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THE INFLUENCE OF HEAD MOVEMENT PARALLAX ON PERCEPTUAL PERFORMANCE UNDER DIRECT AND TV-DISPLAYED CONDITIONS

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Previous research work in the analysis of TV-displayed information has not addressed the contribution of head movement parallax to operator performance. Horizontal head movements while viewing stereo TV produce the appearance of object displacement in direct proportion to the distance of the object from the focal plane. The direction of movement is opposite to that observed under direct-viewed conditions. This phenomenon is termed "pseudo-movement parallax."

The present study was designed to evaluate the influence of head motion parallax cues on measures of stereoacuity under direct-viewing and under TV-viewing conditions. Results of the study indicate that stereoacuity measured with a Howard-Dolman task is neither enhanced nor degraded by the pseudo-movement parallax cues

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SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered) associated with stereo TV. However, these cues have yet to be tested under conditions most likely to show enhanced performance (i.e., where scene ambiguity is great, and objects are unfamiliar).

A major task in future work is to assess the contribution that movement parallax has on operator performance when the TV display system is designed so that the head and the cameras are directly coupled, thus producing veridical head movement parallax cues. An analysis of the implications of this effort is presented, along with recommendations for future research.

OBJECTIVE

To assess the influence of head movement cues on perceptual performance using video-displayed systems under controlled laboratory testing conditions.

RESULTS

Comparison of direct-view and TV-displayed distance judgment estimates indicates that stereoacuity is neither enhanced nor degraded by the pseudo-movement parallax cues associated with stereo TV when measured with a Howard-Dolman task.

RECOMMENDATIONS

Future work needs to be done to assess the contribution that movement parallax has on operator performance when the TV display and camera system provides translational (parallax) cues.

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INTRODUCTION

The prime source of perceptual information available to operators of remote undersea vehicles is a viewing system composed of a single camera operated within commercial broadcast bandwidth specifications. Despite the advanced technology available in today's TV viewing systems, they continue to impose severe restrictions on the type of underwater task that can be undertaken, the speed and accuracy of the operator's performance and the visibility conditions under which the vehicle can operate effectively. These restrictions result from the fact that the televised image does not faithfully reproduce the perceptual information available to a natural observer viewing the actual scene. Loss of perceptual information results from reduced resolution and contrast, inadequate depth of field and field of view, and the absence of the size, depth and form information that is derived from the actions of the natural observer (head and eye movements and changes in accommodation and convergence) as the operator actively inspects a visual scene.

Recent research efforts have been directed toward improving viewing systems in order to enhance perceptual information available to the operator (see reviews of Smith, Pepper, Cole and Merritt, 1979, and Cole, 1980). One of the most promising developments has been TV systems which present image pairs to the observer in a binocular disparity configuration which produces stereopsis. Smith, Pepper, Cole and Merritt (1979) present evidence to indicate significant improvements in task performance utilizing stereo TV, the degree of improvement being dependent on visibility conditions and the amount of manipulator positioning required in the depth plane. While stereo TV shows great promise as a means of improving remote operator performance, there are a number of related factors which undermine the full utilization of binocular disparity cues produced with video systems.

CONVERGENCE AND ACCOMMODATION CUES

Binocular disparity produced by stereo TV conveys a sense of depth as well as objective data which can be employed by the subject to determine distance and depth relationships. However, only a single convergence angle is employed in most stereo systems. That is, the two cameras are converged (and their images completely overlap) at a plane which defines the forward extent of the working volume of the visual scene depicted. Object images beyond this plane are increasingly offset on the monitor face in direct proportion to their distance from the convergence plane, and those objects are seen at increasing distances from the monitor face. While the subject's convergence varies (when viewing the TV display) with increasing image offset, accommodation, which is fixed at the monitor screen, does not vary. Previous research indicates that when a mismatch occurs between convergence and accommodation, the perceived absolute distance will be a result of a compromise between the two cues (Ono, Mitson and Seabrook, 1971). However, recent research (Ritter, 1977) indicates that accommodation plays a relatively minor role in the perceptual processing of information; the importance of dynamic convergence (given by the spatial separation of the images presented on the face of the monitor) has yet to be determined. For these and other reasons to be mentioned later, the perceived depth in a stereo TV scene may be less than under direct viewing conditions, and conflicting cues may result in illusions, including false perceptions in depth.

MOTION CUES

True motion parallax cues are not reproduced by stereo TV systems. Thus, depth information, given by the combination of head and eye movements and the resulting movement of the object-images on the retina, does not exist. Under normal direct viewing conditions, a stationary object viewed while moving the eye or head appears stationary despite transformations (change in shape and position) of the object's image on the retina. It has been proposed that the observer compensates for his eye/head movement in evaluating retinal image changes (Rock, 1966). Compensation theory states that a central mechanism exists which compares head movements with retinal image movements or eye movements required to maintain object fixation. In a study to evaluate this position, Gogel and Tietz (1974) concluded that the observer's perception of the distance of the object was a major factor in determining whether the object appeared to move in a direction with or against head movement, or was perceived to be stationary.

In our stereo display, apparent motion of objects as a result of lateral head movement is not in agreement with the motions which are perceived under direct view conditions. The nature and reasons for these differences are revealed by a comparison of the physical features of the visual scenes and their resulting retinal images for direct and stereo views. Under direct views, all objects located on the plane of the horopter (determined by the fixation point) project images to corresponding areas of the two retinae, while objects at other locations project disparate images; crossed images are projected for objects located nearer than the horopter and uncrossed images for objects located beyond. When the head is moved laterally, objects on the horopter appear to remain stationary, while near objects appear to move against the direction of head movement, and objects beyond appear to move with the head. The amount of apparent movement of an object is directly proportional to its distance from the horopter. A further consequence of these events is that the relative position of objects at different locations in the depth plane changes with movement of the head. For the TV view, the convergence plane of the two cameras produces completely overlapping images, and the effect is similar to the horopter in the direct view; i.e., objects at the plane of the camera's convergence project corresponding images, and near and far objects project disparate crossed and uncrossed images respectively. Here the similarity ends, however, because the images of all objects are painted on a single plane in space; i.e., the TV screen. With head movement, objects at the convergence plane appear to remain stationary, and near and far objects appear to move in proportion to their distance from that plane – but in a direction opposite to those observed in the direct view. A further sense of illusion is produced by the fact that while objects appear to move, their relative positions remain unchanged, a consequence of the single plane locus of all images on the TV screen.

Obviously, the normal stabilization of the visual scene that man achieves despite head/eye movements has evolved out of necessity; chaos would result from having object-images that appear to move with every movement of the head and eyes. The fact that the objects move differentially under the stereo televised scene appears to be further support for the existence of a compensation mechanism. Gogel's (1977) interpretation of a variety of commonly observed visual movement distortions specifies that the amount of movement distortion perceived by the observer is a direct function of the perceived depth of the objects, as the perceived depth is the input information to the compensation mechanism. Because a stereo view provides much more perceived depth than a mono view, the input to the compensation mechanism is much greater. In the absence of actual object-image movement with head motion, overcompensation results from the expectation of movement, producing apparent movement of the objects in the opposite direction. Thus, the relationship between perceived depth and the resulting motion distortion is predicted to be a linear one, dependent upon depth cues, irrespective of how those cues are produced. If the relationship is linear, it is possible that these motion cues could be utilized by the observer in making stereoacuity judgments. The study reported herein was designed to test this proposition.

METHOD

SUBJECTS

The five subjects in the present study are scientists, engineers and/or technicians employed at the Naval Ocean Systems Center (NOSC), Kailua, Hawaii. Four were male, one was female, and the age range was from 19 to 49 years. All subjects had normal or corrected-to-normal visual acuity as determined by a Snellen chart test and normal binocular vision according to the Keystone Telebinocular test.

APPARATUS

Figure 1 provides a graphic description of the video system. The system consisted of two model CC 002 RCA color video cameras fitted with Canon 1:20 TV zoom lens, V6 X 17, with a range of 17 - 102 mm. Each camera was mounted on an Oriel adjustable slide mount in a 90° configuration. A 50/50 half-silvered beam splitter was positioned at a 45° angle between the cameras to bring their line of regard into parallel. The camera aimed through the beam splitter could be moved laterally to produce the four camera separations (disparity views) employed in this study (0.0 cm, 3.125 cm, 6.25 cm and 12.5 cm). The signals from the cameras were transmitted by means of cables to two Model QQA 17/N Conrac monitors positioned at 90° relative to one another. The monitor frames and screens were completely covered by polarized filters oriented to produce reversed direction of polarity for the two monitors. A beam splitting mirror located between the monitors at 45° was aligned so that the frames and screens of the two monitors were superimposed. The observer was seated facing the right monitor and at 90° to the left monitor. Eyeglasses containing polarized filters matched the polarity of the left and right eye filters to that of the left and right monitors, thus insuring that the left eye saw only the left monitor and the right eye saw only the right monitor. With the image of the left monitor reversed to compensate for the reversal caused by the mirror's reflection, the observer experienced a stereoscopic view. The degree of stereopsis was determined by the separation of the two cameras. The right monitor was modified so that the adjustment controls for contrast and brightness were located on the right exterior panel, permitting the images on the two monitors to be matched.

The cameras were directed at a modified Howard-Dolman box located at a distance of 235 cm. The box has a window of 37.5 X 25.0 cm and a depth of 96.0 cm. The diameter of the left rod is 2.495 cm; the diameter of the right rod is 1.922 cm. The subject was informed that the rods were unequal in diameter. Thus, he/she was to avoid size matching and base all judgments of depth on the perception of three-dimensional space. During the experiment, the left rod was kept stationary in the middle of the box and the right rod was moved by the experimenter.

PROCEDURE

Each of the five subjects was given three or four one-hour training sessions. Each session consisted of six conditions: two conditions where the observer viewed the rods directly (Direct View) with either one (Monocular) or both (Binocular) eyes and four conditions which utilized the TV viewing system (TV View), which included camera separation conditions of 0.0 cm, 3.125 cm, 6.25 cm and 12.5 cm. The viewing distance under the Direct View condition was set at 305 cm in order that the rods would subtend the same visual angle at the eye of the observer as under the TV View condition.

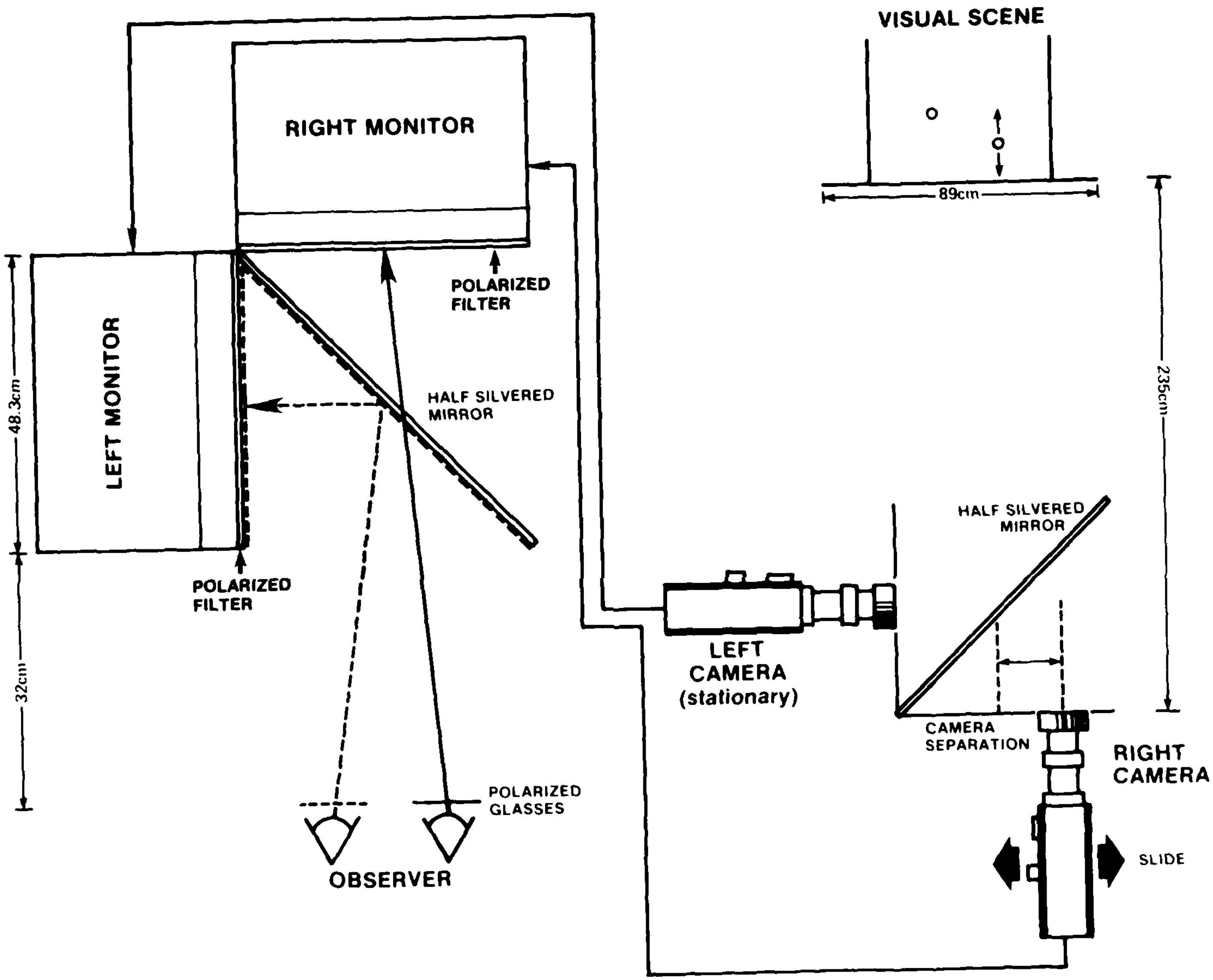

Figure 1. The video display system.

Twelve trials were administered under each of the viewing conditions. On half the trials, the subject was instructed to keep his/her head still, and on the remaining six trials was instructed to move his/her head from side to side ±6 inches. This condition was alternated every three trials. On alternating trials, the experimenter started moving the right rod either from the front or from the back of the box. The subject's task was to say "stop" when the two rods were perceived to be at the same depth. The subject could then make a final adjustment by saying "forward" or "back." Upon hearing the subject say "forward" or "back," the experimenter would say "go" and begin to move the right rod in the appropriate direction. After one or two such final adjustments, the subject would say "good" to indicate that he/she was satisfied to leave the rod there. The experimenter would record the distance from the equal point in centimeters with a "+" for forward and a "−" for behind. The experimenter would then say "ready" and "go" to begin the next trial. Between each set of twelve trials, the experimenter changed cameras or instructed the subject to come from the TV View station to the Direct View station. During the Direct View trials, the Howard-Dolman box was turned from the cameras toward the viewing chair. The subject was then asked to equalize the depth of the rods with one eye covered or with both eyes.

On all trials, the experimenter looked away so as not to inadvertently cue the subject. A curtain separated the subject and the experimenter. The experimenter varied the velocity of rod movement from one trial to the next in order to minimize the opportunity for the subject to use time as a cue.

Each subject was presented with four experimental sessions producing 4 X 6 X 12 data points. For purposes of analysis, the mean of the six trials for each of the two head positions was calculated. Each subject contributed 4 X 6 X 2 data points in the analysis.

RESULTS AND DISCUSSION

The results of a within-groups ANOVA are presented in table 1. Mean error scores were calculated across subjects and replications and are plotted in figure 2 for the two Direct View and four TV View conditions with head either stationary or moving. These results do not appear to support the efficacy of head-movement-produced cues under stereo TV View conditions since there is no consistent improvement in performance under the three stereo TV viewing conditions when the head is moved as compared to when it is held stationary. ($F = 1.16$, $p < 0.34$, $df = 1,4$ for the main effects of head movement.) The Direct View results, on the other hand, do show the expected improvement in stereoacuity performance when movement-produced cues are available ($F = 3.90$, $p < .0125$, $df = 5,20$ for head movement X viewing condition interaction). Under monocular Direct View, mean error scores are reduced by greater than half when the head is moved. Under binocular Direct View, the improvement in performance is much smaller; a result, in all likelihood, of the predominance of binocular disparity cues in bringing the threshold near the actual point of subjective equality.

The main effect of viewing condition also was significant ($F = 10.16$, $p < 0.001$, $df = 5,20$). A comparison (figure 2) of stereoacuity under mono TV (0.0-cm camera separation) as compared to stereo TV (3.125 cm, 6.25 cm and 12.5 cm) replicates our earlier finding (Pepper, Cole and Smith, 1977) of nearly a twofold increase in stereoacuity with the use of stereo TV. The largest gain occurs with increasing the camera separation from 0.0 cm to 3.125 cm, just half the average separation of human eyes. Obviously, this gain is due to the fact that under mono conditions, size matching is the dominant cue determining performance. Further increases in separation to 6.25 cm (average human eye separation)

TREATMENT	SS	DF	MS	F	P <
Subject (S)	4290.15	1	4290.15	55.06	0.0018
Error	311.69	4	77.92		
Day (A)	26.50	3	8.834	2.02	0.1643
Error	52.38	12	4.365		
Head Movement (C)	24.38	1	24.38	1.16	0.3419
Error	84.01	4	21.00		
AxC	2.811	3	0.9371	0.20	0.8922
Error	55.34	12	4.612		
Viewing Cond (B)	1264.24	5	252.85	10.16	0.001
Error	497.64	20	24.88		
AxB	56.76	15	3.784	0.72	0.7528
Error	314.46	60	5.241		
BxC	194.04	5	38.81	3.90	0.0125
Error	199.04	20	9.952		
AxBxC	23.83	15	1.588	0.59	0.8696
Error	161.04	60	2.684		

Table 1. Repeated-measures analysis of variance of depth judgment errors

and 12.50 (double the average separation) appear to bring successively less improvement in stereoacuity.

A final question that can be addressed from these data is: How efficient is this TV system in sensing, relaying and presenting the information at the test site to the operator? The ratio of Direct View to TV View performance provides a useful index of efficiency. Based on the ratio of mean error scores under binocular Direct View and the 6.25-cm camera separation TV View, the efficiency rating of this system for providing stereoacuity information is 0.66. Obviously, there is a good deal of room for improvement in this stereo system. Perhaps it is the inability of the system to reproduce essential visual features which results in a failure to produce superior performance under the wider camera base conditions (hyperstereopsis). A similar comparison of monocular Direct View with the 0.0-cm TV view gives an efficiency value of 0.97, a seemingly good performance of the TV system under mono conditions. However, as mentioned above, in the absence of stereo depth cues, size matching is probably the dominant cue in determining performance. This conclusion is supported by the fact that with the two rods being of different physical size, the observer can only equate their retinal images by positioning the small rod closer than the larger rod. That this is the case can be seen from the average error settings of around 8 cm when stereo information is absent from the TV View and both stereo- and movement-produced cues are absent from the Direct View (figure 2). This fact suggests that our system is an efficient carrier of information for matching image size. On the other hand, when we add movement-produced information to the Direct View condition, two things happen: depth judgment is vastly improved and the efficiency value drops markedly (from 0.97 to 0.38). This outcome, of course, reflects the fact that our TV system conveys no movement-produced information at 0.0-cm camera separation (monocular mode). It shows dramatically, however, the potential of veridical-movement-produced cues (as opposed to the pseudo-movement-produced

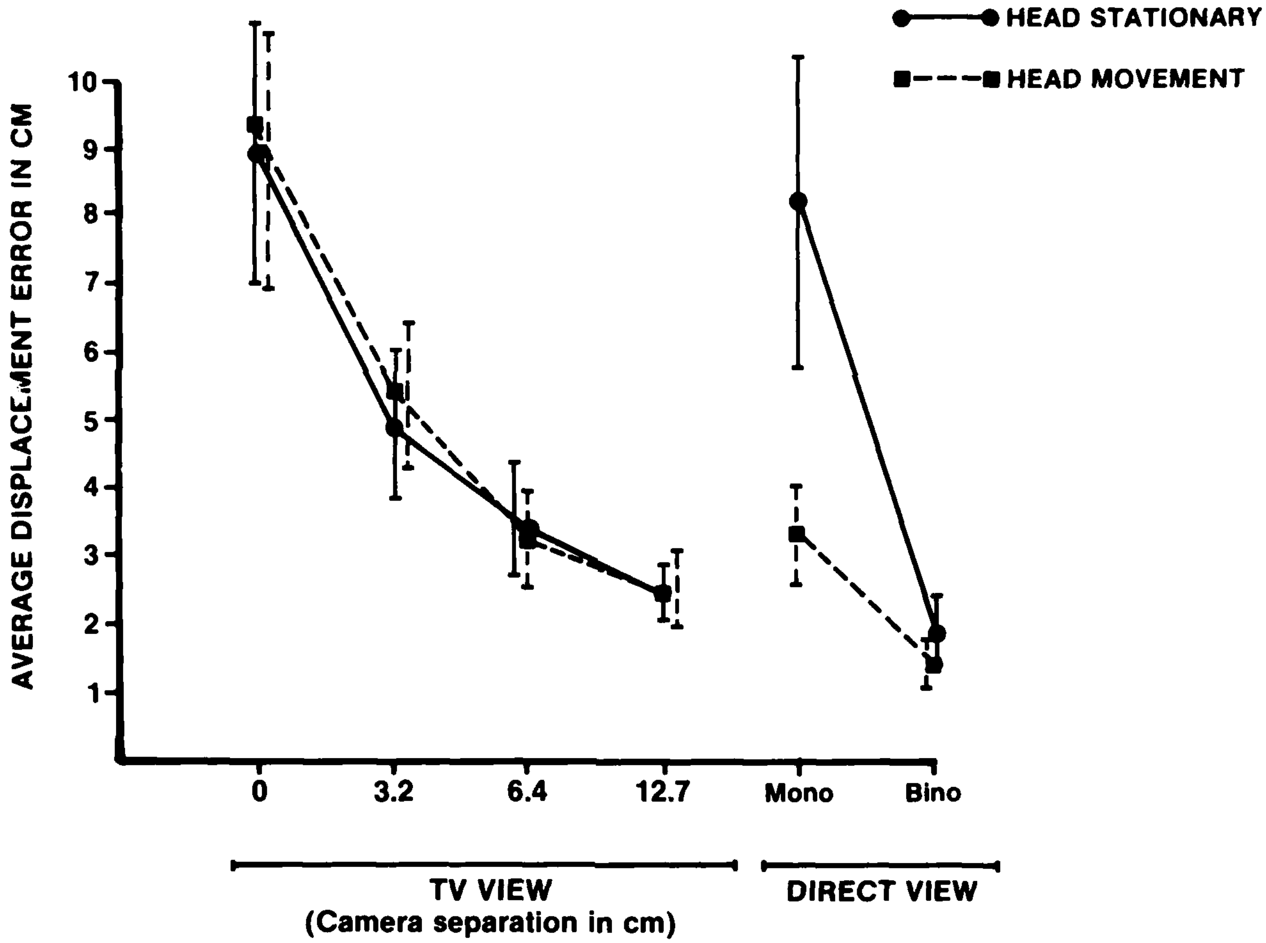

Figure 2. Average displacement error comparison between direct- and TV-viewed conditions.

cues of the present study) for improving depth judgment, and argues strongly for future efforts to develop and test such cues.

RECOMMENDATIONS

While the results of the present study fail to demonstrate the utility of distorted head movement cues in the depth judgment task, the potential for veridical movement cues to aid performance in more complex depth plane positioning tasks cannot be overlooked. These movement parallax cues are primarily translational, and require an isomorphic coupling of the camera system to the head of the operator. The complexity of such head-to-camera coupling is immense, requiring control of vertical, lateral and longitudinal movements in both linear and angular dimensions. Potential methods to provide the appropriate interface between the cameras and the head-coupled display system have been developed by the aerospace industry to solve problems in aiming weapons in combat aircraft.

Another important area of research which has been revealed in the present study involves the adequacy of stereo TV systems to provide sufficient information to enable hyperstereoptic performance. The data presented in figure 2 indicate a marked improvement in performance from 0.0 to 3.125 cm, but to a much lesser extent when the camera base distance was increased to 12.5 cm. If the eye acts as an optical system to resolve disparity (and thus enable judgments of distance or depth), the relationship between the base separation of the cameras and performance should be direct and linear. Our data do not show this result clearly. The basis for our findings may well lie in the method of presenting the stimulus, in the perceptual quality of the stimulus rods themselves, or be due to ceiling effects on the measurement of performance. A necessary next step to understanding our results is to evaluate hyperstereopsis under more closely controlled stimulus presentation conditions. We are presently modifying our laboratory to accommodate such revised conditions.

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