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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

The basic purpose of this experiment was to compare head tracking performance at various angles from the straight ahead position. In our previous laboratory studies (e.g. Shirachi and Black, 1975; Hornseth, Stanley, and Carson, 1976; and Shirachi, Monk, and Black, 1976) head tracking was performed within a ± 15° or less cone about the straight ahead or boresight position. Honeywell has conducted studies in which the subjects aimed their heads as far off boresight as 40° (Hughes, et al, 1970). Their subjects slewed their heads in the direction (over)

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indicated by an arrow, on the head position display they were using, until a target came into the field of view of the helmet mounted display. At this point their task became that of laying a reticle over the target to achieve lock on. The length of time the subjects were actually tracking was only a few seconds. Flight test studies conducted at Tyndall AFB and China Lake (Dietz, et al, 1971 and Grossman, 1974) investigated head tracking performance which included large off-boresight angles. The target motion in these two studies was highly predictable.

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HEAD TRACKING AT LARGE ANGLES FROM THE STRAIGHT AHEAD POSITION

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INTRODUCTION

The basic purpose of this experiment was to compare head tracking performance at various angles from the straight ahead position. In our previous laboratory studies (e.g. Shirachi and Black, 1975; Hornseth, Stanley, and Carson, 1976; and Shirachi, Monk, and Black, 1976) head tracking was performed within a $\pm$ 15° or less cone about the straight ahead or boresight position. Honeywell has conducted studies in which the subjects aimed their heads as far off boresight as 40° (Hughes, et al, 1970). Their subjects slewed their heads in the direction indicated by an arrow, on the head position display they were using, until a target came into the field of view of the helmet mounted display. At this point their task became that of laying a reticle over the target to achieve lock on. The length of time the subjects were actually tracking was only a few seconds. Flight test studies conducted at Tyndall AFB and China Lake (Dietz et al, 1971 and Grossman, 1974) investigated head tracking performance which included large off-boresight angles. The target motion in these two studies was highly predictable.

One of the big advantages of a helmet sight in a high performance aircraft is its off-boresight capability in aiming a fire control system. However, tracking data using a target that is moving rapidly and randomly for an extended period of time is missing. This study is intended to provide data in this area that will be of value to engineers in designing head control systems.

METHOD

Apparatus:

A PDP 11/34 minicomputer with floating point hardware was used to generate the forcing function, digitize and record 4 analog data channels (azimuth and elevation of both the target and head motion), and perform some data analyses. A Honeywell helmet mounted sight (HMS) was used to sense the subject's head angles as he tracked the target. This helmet system weighed 1.65 kg. A Hughes, side mounted, helmet display was used to present the moving target and head position reticle to the subject's right eye. This helmet mounted display weighed .54 kg. An IMLAC PDS-4 computer graphics display generated the target and reticle symbology using the forcing function and the head position signals to position the target symbol relative to the reticle. An Ampex FR-1300 instrumentation tape recorder was used to record the subjects' responses, the forcing function, and a time code. An IBM 370/155 was used for data analysis and plotting.

The forcing function was updated at a 90 Hz rate. The HMS provided head azimuth and elevation angles at a 30 Hz rate. The IMLAC was "free running" at approximately a 1000 Hz refresh rate.

Forcing Function:

The forcing functions were generated from a sum of sine waves with the amplitudes scaled to simulate white noise passed through a second order filter with a break frequency of 0.7 Hz. More information on the forcing function can be found in Appendix A. The phase relationships between the sine waves were randomly varied from subject to subject but remained constant across a given subject's conditions. Pilot study data indicated that there was negligible learning across 6 runs with the same forcing function.

Procedure:

Each subject performed the head tracking under 6 head position conditions. The following mean azimuth and elevation angular positions were used:

0°, 0° (center-center); 0°, +30° (center-up); 0°, -30° (center-down); -45°, 0° (left-center); -45°, +30° (left-up); and -45°, -30° (left-down). Because of symmetry of the left-right neck muscles and pilot study data, only the left hemisphere of head motion was investigated. Performance at angles further off-center were not selected for examination because pilot study data suggested that the limits of head and neck motion may be exceeded at larger angles for some subjects. Other supporting data give the average limit of male neck movement for up flexion at 61° with S.D. of 27° down flexion at 60° with S.D. of 12°, and left or right rotation at 79° with S.D. of 14° (Van Cott and Kinkade, 1972). The maximum excursion of the target from each of the 6 head positions was ±10°. This small excursion was used to increase the probability the target would remain on the subjects' display at all times and not require the subject to search for it. Also, the small target excursions constrained the subjects to track at various mean angular positions within the head motion envelope to provide an adequate representation of head tracking at the specified off-center positions.

Each tracking run was 100 seconds long. The first 9 seconds of tracking were not scored to allow the subject to overcome the initial "start up" error induced by the target suddenly jumping to a random starting position and beginning to move. The following 91 seconds of tracking data were recorded and scored. At the end of each run a rest period of 1 minute was given. After each group of 3 runs, the rest period was extended to 5 minutes. The first 6 runs were practice runs, allowing for the subjects to adjust to head tracking at each angular position. All practice runs were presented to each subject in the same order. The data runs were presented in a randomized order to reduce any possible ordering effects. All subjects' scores asymptoted to an acceptable level of performance during the practice runs.

Subjects:

Fourteen male subjects were used with ages ranging from 16-40. Eye dominance was tested for each subject with about half reporting right eye dominance. The subjects' instructions are given in Appendix B.

RESULTS & DISCUSSION

A subject's performance scores were computed from his radial error data. Radial error is the visual angle from a subject's line of sight to the target at each instant in time. The Duncan's New Multiple Range Test (NMRT) was used to test for statistical differences in performance at the 6 head angle positions. Table 1 shows the 3 homogenous subsets of head positions found using the 50% circular error probability (CEP) metric (a 50% CEP refers to that radius, about the target, within which the subject tracked 50% of the time). The best performances (lowest CEP), denoted by the A subset, was found when the head faced center-center, left-center, and left-down. The next best performance, the B subset, was obtained when the head faced center-center, left-up, left-down, and center-up. The worst performance, subset C, was found when the head faced center-down, center-up, and left-up. It should be noted that the differences between the best position (-45°, 00°) and the worst position (00°, -30°) is small, .15° or 6%. While this difference is statistically significant, it is left up to the designers/engineers to determine if the difference is of practical significance.

Establishment of on target gate rings were done as an analysis procedure after data collection. However, during the experimental runs, the subjects were not required to keep the target within a gate ring, nor were they shown any rings. In analyzing the data, a subject was considered on target if his radial error was less than a specified tolerance. Six on target tolerance rings were used in analyzing the data collected in this experiment. They ranged from 1° to 6°, in 1° increments. Gate times were computed for each tolerance ring. Gate time was defined to be the amount of time a subject kept the target inside the ring. As soon as the target was outside the ring, that gate time ended. If the target was again inside the ring, another gate time was started. To reduce "noise" effects in this gate time measure, an arbitrary dead time zone of .1 seconds was used. This meant that not only must the target be within the ring to start a gate, it must also be within for .1 second. Likewise, it must be outside of the ring for .1 second to end the gate. The mean gate times for each ring, averaged over all positions, are shown in figure 1. Using the Duncan's test, the gate time metric did not prove to be a sensitive measure for distinquishing among the angular positions (Tables 2-7). For all of the tolerance rings, except the 4° ring, performance at the 6 head positions did not differ significantly from each other. The 4° ring indicated that the longest gate times were obtained at all positions except left-up and center-down. The next subset included all positions except left-center.

The time on target (TOT) scores, for each tolerance ring, were computed by multiplying the mean gate times by the number of times the target stayed within the ring. The mean TOTs for each ring, averaged across all positions, is shown in figure 2. The Duncan's test was applied to each of the 6 rings to determine homogenous subsets. As shown in Table 8 for the 1° tolerance band, there are no significant differences among any of the 6 angular positions. As the task becomes easier, by increasing the tolerance ring to 2°, the Duncan's test indicates that 3 homogenous subsets exist. As with the CEP metric, the TOT with a 2° ring has the best scores at the center-center, left-center, and left-down (Table 9). Next best scores are center-center, left-up and down, and center-up. The worst scores are center-center, left-up, and center-up and down. Increasing the ring size to 3°, there are still 3 homogenous subsets (Table 10). The best and second best scores remain the same, while the worst score is found to be the center-down position. With the rings at 4° and 5°, only 2 homogenous subsets are found (Tables 11 and 12). The best scores are the same positions as those in the 2° and 3° rings. The second best positions are also the same as in the 2° and 3° ring plus the center-down position is included in this subset. The 6° tolerance ring, the easiest task, also has 3 homogenous subsets (Table 13). The best positions were found to include all positions except center-down, while the next best included all positions except left-center. For this condition, both significantly different subsets have almost merged into a single subset.

A two way analysis of variance was used to test for significances in RMS error scores. No significant difference was found between azimuth versus elevation RMS errors (Table 14). Significance at the $p = .001$ level was found between the 6 angular positions. The head position by azimuth-elevation dimension interaction was also found to be significant at $p = .001$ level.

A Duncan's test was performed to compare RMS error scores between the 6 angular positions for both azimuth and elevation. Two homogenous subsets were found with the azimuth scores (Table 15). The best performance was the center-center and all left positions. With the elevation RMS error scores, 3 homogenous subsets were found, but with a different grouping than the other metrics have found (Table 16). The best performance was at left-center, left-down, and center-down. This was the only time that the center-down position was in the best performance grouping when multiple groups were found. The next subset contained the left-down, center, center-up, and center-down conditions. The worst position was the left-up position.

CONCLUSIONS

The 3 primary metrics, CEP, TOT, and gate times, all emphasize a different aspect of tracking performance, but they are not independent of each other. Thus, it is not surprising that the Duncan's test should generally designate the same position subsets. In almost all the tests, the best position was the left-center, followed by the center-center and left-down positions. Again, it should be emphasized that all of the differences found were small but statistically significant. However, they may or may not be practically significant. The helmet mounted sight and helmet mounted display used for this experiment were early prototypes. The later models of each unit are lighter and have a much improved center of gravity. Both of these factors may eliminate even the statistical significant differences among the positions within the envelope $\pm 45°$ azimuth and $\pm 30°$ elevation.

APPENDIX A

The sum of sine wave input was chosen such that it simulated white noise passed through the second order system $\left(\frac{A}{S + A}\right)^2$. Eleven sine frequencies, for azimuth were selected on the basis of being equal spaced between 0.10 Hz and 2.00 Hz on a $\log_{10}$ scale. For elevation, the 11 sine frequencies were also spaced equally on a $\log_{10}$ scale with the frequencies being midway between the azimuth frequencies. Their frequencies ranged from 0.12 Hz to 2.32 Hz. An additional requirement placed upon frequency selection was that the resultant input must complete a full cycle at the run's end. Thus, all frequencies must be a harmonic of the fundamental frequency. For this experiment, the fundamental frequency, $f_o = \frac{1}{91.02 \text{ seconds}} = .01099$ Hz.

APPENDIX B

Subject Instructions: "Your task in this experiment will be to head track a rapidly moving target. In the head mounted display, located in front of your right eye, you will notice a reticle at the center of the display. This reticle will always remain at the center of the display as you move your head. Please move your head around a little so that you can see which of the two objects is actually the reticle. The object that moves around on the display, as you move your head, is the target. During the test runs, the target will move around in a rapid, random pattern. Your task will be to move your head so as to keep the center of the reticle as near the center of the target as you can. The test runs will last 90 seconds. After each test run, you will be given a 1 minute rest period before the next run. Please remain seated during these short rest periods. Each test run will require you to track the target with your head aimed in a different direction. You will first be given some practice in tracking at each of the 6 head positions used in the experiment. Then you will be given the experimental runs. After each group of 3 runs you will be allowed to get up out of the chair to stretch and walk around. If at any time you have any questions about what you are to do, be sure to ask for additional instructions or clarifications. Do you have any questions at this time?"

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FIGURES AND TABLES

FIGURE 1

MEAN GATE TIMES FOR EACH GATE TOLERANCE RING, AVERAGED ACROSS ALL HEAD POSITIONS

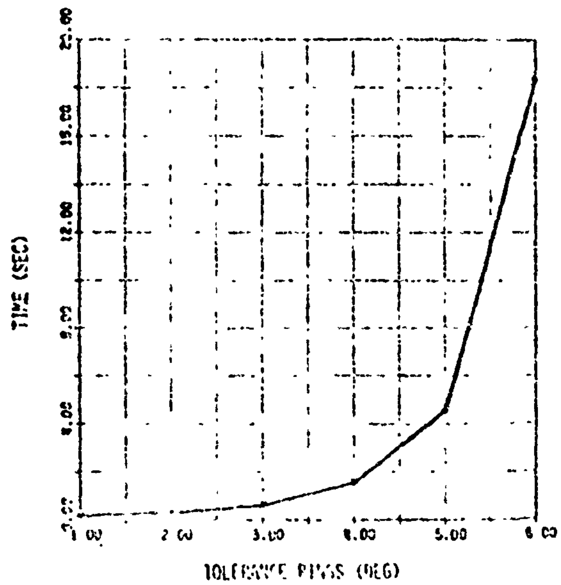

FIGURE 2

MEAN TIME ON TARGET FOR EACH TOLERANCE RING, AVERAGED ACROSS ALL HEAD POSITIONS

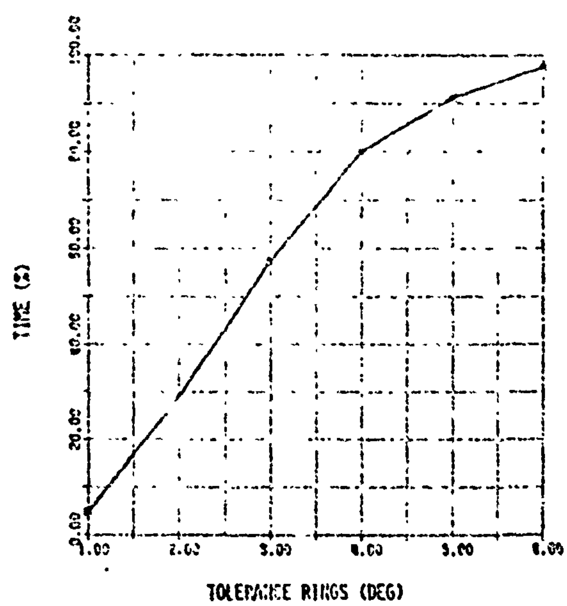

TABLE 1

DUNCAN'S NMRT FOR THE MEAN CEP SCORES AT THE 6 HEAD POSITIONS

CEP (DEGREES)		
EL (DEG)	AZ (DEG)	
	-45	0
+30	2.60 BC*	2.61 BC
0	2.51 A	2.55 AB
-30	2.57 AB	2.66 C

TABLE 2

DUNCAN'S NMRT RESULTS FOR THE 1° GATE TIME SCORES AT THE 6 HEAD ANGLE POSITIONS

1° GATE TIMES (SEC)		
EL (DEG)	AZ (DEG)	
	-45	0
+30	0.15 A	0.16 A
0	0.16 A	0.15 A
30	0.16 A	0.15 A

TABLE 3

DUNCAN'S NMRT RESULTS FOR THE 2° GATE TIME SCORES AT THE 6 HEAD ANGLE POSITIONS

2° GATE TIMES (SEC)		
EL (DEG)	AZ (DEG)	
	-45	0
+30	0.28 A	0.28 A
0	0.29 A	0.28 A
-30	0.29 A	0.28 A

TABLE 4

DUNCAN'S NMRT RESULTS FOR THE 3° GATE TIME SCORES AT THE 6 HEAD ANGLE POSITIONS

3° GATE TIMES (SEC)		
EL (DEG)	AZ (DEG)	
	-45	0
+30	0.60 A	0.59 A
0	0.64 A	0.62 A
30	0.62 A	0.58 A

* For all Duncan's NMRT tables in this report, letters represent homogenous subsets. The mean performance scores contained in a subset do not differ significantly from other means contained in that subset. The means not contained in the same subset are significantly different at the p = .05 level. A given mean can belong to more than one subset.

TABLE 5
DUNCAN'S NMRT RESULTS FOR THE 4° GATE TIME SCORES AT THE 6 HEAD ANGLE POSITIONS

4° GATE TIMES (SEC)		
EL (DEG)	AZ (DEG)	
	-45	0
+30	1.44 B	1.52 AB
0	1.85 A	1.57 AB
-30	1.59 AB	1.33 B

TABLE 6
DUNCAN'S NMRT RESULTS FOR THE 5° GATE TIME SCORES AT THE 6 HEAD ANGLE POSITIONS

5° GATE TIMES (SEC)		
EL (DEG)	AZ (DEG)	
	-45	0
+30	4.54 A	4.62 A
0	5.12 A	4.59 A
-30	4.42 A	4.13 A

TABLE 7
DUNCAN'S NMRT RESULTS FOR THE 6° GATE TIME SCORES AT THE 6 HEAD ANGLE POSITIONS

6° GATE TIMES (SEC)		
EL (DEG)	AZ (DEG)	
	-45	0
+30	17.2 A	19.2 A
0	20.0 A	20.3 A
-30	19.5 A	13.6 A

TABLE 8
DUNCAN'S NMRT RESULTS FOR THE 1° TIME ON TARGET SCORES AT THE 6 HEAD ANGLE POSITIONS

1° TOT (%)		
EL (DEG)	AZ (DEG)	
	-45	0
+30	4.52 A	4.56 A
0	5.15 A	4.73 A
-30	5.22 A	4.66 A

TABLE 9

DUNCAN'S NMRT RESULTS FOR THE 2° TIME ON TARGET SCORES AT THE 6 HEAD ANGLE POSITIONS

2° TOT (%)		
EL (DEG)	AZ (DEG)	
	-45	0
+30	28.2 BC	28.4 BC
0	30.7 A	29.3 ABC
-30	29.6 AB	27.4 C

TABLE 10

DUNCAN'S NMRT RESULTS FOR THE 3° TIME ON TARGET SCORES AT THE 6 HEAD ANGLE POSITIONS

3° TOT (%)		
EL (DEG)	AZ (DEG)	
	-45	0
+30	57.4 B	56.8 B
0	60.3 A	58.7 AB
-30	58.3 AB	55.7 C

TABLE 11

DUNCAN'S NMRT RESULTS FOR THE 4° TIME ON TARGET SCORES AT THE 6 HEAD ANGLE POSITIONS

4° TOT (%)		
EL (DEG)	AZ (DEG)	
	-45	0
+30	79.2 B	78.8 B
0	82.0 A	80.5 AB
-30	79.9 AB	78.3 B

TABLE 12

DUNCAN'S NMRT RESULTS FOR THE 5° TIME ON TARGET SCORES AT THE 6 HEAD ANGLE POSITIONS

5° TOT (%)		
EL (DEG)	AZ (DEG)	
	-45	0
+30	91.6 B	91.7 B
0	93.6 A	92.5 AB
-30	92.2 AB	91.0 B

TABLE 13

DUNCAN'S NMRT RESULTS FOR THE 6° TIME ON TARGET SCORES AT THE 6 HEAD ANGLE POSITIONS

6° TOT (%)		
EL (DEG)	AZ (DEG)	
	-45	0
+30	97.2 AB	97.4 AB
0	98.2 A	97.7 AB
-30	97.7 AB	96.9 B

TABLE 14

ANALYSIS OF VARIANCE TABLE OF RMS ERROR

Source of Variation	DF	Sum of Squares	Mean Square	F	P
A (AZ-EL Dimension)	1	.17	.17	4.53	>.05
B (Angular Positions)	5	.45	.09	5.01	<.001
C (Subject)	13	7.16	.55	65.82	
A X B	5	.27	.05	6.42	<.001
A X C	13	.50	.04	4.56	
B X C	65	1.19	.02	2.19	
A X B X C	65	.54	.01		
Total	167	10.30			

TABLE 15

DUNCAN'S NMRT RESULTS FOR THE AZIMUTH RMS ERROR SCORES AT THE 6 HEAD ANGLE POSITIONS

AZ RMS E (DEG)		
EL (DEG)	AZ (DEG)	
	-45	0
+30	2.23 AB	2.25 B
0	2.15 A	2.15 A
-30	2.23 AB	2.31 B

TABLE 16

DUNCAN'S NMRT RESULTS FOR THE ELEVATION RMS ERROR SCORES AT THE 6 HEAD ANGLE POSITIONS

EL RMS E (DEG)		
EL (DEG)	AZ (DEG)	
	-45	0
+30	2.29 C	2.20 B
0	2.05 A	2.16 B
-30	2.11 AB	2.13 AB