system was successful.

Arner, R. S. Some visual problems of flight. American Journal of Optometry, 1957, 34, 233-240.

Motion parallax, not classical stereopsis, is used in landing a plane. Angular velocity is the primary cue.

Brown, R. H. The effectiveness of a collimated reticle as an aid to visual detection of aircraft at high altitude. U. S. Navy Research Laboratory Report No. 4863.

Investigated reticle effect in simulated high altitude environment detection of targets. Results were not significant.

Christenson, V. R. Airborne USH telemetry package--Agile test pod. Report No. NWC-TP-5223, August 1971, Naval Weapons Center, China Lake, California.

Report describes the PAM/FM/FM telemetry instrumentation for the Agile test pod. This is the first time that man, aircraft, helmet mounted sight and seeker have been integrated into an operational system. The primary purpose was to evaluate the total system capability in target acquisition, lock-on, and tracking in a simulated environment.

Craig, G. L. Gunsight questionnaire data. Memorandum, Naval Weapons Center, Ser. 3570-633, 25 February 1970.

Navy pilots answered a questionnaire asking for a rank order of reticles and comments. From these data an "optimum" sight was drawn.

Furness, T. A. III. The application of helmet-mounted displays to airborne reconnaissance and weapon delivery. AMRL-TR-70-9, USAF Aerospace Medical Research Laboratory.

Reviews the Air Force requirement for new display techniques in aircraft and the advantages and disadvantages of the helmet-mounted display. It can provide an apparent large screen while allowing the image to be collimated to any viewing distance. Display fields of view up to 60° are obtainable. Because HMDs are moveable, a heads-up attitude is possible. On the other hand, helmet-mounted displays interfere with normal binocular vision, may induce retinal rivalry and brightness disparity, and add to helmet weight. An AMRL HMD/HPS test program is described.

Harker, G. S. Headache resulting from use of weapon sight, night vision, individual. U. S. Army Medical Research Laboratory, Fort Knox, Kentucky, USAMRL Letter 4, November 1964.

During test of the weapon sight, several individuals reported headaches. Report seeks to identify feature(s) of sight responsible with goal of eliminating further headaches.

Hasselbring, H. H. A survey of sighting and aiming devices. Final Report, July 1970, NAFI-TR-1557.

General information on past, present and future airborne gun-sights and aiming devices. Basic design considerations, past and currently in use, are reviewed. Outlines current developments in Heads-up Displays, Helmet-mounted Displays, and Head-Position-Pickoff systems.

Heard, J. L., Hayes, D. O., Ferrer, J. J., & Zilgavis, A. Design of an airborne helmet-mounted display. Hughes Aircraft Company, September 1969.

Describes laboratory tests and design studies accomplished for preliminary design of an airborne HMD. The HMD design allows the airborne simulation of several sizes of TV displays. By changing the optics used in the HMD, apparent display sizes from 6 to 22 inches can be provided at an apparent viewing distance of 18 inches. A high resolution CRT provides a high quality TV picture under all magnification conditions. The headset is designed to be easily installed, adjusted, and removed in flight from either the Navy or Air Force standard helmet. The HMD is designed to operate with either 575 or 875 line TV input, 30 Hz frame rate and 2:1 interlace.

Hughes, R. J., Henke, A. H., Schultz, R. L., Blackburn, D. R., & Church, D. A. Helmet-mounted sight/display applications. Honeywell Report No. 12592-FR1 AD 870 448, Volume 1. Summary and Conclusions.

Reports on applications and developments of HMD/S systems. Primary use will be for weapons delivery and target identification. No research has been done on head-eye coordination, just hand-eye tracking movement. Discussed possible ways to slave helmet-weapon system; a 2:1 slave ratio at the gate was suggested. Future uses for HMS/D were warning against missiles and planes, terrain following, landing assistance and navigation.

Hughes, R. J., Henke, A. H., Schultz, R. L., Blackburn, D. R., & Church, D. A. Helmet-mounted sight/display applications. Volume III. Tracking Capabilities. Honeywell Report No. 12592-FR3 AD 870 972.

Reports on applications and developments of HMD/S systems relating to use in the F-15 aircraft. An experiment was conducted comparing HMD/S to conventional tracking systems. Results clearly favored the HMD/S. No fatigue analysis was performed because the extra helmet weight was supported by springs and weights.

Hughes, R. J., Henke, A. H., Schultz, R. L., Blackburn, D. R. & Church, D. A. Helmet-Mounted sight/display applications. Vol. IV. Baseline HMS/D System. Honeywell Report No. 12592-FR4 AD 870 973.

Reports on applications and developments of HMS/D systems relating to projected use in F-15 aircraft. General discussion of elementary baseline systems to be coupled to HMS/D. Research underway so that a target outside the pilot's natural field of view can be seen and also so that real world field of view equals the HMS/D field of view. Peripheral vision losses are a major problem.

Hughes, R. L. Sensor lockup by means of helmet-mounted sight. Honeywell Document No. 14327-TR1 Honeywell Inc., October 1970.

Investigated the basic ability of the human to use an HMS in acquiring a target and also the effect of system error on this ability. It was found that as target motion rate increased, the difficulty of locking the sensor increased, and that a decrease in the size of the sensor also increased the difficulty of locking. In spite of increasing difficulty, however, success in locking the sensor remained high. The experiment indicated that the HMS is a satisfactory means of pointing and locking sensors aimed at moving targets. The human operator is capable of operating the system with a high degree of success after only brief training, and his performance is not degraded significantly by relatively large system errors. It is recommended that further research in cueing symbology be conducted.

Hughes Aircraft Corp. An optimized optical link for helmet mounted display (OOLHMD). Vol. II. Technical Proposal, Report No. TP70-129, December 1970.

Includes review of history of development of helmet-mounted displays, design concepts, and proposed specifications regarding display optics and variable see-through visors. Experience obtained in the development of Electrocular an Early Hughes head-worn display, and more recent prototypes indicates that: accommodation problems disappear quickly with experience, little visual fatigue results from extended wear of HMD, and that the display remains distinct from the surrounding world. Various requirements of a helmet-mounted display system are discussed, including optimizing system weight, exit pupil, field of view, balanced brightnesses to the two eyes, and visor transmittance and reflectance problems in heads-up and heads-down modes.

Hughes Aircraft Corp. Lightweight helmet-mounted display (HMD) optics. Vol II. Technical Proposal, Report No. TP71-43, March 1971.

Reviews general information and background research in helmet-mounted displays. Mechanical, optical, and environmental requirements for an HMD are presented, various design approaches are considered, and a program plan is recommended. The various design approaches considered are: off-axis aspheric-toric reflective systems; off-axis spherical reflector systems; on-axis spherical reflector systems; and refractive systems with beam splitters. Also, the potential of hologram techniques for HMD optics is discussed.

Hughes Aircraft Corp. The Hughes airborne helmet-mounted display (HMD).

Describes Hughes Aircraft Corporation's current display design and illustrates the present helmet system that Hughes has developed. The capabilities of the system are discussed and illustrated. Also described are the specifications of the system.

Jacobs, R. S., Triggs, T. J., & Aldrich, J. W. Helmet-mounted display/sight system study. Technical Report AFFDL-TR-70-83, Vol. 1. Air Force Flight Dynamics Laboratory, Wright-Patterson Air Force Base, Ohio, August 1970.

Describes study investigating the applicability of a combined helmet control-display system for an advanced tactical aircraft of the F-15 type. Part of the study was a survey of human factors data associated with HMDs. The principle parameters reviewed were monocular vs binocular presentation, occluded vs see-through

displays, binocular rivalry, visual subtense of the display, ambient and display illumination, and frame of reference. Most work in binocular rivalry has been concerned with the study of simple visual fields. Rivalry between very complex fields has not been studied. The following generalizations, however, can be made: (1) Rivalry may be a complete alternation of the two fields or a visual mosaic consisting of parts of each, (2) the field with the higher contrast will dominate, (3) the field with the greater contour density will dominate, (4) the brighter field will dominate, (5) rate of alternation increases as the difference in size of items in the two fields increases, (6) alternation is not under complete voluntary control, and (7) time on task reduces alternation rate. Theories attempting to explain rivalry are discussed. Image superimposition is a potential problem in the case of a see-through HMD. It is possible that there will be confusion between the field the pilot wishes to see and the remaining field. Pilot work in this area shows that superimposition of images can yield good information to the observer from both display sources. Variables of interest when images are superimposed are: (1) relative brightness between the two surfaces, (2) relative focus between the two surfaces, (3) relative motion between the two surfaces, and (4) distribution and shape of the elements comprising the two surfaces. Another major potential problem is the interpretability of HMD information when the pilot has his head turned to the left or right. This is a frame of reference question and relates to the possibility of interpreting and responding to a roll error as though it were a pitch error. Several parameters for further laboratory research are outlined.

Results of flight tests using HMD are presented with data on the effects of retinal rivalry, brightness disparity, and spatial disorientation. With no filtering of light to the open eye, retinal rivalry was too great to make HMD useable. Most flying was done with an eyepatch covering the left eye.

Klass, P. J. Navy Pilots to use Helmet Sight. Aviation Week and Space Technology, January 21, 1972.

Discussed Honeywell helmet-mounted sight for use on F4s and F14s, including its use as aid to air-to-ground delivery system. Also discussed the Army's mechanically coupled helmets. Honeywell HMS weighs only 11 oz. The helmet sight is slaved to aircraft weapons by 2 beams of light on the helmet. The possibility of using the helmet for the Agile air-to-air missile system is mentioned. Visual cueing is used so that both pilots can look in the same direction when only one has found the target. Also discussed F-14's use of a visor display instead of a reticle.



Linton, P. M. Helmet mounted displays. Reg. 4011-089-71, December 1971. Naval Air Warfare Center, China Lake, California.

Reviews information pertinent to helmet-mounted displays including concepts, hardware development, perceptual and physical deficiencies; describes some existing systems and makes recommendations. There are three formats applicable to HMD in a single seat aircraft: the one eye occluded, one eye monocular see-through, and the two eye see-through. Format disadvantages of each are discussed, including monocular and binocular factors, brightness disparity, the Pulfrich phenomenon, image contrast, binocular rivalry, eye dominance, and superimposition. Suggests that eye dominance may affect retinal rivalry and therefore problems arise since all existing one-eye HMDs are designed for the right eye. Brightness disparity is a problem because though the eyes can dark adapt independently, pupillary response controlling luminance input occurs in unison. The three main physical deficiencies are weight (and resulting moments of inertia), reduction in pilot's field of view, and safety. Various HMD systems are being developed by North American Rockwell, Electric-Optical Systems (Xerox), Hughes Aircraft Corp., Texas Instrument Co., Honeywell, and Perkin-Elmer. Recommended research includes investigation of ability to shift attention and the relationship of retinal rivalry to eye dominance.

Loper, L. R., & Stout, R. C. The relationship between optical distortion and binocular depth perception. NASA-TN-D-5162. 1969.

Binocular depth perception, a vital function during spacecraft docking and lunar landing, could be degraded by any spacecraft system optical transparency. A study of the relationship between binocular depth perception and optical distortion in the Apollo pressure suit helmets and visors was made to aid in setting optical distortion limits for the helmets and visors. Data obtained from the study indicated that all the helmets and visors which were tested degraded binocular depth perception. As measured by the Howard-Dolman apparatus, there is evidently a systematic effect of optical distortion in the Apollo helmets and visors on binocular stereoscope depth perception. A program for studying this problem in greater depth is outlined.

Miller, B. Helmet-mounted display interest revives. Aviation Week and Space Technology, February 24, 1969.

Traces the current interest in helmet-mounted displays. Covers the usages of the HMD and also some of the problems which must be considered. Some problems are: switching from a daylight system to a night system, retinal rivalry, problems with mirrors and reflectance of light, weight considerations, and acceptance of the system by pilots. Considerable attention is given to

the designs of the major companies who are in the field of HMD research. Those researchers include Perkin-Elmer, Naval Weapons Center, Honeywell, Bell Helicopter, Autonetics, and Electric-Optical Systems.

Nicholson, R. M. The feasibility of a helmet-mounted sight as a control device. Human Factors, 1966, 8(5), 417-425.

The purpose of this research was to investigate the practicality of a helmet-mounted sight as an operational element in a quick-reaction, bore-sighting system. A three-phase experiment program was conducted to determine the human capabilities with the helmet-mounted sight. In a laboratory environment sighting accuracies were obtained on both static and moving targets. Field test data were obtained during high speed, low-altitude flights. The series of tests indicated that the accuracy of the sighting process can be expected to vary between a fraction of a degree and four degrees depending on target angular rate and the target sighting angle.

Roscoe, S. N. The effect of eliminating binocular and peripheral monocular visual cues upon airplane pilot performance in landing. Journal of Applied Psychology, 1948, 32, 649-661.

Six instrument pilots were tested for accuracy of landing under conditions in which the outside visual field was presented on a small, flat surface without direct outside visibility. Safe approaches and landings were made by all pilots in all conditions, but the average error for landings varied under the 3 conditions (periscope, vision reducing goggles, unrestricted outside visibility).

Shontz, W. D., & Trumm, G. A. Perceptual processes and current helmet-mounted display concepts. Honeywell, Inc., Minneapolis, Minnesota. Research Department Life Sciences Group Technical Note TN-1, April 1969.

Current helmet-mounted display (HMD) technology as described by Miller (1969) is evaluated in terms of the man/display problems presented by the state-of-the-art (the one-eye occluded, the one-eye see-through, and the two-eye see-through). The literature on perceptual processes relevant to the proposed HMD design concepts is reviewed. Implications for the design of helmet-mounted displays are discussed in terms of the perceptual and cognitive processes of signed modification, binocular rivalry, and information processing. The current status of HMD design strongly suggests the need for a great deal more human factors research. Neither research nor system development should proceed until a well-defined set of objectives for HMD has been established and

a set of feasible hardware alternatives specified.

Strother, D. D., & Upton, H. W. Head-mounted display/control system in V/STOL operations. Paper presented at National V/STOL Forum of the American Helicopter Society (Preprint No. 532), Washington, D. C., May, 1971.

Examines the requirement in V/STOL operations for head-mounted displays and sights. Pilots will probably never be satisfied with a small panel-mounted display to present pictorial information. This is because use of such a display inherently involves some loss of extra-cockpit visual information. Pilot acceptance of such displays is discussed in the context of continuous monitoring of extra-cockpit information, including horizon line, surface perspective cues for altitude and movement judgments, surface texture cues, and monocular and binocular depth cues. Design requirements for a head-mounted display system are discussed, including retention of the greatest possible field of view, provision of a see-through and collimated image, maximization of learning transfer, consideration of helicopter and V/STOL operational environments, symbology, safety, weight, and night operations. Extra-cockpit visual information which should be reproduced on V/STOL pictorial (forward-looking) displays is discussed. HMD design, optics, electronics, and applications are discussed.

Tufts College. Reticle design: The circle reticle. 1942 Publ. Bd. No. 58183, Washington, D. C. U. S. Department of Commerce, 1947, p. 5.

Experiments were conducted on the target position effect in the Tufts' trainer with an outline of a circle ( $34^\circ$  subtended) as the fiducial mark. Demonstrated that the reticle helps in some cases to overcome target position effect when subject ranges target by keeping it in the context of the circle.

Vallerie, L. L. Displays for seeing without looking. Human Factors, 1966, 8, 507-513.

A laboratory study was conducted to determine the effectiveness of peripheral vision displays for presenting dynamic tracking information during difficult control tasks. Visual switching between information sources is normally an essential part of such tasks. The study clearly demonstrated that tracking performance deteriorates as visual switching increases and that peripheral displays can be used to overcome its adverse effects.

## RETINAL RIVALRY

Aafjes, M., Hueting, J. E., & Visser, P. Individual and interindividual differences in binocular retinal rivalry in man. Psychophysiology, 1966, 3(1), 18-22.

In a group of 12 male and female Ss 18-45 years of age, the alternation frequency of binocular retinal rivalry (BRR) was found to change depending upon the durations of the periods for which the target was fixated, and of the intercalated resting time. Analysis of variance indicated significant interindividual differences in level of mean frequency and in rate of increase.

Alexander, L. T. The influence of figure ground relationships in binocular rivalry. Journal of Experimental Psychology, 1951, 41, 376-381.

When corresponding areas of the two retinas are stimulated simultaneously with different stimuli, one of three things will occur: (1) the fields may fuse, (2) one may be seen to the exclusion of the other, or (3) the fields may alternate. If one visual field is homogeneous while the second is a figure, the figure will be seen continuously. If slightly different plane projections of a solid object are presented stereoscopically to corresponding areas of each eye, the two images will fuse and produce the perception of depth. If these two cases represent extremes of a continuum, between them are conditions in which the fields alternate. This alternation has been called binocular rivalry. Rivalry may be seen in two forms: (1) successive rivalry--the alternation is complete and the two fields supercede one another completely, and (2) simultaneous rivalry--both images may be seen at the same time but only one or the other of the fields is visible at any one place. Tested the hypothesis that the rate of alternation in binocular rivalry is a function of "figure strength." Figure strength is defined in terms of resistance to distortion, impressiveness, articulation, density of energy, symmetry, brightness difference between figure and ground, and continuity of figure contour. It was concluded that "strong" figures will alternate more rapidly than "weak" ones when viewed stereoscopically.

Alexander, L. T. & Bricker, P. D. Figure-ground contrast and binocular rivalry. Journal of Experimental Psychology, 1952, 44, 452-454.

When two halves of a stereogram contain figures which are different, the figures may fuse and produce the effect of depth. If the figures are different enough, they do not fuse, but instead alternate. In a previous experiment it was shown that retinal rivalry rate is greater if (1) the figure contour is continuous instead of broken, and (2) there is greater contrast between the

figure and the ground. This experiment was an attempt to describe more fully the rate-contrast relationship. Five stereograms were used. The left half of each consisted of a series of black vertical bars and the right half consisted of black horizontal bars. The bars were produced on background greys of varying shades producing figure-ground contrast ratios ranging from .86 to .98 for the five stereograms. No systematic relationship was found in this experiment between figure-ground contrast and rate of alternation. It was suggested that the higher intersubject variability found in this experiment was due to the massing of trials.

Bagby, J. W. A cross-cultural study of perceptual and predominance in binocular rivalry. Journal of Abnormal and Social Psychology, 1957, 54, 331-334.

Twelve Mexican and 12 matched American Ss were simultaneously presented 10 stereogram slide pairs of similar scenes--one Mexican and one American. Ss more readily saw the scene specific to their own culture, indicating that past experience organizes perception under conditions of binocular rivalry.

Berry, J. W. Ecology and socialization as factors in figural assimilation and the resolution of binocular rivalry. International Journal of Psychology, 1969, 4(4), 271-280.

Two distinct relationships could facilitate handling of data in the area of culture and personality. A direct relationship, based upon unique sensory ecology of various cultural groups, parallels laboratory studies relating frequency of prior exposure and perceptual response. An indirect relationship obtains in perceptual responses mediated by social, personality, and developmental factors. Temme, Scot, and Eskimo Ss yielded data supporting the proposed distinct relationships. In one investigation, Ss drew what they saw after tachistoscopic presentations of 9 stimuli. In a second investigation, Ss reported what they saw when materials from their own and different cultures were presented stereoscopically, under conditions productive of binocular rivalry. Further investigations could decide whether all perceptual problems can be handled by means of the relationships described.

Biersdorf, W. R., & Lawwill, T. An electrophysiological method for the study of binocular rivalry. Behavior Research Methods & Instrumentation, 1968, 1(1), 24-26.

Describes a technique for recording cortical evoked responses from human Ss in binocular rivalry. Each target is illuminated with flickering light at different frequencies upon a steady background. While the S continuously indicates with a response key which

target he is seeing, the cortical responses are tape recorded. The tape recording is later analyzed by average response computer separately for each eye, seeing and not seeing. This simultaneous record of the functioning of both eyes eliminates confounding variables found in earlier methods. Controls are included for rivalry changes during a stimulus cycle and for S motory response time.

Blake, R. R., Fox, R., & McIntyre, C. Stochastic properties of stabilized-image binocular rivalry alternations. Journal of Experimental Psychology, 1971, 88(3), 327-332.

Conducted an experiment which consisted of a stochastic analysis of rivalry alternations produced by stimuli retinally stabilized by the method of enduring afterimages to determine whether the source of the random effect resided in a central mechanism or could be attributable to peripheral receptor variables, e. g., eye movements. The patterns of stabilized-image rivalry of 3 trained male SS were analyzed by a runs test, autocorrelation, and by fit to a theoretical gamma distribution. Analysis revealed that the successive durations were sequentially independent random variables similar to the pattern found for unstabilized rivalry. These data demonstrated that the source of the random effect must reside within a central mechanism and cannot be due to peripheral receptor variables.

Bokander, I. The importance of arousal potential and light intensity in stereoscopically induced perceptual conflict. Psychological Research Bulletin, 1965, 5, 1-7.

In perceptual conflict of the binocular rivalry type, the object field with the greatest arousal potential or greatest light intensity will dominate. The interaction between these two factors is such that the brighter field will dominate over the fainter whether there is greater or equal arousal potential in one of the object fields in relation to the other. Discussion was centered around the question of whether eventual eye dominance can be eliminated through relative changes in the light intensity of the two object fields.

Bokander, I. The importance of collative-affective and intensive arousal potential in stereoscopically induced perceptual conflict. Scandinavian Journal of Psychology, 1966, 7(4), 234-238.

In perceptual conflict of the binocular rivalry type the object field with the greatest collative-affective or intensive arousal potential will dominate. The interaction between these two factors is such that the brighter field will dominate over the fainter whether there is greater or equal collative-affective arousal

potential in one of the object fields in relation to the other. Discussion was centered around the question of whether eventual eye dominance can be eliminated through relative changes in the light intensity of the two object fields.

Bokander, T. Pupillographic recording in stereoscopically induced perceptual conflict. Perceptual & Motor Skills, 1967, 24(3)(2) 1031-1037.

Describes a pupillographic method for recording the input/inhibition relationship in stereoscopically induced perceptual conflict between different objects. By means of an infrared technique for photographing the pupils, it is shown which eye is inhibited and which is not at a specific moment of retinal rivalry. A series of such instantaneous tests of input/inhibition relationship were used to establish which of the two stereoscopic object fields had dominated perception during a 60-second interval. The test was based on the fact that no pupillary reflex was found when an inhibited eye was stimulated by a flash during binocular rivalry. A possible use of the pupillographic method in research on so-called motivated perception was discussed.

Bradshaw, J. L. Brightness of the dominant field, and pupillary reflexes in retinal rivalry. British Journal of Psychology, 1969, 60(3), 351-356.

Two visual fields of differing brightness presented separately to the two eyes were superimposed. Where perceptual dominance of the brighter or darker field, in a retinal rivalry situation, was manipulated by the imposition of superimposed patterning, no changes were found in pupillary base lines. This finding is discussed in connection with reports that during rivalry there is suppression of a flash-evoked pupillary reflex elicited from within the nondominant field. The interactions of other suppressive and reflex phenomena occurring during vision are considered within this context.

Breese, B. B. On inhibition. Psychological Monographs, 1899, 3, No. 1.

Reported that S's attempts to influence rivalry were accompanied by eye movements, although when eye movements were prevented, rivalry continued. Demonstrated that the rate of fluctuation of rivaling field varies directly with the amount of illumination. (See Woodworth & Schlosberg, 1954).

Hecox, M. H. Binocular rivalry. Psychological Review, 1909, 16, 410-415.

If one field in a binocular rivalry situation is brighter than the other, the phase length of the brighter is increased. There is, however, no change in the rate of fluctuation (See Woodworth & Schlossberg, 1954).

Cobb, W. A., Morton, H. B., & Hittlinger, G. Cerebral potentials evoked by pattern reversal and their suppression in visual rivalry. Nature, 1967, 216(5120), 1123-1125.

Described an experiment in binocular rivalry using 12 Sx and EEG response measurements. Variations in the target size, pattern, and lumination were described. No consistent differences in amplitude were found between responses to stimulation of the dominant or suppressed eyes.

Cobb, W. A., Hittlinger, G., & Morton, H. B. The EEG society: Visual potentials evoked in binocular rivalry. Electroencephalography & Clinical Neurophysiology, 1967, 23(4), 397-398.

If different images fall on congruent areas of the two retina they may not be fused; first one is seen, then the other, and binocular or visual rivalry is said to exist. Lansing and Van Balen have claimed that flicker to the "dominant" eye gives rise to larger cerebral responses than does flicker to the "suppressed" eye. Average evoked responses to flicker or to single flashes were recorded from an occipital electrode referred to the vertex or the ear; the eyes were stimulated alternately or in random order, the S indicating which eye was dominant by closing 1 of 2 switches, the responses being thus routed to the appropriate channel of the averager. No differences were found. When one eye was flickered continuously the output of a filter tuned to the flicker rate was sometimes reduced by continuous bright illumination of the other eye (Lansing); it was shown that this effect could be due to mechanisms not involving rivalry. If a text was read by the continuously flickered eye the evoked response might be larger than when the text was read by the unflickered eye (Van Balen); this may be in part related to the effect of pattern vision, not rivalry. Thus, it is unconfirmed that the state of "suppression" results in any reduction of the visual cortical response. Some of the sources of confusion in this type of experiment are discussed.



Cogan, R., & Goldstein, A. G. The stability of binocular rivalry during spaced and massed viewing. Perception & Psychophysics, 1967, 2(4), 171-174.

Considered stability of binocular rivalry rates during extended periods of spaced and massed viewing by untrained observers. In Experiment 1, no relationship was found between eyeblink rates and rivalry rates, and a visual vigilance task reported simultaneously with rivalry reporting proved to be a useful indicator that Ss maintained attention during the viewing period; the vigilance task did not disrupt rivalry data. In Experiment 2, Ss reported rivalry during 10 minutes of continuous or 10 minutes of noncontinuous viewing on each of three consecutive days. The vigilance task was presented to all Ss. After the first minute of viewing, during which conditions were alike for all Ss and rivalry rates differed only slightly, the rates of the spaced groups increased while the rates of the massed groups showed little variation.

Collier, S. C., & Boyan, W. Objective measurement of dominance control in binocular rivalry. Perception & Psychophysics, 1970, 8(6), 437-439.

Six male undergraduates attempted to identify stimuli superimposed on either of two dichoptically viewed rivalry patterns. Ability to influence dominance switches was confirmed with this objective procedure, by reason of a decreased error rate (1) with 3-second advance knowledge as to which pattern would receive a test stimulus, and (2) with knowledge that an 83% majority of all stimuli would be presented in a given field. However, even when test stimuli were self-initiated, dominant-field and suppressed-field scores were not close to the error rates predicted on the basis of monocular levels and of random guessing, respectively, indicating either misjudgments of pattern dominance or, more likely, a failure of the dominant field to totally suppress its opponent.

Crain, K. J. Binocular rivalry, perceptual closure, and intelligence test performance. Dissertation Abstracts, 1958, 18, 1095.

Investigated whether binocular rivalry bears a relationship to performance on tests of perceptual closure. No relationship was found. Previous data indicated that the relation between Full Scale IQ and rivalry was primarily a reflection of that between the Performance Scale and rivalry. Further analysis proved that the latter two were not related through the mediation of some stronger relation to certain subtests but rather to performance on the total scale as a unit. It was concluded that rivalry is a phenomenon which, in its relation

to intelligence, is of general scope, and that it could hardly function in this regard as a visual "skill". The suggestion was made that binocular rivalry and intelligence are related in that both are reflections of the same brain processes.

Crain, K. J. Binocular rivalry: Its relation to intelligence and general theory of its nature and physiological correlates. Journal of General Psychology, 1961, 64, 259-283.

One study investigated the relationship between binocular rivalry and reading ability. No significant relation was found. Another study investigated whether rivalry was a factor related to IQ. The Wechsler-Bellevue test scores and rivalry rates were used. A correlation was found with the whole score on the Wechsler-Bellevue but there was no significant correlation with any subtest.

Creed, R. S. Observations on binocular fusion and rivalry. Journal of Physiology, 1935, 84, 381-393.

When two patterns of similar design but different color are placed simultaneously in a stereoscope, the design of one is seen but the color is modified.

Diaz. On binocular alternating vision. Ann. J'ocul., 1928, 165, 721.

Canejo designed a colored figure for study in a stereoscope composed of concentric circles in the two temporal fields. Steady fixation of the center leads to perception of a confusion of mixed lines alternating with a perception of complete circles. Possible explanations were considered.

Engel, E. The role of content in binocular resolution. American Journal of Psychology, 1956, 69, 87-91.

Studies of binocular rivalry characteristically ignore the content of the discrepant patterns employed. To study the role of content, stereograms presenting an upright and an inverted photo of a man's face were viewed by 12 observers. Results showed that the upright face predominated. Since the upright face is the more frequently encountered in everyday experience, the results were interpreted as contradicting perceptual theories that consider sensory organization to be "wholly prior to and independent of content". Implications for Kohler's treatment are given.

Engel, E. Binocular fusion of dissimilar figures. Journal of Psychology, 1958, 46, 53-57.

Tested a hypothesis of binocular fusion, that only if identical stimulation (or nearly so) falls upon the two retinae do we

avoid double vision or rivalry. Stereograms were exposed to the two eyes, targets being composed of two different faces, taken largely alike, but with somewhat differing sizes and positions of heads, light, shade and orientation. Over 10 Ss viewed these and described their observations. Almost invariably a continuous fused impression of a single face was reported, usually a fused impression of the two faces so exposed, often one appearing to dominate as checked by extinguishing one target and then the other.

Fleischer, E. The experimental foundation of binocular color vision (Experimente le Grundlage des binokularen Farbensehens). Pflug. Arch. f. d. ges. Physiol., 1931, 228, 724-730.

The three-component theory is taken for the basis of the explanation of retinal rivalry. By an experiment with grays lighter or darker than their backgrounds, it was found that retinal rivalry occurs only when the two colors to be fused are of unequal brightness as compared with the background, i.e., one lighter than the background and the other darker than the background.

Fox, R., & Check, R. Forced-choice form recognition during binocular rivalry. Psychonomic Science, 1966, 6(10), 471-472.

Forced-choice form recognition thresholds were obtained for both eyes concurrently under rivalry suppression and nonsuppression and for a nonrivalry control condition. Suppression produced a significant decrement in recognition; nonsuppression and non-rivalry did not differ significantly. These data support the hypotheses that suppression represents an inhibitory state and that nonsuppression represents a state of normal visual sensitivity.

Fox, R., & Check, R. Binocular fusion: A test of the suppression theory. Perception and Psychophysics, 1966, 1(10), 331-334.

Binocular fusion may be due to interocular inhibitory suppression, a hypothesis difficult to evaluate by phenomenal inspection. A test probe method (reaction time to a light pulse) was used to measure visual sensitivity during binocular rivalry and fusion. The absence of inhibitory effects during fusion fails to support the suppression theory of fusion.

Fox, R., & Herrmann, J. Stochastic properties of binocular rivalry alternations. Perception & Psychophysics, 1967, 2(9), 432-436.

The extent to which binocular rivalry phases are sequentially related was assessed by the Lambda statistic and by autocorrelation. Both measures indicate that the duration of successive phases are independent. The frequency distributions of suppression and nonsuppression phases can be fitted by gamma

distributions. The results are consistent with models of the rivalry process that incorporate independence assumptions.

Fox, R., & Check, R. Detection of motion during binocular rivalry suppression. Journal of Experimental Psychology, 1968, 78(3) (1), 388-395.

During binocular rivalry suppression of a static target, an element of the target was put in motion and detectability of the movement was assessed by RT. Rate and pattern of movement and the method of rivalry induction were varied in 4 experiments. In all cases RT to movement during suppression was significantly increased relative to nonsuppression control conditions. The magnitude of the increase was inversely related to the strength of the movement stimulus. Results supported the hypothesis that suppression is an inhibitory state that acts nonselectively on all stimulus attributes falling within the suppressed retinal region.

Fox, R., & Rasche, F. Binocular rivalry and reciprocal inhibition. Perception & Psychophysics, 1969, 5(4), 215-217.

Any explanation of binocular rivalry based on a reciprocal inhibition mechanism would require that unilateral increases in the stimulus strength of the rivalry target in one eye produce increases in the mean nonsuppression duration of that eye and concomitant decreases in the mean nonsuppression duration of the contralateral eye. To test that hypothesis, the stimulus strength (in this case, contrast) of one rivalry target was varied (.1, 1, 10, and 100 ft-L) while the strength of the target in the other eye remained constant. The data, obtained from 6 experienced male Ss with normal vision, indicate that variations in stimulus strength do not alter the mean nonsuppression duration of the recipient eye. This offers a fundamental difficulty for the reciprocal inhibition concept. A model that assumes partially independent suppression and dominance mechanisms is suggested as a more adequate alternative.

Freides, D., & Hayden, S. P. Monocular testing: A methodological note on eidetic imagery. Perceptual & Motor Skills, 1966, 23, 88.

The possibility that "fragmentation" or fading in and out of the eidetic visual image, might be due to binocular rivalry was tested by changing from the standard binocular to a monocular testing procedure. Some Ss reported eidetic images only in one eye while others were bilaterally eidetic. Preliminary neurological implications are suggested as the cause. It is recommended that further studies on eidetic imagery include a monocular testing procedure.

George, R. W. Cancer and other disorders related to certain perceptual tests. Perceptual & Motor Skills, 1970, 30(1), 155-161.

The rate of reversals possibly experienced in observing ambiguous figures and in binocular rivalry are shown to distinguish at a statistically significant level among 31 cancer patients, 12 patients with duodenal ulcers, 15 rheumatoid arthritics, and 39 controls with miscellaneous disorders; also between 17 matched pairs of schizophrenics with and without cancer. Results are discussed in terms of the part played by the integrative systems of the organism both in relationship to the test results and the disorders experienced.

Goldstein, A. G. Retinal rivalry and Troxler's effect. Psychonomic Science, 1967, 7(12), 427-428.

Tested the proposition that Troxler's effect is an interactive process, i.e., retinal rivalry between the occluded and non-occluded eye. It was assumed that in one-eyed individuals binocular interaction was eliminated. Troxler disappearances were measured in monocular and normal Ss. Monocular Ss reported fewer disappearances at each of 8 visual meridians. Neither a strong interactive nor noninteractive interpretation is supported by these data.

Goldstein, A. G. Retinal rivalry and Troxler's effect: A correlation. Perception & Psychophysics, 1968, 4(5), 261-263.

Measured retinal rivalry and Troxler disappearances in 30 undergraduate Ss. Correlations suggesting a significant relationship between the two phenomena are reported.

Goryo, K. The effect of past experience upon the binocular rivalry. Japanese Psychological Research, 1969, 11(2), 46-53.

Examined the effect of the amount of past experience on the binocular rivalry between portraits of male students (F-figure) and a geometrical figure (G-figure). Prior to the observation of binocular rivalry by haploscope, F-figures with different frequencies in the paradigm of paired-associate learning between F-figures and the family names randomly assigned to them were presented to four male and one female undergraduate. Results showed that the relative dominance of F-figure over the other in binocular rivalry systematically increases as the frequency of previous presentation of the F-figures increases.

Hastorf, A. H., & Myro, G. The effect of meaning on binocular rivalry. American Journal of Psychology, 1959, 72, 393-400.

Pairs of stamps and photographs containing human faces were presented stereoscopically, one to each eye, with one face right side up and the other upside down. More right side up faces were seen than upside down ones. It appeared that the meaningful content of stimuli plays a significant role in the organization of experience.

Hirata, K., & Osaka, R. Tachistoscopic recognition of Japanese letter materials in left and right visual fields. Psychologia: An International Journal of Psychology in the Orient, 1967, 10(1), 7-18.

Under traditional successive and simultaneous conditions, there was better recognition in the right visual field. With single letter and nonletter materials, there was no significant difference. Both eyes showed a slightly faster tendency concerning verbal reaction in the right visual field. In the immediate memory experiment, higher scores were shown in the temporal visual field. In the 4 experiments, only the left eye showed significant differences between the visual fields. "Three factors were discussed--attentional processes, superior sensitivity of the nasal retina and eye dominance."

Horne, E. P., & Hart, H. C. Perceptual thresholds and spontaneous cortical rhythms. Journal of General Psychology, 1960, 62, 185-188.

Measures of perception and specific cortical responses were obtained for 31 male college students. The measure of visual perceptual threshold, retinal rivalry rate, and Thurstone's Dotted Outlines test were unrelated to each other and unrelated to the measures of cortical activity used.

Horowitz, M. W. An analysis of the superiority of binocular over monocular visual acuity. Journal of Experimental Psychology, 1949, 39, 581-596.

In nearly all cases there are lower thresholds for binocular visual acuity than for monocular visual acuity. It is not clear why this should be so. An experiment was conducted to investigate the possibility that in conventional monocular acuity testing the occluded eye is still a participant in the visual setup although this is often overlooked. Two specific hypotheses were tested: (1) the low intensity of the occluded eye will increase the diameter of the pupil of the nonoccluded eye resulting in a lowered monocular activity, and (2) the difference in intensity and pattern in the two eyes will result in either

rivalry or fusion of the dissimilar fields, leading to a reduction in monocular acuity. Both hypotheses were supported, but it is difficult to determine their relative contributions. Three factors commonly involved in rivalry would limit the contribution of the second factor. They are: (1) the higher intensity image usually predominates, (2) contours tend to dominate over plain fields, and (3) the field commanding interest tends to dominate. When two fields which do not easily fuse into a unitary perception of a single test object are presented separately to the two eyes, any of three perceptions may result: (1) the two fields may be seen superimposed; (2) one of the fields may dominate (This may be expected if one eye is dominant or has much greater visual acuity than the other); (3) parts of each field may be seen at the same time. When the binocular combination of dissimilar fields does occur, results are frequently unexpected; they cannot be described as intermediate. For instance, the presentation of black to one eye and white to the other results in the perception of lustre. If the intermediate gray is presented to both eyes, the binocular combination is unlike the effect produced by different fields of black and white.

Humphiss, D. The measurement of sensory ocular dominance and its relation to personality. American Journal of Optometry & Archives of American Academy of Optometry, 1969, 46(8), 603-615.

Describes a method for measuring sensory retinal rivalry. By comparing the measurements of the right and left eye, a measure of dominance of one over the other was obtained. Dominance was then correlated with each of a battery of neuropsychological and psychological scores. Results indicate that children with normal vision have little or no sensory ocular dominance. Although dominance increases with age, in normal persons it remains small. In some a marked dominance exists, often for no ocular reason. Retinal rivalry scores relate to some form of psychological rigidity which increases with age. The nature of this remains unknown, although it would seem to be a type of perseveration.

Indow, T., & Koyazu, T. Experiments on induction in the binocular field composed of the independent monocular fields. Japanese Psychological Review, 1960, 2, 142-151.

Induction induced by a figure in a particular position of the field is, by definition, the change in electrical excitability of the eye which is due to the figure and becomes observable through the stimulation of a white patch as a probe. Induction seemed independent of retinal origin to the extent that the same result was obtained when the whole figure was presented to one eye as when different components were presented to the two eyes.

Jacobs, R. S., Triggs, T. J., & Aldrich, J. W. (See Helmet-mounted Displays)

Kakizaki, S. The effects of preceding conditions upon binocular rivalry I. Japanese Journal of Psychology, 1950, 20(2), 24-32. (a)

Ss were presented with light patches crossed with diagonal lines, one to each eye. Diagonals in each patch were at right angles to the other. One eye was given an exposure of varying duration preceding the binocular exposure. Results indicate that pre-exposure by its figurality does influence binocular rivalry.

Kakizaki, S. The effects of preceding conditions upon binocular rivalry II. Japanese Journal of Psychology, 1950, 20(4), 11-17. (b)

Continues the report on effect of prior stimulation on binocular rivalry. Length of preceding stimulation was not directly related to duration of the aftereffect. It persisted for at least 5 or 6 minutes. Binocular color rivalry showed the same effect as figure rivalry.

Kaplan, I. T., & Mettay, W. Light intensity and binocular rivalry. Journal of Experimental Psychology, 1964, 67(1), 22-26.

A luminous bar was presented to each eye so that the two bars appeared to cross in the center of the binocular field. Rivalry occurred at the intersection, where each bar seemed alternately before or behind the other. Raising the illumination of both bars increased their alternation rate to a level that held constant at higher brightnesses, until the rate declined when the light became very intense. With both bars illuminated equally, one S reported the left bar dominant more than half the time; another S reported the right bar dominant. Raising the illumination of one bar increased the duration that it prevailed. Prevalence increased steeply at low intensities, leveled off at higher intensities, and finally declined when the bars became glaringly bright. After viewing two bright bars, Ss reported rivalry between their afterimages, which demonstrates that rivalry can occur when the stimuli occupy fixed retinal locations.

Kaufer & Reiss. Stereoscopic perception as a tool in psychotherapeutic research. Perceptual & Motor Skills, 1960, 10, 241-242.

49 male and 21 female psychiatrists were presented, stereoscopically, a nude male and female, a cow and a bull, the Washington Monument and the Jefferson Memorial, and an abstract and an impressionist painting. Chi-square analysis indicated that at the .01 level the



males predominantly saw first the nude male and the Washington Monument; the women saw the female and the Jefferson Memorial. The abstract-impressionist paintings produced differences at the 5% level of significance, with males preferring impressionist art. The cow and the bull produced perfect fusion for both groups and hence no difference. Eye dominance proved to be of no importance, the results being the same regardless of the right or left position of the stimulus or S's eyedness. It was concluded that the stereoscope can be used to study attitudes which reflect the self-concept of the viewer.

Kephart, N. C., & Revesman, S. Measuring difference in speed of performance. Optometrist Weekly, 1953, 44, 1965-1967.

Tachistoscopic study indicating that when a different field is exposed to each eye, one eye will see more than the other in the same length of time.

Kirkwood, B. Comment on Goldstein's "Retinal rivalry and Troxler's effect." Psychonomic Science, 1968, 11(2), 54.

Suggests that A. G. Goldstein's data on Troxler's effect reflect the influence of eye-movement rather than the variables specified by the author. An alternative test of Goldstein's retinal interaction is briefly outlined.

Kleiven, J., & Rommetveit, R. Meaning and frequency in a binocular rivalry situation. Scandinavian Journal of Psychology, 1970, 11(1), 17-20.

When a word perception task was studied with 24 undergraduates under conditions of binocular rivalry, the meaningful one of two rivaling strings of letters was identified more often than the other. Differences in frequency of the trigrams in the Norwegian language had no effect.

Lack, L. Binocular rivalry control and selective attention. Australian Psychologist, 1967, 2(1).

Binocular rivalry (BR) offers distinct advantages in studying selective attention. In two experiments it was verified that Ss can exert some initial control over BR fluctuations by following the E's instructions for "slow" and "rapid" rate and the Ss can improve their control (increased rapid rate and decreased slow rate) by practicing the two instructions. The second study with 28 Ss in four groups showed that the increased control is significantly dependent on amount of practice but not on amount of previous "passive" viewing. It is suggested that with practice one can develop the facility of selective attention in

BR to the same extent as selective ability within other sensory modalities.

Lack, L. C. The effect of practice on binocular rivalry control. Perception & Psychophysics, 1969, 6(6B), 397-400.

Investigated the effects of passive viewing and the practice of the control instructions, "slow rate" and "rapid rate" on a measure of binocular rivalry (BR) control. Four groups of 8 male and female undergraduates each had different amounts of passive viewing of BR followed by different amounts of control instructions to complete a total of 50 minutes of testing spaced over 10 days. There were increases of passive rate as long as Ss practiced only the "passive rate" instructions. This had an effect of increasing the rapid rate and slow rate of the 1st control practice day. However, "passive rate" practice had no significant effect on the measure of BR control. Successive practice days of "rapid rate" and "slow rate" instructions produced an increase in rapid rate and decrease in slow rate resulting in an increase in the measure of control.

Lack, L. C. Effects of knowledge of results and spacing of practice trials in training of control of binocular rivalry. Perceptual & Motor Skills, 1970, 31(3), 827-830.

Investigated the effects of knowledge of results (KR) and compared its effects with spacing of practice. 60 undergraduates in four experimental groups practiced, under binocular rivalry, control instructions of "slow rate" and "rapid rate" for a total of two minutes each on 10 successive test sessions. The effects of distribution of practice and knowledge of results (KR) on the increase of control of binocular rivalry were investigated using a 2 x 2 factorial design. All experimental groups except the massed practice group with no KR showed significant decreases of slow rate, increases of rapid rate, and, consequently, significant increases of control of binocular rivalry. The increase of such control with practice was facilitated significantly by spacing but was most dramatically affected by KR. Results indicate that both KR and the distribution of practice are significant independent variables which seem to be additive in their effects.

Lack, L. C. The role of accommodation in the control of binocular rivalry. Perception & Psychophysics, 1971, 10(1), 38-42.

A recent investigation by G. A. Fry indicates that accommodation provides the basis of binocular rivalry (BR) control through the blurring of retinal images. However, the present study with 9 normal-sighted nonacademic staff members, found that the

introduction of very small artificial pupils (.5 mm.) did not reduce BR control. It is concluded that if accommodation changes are occurring with large pupils, the resulting image blurring plays no part in control of rivalry. Experiment 2, with 20 undergraduates with normal vision, tested the effect of paralyzed intrinsic eye muscles and found almost the same degree of control as in the normal state. The slight decrease of control that was present was attributed to a general performance decrement, since slight performance decrements with eye paralysis were also found in a visual RT task and hand dynamometer test. In Experiment 3 with 28 normal-sighted undergraduates, it was found that the increased control that was obtained over several practice sessions was mostly retained during subsequent eye paralysis. These findings and a very significant control of rivaling afterimage stimuli under eye paralysis strongly suggest a central component of BR control rather than one based on accommodation.

Levelt, W. J. On binocular rivalry. Soesterberg, Netherlands, Institute of Perception RVO-TNO, 1965.

Rivalry may arise if both eyes are presented with stimuli differing in such a way that binocular fusion cannot occur. The dominant field on one eye seems to inhibit the field of the other eye. The disappearance of one of these "images" is not always the effect of stimulation of the other eye. It can also be caused by spontaneous fading, called Troxler's effect. This is most distinct if a target is peripherally presented to the first eye, while the other eye is presented with a homogeneous field, in which case the target seems to disappear occasionally. Since this effect is not due to binocular rivalry, it is called "spurious rivalry". The perceptual conflict can be attributed to the incompatibility of two mechanisms: binocular brightness averaging, and contour mechanisms.

Levelt, W. J. The alternation process in binocular rivalry. British Journal of Psychology, 1966, 57(3-4), 225-238.

Alternation frequency in binocular rivalry and relative dominance of stimuli in the right and left eyes are described in terms of an alternation model. The model is based on the assumption that the mean duration of the dominance of the stimulus in one eye is independent of the strength of this stimulus; the duration is assumed to be dependent only upon the strength of the stimulus in the contralateral eye. A provisional definition of stimulus strength is given. Evidence for assumptions and model is presented by a review of experimental literature on dominance and alternation in binocular rivalry, and by a number of experiments. Normal binocular fusion is considered.

Levelt, W. J. Note on the distribution of dominance times in binocular rivalry. British Journal of Psychology, 1967, 58(1-2), 143-145.

Dominance periods of a stimulus in binocular rivalry show a characteristic time distribution that gives important clues as to the underlying mechanism in alternation. It is shown that the distribution can be approximated by a T function, which has a positive integral exponent. The function describes a poisson distribution. This suggests the existence of an underlying dominance generating process that is discrete in nature. The parameters of this process are determined by properties of the recessive stimulus in the other eye. The discrete events may be flicks of eye movement.

Levelt, W. J. On Binocular Rivalry. The Hague: Mouton, 1968.

Rivalry is considered a result of conflict between two visual mechanisms, namely binocular brightness averaging which operates so as to average out the brightness for corresponding points of the two eyes, and the second is a contour mechanism which acts so as to leave the area in the vicinity of a distinct contour unimpaired. This means that for the particular situation where symbolic information is presented to one eye, and a textured field (such as a ground map) to the other, the textured field is going to be particularly degraded at the contours of the symbolic information. (Summary from Jacobs, Triggs, and Aldrich, 1970)

Linton, P. M. (See Helmet-mounted Displays)

Lo Scuito, & Hartley. Religious affiliation and open-mindedness in binocular resolution. Perceptual & Motor Skills, 1963, 17, 427-430.

Using 20 Ss (10 Catholic and 10 Jewish), E determined that people tend to see words or pictorial symbols associated with their religion when it and an appropriate word or symbol of another religion are viewed through a stereoscope. This tendency is stronger among more dogmatic subjects.

Martin, J. I. Effects of binocular fusion and binocular rivalry on cortically evoked potentials. Electroencephalography & Clinical Neurophysiology, 1970, 28(2), 190-201.

Employed two stimulus patterns to obtain pattern-characteristic responses to monocular stimulation in an experiment with 5 adult Ss. Various combinations of the stimuli in monocular and binocular presentation, together with Ss' perceptual judgement of dominance

In conditions of rivalry, yielded 12 experimental conditions. Correlations and T-statistics were computed for the evoked potentials obtained under several combinations of experimental conditions. Results indicate that the physiological record obtained under conditions of binocular stimulation is not composed of equal contributions from each monocular source. There was not apparent definite relation between the pattern which was perceived under conditions of rivalry and the resulting wave form of the evoked potential. The utilization of cortically evoked potentials as a physiological indicator of subjective phenomena under conditions of binocular rivalry does not appear to be substantiated. A form of electrophysiological dominance appears to exist which seems to be unrelated to either momentary or general perceptual dominance, but may be related to an interaction of the eye-of-origin with the physical characteristics of the stimulus.

Maenes, M. A phenomenological description of retinal rivalry. American Journal of Psychology, 1930, 42, 260-269.

Using a Ludwig tropostereoscope and observing simple and slightly dissimilar figures through differently colored monochromatic filters, it was found that one figure is definitely connected with one color. Changes were apprehended as being changes in one member of the pair (the passive) brought about by the other member (the active); the active member expands and contracts, and being nearer the observer phenomenologically blots out or exposes the passive. In the second part of the experiment a haploscope with two parallel cardboard tubes, 4 feet long and 2 inches in diameter was used. Using the same colors and slightly different figures, the description of the experience was the same. Rivalry is a tridimensional experience, in which the active color spreads over the passive, which shines through as the active withdraws. Stimulating one eye with black horizontal lines on a white ground and the other with vertical lines, it was found that a stable figure never resulted; usually the horizontal line was the more active.

Meredith, G. M., & Meredith, C. G. W. Effect of instructional conditions on rate of binocular rivalry. Perceptual & Motor Skills, 1962, 15(3), 655-664.

Investigated the effect of three instructional conditions on the rate of binocular rivalry. Results indicated a distinct effect associated with each of the instructions. Sex differences were not found to be significantly different. A number of variables which may influence the rate of reversal were discussed, including attention, set, attitude, and intention.

Meredith, G. M. Some attributive dimensions of reversibility phenomena and their relationship to rigidity and anxiety. Perceptual & Motor Skills, 1967, 24(3)(1), 843-849.

Compared a binocular rivalry field with a figure reversal field along 33 rating dimensions. Thirteen of the scales differentiated the two fields. Personality measures of rigidity and anxiety were obtained for each S and related to scale performance. While rigidity was found correlated to attributes assigned to the two visual fields, anxiety correlated significantly with several of the ratings. The attributive rating method appears promising for inferring elevations in tension level.

Michael, J. A., & Stark, L. Electrophysiological correlates of saccadic suppression. Experimental Neurology, 1967, 17(2), 233-246.

Both binocular rivalry and saccadic suppression produce an elevation of the visual threshold and a diminution of the pupillary reflex. In addition, binocular rivalry is known to be accompanied by a reduction in the amplitude of the visually evoked response (VER) produced by stimuli delivered to the suppressed eye. In an attempt to discover whether saccadic suppression has a similar effect on the VER, Ss were placed in a situation in which saccadic suppression could be produced, and the VER was examined under three conditions: suppression occurring with the presentation of stimuli before and synchronously with the beginning of a saccade, and with the intensity of the stimuli increased to a level where no suppression occurs. In all cases where suppression was reported obvious concurrent changes in the wave shape of the VER were observed. When no suppression occurred the VER was essentially unchanged. This additional similarity between binocular rivalry and saccadic suppression suggests that the two phenomena may share a common mechanism at the higher levels of the visual system. It is suggested that such a common mechanism may be located at a point in the visual system where monocularly oriented data processing occurs.

Miller, E. F. Evaluation of certain visual and related tests: Retinal rivalry. U.S. Navy School of Aviation Medicine Research Report, 1958, Project No. NM 14 01 11, Sub. 6, No. 5, II, page 8.

The habitual and accelerated retinal rivalry rates as tested by Renshaw were found to be distributed in a normal manner among 112 Naval cadets. Ss could voluntarily increase rate of alternation by about 9 cycles per minute. A retest reliability was found for both habitual ( $r = +.02$ ) and accelerated ( $r = +.18$ ) rivalry rates.

Murray-Peckham, R. The principles of binocular fusion and stereoscopic vision. Clinical Research Reports, Optical Research Institute, 1940, 6, 138.

Discusses stereoscopic acuity, perspective, identical retinal points, parallax, and retinal rivalry.

Mull, H. K., Ord, N., & Locke, N. The effect of two brightness factors upon the rate of fluctuation of reversible perspectives. American Journal of Psychology, 1954, 67, 341-343.

Results of experiments are presented in which Necker cubes were presented under different conditions of contrast or illumination indicated that neither factor influences rate of fluctuation. The two factors considered were brightness contrast between contour and background, and illumination.

Mull, H. K., Armstrong, G., & Telfer, B. The effect of brightness upon reversible perspectives and retinal rivalry. American Journal of Psychology, 1956, 69, 123-125.

The findings of a previous study are continued. In that study, conducted by Mull, Ord, and Locke (1954), results were given of the effect of two brightness factors upon the rate of fluctuation of reversible perspectives. In the present study, the fluctuations of a maltose cross and of blue-red retinal rivalry seem to be unaffected by contrast or by illumination with one exception. In faint light, the rate of rivalry shift of colors is much slower than in bright light. Suggests that the shifts of retinal rivalry for colors seen in bright light may be supposed to involve much the same mechanism as that accounting for the reversals of perspective.

Murroughs, T. R. The relationship of retinal rivalry to reading achievement. American Journal of Optometry, 1951, 28, 581-588.

No relationship was found between retinal rivalry and reading achievement.

Murroughs, T. R. Relationship of retinal rivalry and stereopsis. Optometric Weekly, 1951, 42, 1793-1795.

Data are presented which indicate that the functions of retinal rivalry and stereopsis develop as independent binocular functions.

Ogle, K. N. Some aspects of stereoscopic depth perception. Journal of the Optical Society of America, 1967, 57(9), 1073-1081.

Emphasis is placed on experiments that provide evidence for a physiologic basis for the phenomenon: existence of limiting

disparities, relationship to double images, role of simultaneous stimuli, the limiting delay between stimuli to the two eyes, role of vertical disparities, effect of unequal luminances, the role of training and strabismus surgery, etc. A general discussion of the theories of stereoscopic depth perception deals with psychological cues, fixation and fusional eye movements, Hering theory of local signs, Gestalt point of view, and suppression theories. A few current problems are then considered: duration of stimuli, role of eye movements, effect of binocular rivalry, relationship of perceived depth to angular disparity, adaptation to conflicting empiric cues and stereoscopic depth, and the induced effect.

Ono, H., Hastorf, A. H., & Osgood, C. E. Binocular rivalry as a function of incongruity in meaning. Scandinavian Journal of Psychology, 1966, 7(4), 225-233.

The 3rd of a series of 3 papers dealing with semantics of facial expressions. The purpose of this experiment was to determine whether the ratings of two stimulus inputs on semantic differential scales would predict the experience of binocular rivalry. The stimuli used were five full-face photographs of a man expressing different emotions. These stimuli were rated on the semantic differential and all possible pairs of these stimuli were used as stereograms. The hypothesis that semantically incongruous stimulus inputs would lead to binocular rivalry and that congruous ones would lead to an absence of rivalry was supported.

Peckham, R. H. Eye movements during "retinal rivalry". American Journal of Psychology, 1936, 48, 43-63.

Found no relationship between eye movements and rate of alternation of phase length of rivaling fields.

Pettigrew, T. F., Allport, G. W., & Barnett, E. D. Binocular resolution and perception of race in South Africa. British Journal of Psychology, 1958, 49, 265-278.

Stereoscopic presentations of pictures of whites and blacks were made. It was found that Ss correctly identified members of own racial group best. No theory is proposed but supports the idea that resolution of binocular conflict is affected by cultural membership, expectancies and subjective attitudes.

Pickford, R. W. Binocular color combinations. Nature, 1947, 159, 268-269.

Experiment consisted of stereoscopic presentation of all combinations of 9 different colors to experienced O with



normal color vision who rated degree of fusion from 0 to 1. Concluded from factor analysis that complementary colors are very difficult to combine and that bright colors are difficult to combine with dark colors. Used to substantiate 4-color theory and that color combinations may take place in retina.

Platz, A., Uhr, L., & Miller, J. G. A pilot experiment on the effects of meprobamate on stereoscopic retinal rivalry of complementary colors. Perceptual & Motor Skills, 1960, 10, 230.

The tranquilizer meprobamate was given to the S before he viewed two plates of complementary colors, one to each eye and superimposed by the stereoscope. A 16% decrease in the number of reversals occurred under meprobamate as compared to a placebo.

Ravey, J. A study of sensory interactions. Papers in Psychology, 1969, 3(2), 67-68.

Investigated the findings by V. Urbantschitsch in 1903 that, "in binocular rivalry, unilateral auditory stimulation heightens the acuity of the ipsilateral eye." Red and green stimuli were presented to 40 Ss in four groups receiving various presentations of auditory stimuli. Results did not support the previous finding. The possible physiological mechanisms of sensory interaction are discussed.

Rommetveit, R., Toch, H., & Svendsen, D. Effects of contingency and contrast contexts on the cognition of words: A study of stereoscopic rivalry. Scandinavian Journal of Psychology, 1968, 9(2), 138-144.

Two typographically very similar words (like 'hell' and 'tell') were presented in a binocular rivalry situation, each appearing after a contrast context (e.g., 'heaven') or a contingency context (e.g., 'devil') had been presented to both eyes. Context effect was then assessed in terms of the frequency with which the context-relevant word was reported as seen. The effect of contrast compared with contingency context was weak when context and test words were presented consecutively, but strong when the context stimulus appeared above the rivalry pair on the same stereogram.

Rommetveit, R., & Kleiven, J. Word generation: A replication. Scandinavian Journal of Psychology, 1968, 9(4), 277-281.

Examined binocular rivalry in a word perception task with printed Norwegian stimulus material, using 30 undergraduates. Two types of resolution, choice of one image only or combination of both images, were again observed. The letter pair R/G tended to be seen as R only, G only, RG, or GR, depending upon which resolution

yielded a word. Perceptual strategy was determined in part by a superordinate search for word meaning. Fully confident generations of words from monocular nonword strings were not obtained very often.

Sampson, H. Recall of digits projected to temporal and nasal hemiretinas. Quarterly Journal of Experimental Psychology, 1969, 21(1), 39-42.

14 right-handed, right-eye dominant Ss recalled digits when different ones were projected simultaneously to either temporal or nasal retinas. The principal findings were: (1) recall of digits projected to nasal retinas was significantly better than when projected to temporal retinas, and (2) information projected to the right eye was recalled significantly better than that projected to the left eye. It is shown that the relative ineffectiveness of the recall of input from the nondominant eye can be attributed almost wholly to the relative inefficient recall of digits projected to the left temporal retina.

Sampson, H., & Horrocks, J. B. Binocular rivalry and immediate memory. Quarterly Journal of Experimental Psychology, 1967, 19(3), 224-231.

Three experiments examined features of a simple memory task on which right-handed, right-eye dominant Ss were reported to recall digits projected to the right eye more accurately than those projected simultaneously to the left eye. Superior recall by these Ss of information projected to the right eye was observed only when stimuli projected simultaneously to both eyes were seen as overlapped in the binocular percept. Under monocular presentations, accuracy of recall was not related to the eye with which stimuli were viewed. The binocular overlap condition has a significance other than that of simply increasing the difficulty of identifying the elements in a visual display for there were no differences in accuracy of recall from each eye when overlapped stimuli were viewed monocularly. More accurate recall of right eye information appears to reflect the resolution of a conflict between inputs from each eye. The possible relation of this finding to cerebral dominance is also discussed. Order of recall depended mainly on spatial cues provided by the experimental situation.

Sarbin, T. R., & Wenk, E. A. Revolution of binocular rivalry as a means of identifying violence-prone offenders. Journal of Criminal Law, Criminology & Police Science, 1969, 60(3), 345-350.

Ss were 20 pairs of matched young criminals, 1 with a background of violence, 1 with a nonviolent background. Ss were shown stereoscopic materials in which one eye saw a violent scene and one a neutral scene. It was expected that violent Ss would see more

violent than neutral scenes. No difference was found. This was attributed to conscious suppression of violent reports by violent Ss who were thought to suspect the purposes of the experiment. Ways of improving such studies are discussed.

Siegal, H. H. Diagnostic significance and meaning of retinal rivalry. Optometrist Weekly, 1949, 40, 115-116.

Retinal rivalry is considered useful in establishing the efficiency of a lens prescription, the degree of deterioration in visual behavior, and the progress in visual training.

Smith, P. K. Image fragmentations with afterimages and in binocular rivalry. Psychonomic Science, 1968, 10(8), 275-276.

"Structured" and "unstructured" fragmentations of a simple geometric figure were compared in conditions of binocular rivalry, and afterimage viewing, for 10 Ss. For all Ss "structured" fragmentations were found to be much less common and less stable in rivalry.

Springbett, B. M. Some stereoscopic phenomena and their implications. British Journal of Psychology, 1961, 52, 105-109.

Stereoscopic observations involving simple contrast, the Wertheimer-Benussi figure, and some geometric illusions lead to the conclusion that these phenomena are produced by processes within the visual system stemming from one eye. Contours or surfaces presented to one eye may be erased when a moving contour is presented to the other eye.

Storch, H. R. Retinal rivalry: Its relation to reading disability, eye movements in reading, ocular dominance, and visual acuity. Dissertation Abstracts, 1958, 19, 578-579.

Investigated whether retinal rivalry is a factor in reading disability. Also investigated the relationship between retinal rivalry and eye dominance and between retinal rivalry and visual acuity. The experimental group consisted of 98 children possessing average general intelligence and who were at least one year retarded in reading. The control group consisted of 99 children within the same range of general intelligence who were reading at or above the expected level in reference to mental age. There were no statistically significant differences between the groups regarding the extent of retinal rivalry. There was a tendency for certain visual anomalies to occur among retarded readers during retinal rivalry. There was no significant difference in the percentage of eye dominance for each group as revealed by the Harris Tests of Lateral Dominance. Whereas ap-

proximately 75% of the population showed definite eye preference on the Harris Tests, the majority showed no decided eye preference on the retinal rivalry tests. Eye preference showed little relation to visual acuity.

Toch, H. H., & Schulte, R. Readiness to perceive violence as a result of police training. British Journal of Psychology, 1961, 52, 389-393.

A group of men who had undergone a three-year course in law enforcement were tachistoscopically presented with a 'violent' picture to one eye, and a matched 'neutral' picture to the other. The results were compared with those obtained from novices in the training program and from psychology students. The trained subjects were found to see 'violent' scenes fully as often as they saw neutral ones, whereas the control subjects reported comparatively few violent pictures. It was concluded that specialized training may supplement past experience in areas in which the average person may become perceptually 'sensitive' in situations which ordinarily rarely occur.

Treisman, A. Binocular rivalry and stereoscopic depth perception. Quarterly Journal of Experimental Psychology, 1962, 14, 23-37.

It is shown that similar color information can be 'filtered' out from both eyes; stereopsis is not incompatible with rivalry and suppression of one aspect of the stimulus, and that the strongest cue for perception of stereoscopic depth is intensity difference at the boundaries of the figures in the same direction at each eye.

Ueno, H., & Suzuki, Y. Studies on sensory deprivation: VI, Part 3. Effect of sensory deprivation upon perceptual functions. Tohoku Psychologica Folia, 1967, 26(1)(2), 17-20.

Studied the effect of sensory deprivation on perceptual function in relation to two hypotheses and tests: (1) that deprivation impairs the organization of perceptual stimuli, examined via size constancy and (2) that sensory deprivation increases the activity of perceptual function examined via binocular rivalry. Results support these hypotheses. Selective influence of sensory deprivation of EEG and electric flicker were also explored, but results were inconclusive.

Wales, R., & Fox, R. Increment detection thresholds during binocular rivalry suppression. Perception & Psychophysics, 1970, 8(2), 90-94.

In two experiments, 2-choice forced-choice duration thresholds for increment test flashes were estimated during phases of rivalry

suppression and nonsuppression and for a nonrivalry monocular control condition. Two males, 20 and 23 years old, served as Ss. Thresholds of both eyes of each S were measured and, to maximize correct detections, feedback was given after every trial and Ss were relieved of the task of continually reporting changes in rivalry phases. Results support the conclusion that suppression constitutes an elevation in threshold, on the order of .5 log units relative to thresholds found during nonsuppression and monocular conditions. Data reinforce the conclusion that rivalry suppression is an inhibitory state that nonselectively attenuates all classes of inputs falling within the spatial boundaries of the suppressed target.

Washburn, M. F. Retinal rivalry as a neglected factor in stereoscopic vision. Proceedings of the National Academy of Science, 1933, 19, 773-777.

Experimentation with a stereoscope demonstrated that the stereoscopic perception of solidity is not derived from a retinal pattern composed of two images of an object obtained from different points of view. The author also reports an experiment which demonstrated a result she finds reported nowhere else in the literature; namely, that rivalry occurs in connection with ordinary vision of solid objects. The author states, "No one so far as I can find has hitherto suggested that retinal rivalry plays an important part in the perception of solidity, but from the evidence presented in this paper such a conclusion seems probable."

Washburn, M. F., & Manning, P. Retinal rivalry in free vision of a solid object. American Journal of Psychology, 1934, 46, 632-633.

Retinal rivalry can be experienced without the use of a stereoscope while viewing a solid object. Retinal rivalry is observable under normal conditions by using binocular observation.

Whittle, P. Binocular rivalry and the contrast at contours. Quarterly Journal of Experimental Psychology, 1965, 17, 217-226.

Binocular rivalry was recorded between various achromatic figures in or near the fovea. For a pair of intersecting contours, one in the field of each eye, it was found that the percentage of time for which a contour was dominant at the point of intersection increased with the contrast at that contour and also with average luminance when contrast was constant. For 1 degree circles in corresponding positions in the two fields, one darker than its surround and one lighter, the same results were obtained. Various auxiliary results, on rate of rivalry, eye dominance, the occasional mixture of the rivaling stimuli, and binocular lustre, are given. Finally,

the relationship between predominance in rivalry and perceived brightness is discussed.

Whittle, P., Bloor, D. C., & Pocock, S. Some experiments on figural effects in binocular rivalry. Perception & Psychophysics, 1968, 4(3), 183-188.

The following questions were investigated in four experiments: (1) does a stimulus which is dominant in rivalry tend to make nearby stimuli seen by the same eye dominant also? The results suggest that it does not. (2) Under what conditions do nearby stimuli rivaling with opponents of equal strength, rival synchronously? It was shown that contour segments belonging to the same line, even when seen by different eyes, rival synchronously. Mere contiguity, however, does not lead to synchrony.

Wilde, K. Figure and surface in retinal rivalry (Figur und Flaette in Wittstreit) Psychol. Forsh. 1937, 22, 26-38.

Investigated whether retinal rivalry furnishes criteria to help distinguish importance of peripheral and central factors in visual perception. The strength of a figure is the relative time it is dominant in a rivalry situation. Findings: (1) In rivalry between a figure and an empty surface, the figure predominates. (2) In rivalry between two figures, individual differences are found. (3) The 'strength' of a figure depends on strength of contour, but is independent of surface extent and inner contours. (4) The strength of the figure also depends on gestalt factors and direction.

Wolf-Heidegger, G. Zur Demonstration der binocularen farbenmischung und des Wettstreits der Sehfelder. Ophthalmologica, 1946, 112, 102-103.

When spectacles having one lens blue and the other red are presented to a subject to be worn, the subject first sees half the visual field as blue and half as red. Then the two colors disappear and the view appears in mixed color, which is known as color mixing.

Woodworth, R. S., & Schlosberg, H. Experimental Psychology. New York; Holt, Rinehart and Winston, 1954, pp. 399-401.

These generalizations are based upon the work of Breese (1899, 1909). Rivalry occurs between corresponding areas of the two retinas, not between the entire retinas. The following factors were found to change the rate of alternation when parallel changes were made in the two monocular fields: light intensity (cycle duration decreases with increased illumination); area of field (the larger the field the more rapid the alternation); diststructures of lines (alternation

is slower with blurred lines); alternation is more rapid with central than with peripheral vision. The following factors were found to influence the prevalence of fields during binocular rivalry: light intensity (the brighter is more prevalent); presence of figures; movement (when both fields contain figures that which moves will be prevalent); attention.

Zeman, S. S. A summary of research concerning laterality and reading. Journal of the Reading Specialist, 1967, 6(3), 116-123.

Examined the relationship of laterality to reading. From four studies involving the use of matched pairs it was shown that no significant differences existed in regard to (1) handedness and reversals, (2) eye dominance, hand dominance, and hand vs eye dominance and reading disability, and (3) mirror drawing, ear or foot preference and retardation in reading. Asks the question of whether investigations regarding the relationship of laterality to reading are an area that has been substantially researched. If so, perhaps the research time being devoted to this area could be used more advantageously in studying other relationships in respect to reading.

## VISUALLY COUPLED SYSTEMS SYMPOSIUM

Biberman, L. M. Perception of displayed information. Proceedings of the Symposium on Visually Coupled Systems Development and Application, Technical Report AMD TR 73-1, December 1972.

The work of Harry Snyder has shown that for photographs and high frequency rasters on television type displays, the concept of the MTFM is a good predictor of an observer's ability to extract information from displayed imagery. The pertinence and limitations of MTFM are reviewed. The work of Frederick Rosell has shown the signal-to-noise ratio required to achieve a variety of visual tasks on imagery viewed on an ideal display. The results of his work make possible the meaningful evaluation of systems as well as more exact designs for required performance. In the case of the more usual real displays with rasters of 490 lines as currently used in this country two effects, aliasing and masking, combine to reduce information transfer. These effects are discussed and their optical and acoustical counterparts demonstrated.

Catanzaro, C. Operational aspects of VTAS. Proceedings of the Symposium on Visually Coupled Systems Development and Application, Technical Report AMD TR 73-1, December 1972.

Abstract not available

Chaikin, G., & Enderwick, T. Field test of air-to-ground target acquisition performance with a visually coupled system. Proceedings of the Symposium on Visually Coupled Systems Development and Application, Technical Report AMD TR 73-1, December 1972.

A field test was conducted at Redstone Arsenal, during late Spring, 1972, to (1) define the capability of human operators to detect and recognize tank-type targets and to then lock a tracking gate in a television display onto the target in preparation for a missile launch; (2) evaluate the use of a complete visually coupled system, including a helmet-mounted TV subsystem integrated to perform the above task; (3) evaluate the effects of employing a simple, stabilized optical aid for target search and recognition prior to acquisition on the TV display for subsequent lockon; and (4) secure data on target acquisition, target recognition, visual transfers and other task elements during mask/unmask and higher altitude profiles. A seeker was installed in the nose of a dummy missile, rail-mounted on a UH-1M helicopter. The field-of-view of the seeker, aimed by the helmet pointing subsystem, was presented to the operator via a helmet-mounted TV display. Three procedural modes were investigated for initial target recognition--unaided, use of a stabilized zoom-optic, and use of a stabilized zoom-optic with final magnification nominally equated with that of the helmet-mounted TV display.



Military vehicles, located in the open, against treelines, and in clutter, served as prebriefed targets. High altitude flights were run at each of three altitudes; low altitude flights were run at each of three nominal standoff ranges for both standard and silicon vidicons. This paper describes background, objectives, test conditions, measurements, instrumentation and general results.

Chatten, J. B. Foveal hat, a head aimed TV system with foveal/peripheral image format. Proceedings of the Symposium on Visually Coupled Systems Development and Application, Technical Report AMD TR 73-1, December 1972.

This remote visually coupled sensor system was developed and tested at Control Data Corporation on a series of contracts under the sponsorship of Advanced Research Projects Agency, Rome Air Development Center and Aerospace Medical Research Laboratories. It differs from previously implemented head-aimed television systems, in that the operator is presented with a compsite image format consisting of a wide-field, low-resolution peripheral image with a narrow-field, high-resolution image embedded in its center. The two images are presented at the same scale and in registry. They form a rough approximation to the distribution of normal visual acuity within the system field of view. This particular system implementation uses stationary TV cameras whose optic axes are deflected by a gimbal mounted mirror servoed to track operator head position and a display device utilizing stationary high resolution CRTs to form a foveal/peripheral image which is optically coupled to the operator's field of view through a jointed optical relay which also serves as a head position sensor. This remote viewing sub-system has been integrated with a remotely operated vehicle and experiments in remote driving performed. Experimental results are presented.

Cohen, B. J., & Markoff, J. I. Minimixation of binocular rivalry with a see-through helmet mounted sight and display. Proceedings of the Symposium on Visually Coupled Systems Development and Application, Technical Report AMD TR 73-1, December 1972.

When completely independent images are presented to each eye, fusion cannot normally occur. Instead, either an involuntary alternation occurs between the two images (binocular rivalry) or one of the images is "suppressed," and visual performance is degraded. If the images are only partially independent (see-through display) the observer can control this alternation and presumably reduce degradation. During the development of one version of the Honeywell Helmet Mounted Sight and Display (HMS/D) system, it was suggested that presenting a gunsight reticle to one eye and target imagery to the other eye, sequentially, or with an inter-ocular delay interval (IOD), might minimize binocular rivalry. In order to

determine the relationship between binocular rivalry and visual performance, an experiment was performed in which target recognition performance was measured as a function of inter-ocular delay interval. A factorial design with repeated measures on all factors was used to analyze the effects of six levels of inter-ocular delay (IOD), and two levels of method of presentation. The dependent variable was target recognition time. It was hypothesized that if binocular rivalry did exist, and if it occurred even when only temporal summation linked the images to the two eyes, visual performance would be best when display imagery was present to only one eye, and worst when presented to both simultaneously. It was further hypothesized that performance would fall off in a regular fashion between these two extremes as the IOD was decreased. Statistical analysis of the data failed to confirm these hypotheses, and it was concluded that the influence of binocular rivalry on target recognition tasks was negligible with a see-through display. It was suggested that future research concentrate on this phenomenon using more difficult visual tasks.

Coluccio, T. L., & Mason, K. A. The viewing hood oculometer; a sighting control and display feedback system. Proceedings of the Symposium on Visually Coupled Systems Development and Application, Technical Report AMD TR 73-1, December 1972.

The measurement of target position in reconnaissance imagery in both the real-time airborne environment as well as the real-time ground based station, is a vital military function. Manual techniques involving maps, reticles, cross hairs, etc. are time consuming and cumbersome. A study was performed which demonstrated that an oculometer eye direction monitor can be used to rapidly and easily determine target position on the screen of a real-time reconnaissance display. The oculometer technique provided instant target position readout to an accuracy of 0.3 degrees in terms of visual angle, or 0.1 inch on the display contract and flight tested by RADC, thus proving the practical application of this technique. Several other reconnaissance oriented applications of the viewing hood oculometer appeared evident as a result of these preliminary tests. One such application is currently being implemented, namely the use of the oculometer as a ground based psychophysical research tool. This study will investigate how the manipulation of several real-time display variables will affect operator performance during detection and recognition tasks.

Dietz, F. H. Evaluation of the helmet mounted sight. Proceedings of the Symposium on Visually Coupled Systems Development and Application, Technical Report AMD TR 73-1, December 1972.

The Helmet Mounted Sight (HMS) evaluation was conducted by the 4750th Test Squadron of the Aerospace Defense Command for the

Air Force Systems Command. This test was directed by the United States Air Force Chief of Staff to provide quantitative data required to make optimum decision on the use of the HMS in a proposed advanced weapon system. The overall objective of the test program was to determine the utility of the HMS system under high "G" conditions in acquiring and tracking a high performance target in a maneuvering environment. The concept of operation and utilization of the system is presented by the lead OT&K test pilot who directed, organized, planned, and flew in the evaluation. The experimental design allows an in depth statistical investigation of open loop pilot head tracking skills in the high "G" environment. To accomplish the objectives, four flight test profiles were devised. Profiles 1 and 2 provided a systematic approach of controlling the independent tracking variables ( $G_x$ , angular rate, off-boresight angle, etc.) while still providing realistic quantitative data which can be used to define requirements and specifications of future systems. Profile 3 exercised the HMS in a controlled environment of high "G" and variable line-of-sight rates and angles. The test was culminated by flying selected offensive air combat maneuvers against a fighter target. Quantitative tracking data at various discrete "G" levels and off-boresight angles for constant line-of-sight, variable line-of-sight angles and a comparison of Fire Control System lock-ups during air combat maneuvers are presented. It is concluded that the HMS does have utility in a high "G" maneuvering environment to effectively and accurately position a fire control system/mis-sile antenna.

Eliason, D. D. Pilot acceptance of visually-coupled systems (VCS). Proceedings of the Symposium on Visually Coupled Systems Development and Application, Technical Report AMD TR 73-1, December 1972.

Experimentation with head mounted visually-coupled aids has been in progress for some time. The author feels that we are past the point of using "cluges" or breadboard models. It behooves the developers to get on with the serious business of pressing technology to get a safe, comfortable, yet serviceable helmet. This paper outlines the various inputs to the headgear design process and explores the various schemes that are being developed for standard helmets and how they apply to head mounted devices. A report on the past uses of helmet-mounted sights is presented. Results of a user acceptance survey, conducted on the two Navy squadrons currently equipped with visual target acquisition system, are presented. This data indicates that helmet bulk and weight and method of reticle presentation are the most disturbing factors. Technological developments which resolve these objections are then explained and summarized. A survey of current and future headgear and fitting methods is given.

Feaster, A. V. Application of VCS. Proceedings of the Symposium on Visually Coupled Systems Development and Application, Technical Report AMD TR 73-1, December 1972.

As the Air Force strives to develop new weapons systems for fighter aircraft, it becomes increasingly clear that parallel emphasis must be placed on advanced avionic systems which allow efficient and effective use of the new armament. In the advancement of weapons technology for air-superiority fighter applications, one area of developmental interest has centered on increasing the effective weapons envelopes over those of current systems. It is in this area (of expanding fighter weapons envelopes) that visually coupled systems technology may have its greatest impact. In this respect, the pilot is considered an essential element of the fire control system, and visually coupled systems such as a helmet-mounted sight/display offer a means of increasing pilot participation to weapons management. These facets of visually coupled systems and others that remain to be identified and developed are considered of major significance to the operational success of wide coverage weapons systems, especially in the air superiority role. This paper describes one of the wide coverage weapons systems being developed at the Air Force Weapons Laboratory and identifies a few of the ways in which visually coupled systems might enhance the operational utility of this particular weapon concept.

Ferrin, F. J. F4 visual target acquisition system. Proceedings of the Symposium on Visually Coupled Systems Development and Application, Technical Report AMD TR 73-1, December 1972.

The F4 Visual Target Acquisition System (VTAS) is the first helmet sight system to be deployed by the U. S. As such, it represents an important milestone in the development of visually coupled systems. Since visual acquisition of the target is performed initially during close air-to-air combat, slaving the weapon system to the pilot's line of sight (LOS) provides a rapid method for weapon lock-on and launch. The VTAS system determines the pilot's LOS direction by using electro-optic means, and, through utilization of a small digital computer, provides LOS electrical outputs to the radar and missile seekers. This paper describes the helmet sight concept using rotating infrared beams in the cockpit for determining the helmet-mounted detector locations and from this the pilot's LOS direction. The system evolution, starting with its inception in 1963 and including the developments leading to the Navy procurement of VTAS in 1970, is summarized. A functional description is given which discusses operating modes, interfaces with the fire control radar and Sidewinder missiles, and pilot interaction. System component characteristics are discussed

for the Helmet Mounted Unit (HMU), the Sensor Surveying Unit (SSU), and the Sight and Missile Control Unit (SMCU). The paper concludes with a discussion of system modifications since the initial F4 VTAS design and an overview of present development programs.

Foots, L. L., Schone, R. G., & Adamski, D. F. An optimized head coupled TV for remotely manned driving and manipulation tasks. Proceedings of the Symposium on Visually Coupled Systems Development and Application, Technical Report AMD TR 73-1, December 1972.

A head coupled TV (HCTV) system which will allow a remote operator to control a vehicle at relatively high speeds (20 mph) as well as to do intricate bomb defusing tasks using dexterous remote manipulators mounted on the vehicle will be described in detail. Areas that will be covered are: head position sensing system, head mounted display, human factors considerations, use of miniature cathode ray tubes in the head mounted display, helmet fitting and design, and imaging optics as applied to the head mounted display. The HCTV will be used on a remotely manned "dud" retrieval vehicle at the Eglin AFB test range. The system will have a dual-resolution foveal/peripheral format that conserves video bandwidth while providing the visual detail needed to operate the vehicle effectively. The system will be designed to allow easy conversion to a stereo foveal/peripheral format developed by MBA in 1972 that will allow its efficient use with dexterous manipulators (also developed by MBA) which will be added to the vehicle at a later date. The system will be compared with the ARPA/Air Force HAT/RQV system. Design details and available performance data will be presented. The system to be discussed is succinctly defined in the accompanying diagrams (preliminary data). The system is a synthesis of recent work previously performed by Schwartz/Adamski (1971-MBA), Van Buskirk (1971 - Naval Weapons Center), Jones (1971 - NASA/Ames), Seward (1971 - Hughes Aircraft) and Chatten (1970 - CDC). These systems and their relationship to the subject system will be reviewed.

Furness, T. A. Overview of VCS development program at AMRL. Proceedings of the Symposium on Visually Coupled Systems Development and Application, Technical Report AMD TR 73-1, December 1972.

Abstract not available

Grossman, J. D. A flight evaluation of pilot/helmet mounted sight visual acquisition and tracking performance. Proceedings of the Symposium on Visually Coupled Systems Development and Application, Technical Report AMD TR 73-1, December 1972.

AGILE is an air intercept missile currently being developed by the Naval Weapons Center, China Lake, California. It will be capable of acquiring and firing at targets at large off-boresight angles. The

ability of pilots to visually acquire and track targets accurately and rapidly at large off-boresight angles is an important consideration in the design of the AGILE missile system. A series of flight tests were thus conducted to ascertain pilot acquisition and tracking performance while the following varied: (1) off-boresight position of the target, (2) acceleration load on the pilot observer, and (3) angular rate of the target line of sight. Also of interest were variations in target range/size and buffet or turbulence. The relative geometry of the flight test engagements was designed to simulate the air combat environment. In this way, the data was hoped to be representative, in terms of the variables mentioned, of air combat.

Harmon, G. L., Jones, D. B., & Will, H. C. Helicopter flight test evaluation data involving helmet sight acquisition and automatic optical pattern tracking. Proceedings of the Symposium on Visually Coupled Systems Development and Application, Technical Report AMD TR 73-1, December 1972.

Target acquisition for automatic tracking has been revolutionized by the use of the helmet sight. This process which entails simply looking at the target while holding the head steady and pressing the automatic track button, was widely preferred over other acquisition techniques because of its speed, ease and reliability. The paper presents VCS related portions of a study which was performed in conjunction with the Marine Corps to evaluate various manual and automatic electro-optical tracking techniques. A helmet sight was integrated into a helicopter-borne utility gimbal system, SLOT (Stabilized Line of Sight Optical Tracker). While airborne during target acquisition with the helmet sight, the SLOT gimbal was slaved to follow head motions. In this manner the gimbal mounted television cameras, a laser designator, and the correlation tracker optic axis were pointed toward the target. After looking at the target, the operator initiated lock-on and the electro-optical area correlation tracker mounted on the gimbal automatically tracked the aim point selected by the operator. Next the operator would typically control the line of sight to the target by viewing the scenes on his television monitor and applying appropriate track stick update commands. Video tape recordings of the view of the target as seen by the gimballed TV system were taken during the evaluations. Fluctuations of the target with respect to the optic axis of the gimbal were measured on a film reader to determine tracking performance of both the helmet sight and the automatic trackers. The video data clearly showed the utility of using helmet sight acquisition and automatic pattern tracking to supplement the operator.

Haywood, W. J., Jr. A new precision electro-optical technique for measuring pilot line of sight in aircraft coordinates. Proceedings of the Symposium on Visually Coupled Systems Development and Application, Technical Report AMD TR 73-1, December 1972.

An advanced electro-optical technique for sensing the line of sight of a pilot has been developed and an experimental breadboard has been built and delivered to the performance requirements section of the 6570th Aerospace Medical Research Laboratory. Precision and high slew speed is achieved by using a new electro-optical proportional detector with light-emitting diodes developed by Raytheon Company. The basic technology is discussed, and the experimental results achieved are presented. In addition, discussion of the system performance capabilities is presented.

Kenneally, W. J., Keane, W. P., & Milelli, R. J. Operational Evaluation of AMD characteristics. Proceedings of the Symposium on Visually Coupled Systems Development and Application, Technical Report AMD TR 73-1, December 1972.

The U.S. Army Avionics Laboratory is currently conducting a multi-year man/machine study to determine the capabilities and limitations of HMD's as applied to low level flight operations. The proposed paper will present the results of a number of specific investigations directed to answering questions as to the operational performance of such a concept for low level operations with independent variables being resolution, FOV, and symbology. Man/machine investigations have been conducted in both a moving-base helicopter simulator (TASS) as well as in a unique airborne simulator RAVE (Research Aircraft for Visual Environment). These investigations have provided for both quantitative measurements of system performance, physiological workload, and modified Cooper-Harper ratings. Conclusions as to the design characteristics of operationally acceptable HMD's for tactical operations are presented.

Kocian, D. F. Development of a helmet-mounted visor display. Proceedings of the Symposium on Visually Coupled Systems Development and Application, Technical Report AMD TR 73-1, December 1972.

This paper describes the research and development involved in the evolution of a helmet display technique that utilizes the helmet visor as the last optical component of the display system and which may be suitable for integration into high-performance tactical aircraft. It is a well known fact that one of the aircrew member's most important problems in tactical aircraft is obtaining sufficient information to adequately perform his mission requirements. In order to accomplish the flight control, navigation, reconnaissance, and weapon delivery tasks he is required to perform, he must have a satisfactory view of the external environment and displayed

information from aircraft systems. To date, neither tactical aircraft cockpit/canopy design nor panel mounted display designs have been tailored to the perceptual capabilities and requirements of the operator to provide this view. The development of a helmet-mounted visor display was, therefore, an attempt to provide the airborne operator with a display which successfully met the known requirements for a satisfactory airborne display such as field-of-view, resolution, display magnification, and contrast against backgrounds of high ambient brightness, while not significantly impairing the operator's outside view or degrading his total performance during flight. This paper will first describe the problems and design constraints that were imposed during the development of the visor display as a result of experience with hardware that was then available and flight testing completed up to this period of time. The paper discusses the design concept study employed to determine the particular technique to be used for providing a visor display and the engineering and fabrication problems associated in building the prototype visor display delivered to Aerospace Medical Research Laboratory during February of 1972.

Krautman, L. W., & Hatlelid, J. E. Simplified high accuracy guidance (SHAG). Proceedings of the Symposium on Visually Coupled Systems Development and Application, Technical Report AMD TR 73-1, December 1972.

Simplified High Accuracy Guidance (SHAG) is a new concept in air-to-air missile guidance which is being developed under a joint Air Force Avionics Laboratory -- Air Defense Weapons Center program. The aim of the program is to simplify missile guidance which should lead to increased reliability and lower cost per missile. Ground based computer simulation has demonstrated the feasibility of this guidance concept. An airborne simulation using a helmet mounted display is being developed as part of the flight test program to more realistically simulate the guidance concept. This airborne simulation can be used as a design tool for optimizing the guidance concept and as a pilot training device. The Air Force Avionics Laboratory has a contract with Honeywell, Inc. to develop hardware for a flight test demonstration of this guidance concept. Ten AIM-26 missiles are being modified to demonstrate the SHAG concept. These missiles will be launched by the Air Defense Weapons Center, Tyndall AFB, Florida, beginning early in calendar year 1973.

Kuipers, J. The SPASYN, A new transducing technique for visually coupled control systems. Proceedings of the Symposium on Visually Coupled Systems Development and Application, Technical Report AMD TR 73-1, December 1972.

The SPASYN (Space Synchro) is a five degree-of-freedom transducer which provides a precise and continuous measure of the thr..



relative translation (polar coordinates), between two independent rigid body frames. The Transducer consists of a Radiator fixed to one body frame and a Sensor fixed to the second body frame, both electrically connected to the System Electronic Unit (SEU). The signal detected in the Sensor, as a result of the modulated vector field issuing from the Radiator, is operated upon by electronic coordinate transformation circuitry in the SEU yielding a measure of the five angles. The nature of the radiated vector field structure is described and the various coordinate transformations involved in relating the two principle frames are discussed. The SPASYN is presented as an elegant solution to the Helmet Mounted Sight application in a Visually Coupled Control System. However, in addition to other applications which interface man with machine, some multi-degree-of-freedom control problems which do not involve man directly in the loop are suggested as candidate applications for the SPASYN. Some of these are: Inertial platform transfer alignment, automation of Boom/Receptacle coupling in Air-to-Air Refueling, Stationkeeping for drones and RPV's, VTOL aircraft instruments landing aid, automatic docking of marine craft, at-sea replenishment navigational aid, etc.

Latta, J. N. Design of holographic element systems for helmet displays. Proceedings of the Symposium on Visually Coupled Systems Development and Application, Technical Report AMD TR 73-1, December 1972.

The application of reflection holograms to helmet displays has recently generated considerable interest because of their low weight and ability to conform to an arbitrary surface. These systems therefore accommodate to the environment of the observer rather than have the observer adjust to a new visual systems within the helmet. When including holographic elements in the helmet a new set of factors must be considered apart from those applied to conventional optics. These include, for example, the recording and reconstruction wavelength and their respective spectral widths, properties of the emulsion, geometries necessary to record and reconstruct the hologram, and shrinkage or swelling of the emulsion. To effectively design systems which include these parameters, a computer-based analysis and design tool has been applied to the hologram helmet display problem. The initial efforts were directed towards a better understanding of the basic holographic properties which influence the image quality. A predominant factor is the hologram dispersion when the illumination originates from a source with a spectral bandwidth. Another consideration is the introduction of aberrations when the wavelength is shifted from construction to reconstruction. These factors and others will be discussed and their impact on the system performance will be considered. With an understanding of the basic properties, the design of more complex systems is possible. Using a generalized hologram optimization program in conjunction with

hologram ray tracing programs, several designs have been completed which incorporate two holographic elements to reduce both the dispersion and aberrations. These systems are discussed and compared to the performance of a single element system. The problem, potential, and application of holographic elements to helmet displays are discussed.

McCauley, D. G., Simpson, G. E., Murbach, W. J., & Holloway, H. A holographic optical element for visual head-up display application. Proceedings of the Symposium on Visually Coupled Systems Development and Application, Technical Report AMD TR 73-1, December 1972.

The Navy AGILE Quick Turn missile avionics system calls for the development of a holographic flight helmet mounted visual head-up display. A Fresnel mirror-like holographic optical display element is molded to the helmet visor, and the sighting and weapons status indicator symbology that illuminates the hologram is located within the helmet at points of opportunity. A crisp image of this symbology appears fully eye accommodated at infinity, superimposed on the pilot's unobscured normal visual field. The technology developed is the fabrication of off-axis and off-bisector reflection-type holographic optical elements, recorded in dichromated gelatin deposited on Plexiglas flight visors. It is demonstrated that chromatic lateral dispersion is reduced to a nonperceptible level using multiple holographic optical display elements in series.

McMillan, D. R. Utilization of visually coupled systems for aircraft in a digital communications environment. Proceedings of the Symposium on Visually Coupled Systems Development and Application, Technical Report AMD TR 73-1, December 1972.

This paper examines the utilization of visually coupled systems for certain interfaces between a flight crew and its avionics system in a digital communication environment. The environment considered is that of the SEEK BUS system, currently being developed under direction of the Electronic Systems Division of USAF/AFSC. The interface between digital avionics systems and the outside world is a natural one in a digital communication environment, but the interface between flight crew and avionics system includes gaps which must be bridged by appropriate translation systems. Certain functional interfaces are particularly suited for the use of visually coupled systems in this translational role. Unique functional requirements for avionics systems operating in the SEEK BUS environment are summarized to highlight specific interfaces which might be enhanced by visually coupled systems. General guidelines are developed for implementing visually coupled interfaces with components of the avionics system which provide capabilities peculiar to the SEEK BUS environment. Functional requirements for these interfaces are identified in generalized block diagrams, to indicate the nature of control and

feedback interactions which should be accomplished with partial and complete visually coupled systems. Discussion of specific interfaces is concluded in two parts. The first part describes a set of interfaces which were studied in an operational testbed, using two jet instrument trainers coupled with a general-purpose digital computer and various display and data entry devices to simulate representative future digital avionics capabilities. Visual feedback capabilities which were implemented are described, including Head-Up Display cues for en-route and weapons delivery guidance and Panel Display presentations of the tactical situation. The second part considers the potential for visual input capabilities to complement feedback capabilities described above. The intent is to indicate specific development opportunities for obtaining complete visually-coupled cockpit interfaces in the SEEK BUS environment.

Merchant, J. & Morrisette, R. Aerospace medical research laboratory/Honeywell remote oculometer. Proceedings of the Symposium on Visually Coupled Systems Development and Application, Technical Report AMD TR 73-1, December 1972.

The first part of the paper will discuss some potential applications of the concept of using the eye as a controller along with planned human factors research. The second part of this paper will present a description of the Honeywell Radiation Center Remote Oculometer developed for the 6570th Aerospace Medical Research Laboratory. Basically, the Remote Oculometer is a device that operates at a distance from the eye, requires no head mounted equipment, tracks the operator's eye throughout a one cubic-foot motion box, and produces instantaneous signals of the eye line-of-sight. One potential application is in the area of air-to-air combat. The use of the eyes as a control device for an aircraft fire control system would give an off-boresight capability, provide for head-out-of-the-cockpit operation, allow quick target acquisition, permit the use of natural and highly learned skills, require no reticle, and allow the operator to track a target while sustaining high G-loadings. The first in-house study will be designed to compare eye, head, and stick tracking performance. A later study will be of eye tracking performance as a function of  $G_z$  on a centrifuge. A second application is the implementation of a dual-resolution display system in which a high-resolution, narrow-field-of-view scene is displayed wherever the eye is directed within a low-resolution, wide-field-of-view display. Research will be designed to study human performance using such a system.

Preston, T. W. Baseline VTAS for AGILE. Proceedings of the Symposium on Visually Coupled Systems Development and Application, Technical Report AMD TR 73-1, December 1972.

This paper describes the baseline Visual Target Acquisition System (VTAS) for the development of AGILE avionics. Among the other

objectives of the AGILE VTAS program are those of developing a dual cockpit system that can be used at very large off-boresight tracking angles.

Sawamura, R. T. The ultrasonic advanced helmet-mounted sight. Proceedings of the Symposium on Visually Coupled Systems Development and Application, Technical Report AMD TR 73-1, December 1972.

An Aerospace Medical Research Laboratory-sponsored effort was initiated to design, develop and fabricate an ultrasonic sight system that could be used in laboratory and experimental flight testing for a visually-coupled control system. The ultrasonic concept evolved from an investigation of current technology applicable to the development of an Advanced Helmet Mounted Sight (AHMS) which would offer improvements to present line-of-sight (LOS) sensing systems. The system incorporates ultrasonic linkages between a stationary cockpit reference and helmet-mounted sensors to provide ranging information necessary for LOS and head position determinations. The concept lends itself to a variety of installations that include two-cockpit operations with  $4\pi$  steradian LOS spherical coverage, roll sensing, and head positioning for high-performance aircraft. An analytical and experimental study effort to attain high system accuracies and workable signal-to-noise ratios within candidate-aircraft acoustical environments was pursued. Highly accurate operations within cockpit environments were assured by compensating for speed-of-sound variations and through a judicious characterization of the ultrasonic signals. A feasibility model was packaged as flight hardware components using U.S. Navy Visual Target Acquisition Set (VTAS) hardware housings to facilitate future flight test evaluations using VTAS-configured aircraft and to permit the use of VTAS accuracy test stations. The developed system exhibits increased accuracy over wider angular and translational coverages with respect to the VTAS electro-optical system. Improvement in weight, durability, g-environment, and cost are achieved primarily by replacing the moving part light source assemblies with durable low-cost ultrasonic transducer assemblies. The concept gives promise to helmet weight reductions and further accuracy improvements.

Self, H. C. The construction and optics problems of helmet-mounted displays. Proceedings of the Symposium on Visually Coupled Systems Development and Application, Technical Report AMD TR 73-1, December 1972.

This paper examines the optics of helmet-mounted displays from the viewpoint of applied elementary physics. The text is written in layman's language for the nonoptics engineer and the human factors specialist to assist them in understanding, evaluating, and specifying these devices and to avoid common misconceptions. It was

written because of the absence in the literature of any treatment of helmet-mounted display optics. The appendix covers simple magnification, diameter of the exit pupil, and optical length of helmet-mounted displays. The body of the text discusses these topics as well as optical combiners, partial mirrors, image relaying devices, etc. Optical systems with and without exit pupils are discussed, with most emphasis on the former.

Upton, H. W., & Strother, D. D. Design and flight evaluation of a head-mounted display and control system. Proceedings of the Symposium on Visually Coupled Systems Development and Application, Technical Report AMD TR 73-1, December 1972.

The design and experimental evaluation of a head-mounted display (HMD) system used for night and instrument flight by helicopter pilots is described. The total system consists of the display, headtracking mechanism, and sensor. The paper outlines the requirements for the system and discusses the Human Factors problems, including comfort, safety, and visual characteristics of the display. The results of experimental flight test programs in which the system was evaluated for use in monocular form, binocular stereo and as a dual information display are reported. A discussion of the future of the Head-Mounted Display is presented.

Vickers, D. L. Helmet-mounted 3-D display. Proceedings of the Symposium on Visually Coupled Systems Development and Application, Technical Report AMD TR 73-1, December 1972.

Abstract not available

Winner, R. N. A color helmet mounted display system. Proceedings of the Symposium on Visually Coupled Systems Development and Application, Technical Report AMD TR 73-1, December 1972.

A miniaturized Field-sequential color television system is described which has the potential to display high resolution raster scanner images in a wide range of hues. Alternative methods of generating color images leading to this design are surveyed briefly and design tradeoff summaries are given which indicate the field-sequential method to be superior for high information density color display systems. A discussion of the system advantages to be gained, through the use of color, includes: increased dynamic range, marked separation of display variables for cueing, reduction in search time, improved target discrimination, and reduction of display clutter. Extension of this technique to the display of high resolution raster scanned images at reduced bandwidth is presented, as well as new techniques for accomplishing field sequential color from black and white CRTs using stationary, miniaturized selectively activated color filters. An exploratory development model color HMD developed by Hughes for the U.S. Air Force, Aerospace Medical Research Laboratories (AMRL/HER) is illustrated and described.

Woodson, R. A. Specifying, aligning and testing imaging optics of helmet mounted displays. Proceedings of the Symposium on Visually Coupled Systems Development and Application, Technical Report AMD TR 73-1, December 1972.

The field of helmet-mounted displays is so new that it has not yet developed appreciable published literature. Those working in this field include engineers and designers who have various backgrounds and education in a variety of disciplines. This paper is somewhat tutorial to provide pertinent technical information not readily available or easily learned without help. The source of much of this information is found in experience - both the broad optical experience of many years in the general field of optical instrumentation and the special experience gained from actual work in the assembly, alignment and testing of Honeywell's Model 6 Helmet Mounted Display, and in the specifying of the imaging optics for the next generation of Helmet Mounted Displays which are now under development. Graphical methods useful in the preliminary optical design are presented. The importance and the theory of pupil imagery is covered. Image brightness, ambient brightness, resolution, contrast, magnification, Modulation Transfer Function and orientation are discussed. Special problems associated with Fiber Optic Bundles are pointed out. The specification of visor combiners is given special attention. Ghost images, "white-out", distortion, collimation, boresighting and image stabilization are explained. Trade-offs of field of view versus other optical parameters are presented.

Zirkle, G. W., Stobie, W. H., & Curtin, J. G. Weapons airborne testing - training system (WATTS). Proceedings of the Symposium on Visually Coupled Systems Development and Application, Technical Report AMD TR 73-1, December 1972.

The applications of advanced control/display technology to military pilot training and Weapon Systems evaluations are the primary goals of the Weapons Airborne Testing-Training System (WATTS). The emphasis of this paper is on the training aspects of the system, since this appears to provide the more immediate application to meet a specific operational requirement and the potential payoff is greater. The problem that we have addressed is air combat maneuver (ACM) training for the Air Force Fighter Pilot population. In the present curriculum for Undergraduate Pilot Training, there is virtually no instruction time allocated for these flight maneuvers. The presentation of a simulated maneuvering target to the pilot for tracking and terminal gun solutions is the approach taken for operational implementation of the WATTS concept. The WATTS concept provides a highly versatile in-flight testing and training capability for a variety of aircraft weapons systems. It features the presentation of computer generated targets on a Head-Up Display or Helmet Display based on appropriate relative geometry computation performed in an

on-board digital computer. Additionally, it employs computerized bullets, bombs, etc. as appropriate and associated performance measures based on miss distance computations. Because WATTS does not employ an actual target or armament system, a wide variety of both can be evaluated on a single flight. Also a broad range of encounter geometry can be evaluated with almost all flying time devoted to obtaining data. Encounter conditions can easily be controlled or repeated as required and a complete magnetic tape recording of all desired data can be provided. WATTS was conceived by MDC as an outgrowth of extensive studies, development effort, and design improvements on air-to-air gun sight systems for the F-4 and F-15. Much of the manned and digital simulation math modeling and computer programming associated with these gunnery efforts is applicable to WATTS. The concept is also applicable to air-to-ground gunnery and weapon delivery systems and to the in-flight evaluation of flight control configurations relative to the various fire control and weapon delivery tasks. As a training or testing device; it appears particularly useful as a vehicle to facilitate the transition from ground-based simulators to full in-flight performance.