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THE EVALUATION OF PARTIAL BINOCULAR OVERLAP ON CAR MANEUVERABILITY: A PILOT STUDY

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INTRODUCTION

An engineering approach to enlarge the helmet-mounted display (HMD) field-of-view (FOV) and maintain resolution and weight by partially overlapping the binocular FOV has received renewed interest among human factors scientists. Some evidence has been accumulated to suggest that any panoramic display, when binocular overlap is less than 100%, will be objectionable. As far back as 1962, overlapping the monoculars was used to obtain an ultrawide-field display with a 40-deg overlap for the Army.[1] Whether any visual problem was experienced with such a display was not known.

Panoramic HMDs, employing a similar approach, were later built as flight simulators.[2,3,4] It was reported[3] by CAE Electronics that luning or edge effect, described as two dark bands forming a distinct border in an otherwise uniform field around the central binocular overlap, was observed in these displays and attributed to binocular rivalry. McLean and Smith[5] reported that "partially overlapped fields (40-deg) are usually annoying, but with about 30 minutes of use most observers report not even being aware of the juncture areas." They also noted that head movements were increased with the partially overlapped HMD, during helicopter flights. Greene[6] reported a helicopter flight experiment in which pilots noticed increased illumination in the overlapped portion (20-deg) of the field. The pilots were slightly annoyed by the "luning" border, as well as by occasional minor eye fatigue. Greene noted that when higher distortion was present in a setup of 45-deg overlap, "airspeed/altitude performance decreased significantly, pilot ratings dropped significantly, and head motion increased." In addition, the pilots reported that "double vision, head aches and eye fatigue were common." All of the above studies used divergent optical arrangements (i.e., monoculars tilted outwards to create the partial overlap). Melzer and Moffitt[7,8] evaluated both divergent and convergent configurations (along with two other methods) for reducing edge effects. They found that there was less "luning" in the convergent display (i.e., with monoculars tilted inwards to create the partial overlap). Melzer and Moffitt stated that angular overlaps of at least 20-deg have been suggested but did not provide any reference.

Do edge effects and increased head motion affect performance? Melzer and Moffitt[8] reported that their studies show the ability to detect small targets is not affected by the edge. Kruk and Longridge[9] found no performance degradation in target detection, motion detection, or target tracking for a binocular overlap of 25-deg and 45-deg. There was degradation at the edges of the 25-deg overlap. Landau[10] found that a 17-deg overlap condition used in her recognition study produced degraded performance, while the 38-deg overlap did not reveal appreciable differences in accuracy or temporal performance. She also affirmed earlier reports of tendencies for head movement, binocular rivalry, and brightness variations. Whether conditions under which performance degradations were found simply reflect binocular probability summation[11], which is known to enhance binocular vision over monocular, will require further exploration.

It is evident, based on our brief literature review, that any panoramic display with a binocular overlap, less than a minimum amount, annoys the viewer, degrades performance, and elicits undesirable behavior. Whether these factors affect certain tasks performed in a dynamic environment is not clear and can not be adequately predicted. Our specific concern is the extraneous head motion that has been reported. These extraneous head motions, as suggested by the authors, were attributed to image distortion and alignment accuracy. From a system design point of view, it is important to establish whether increased head motion results in diminished performance and to verify if the cause for the increased head motion is display distortion[12]. If so, careful aberrational corrections of the HMD optics, as well as expensive and sophisticated image source distortion correction circuitry may be required. In this pilot study, the effect of varying distortion-free binocular overlap was evaluated with professional drivers maneuvering a car through an obstacle course. The experiment was conducted at the Transportation Research Center of Ohio (TRC), East Liberty, OH.

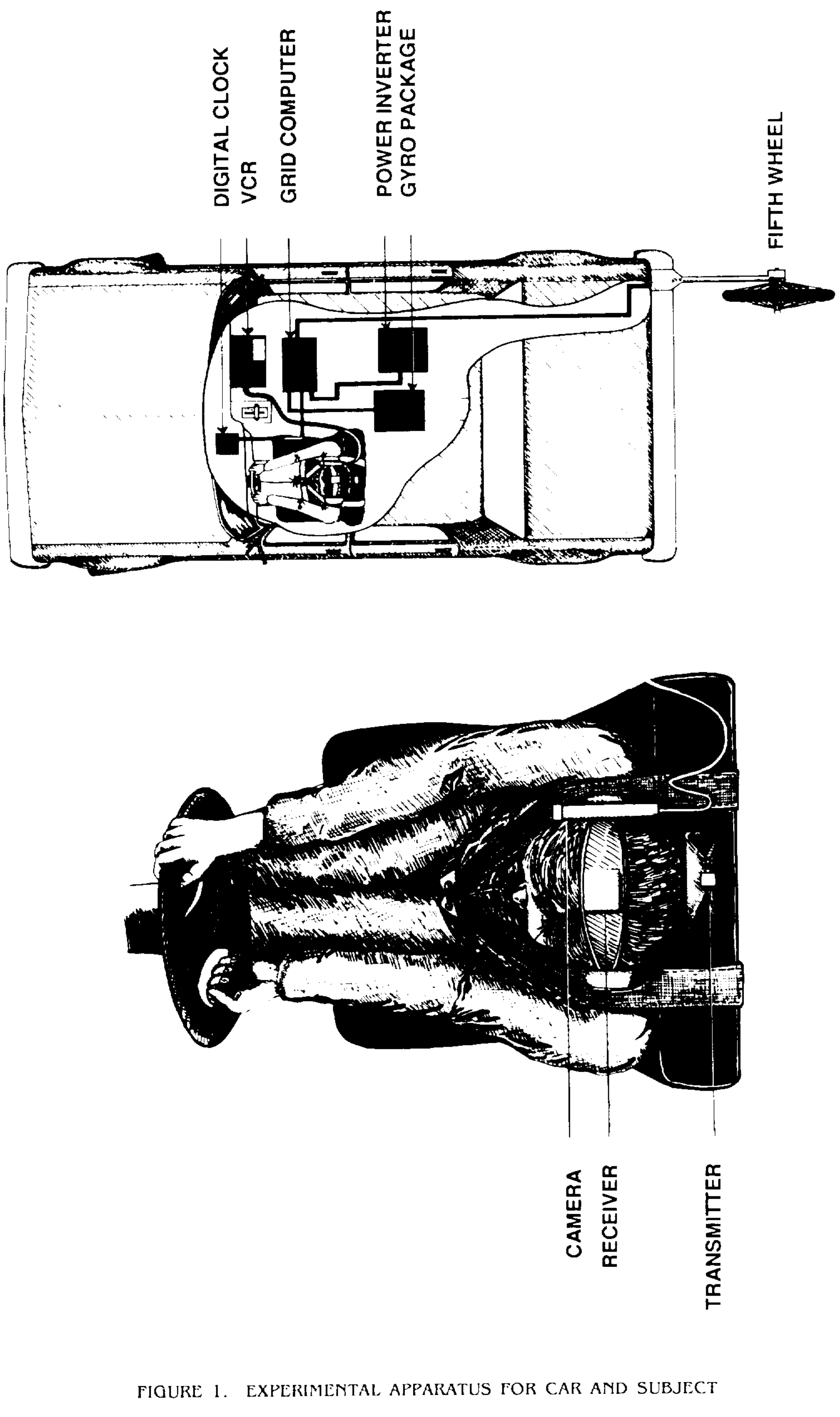


FIGURE 1. EXPERIMENTAL APPARATUS FOR CAR AND SUBJECT

METHODS

SUBJECTS

Subjects were two male, age 34 and 39, highly experienced test drivers employed by the TRC. Both subjects were right handed and right eye dominate, with corrected 20/20 vision.

APPARATUS

The 1989 Chrysler Aries car, used for this experiment, was fitted with several data collection devices. Figure 1 shows the equipment layout inside the car. A Polhemus 3-Space tracker was used to record the subject's head movement in the azimuth and elevation planes. The head tracker's magnetic field transmitter was mounted over the driver's seat of the car. The receiver was mounted on a head band with ear cups and worn by the subject. Resulting from the fact that the on-board Grid computer could only accept analog data, an external digital-to-analog converter was constructed to translate the 3-Space tracker's digital head orientation angles into analog voltages in real time, before interfacing with the Grid computer (see Appendix 1). The Grid computer also recorded the vehicle dynamics, including car velocity and yaw rate, and provided the synchronizing timing signals. A calibrated fifth wheel was towed on the back of the car to measure car speed. The rate of car turn (yaw rate) was measured with a Humphrey gyro package. Car velocity, yaw rate, head azimuth and elevation angles were digitized by the Grid computer's peripheral data acquisition add-on board at 120 Hz (even though the head tracker was running at about 60 Hz). A Panasonic miniature color camera (CD1) was mounted on the side of the driver's head band pointing toward the front windshield of the car. The camera followed the driver's line-of-sight and recorded what the driver was viewing throughout each experimental trial. A microphone was also provided to record driver's comments, if any, as he maneuvered through the course. The outputs of the camera and microphone were recorded on a portable VHS VCR. The VCR recording was synchronized with the Grid computer at the beginning of each trial by pointing the camera and recording a digital clock display controlled by the Grid computer. The subjects were fastened into the car with two overlapping safety belts pulled tightly across their chests and waists to ensure little to no body movement, but free head movements.

PROCEDURE

Subjects performed a driving maneuverability task. The subjects were instructed to drive a car through an obstacle course as quickly and as accurately as possible. Some familiarization training was allowed on the obstacle course for both subjects. The time to complete each course was recorded using TRC's Alge stopwatch. An experimenter at the start gate signalled the start of each trial to the driver and to a second experimenter, by waving his/her arm. Simultaneously, the second experimenter, standing at the stop gate, started the stopwatch. The second experimenter stopped the stopwatch as the car passed the stop gate. The estimated accuracy was within a full second. A typical trial lasted approximately 30 seconds with a 5-10 minute interval between each trial. During this time interval, data were downloaded from RAM to the internal hard disk drive.

DESIGN

Independent measures included six varying obstacle courses and six different fields-of-view and overlaps (FOV/OVLP). The obstacle courses were located at one corner (approximately 600 x 800 feet) of the experimental area referred to as the Vehicle Dynamics Area (VDA). The test surface (asphalt) had a one-percent downward slope. The entire obstacle course was broken into three sections, marked out by pylons. The three sections became six courses by having the subjects drive in one direction, and then in the other. Figure 2 represents the layout of the courses.

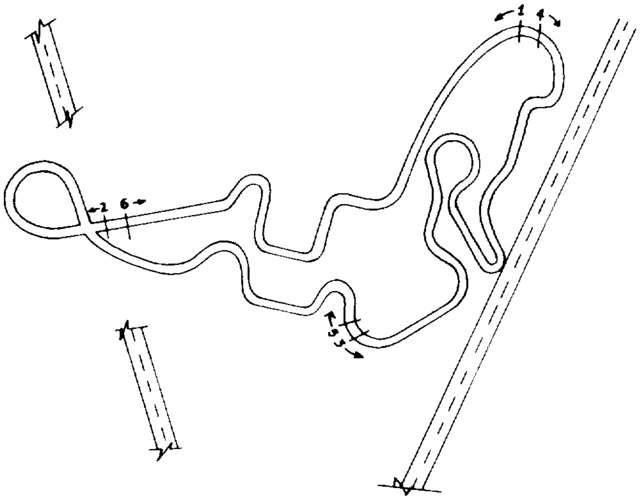


FIGURE 2. DIAGRAM OF THE SIX OBSTACLE COURSES

Both FOV and OVLP were simulated using baffles over a clear plastic eye-protective goggle, without any intervening optics, resulting in a *distortion-free, eye-limited* viewing condition. The individual subject's inter-pupillary distance (IPD) and eye relief (cornea to goggle) were measured to calculate the appropriate opening of a 4 x 3 aspect ratio rectangular format on the goggles for each FOV/OVLP. Black masking tape was used to cover the entire goggle except the desired opening in the front. The six FOV/OVLP conditions consisted of 180-deg (untapped goggle), 60-deg with 100% binocular overlap, 60-deg with 80% overlap (convergent and divergent) and 60-deg with 50% overlap (convergent and divergent). The definition used for the percent of overlap calculation is the amount of binocular overlap, divide by the total horizontal FOV (and not individual monocular FOV). This was to ensure a constant total horizontal FOV for all conditions, except the 180-deg which served as the baseline condition. Therefore, the 60-deg 80% overlap condition consisted of a binocular area of 48-deg, flanked by two 6-deg monocular areas. The 60-deg 50% overlap condition consisted of a binocular area of 30-deg, flanked by two 15-deg monocular areas. Seventy-two trials were made up of a random ordering of two replications of six FOV/OVLP and six obstacle courses. The number of trials run each day was weather and time dependent. The whole VDA was covered with snow during the entire study, but the obstacle course was plowed and allowed to dry before experimental trials were run.

Dependent measures included course time (measured by stopwatches), error (displaced pylons), and head and vehicle dynamics (recorded with on-board equipment). The course time and error data were analyzed for the whole course, while car velocity, car turning rate, head azimuth velocity and movement, were extracted from the head and vehicle raw data only during the interval when the car was in and out of a turn. A program similar to a digital storage oscilloscope was developed on the Apple Macintosh, allowing the user to time-tag the head and vehicle traces in each trial for the beginning and end of each turn.

RESULTS

Analyses of variance were performed on the dependent measures, using subject, FOV/OVLP and course as the factors. The variability of the two replications was used as the error term. The Bonferroni procedure was used to make pairwise comparisons of FOV/OVLP, and course with an experimentwise error level of .05. There were no significant interactions between course and FOV/OVLP for all analyses.

Figure's 3 and 4 show course time and course errors as a function of FOV/OVLP. Course time analysis did not show any significant effect for FOV/OVLP (p=.907), but did show a significant effect (p=.0001) for course. Analyses on course errors indicated that FOV/OVLP and course had no significant effects, (p=.194) and (p=.076), respectively.

Significant main effects of FOV/OVLP were found for head velocity (p=.0001) and magnitude of head azimuth movement made during a turn (p=.0001). Paired t-tests showed a significant difference between the 180-deg and all other FOV/OVLP combinations. Figures 5-11 show head velocity, head azimuth movement, head turning time, car velocity, car turning rate, proportion of head directional change, and head leads car, respectively.

Significant main effects for course included head velocity, head azimuth movement, head turning time, car velocity, car turning rate (p=.0001) and the head leads car (p=.024). T-tests showed that in most cases, course six was significantly different from all other courses.

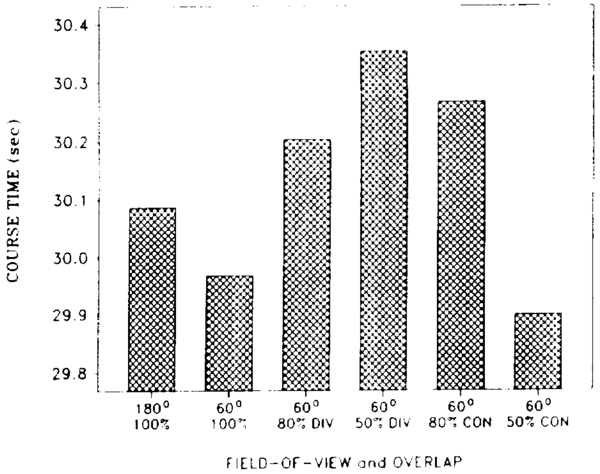


Fig. 3 Course Time plotted as a function of Field-of-View and Overlap.

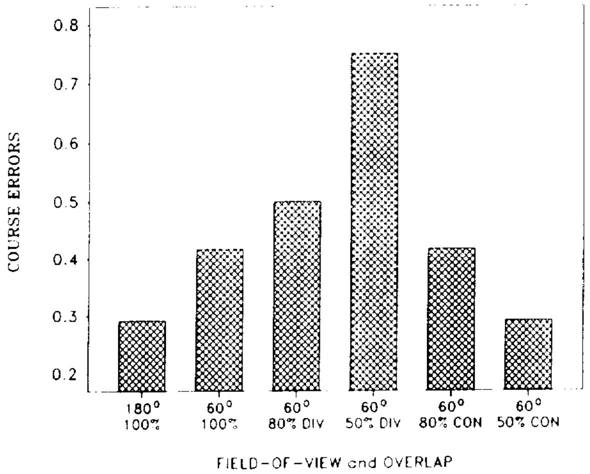


Fig. 4 Course Error plotted as a function of Field-of-View and Overlap.

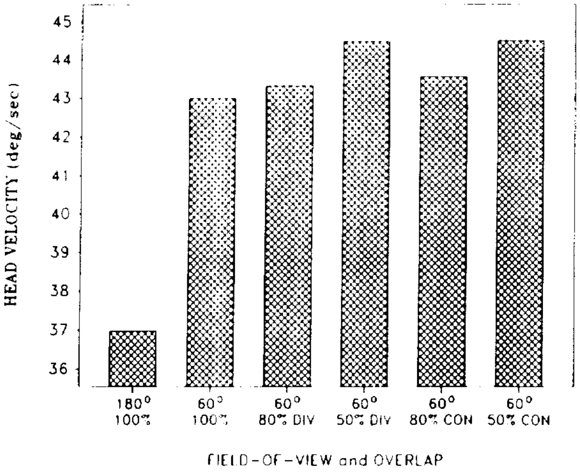


Fig. 5 Head Velocity plotted as a function of Field-of-View and Overlap.

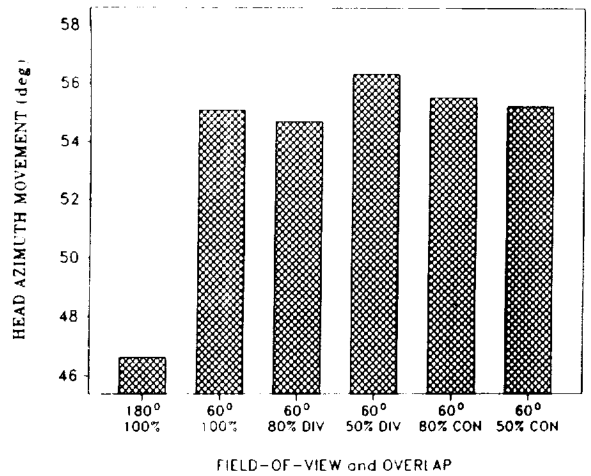


Fig. 6 Head Azimuth Movement plotted as a function of Field-of-View and Overlap.

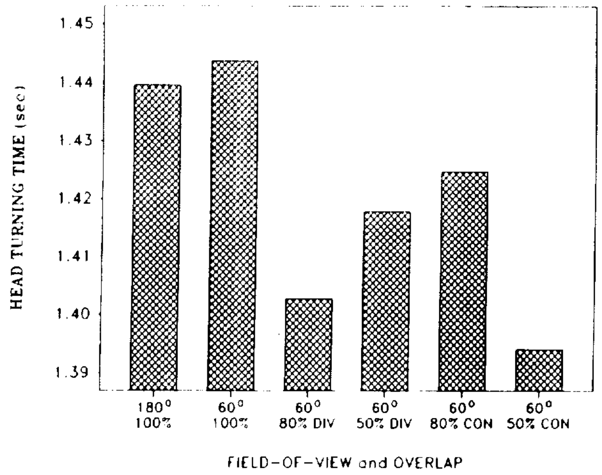


Fig. 7 Head Turning Time plotted as a function of Field-of-View and Overlap.

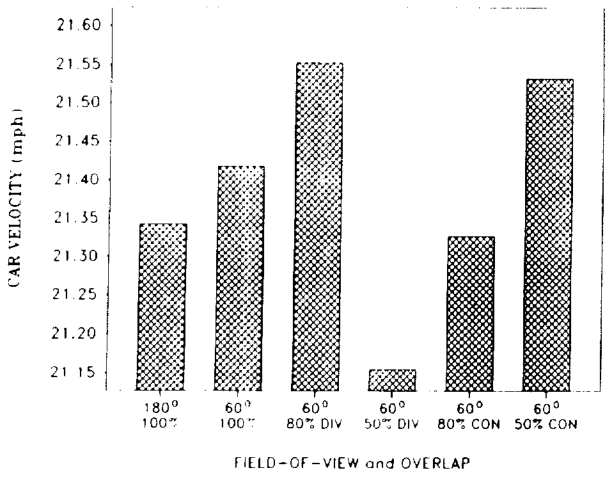


Fig. 8 Car Velocity plotted as a function of Field-of-View and Overlap.

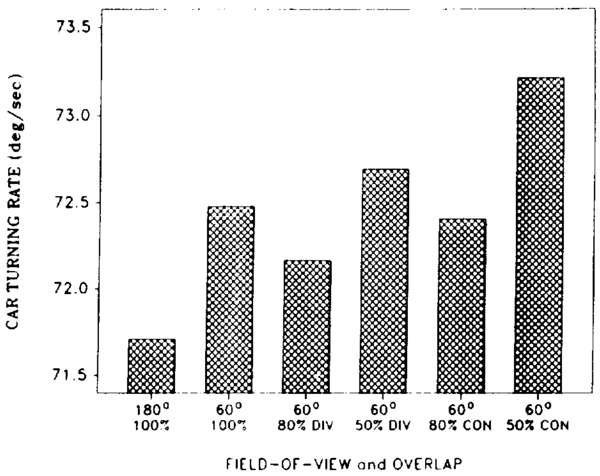


Fig. 9 Car Turning Rate plotted as a function of Field-of-View and Overlap.

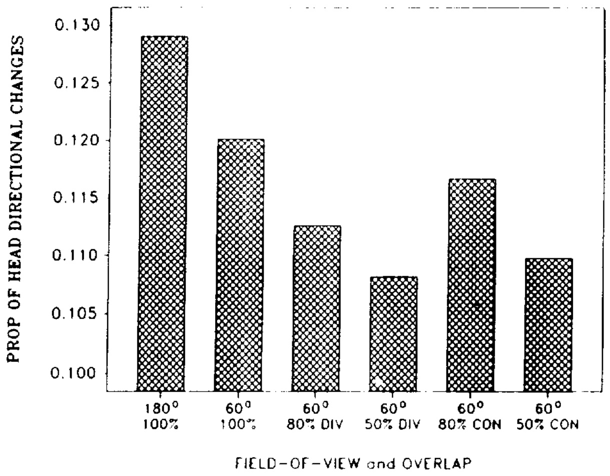


Fig. 10 Proportion of Head Directional Changes plotted as a function of Field-of-View and Overlap.

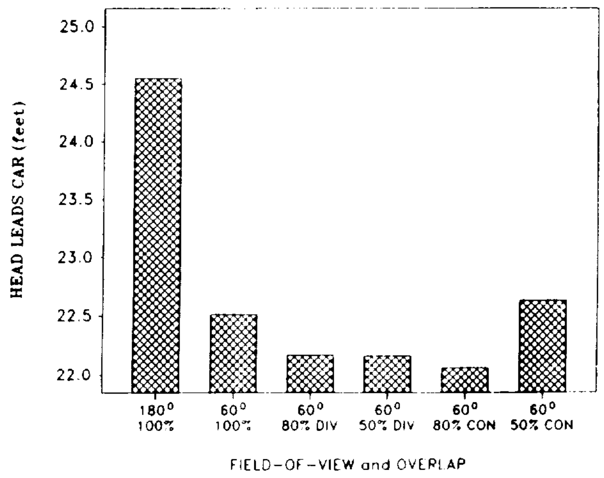


Fig. 11 Head leads Car plotted as a function of Field-of-View and Overlap.

CONCLUSIONS

Our subjects did not comment on any specifics regarding partial overlap conditions. It should be emphasized that because a rectangular format was used, the edge effect consisted of two "straight" borders. Subjects felt the 60-deg FOV did not inhibit them from performing the task in our study, but did not believe that 60-deg FOV would be sufficient for driving on busy city streets. Their performance on the course, as measured by course time and error, supported, at least the first half of their casual observations.

The major finding (Fig. 6) of any practical significance in this experiment is that across the 60-deg conditions, subjects moved their heads a greater distance (by about 5-degrees on each side) than in the 180-deg condition, presumably to compensate for the lack of FOV. Across all FOV/OVLP combinations, the elapsed times for completing a turn (Fig. 7), car velocity (Fig. 8) and turning rate (Fig. 9) were similar. Thus, this larger head movement translates directly into higher head velocity (Fig. 5). Though not significant, there is a slight trend suggesting that 50% overlap produced higher head velocities than 80%, which is higher than 100%. However, we can not rule out the association proposed by Greene[6]. Greene suggested that the higher head velocity is related to higher display distortion. A follow-on study, in which more subjects participate, and/or has more than one task, would be required to ascertain that partial overlap induces higher head velocities, even when there is no distortion. One indication that our subjects were not working as hard is that their head velocities were found to be in the 40-deg/sec range, compared to the 10-deg/sec range reported by Greene. One would assume, based on everyday experience, that a heavier workload would result in slower head motions.

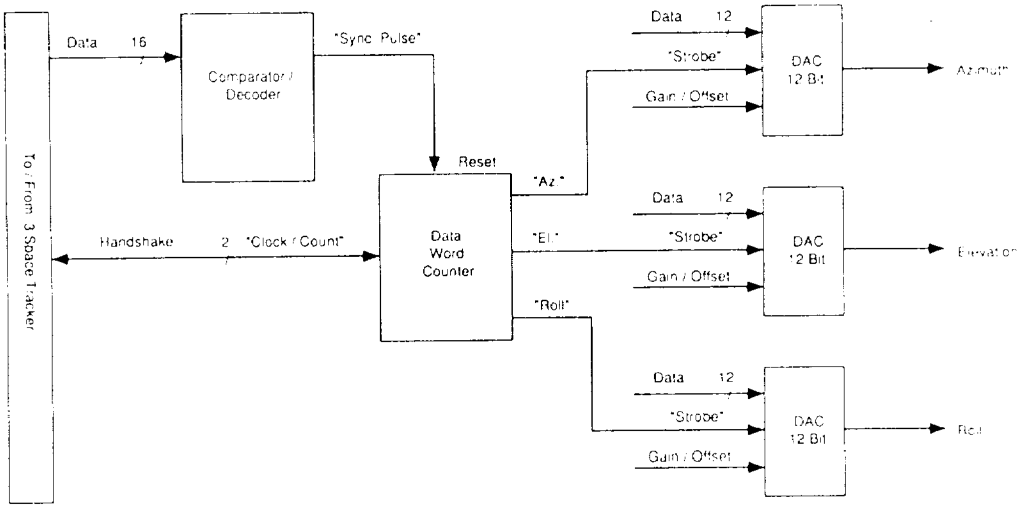
Our head movement (head directional reversals) data (Fig. 10) did not support McLean and Smith's[5] observation. In fact, our data indicate that smaller overlaps produce less head movement. Again, because the differences were not significant, we can not say conclusively that decreased head motion is due to lack of binocular overlap.

Melzer and Moffitt[7,8] reported that there is less luning in convergent overlap[14]. We found no consistent differences between divergent and convergent overlap in terms of course time, error, head velocity or head movement. It is important to point out that in a convergent display, contrary to the divergent display and human binocular vision, the right eye will see more of the left (nasal) visual field and the left eye will see more of the right (nasal) visual field; subsequently if a target is moving from right to left, the left eye will detect the target before the right eye picks it up. This may cause confusion if the convergent panoramic display is not totally fused by the two eyes. We couldn't directly test this possibility in this study, but if we assume that the peripheral field is used in negotiating turns, then the measure of how soon the subject looks into the turn may detect that fine difference in the right/left eye reversal. Again, we found no significant difference (Fig. 11) between convergent and divergent configurations.

It is quite clear that our study, based on simple car maneuverability and two subjects, reveals differences in FOV, but nothing significant between binocular overlap levels and configurations. This tentatively indicates that some tradeoffs of binocular vision for a larger overall display FOV are acceptable. However, the need for further systematic experimentation in this area, to examine other relevant factors, is apparent.

APPENDIX

Append. 1[16]:



Block Diagram of the Digital-to-Analog Converter for 3-Space Tracker.

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12. Because most HMDs use F Theta mapping, there will always be a requirement for distortion correction. The system designer needs to balance between minimizing any residual distortion to a reasonable level and the costs. Another point relating to the distortion that should be made is that tilting of the monoculars to create the panoramic display does not result in a trapezoidal distortion, as concluded by at least two studies[2,7]. The reason for this is that most HMDs will be utilized as a one power telescope[13].

13. Shenker, M., "The power of one power," SPIE International Lens Design, 1354, 647-653 (1990).

14. The object/background depth relationship between convergent and divergent overlaps brought forth by Melzer and Moffitt[7,8] as the explanation of less luning in convergent display is rather intriguing and worth further exploration. However, there is an alternative hypothesis: In the convergent display both edges lie in the nasal visual field, therefore, falling on the temporal retina which is not as well tuned to binocular disparity[15] as compared to the nasal retina. Perhaps, they are less sensitive to binocular rivalry as well, which may account for the less "luning" in a convergent display. An experiment is planned to examine this hypothesis in the future.

15 Pettigrew, J., "The neurophysiology of binocular vision," Sci. Am. 227, 84-95 (Aug 1972).

16. Detailed schematics will be available upon request to Brian Tsou, AL/CFHV, WPAFB, OH 45433.

ACKNOWLEDGEMENTS

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