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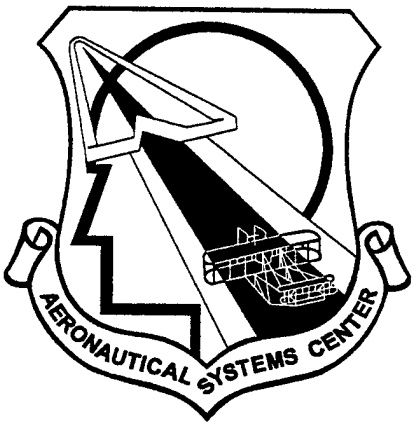

B-1 ENGINEERING RESEARCH SIMULATOR (ERS) DATA LINK STUDY

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FINAL REPORT FOR JULY 1998 – DECEMBER 1998

ENGINEERING DIRECTORATE
AERONAUTICAL SYSTEMS CENTER
AIR FORCE MATERIEL COMMAND
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13. ABSTRACT *(Maximum 200 words)*

The primary objectives of this evaluation were to 1) establish a B-1 defensive and offensive station base line performance using audio tasking, and 2) compare the base line performance with performance for a freetext message and an integrated mode. This study looked at interface issues, not specific hardware. Two part-tasks, retargeting (OSO) and threat updating (DSO), were used. The dependent measures for both tasks were key strokes per target or threat, time per target or threat, errors per target or threat, and Subjective Workload Analysis Technique (SWAT). Repeated measures multivariate analysis of variance for the OSO task showed the integrated mode was significantly ($p<0.05$) lower for number of strokes, time, errors and workload than the audio or freetext modes. Subjective rank ordering of the three modes indicated the WSO's unanimous preference for the integrated mode. Due to experimental constraints, only the audio and freetext modes were compared in the DSO task. The DSO results were mixed--audio performance was better for strokes but required more time than the freetext mode. The integrated mode is recommended for the OSO and DSO stations.

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EXECUTIVE SUMMARY

The Link 16 data format was designated on October 18, 1994, as the Department of Defense primary data link for all Service and Defense Agency C3I and weapon system applications. In preparation for the integration of Link 16 into the B-1, the B-1 System Program Office requested the Crew Station Evaluation Facility to perform a series of human-in-the-loop studies evaluating B-1 Link 16 system human interface.

The primary objectives of this evaluation were to 1) establish a B-1 defensive and offensive station base line performance using audio tasking, and 2) compare the base line performance with performance for a freetext message and an integrated mode. This study looked at interface issues, not specific hardware. Two part-tasks, re-targeting (Offensive System Officer (OSO)) and threat updating (Defensive System Officer (DSO)), were used. Due to experimental constraints, only two modes, audio and freetext, were tested for the DSO task. The dependent measures for both tasks were key strokes per target or threat, time per target or threat, errors per target or threat, and Subjective Workload Analysis Technique (SWAT). The OSO and DSO tasks were analyzed separately.

The repeated measures Multivariate Analysis of Variance (MANOVA) for the OSO task showed the integrated mode was significantly ($p<0.05$) lower for number of strokes, time, errors and workload than the audio or freetext modes. Subjective rank ordering of the three modes indicated the Weapon System Officers (WSOs) unanimous preference for the integrated mode.

For the DSO task, the MANOVAs for strokes and time showed significant ($p<0.05$) main effects for modes. The main effects for error and workload were not significant ($p<0.05$). The number of strokes was higher for the freetext compared to the audio mode, but the time to accomplish the task was less. Although more strokes were required, the compactness of the task permitted more efficiency and, thus, the lower time.

The results support the conclusion that the integrated mode significantly decreased the number of strokes, time, and errors to accomplish the retargeting task, and was the preferred mode by the WSOs. Also, the lower SWAT scores suggest a lower workload associated with the integrated mode. The integrated mode is recommended for the OSO and DSO stations.

1. INTRODUCTION

The success of future battlefield operations will depend on how efficiently forces attack an extremely complex array of targets while at the same time countering a diverse set of threats, including advanced offensive information warfare capabilities. Battlefield success will be achieved through the integration of ground and airborne weapons systems via digital data links. Real-time, high capacity data transfer between weapons platforms and Command, Control, Communications, Computers, Intelligence, Surveillance and Reconnaissance (C4ISR) systems are required for more effective battle management as the density of the air combat environment increases. As conditions change during mission execution, both air and ground crews require an effective capability to exploit new and updated information from off-board sensors.

Joint Tactical Information Distribution System (JTIDS) or Link-16 (the NATO term for JTIDS) is the backbone for the United States Navy and Air Force air and maritime operations. The Link-16 terminal implements the Tactical Digital Information Link-J (TADIL-J) message standard. Its architecture provides a common communications net to a large community of airborne and surface elements within line-of-sight. The Link 16 data format was designated on October 18, 1994, as the Department of Defense (DoD) primary data link for all Service and Defense Agency C3I and weapon system applications.

JTIDS and Multi-functional Information Distribution System (MIDS), in conjunction with a host system, support the exchange of joint approved Military Standard (MIL-STD) 6016 Tactical Digital Information Link (TADIL) J messages. JTIDS and MIDS, in addition to fixed format messages, are capable of freetext messages and variable message formats.

In preparation for the integration of Link 16 into the B-1, the B-1 SPO requested the CSEF to perform a human-in-the-loop study evaluating human performance differences between the audio tasking of the Weapon System Officer (WSO) and his/her tasking using the Link 16 digital message system.

1.1 TEST OBJECTIVE

This is the first in a series of studies to look at the B-1 controls and displays relative to implementing the Link 16 in the B-1. The primary objectives of this evaluation were to 1) establish a B-1 offensive and defensive station base line performance using audio tasking, and 2) compare the base line performance with two levels of data link performance. The base line condition was compared to 1) digital freetext message with operator manual input, and 2) digital data link message integrated into the B-1B avionics system. This study evaluated the B-1 data link human interface; it did not evaluate hardware per se.

2. METHOD

2.1 SUBJECTS

Eleven Weapon System Officers (WSO) participated in the evaluation. All subjects were qualified B-1 WSOs and represented a random sample. Total flying hours ranged from 650 to 4000 hours with an average of 2507 hours. B-1 specific flying time ranged from 250 to 2250 hours with a mean of 1170 hours. The mean age was 34.9 years.

2.2 APPARATUS

2.2.1 Crew Station Evaluation Facility (CSEF)

The Crew Station Evaluation Facility is an Air Force human-in-the-loop simulation facility managed and operated by the Crew Systems Branch (ASC/ENFC) under the Flight Systems Engineering Division (ASC/ENF). ASC/ENF is part of the Engineering Directorate (ASC/EN) at Wright-Patterson AFB. CSEF is a customer-funded facility that supports System Program Offices in their acquisition engineering through crewmember – vehicle interface evaluations using human-in-the-loop real-time simulation. Currently, the CSEF has the capability to perform full and part mission simulations for a variety of aircraft including the F-22, F-16, B-1, KC-135 and T-38.

2.2.2 Test Bed

The B-1 Engineering Research Simulator (ERS) is supported by the B-1 SPO (ASC/YDE) and operated and maintained by CSEF. The B-1 ERS contains the pilot, co-pilot, offensive and defensive stations. The system does not employ a motion base or a visual system. The cockpit controls and displays are currently configured in a mixture of configurations. The forward cockpit is between Block B and C, the Defensive station is Block F and Offensive station is Block E.

2.2.3 Voice Recording System

A Creative Technology Ltd. Wave Studio, version 3.2.1.0, recorded the voice messages for the audio condition. The same male voice recorded all messages. The voice messages simulated an AWACS controller directing the OSO to update the target information or the DSO to update the threat data. The presentation of the recorded message was automatically controlled by the B-1 ERS computer system. The audio message was only presented once.

In order to assess the audible intelligibility of the recorded messages and B-1 ERS headsets, the system was tested using word lists patterned after the Modified Rhyme Test. The Air Force Research Laboratory at Wright-Patterson AFB generated the word lists. A male voice recorded two separate 50-word lists for testing purposes (see Appendix A). Six subjects were tested (three subjects per word list) seated in the B-1 ERS wearing the headsets used during the study's data collection sessions. From the Human Engineering Guide to Equipment Design (1972, p. 174), a formula (percent correct ={number right – (number wrong/5)] x 2) was used to score the multiple choice answer sheets. In MIL-STD-1472E (1996), DOD Design Criteria Standard for Human Engineering, a 97% speech intelligibility (SI) for voice communication indicates exceptionally high intelligibility. The results of our SI test indicated an intelligibility level of 98.8%.

2.2.4 *Experimenter's Console*

The test engineer controlled the simulator operation and selected appropriate test parameters such as test subject number, test session number, etc., using a keyboard. The test engineer sat behind the WSO wearing a headset to monitor the audio voice messages.

2.3 *TASKS*

Two part-tasks were used to compare the performance for the base line audio condition and two data link configurations. These were: 1) Retargeting (OSO), and 2) Updating threats (DSO). The CSEF modified the Defensive Station Upgrade Program (DSUP) mission for the Defensive System Operator (DSO) task, and modified a mission from the B-1 Weapon Flexibility Study for the Offensive System Operator (OSO) task.

2.4 *TARGETS/THREATS*

Three target and three threat groupings were used. The targets/threats represented a continuum of difficulty; i.e., one target or threat for the easiest condition, a grouping of 3 targets or threats for the middle condition, and 5 targets or threats for the most difficult condition. Four different targets and four different threat sets were used to limit the number of times the subject entered the same target or threat coordinates. For example, there were four 1-target packages, four 3-target packages and four 5-target packages. The same approach applied to the threat groupings. See Appendix B for target and threat data.

2.5 *AUDIO AND FREETEXT MESSAGE FORMAT*

The OSO audio and/or freetext messages (FTM) were based on the 9-line In-Flight Target Assignment (ITA) format (see Table 1). While the use of additives (a predetermined value added by the crew member to the transmitted value) is operationally approved and occasionally implemented, typically, secure voice is available and; therefore, additives are not necessary. Additives were not used during this study. Only the appropriate lines of the 9-line message, as defined for this study, were used (Items # 1, 2, 3, and 4). The same information was supplied verbally (recorded message) for the audio condition. For example, the voice message for a one-target scenario was: "Strike 01. Target group 20. Change target 6. New target information as follows: Item 1: N3406.010 W11715.250, 01100. Item 2: 1225-1235. Item 3: one. Item 4: N3424.0 W11720.0." For the same one-target scenario the FTM read:

ALERT: Target group 20 Chg target 6 New target information as follows:
ITEM 1: N3406.010 W11715.250 01100
ITEM 2: 1225-1235
ITEM 3: 1
ITEM 4: N3424.0 W11720.0

A different format was used for the DSO messages. As an example, for a DSO task updating one threat, the subject heard the voice message "Strike 01. Badger active N3435.5 W11745.5." For the same scenario, the freetext message read: "ALERT: SA7 N3435.5 W11745.5." Code words indicated the type of threat; i.e., Badger was the code word for a SAM 7 missile.

Voice message duration for the OSO task ranged from 43.49 seconds to 127.23 seconds. For the DSO task, the voice message duration ranged from 14.5 to 71 seconds. The average message length for both tasks by target and threat grouping is presented in Table 2.

TABLE 1. IN-FLIGHT TARGET ASSIGNMENT FORMAT

ITEM 1: Target Coordinates (WGS-84), Elevation
ITEM 2: Time on Target (TOT)
ITEM 3: # Weapons/Interval (msec)
ITEM 4: Initial Point (IP)
ITEM 5: Offset Aim Point(s) (OAP)
ITEM 6: Ingress
ITEM 7: Egress
ITEM 8: Remarks

Authentication _____

TABLE 2. AVERAGE MESSAGE LENGTH			
OSO TASK	AVERAGE DURATION (Seconds)	DSO TASK	AVERAGE DURATION (Seconds)
1 Target	49.01	1 Threat	15.25
3 Targets	87.93	3 Threats	39.25
5 Targets	121.46	5 Threats	66.5

2.6 DATA LINK CONTROLS/DISPLAYS

2.6.1 OSO Controls/Displays

The task-relevant Multi-Function Display (MFD) pages were modified to provide a data link capability for the study. The top portion of the MFD page displayed the data link free form text message (FTM). When a FTM was received, the words "LINK 16" flashed at the bottom of the MFD page. The OSO viewed the FTM with one button push. The FTM area measured 4 lines with 55 characters per line. Navigation data normally displayed in this area was still available on the second OSO MFD from the navigation page (i.e., the normal page displayed on the right MFD).

For this study, other OSO controls were modified to provide a means to display the FTM, a FTM scroll capability, and a control to enter the new data into the mission plan (integrated condition). The FTM area was displayed for the freetext and integrated conditions. In addition, for the integrated condition, a data link page displayed the new target coordinates (see Appendix C).

For the integrated condition, the OSO received an FTM alerting him/her to new target coordinates. The OSO maneuvered to the data link page. The OSO viewed the FTM, simultaneously, with the Link 16 page to verify that the new target information was correct on the Link 16 page. To enter the FTM information automatically into the mission plan, the OSO pushed the "accept" button. No manual data entry was required for the integrated condition.

TABLE 3. CONTROLS/DISPLAYS						
CONTROL/DISPLAY	FUNCTION	OSO	DSO	Audio	FTM	Inte-grated
FTM View	Displayed the FTM on the top portion of the MFD	X	X		X	X
Scroll	Scroll the FTM up and down	X	X		X	X
Start/Stop	Start and stop each trial	X	X	X	X	X
Accept	Automatically input the new target data into the mission plan	X				X
Link 16 page	Displayed in action point table format the new target information	X				X
Integrated Keyboard (IKB)	Entered alphanumeric data and maneuvered through the various MFD pages	X	X	X	X	X
MFD	Displayed relevant function page	X	X	X	X	X

2.6.2 DSO Controls/Displays

As described for the OSO, a similar FTM area and controls were provided for the DSO MFD, specifically the Defensive Order of Battle page (see Appendix D). The DSO data link controls/displays were only used for the freetext condition. For the audio condition the standard MFD page (without FTM) was displayed.

2.7 PROCEDURE

Two groups of four subjects and one group of three subjects participated in the study. Subjects were briefed on the general study purpose, study particulars, B-1 ERS study-relevant controls and displays, and the Subjective Workload Assessment Technique (SWAT).

SWAT has two phases: scale development and event scoring. The scale development trains the subjects on the use of the three descriptors (time load, mental effort, and psychological stress) and obtains data on how each of these descriptors individually affects the WSO's own perception of workload. This data was obtained by each WSO rank ordering 27 SWAT cards to establish his/her own personal SWAT profile. The event scoring was the verbal data collection after each test trial.

After completing the briefing session, each subject had individual hands-on simulator practice time to familiarize himself with the B-1 ERS and perform several practice trials. As a minimum, all subjects performed 5 practice trials. Subjects were encouraged to perform as many practice trials as necessary to feel comfortable with the equipment and the tasks. Once all subjects had completed the hands-on practice session, the testing session began. The sequence of events for a group of four WSOs is depicted in Table 4. With the group of three WSOs, the three subjects alternated turns in the simulator instead of testing by twos. They maintained consistency with the other two groups of four by completing four test blocks on day 1 and 6 test blocks on day 2.

TABLE 4. SEQUENCE OF EVENTS					
DAY 1	BRIEFING ALL	INDIVIDUAL HANDS-ON PRACTICE	LUNCH	WSO 1-2 TESTING	WSO 3-4 TESTING
DAY 2	WSO 1-2 TESTING	DEBRIEFING	LUNCH	WSO 3-4 TESTING	DEBRIEFING

At the beginning of a trial the simulator was positioned approximately 10 minutes from the bombing target area between 1000 to 4000 feet altitude depending on the scenario. The MFD was on the list page (menu page). A time limit of 10 minutes was imposed on all test trials. If the subject exceeded the time limit, the test trial automatically ended. Once a subject completed his task, he indicated its completion by pressing a stop button. The test engineer recorded the subject's SWAT scores and continued on to the next test trial.

For the audio condition, the subjects' notes of the audio message; i.e., new target or threat information, were collected for later use.

2.8 DATA COLLECTION SESSION

Two subjects alternated time in the simulator. While one subject tested, the second WSO relaxed in a waiting area. After each block of 6 trials, the subjects rotated. On day 1, all subjects had a test session in the afternoon. On day 2, two subjects tested in the morning and two subjects tested in the afternoon. The exception to this sequence is discussed for the group of three subjects in the procedures section. Each subject ran a complete block of one task before testing on the second task. Prior to the start of each task for the first time, the subject performed at least one practice trial to refresh his memory on the upcoming task.

2.8.1 Objective Data

Performance data were collected for time to complete the task, number of errors made, and the number of keystrokes. For analysis purposes, the dependent measures were computed as time per target/threat, number of errors per target/threat, and number of strokes per target/threat.

2.8.2 Subjective Data

SWAT data were collected after each test trial and a debriefing questionnaire collecting preference data was administered after the subject's final test session.

2.9 EXPERIMENTAL DESIGN

The design was divided into two separate designs, the OSO task was a 3 x 3 repeated measures Multivariate Analysis of Variance (MANOVA) and the DSO task was a 2 x 3 repeated measures MANOVA.

2.9.1 OSO Task

Four trials were accomplished for each condition for a total of 36 trials per subject. The order of the mode of presentation and the targets was randomized. The presentation mode was constrained not to appear more than 4-5 times in any one position of order across the subjects. The 36 trials were subdivided into 6 blocks with 6 trials in each block. Each block represented one mode; i.e., there were 2 blocks of audio trials, 2 blocks of freetext trials, etc. The order of the blocks was randomized across subjects and the order of the target groups was randomized within the blocks. The order of presentation of the tasks was also randomized; i.e., half the subjects were randomly assigned to test the OSO task before the DSO task, and vice versa. See Appendix E for the order of presentation.

TABLE 5. OSO EXPERIMENTAL DESIGN

OSO TASK RETARGETING WSO 1-12*				
MODE	TARGETS			
	Target Group1	Target Group2	Target Group3	
AUDIO	44 trials	44 trials	44 trials	
DATA LINK FREETEXT	44 trials	44 trials	44 trials	
DATA LINK INTEGRATED	44 trials	44 trials	44 trials	
Total	396 trials			

*Note: the study was designed for 12 subjects. One subject dropped out without prior notice; thus, a replacement was not available. The above table reflects the actual number of trials tested for 11 subjects.

2.9.2 DSO Task

Four trials were accomplished for each condition for a total of 24 trials per subject. The order of the mode of presentation and the threat groups was randomized. The presentation mode was constrained not to appear more than 6 times in any one position of order. The 24 trials were subdivided into 4 blocks with 6 trials in each block. Each block represented one mode; i.e., there were 2 blocks of audio trials, and 2 blocks of freetext trials. The order of the blocks was randomized across subjects and the order of the threat groups was randomized within the blocks. See Appendix E for the order of presentation.

A DSO integrated condition was not tested. For an integrated DSO condition, the threat update would automatically occur; i.e., the new or revised threat information would automatically appear on the Threat Situation Format (TSF). No DSO input would be required, ergo; we did not test this condition.

TABLE 6. DSO EXPERIMENTAL DESIGN

DSO TASK UPDATING THREATS WSO 1-12*				
MODE	THREATS			
	Threat Group 1	Threat Group 2	Threat Group 3	
AUDIO	44 trials	44 trials	44 trials	
DATA LINK FREETEXT	44 trials	44 trials	44 trials	
Total	264 trials			

*Note: the study was designed for 12 subjects. One subject dropped out without prior notice; thus a replacement was not available. The above table reflects the actual number of trials tested for the 11 subjects.

3. *RESULTS*

Through the use of several descriptive and inferential procedures provided by SPSS (Statistical Package for the Social Sciences, 1993) release 6.0, the experimental data were analyzed separately for each of the two tasks. The major statistical procedure used to test the effect of differences between modes on the four dependent measures---strokes per target/threat, time per target/threat, errors per target/threat and SWAT---was a repeated measures Multivariate Analysis of Variance (MANOVA). Repeated measures MANOVAs were completed in a two step process. First, the overall data for the particular task under all target or threat conditions were analyzed. If the SPSS multivariate criterion tests were significant at the alpha .05 level, differences between modes under each target or threat condition were examined. MANOVAs, associated with this second step, provided estimates that could be generalized to the population.

3.1 OSO Task

Figure 1 displays the average values for strokes, time, and SWAT for all subjects across all replications (N=99). Figure 2 displays average error. As shown, the integrated mode is associated decidedly with the lowest values for all of the dependent measures. In particular, note that error is zero in all cases in the integrated mode. The freetext mode is lower than the audio mode in time and SWAT, but is higher in average strokes and errors. More indices of central tendency and dispersion, including minimum and maximum values, are shown in Appendix F, Table 1. Median values are graphically displayed in Appendix F, Figures 1 (strokes, time, and SWAT) and 2 (error). Some positive skew exists in the data, but does not impact further analysis.

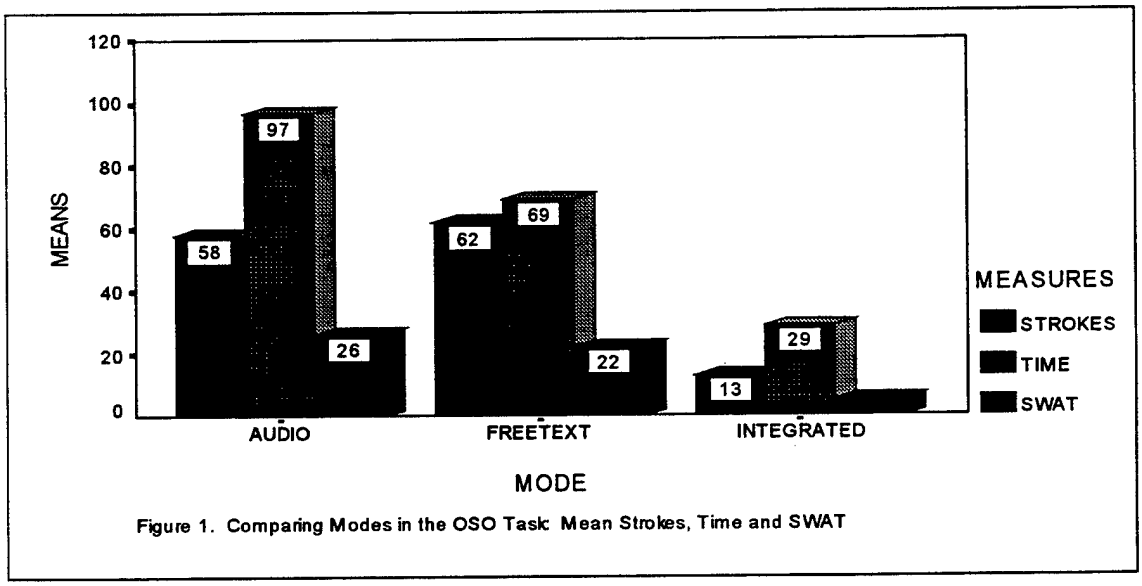

Figure 1. Comparing Modes in the OSO Task: Mean Strokes, Time and SWAT

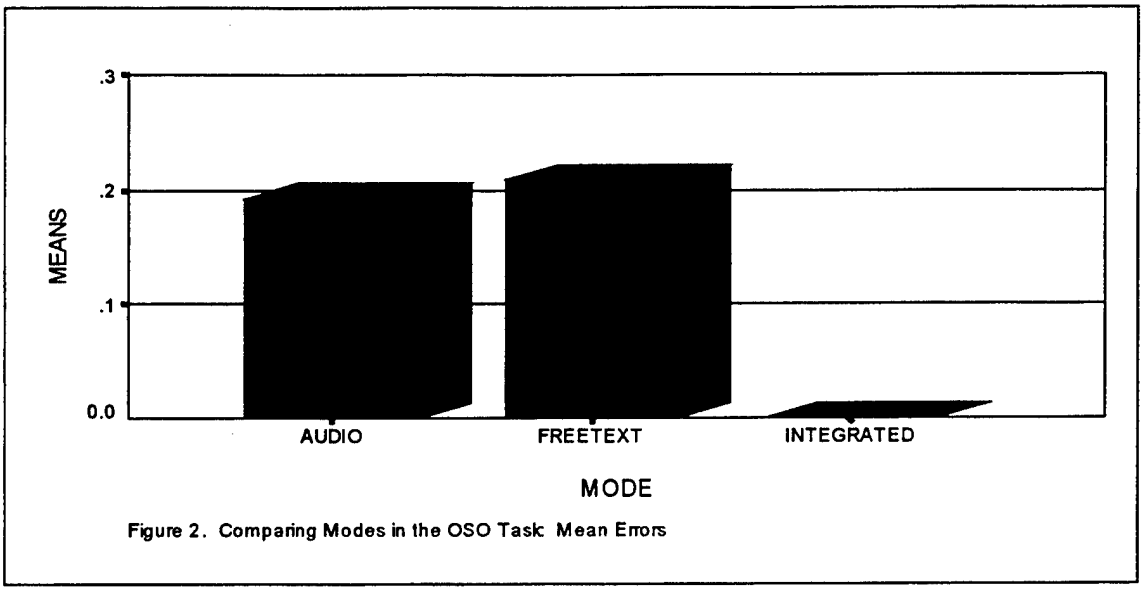

Figure 2. Comparing Modes in the OSO Task Mean Errors

Prior to testing the null hypothesis of no difference between the modes, the dependent measures were correlated, revealing that strokes, time, and error (S-T-E) were significantly correlated with each other ($p<0.05$), while SWAT was not correlated with any of the other measures (Appendix F, Table 2). This required a "doubly multivariate" repeated measures analysis investigating strokes, time, and errors simultaneously. A separate analysis considered SWAT. Both repeated measures MANOVA (Appendix F, Tables 3 and 4, for S-T-E and SWAT, respectively) show significant ($p<0.05$) multivariate tests for the main effects of mode and target, as well as for their interaction. Given the significant interactions, further analysis focused on simple main effects, wherein the three communication modes were compared within each of the target conditions. Figures 3 through 8 display the average values for the dependent measures. For all conditions, the integrated mode is much lower in value than the other two modes. Note that freetext remains highest in mean strokes for each of three target conditions, just as in the overall case, but its associated mean error is lower than that associated with the audio mode for the most difficult target condition. Numerous measures of central tendency and dispersion for each mode by target condition are shown in Appendix F, Table 5. Also, as with the overall case, median values are graphically portrayed in Figures 2 through 7, Appendix F. Note that less positive skew (as demonstrated by the difference between mean and median) on each of the dependent measures is associated with the high target condition than for the other target conditions.

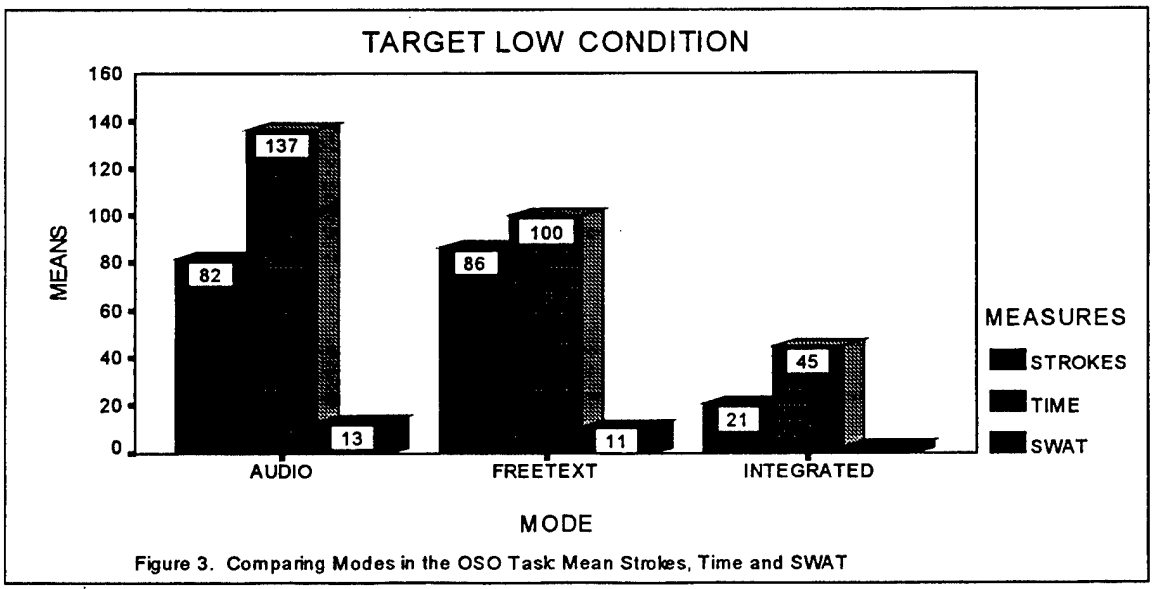

Figure 3. Comparing Modes in the OSO Task Mean Strokes, Time and SWAT

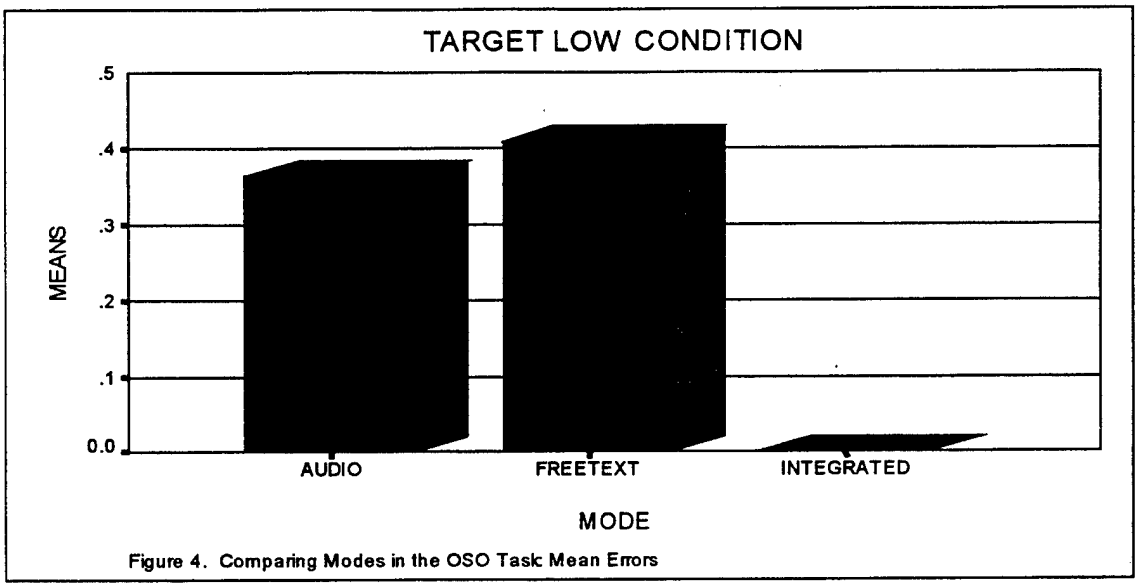

Figure 4. Comparing Modes in the OSO Task Mean Errors

Note that low, medium and high target conditions equal 1 target, 3 targets, and 5 targets.

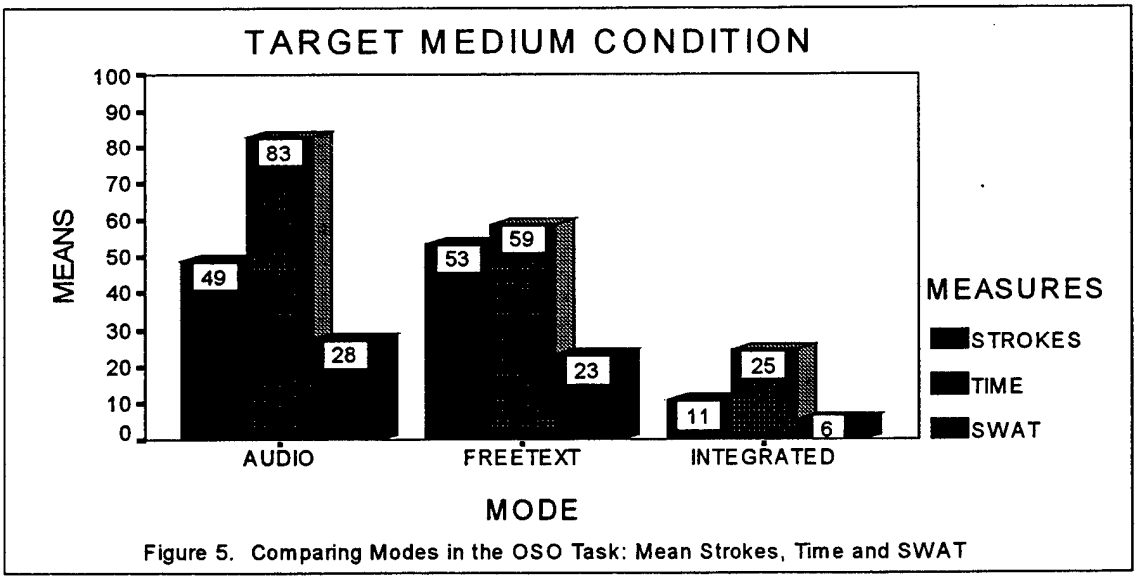

Figure 5. Comparing Modes in the OSO Task: Mean Strokes, Time and SWAT

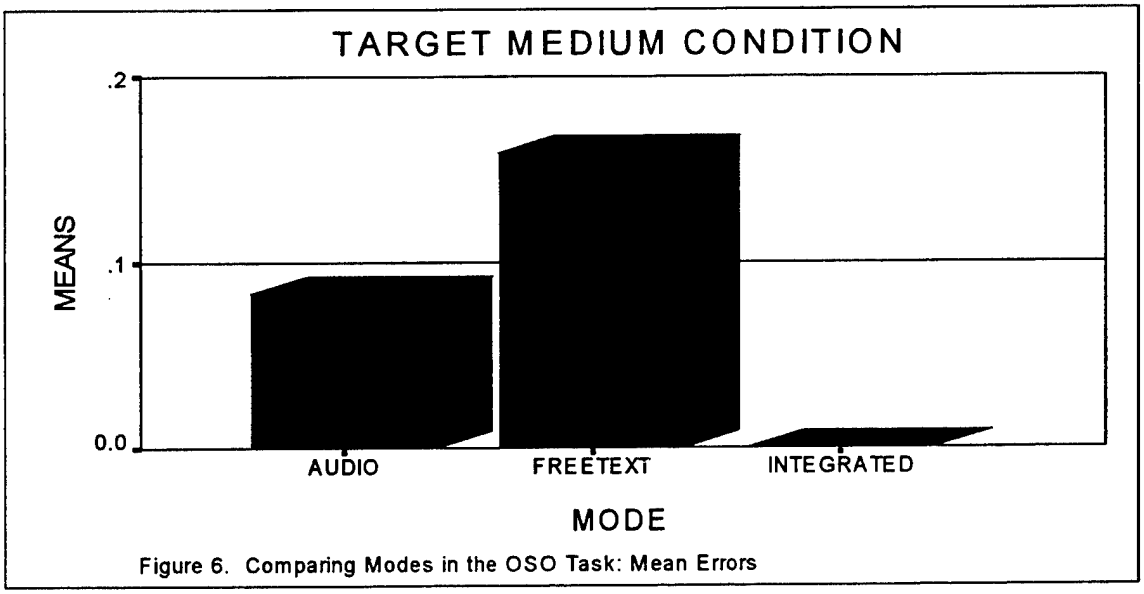

Figure 6. Comparing Modes in the OSO Task: Mean Errors

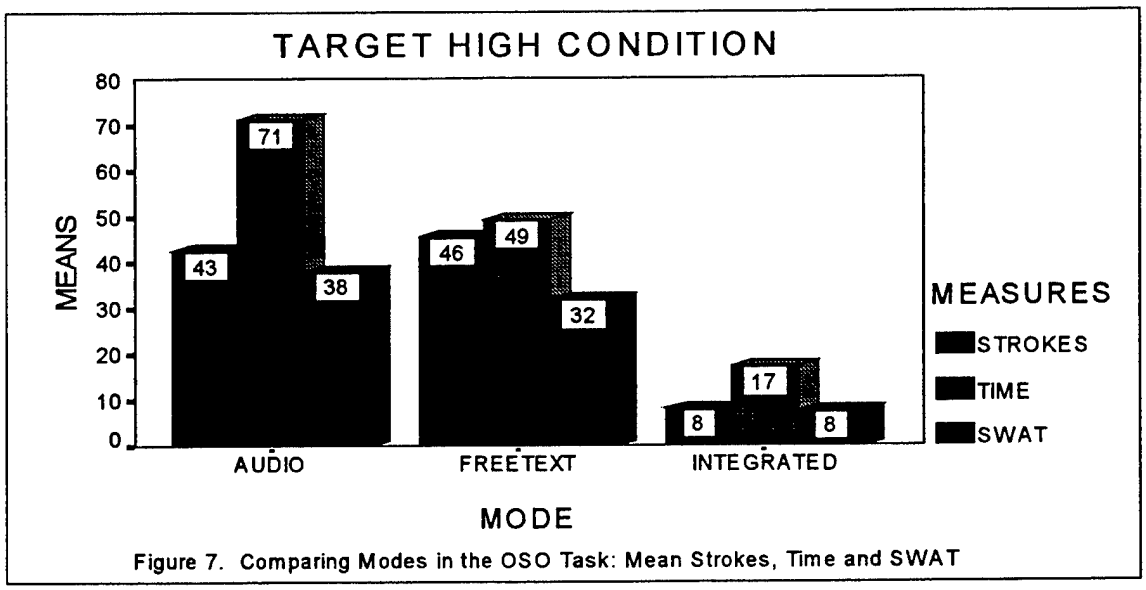

Figure 7. Comparing Modes in the OSO Task: Mean Strokes, Time and SWAT

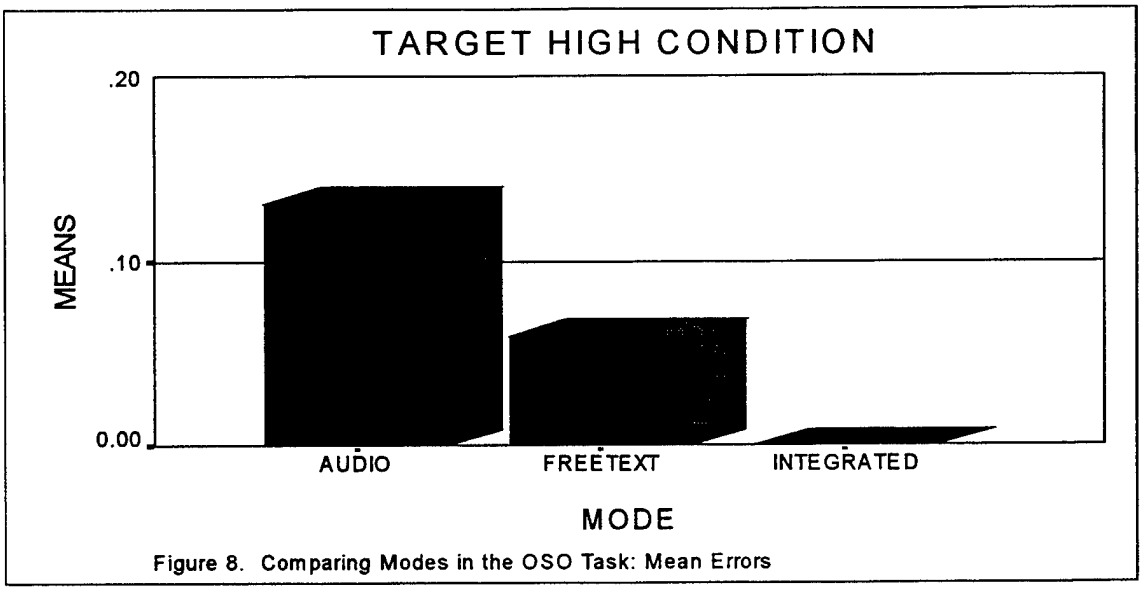

Figure 8. Comparing Modes in the OSO Task: Mean Errors

Separately, within each target condition, the modes were compared through repeated measures MANOVAs. Again, as in the overall condition, strokes, time, and error were analyzed, simultaneously, and SWAT by itself. Statistics derived from these MANOVAs resulted in Tables 7 through 9, which display an association measure of effect, similar to correlation, "eta-squared," for the low to high target conditions, respectively. The repeated measures "eta-squared" is derived by dividing the sum of squares for the effect of interest by the sum of squares for error added to the sum of squares for the effect of interest. The effect of interest is either of the two orthogonal contrasts, freetext minus audio (FT-A), and integrated minus the average of audio plus freetext (I-avg (A+T)). These contrasts are transformed dependent variables provided by the MANOVA procedure. For each of the four dependent measures in each of the target conditions, the strength of the association is greatest with the latter contrast than the former. For example, the difference between integrated and the other two modes in combination accounts for 98.7%, 99.16% and 99.1% of variance in strokes for the low to high target conditions, respectively, compared to 31.17%, 58.61% and 27.97% for the difference between freetext and audio. For each of the contrasts, strokes and time account for more of the variance than error or SWAT. Included with the sample eta-squared values are estimates for the degree of association in the population. A formula provided in Bray and Maxwell (1990, p.37) adjusts the sample for the more general case. Table 10 displays the values over all target conditions.

Aside from eta-squared values for each contrast, the SPSS procedure provides parameter estimates for univariate tests of mean differences. These are shown in Tables 11 through 13 for the low, medium and high conditions, respectively. As in the previous tables, the difference between integrated and the other two modes is much greater than the difference between freetext and audio for all four dependent measures under all target conditions. For instance, in the integrated mode, the WSOs took less time than in the other two modes combined; 73.48, 46.39 and 42.91 seconds for the low to high target condition, respectively. In contrast, in the freetext mode, the WSOs took on average 36.59, 24.17 and 21.87 seconds less than in the audio mode. Also, the differences between the two contrasts are stark for strokes and time compared to errors and SWAT; the disparity for strokes and time being greater under the low target condition than under the other two. Note the difference in strokes and error between freetext and audio is generally positive, indicating freetext was worse than audio. In order to generalize beyond the sample, 95% confidence intervals around the mean differences are provided. Table 14 displays values over all target conditions. Finally, in regard to the OSO task, replications and an experience variable were found not to be significant ($p>0.05$) in the main effects or interactions (with mode).

TABLE 7. COMPARING CONTRAST EFFECTS IN THE OSO TASK: ETA-SQUARED

*p<.05, **p<.01 A=audio; FT=freetext; I=integrated	TARGET CONDITION							
	LOW							
	MEASURE							
	STROKES		TIME		ERRORS		SWAT	
	CONTRAST		CONTRAST		CONTRAST		CONTRAST	
	FT-A	I-avg(A+FT)	FT-A	I-avg(A+FT)	FT-A	I-avg(A+FT)	FT-A	I-avg(A+FT)
SAMPLE	.3117	.9870**	.8697**	.9523**	.0107	.4204*	.0212	.2838
POPULATION ESTIMATE	.2405	.9856	.8563	.9474	(-.0916)	.3604	(-.0800)	.2097

TABLE 8. COMPARING CONTRAST EFFECTS IN THE OSO TASK: ETA-SQUARED

**p<.01 A=audio; FT=freetext; I=integrated	TARGET CONDITION							
	MEDIUM							
	MEASURE							
	STROKES		TIME		ERRORS		SWAT	
	CONTRAST		CONTRAST		CONTRAST		CONTRAST	
	FT-A	I-avg(A+FT)	FT-A	I-avg(A+FT)	FT-A	I-avg(A+FT)	FT-A	I-avg(A+FT)
SAMPLE	.5861**	.9916**	.8477**	.9371**	.1421	.2327	.1196	.5984**
POPULATION ESTIMATE	.5433	.9908	.8319	.9306	.0533	.1534	.0285	.5569

TABLE 9. COMPARING CONTRAST EFFECTS IN THE OSO TASK: ETA-SQUARED

**p<.01 A=audio; FT=freetext; I=integrated	TARGET CONDITION							
	HIGH							
	MEASURE							
	STROKES		TIME		ERRORS		SWAT	
	CONTRAST		CONTRAST		CONTRAST		CONTRAST	
	FT-A	I-avg(A+FT)	FT-A	I-avg(A+FT)	FT-A	I-avg(A+FT)	FT-A	I-avg(A+FT)
SAMPLE	.2797	.9910**	.8126**	.9650**	.3062	.2638	.2537	.6628**
POPULATION ESTIMATE	.2052	.9900	.7932	.9613	.2344	.1876	.1765	.6279

TABLE 10. COMPARING CONTRAST EFFECTS IN THE OSO TASK: ETA-SQUARED

*p<.05, **p<.01 A=audio; FT=freetext; I=integrated	TARGET CONDITION							
	OVERALL							
	MEASURE							
	STROKES		TIME		ERRORS		SWAT	
	CONTRAST		CONTRAST		CONTRAST		CONTRAST	
	FT-A	I-avg(A+FT)	FT-A	I-avg(A+FT)	FT-A	I-avg(A+FT)	FT-A	I-avg(A+FT)
SAMPLE	.5112**	.9936**	.8958**	.9651**	.0095	.3718*	.1493	.5828**
POPULATION ESTIMATE	.4618	.9929	.8853	.9616	(-.0907)	.3083	.0632	.5406

TABLE 11. COMPARING CONTRAST EFFECTS IN THE OSO TASK: MEAN DIFFERENCES

**p<.01 A=audio; FT=freetext; I=integrated	TARGET CONDITION							
	LOW							
	MEASURE							
	STROKES		TIME		ERRORS		SWAT	
	CONTRAST		CONTRAST		CONTRAST		CONTRAST	
	FT-A	I-avg(A+FT)	FT-A	I-avg(A+FT)	FT-A	I-avg(A+FT)	FT-A	I-avg(A+FT)
MEAN DIFFERENCE	4.5227	-63.4429**	-36.5935**	-73.4795**	.0455	-.3864	-1.8816	-9.4159
LOWER LIMIT 95% C.I.	-.2125	-68.5790	-46.5722	-85.0647	-.2626	-.7060	-10.8884	-19.9555
UPPER LIMIT 95% C.I.	9.2579	-58.3069	-23.0490	-61.8942	.3535	-.0667	7.1248	1.1237

TABLE 12. COMPARING CONTRAST EFFECTS IN THE OSO TASK: MEAN DIFFERENCES

**p<.01 A=audio; FT=freetext; I=integrated	TARGET CONDITION							
	MEDIUM							
	MEASURE							
	STROKES		TIME		ERRORS		SWAT	
	CONTRAST		CONTRAST		CONTRAST		CONTRAST	
	FT-A	I-avg(A+FT)	FT-A	I-avg(A+FT)	FT-A	I-avg(A+FT)	FT-A	I-avg(A+FT)
MEAN DIFFERENCE	4.6742**	-40.3673**	-24.1656**	-46.3904**	.0758	-.1212	-4.3841	-19.6533**
LOWER LIMIT 95% C.I.	1.9068	-42.9789	-31.3843	-54.8563	-.0554	-.2763	-12.7643	-30.9972
UPPER LIMIT 95% C.I.	7.4416	-37.7556	-16.9469	-37.9245	2.0690	.0339	3.9962	8.3094

TABLE 13. COMPARING CONTRAST EFFECTS IN THE OSO TASK: MEAN DIFFERENCES

**p<.01 A=audio; FT=freetext; I=integrated	TARGET CONDITION							
	HIGH							
	MEASURE							
	STROKES		TIME		ERRORS		SWAT	
	CONTRAST		CONTRAST		CONTRAST		CONTRAST	
	FT-A	I-avg(A+FT)	FT-A	I-avg(A+FT)	FT-A	I-avg(A+FT)	FT-A	I-avg(A+FT)
MEAN DIFFERENCE	3.0045	-35.9339**	-21.8674**	-42.9121**	-.0727	-.0955	-6.2204	-27.1306**
LOWER LIMIT 95% C.I.	-.3926	-38.3498	-29.2676	-48.6749	-.1499	-.2078	-13.7374	-40.7657
UPPER LIMIT 95% C.I.	6.4016	-33.5181	-14.4673	-37.1493	.0044	.0169	1.2965	-13.4954

TABLE 14. COMPARING CONTRAST EFFECTS IN THE OSO TASK: MEAN DIFFERENCES

*p<.05, **p<.01 A=audio; FT=freetext; I=integrated	TARGET CONDITION							
	OVERALL							
	MEASURE							
	STROKES		TIME		ERRORS		SWAT	
	CONTRAST		CONTRAST		CONTRAST		CONTRAST	
	FT-A	I-avg(A+FT)	FT-A	I-avg(A+FT)	FT-A	I-avg(A+FT)	FT-A	I-avg(A+FT)
MEAN DIFFERENCE	4.0670**	-46.5820**	-27.5410**	-54.2614**	.0162	-.2010*	-4.1619	-18.7335**
LOWER LIMIT 95% C.I.	1.2649	-49.2224	-34.1582	-61.5272	-.1004	-.3851	-11.1634	-29.9023
UPPER LIMIT 95% C.I.	6.8691	-43.9416	-20.9238	-46.9955	.1149	-.0169	2.8395	-7.5647

3.2 DSO Task

Figure 9 displays the average values for strokes, time, and SWAT for all subjects across all replications (N=66). Figure 10 displays average error. As in the OSO task, the freetext mode is lower in time and SWAT than the audio mode and higher in strokes. However, unlike the OSO task, error on average is lower in the freetext condition. More indices of central tendency and dispersion are displayed in Appendix G, Table 1. Figures 1 (strokes, time, and SWAT) and 2 (error), Appendix G show some positive skew in the data as in the OSO task, but does not impact further analysis.

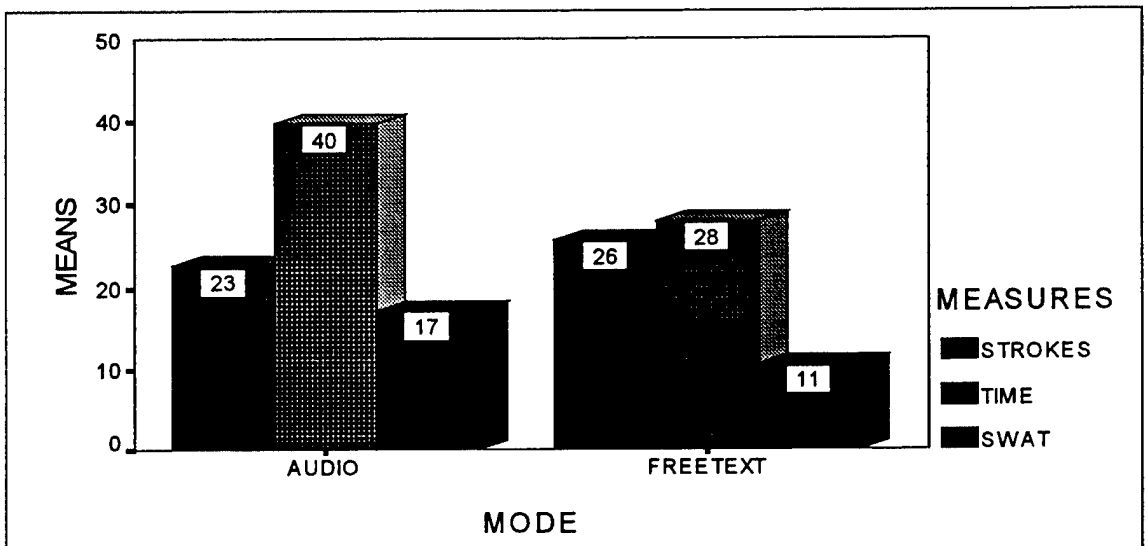

Figure 9. Comparing Modes in the DSO Task: Mean Strokes, Time and SWAT

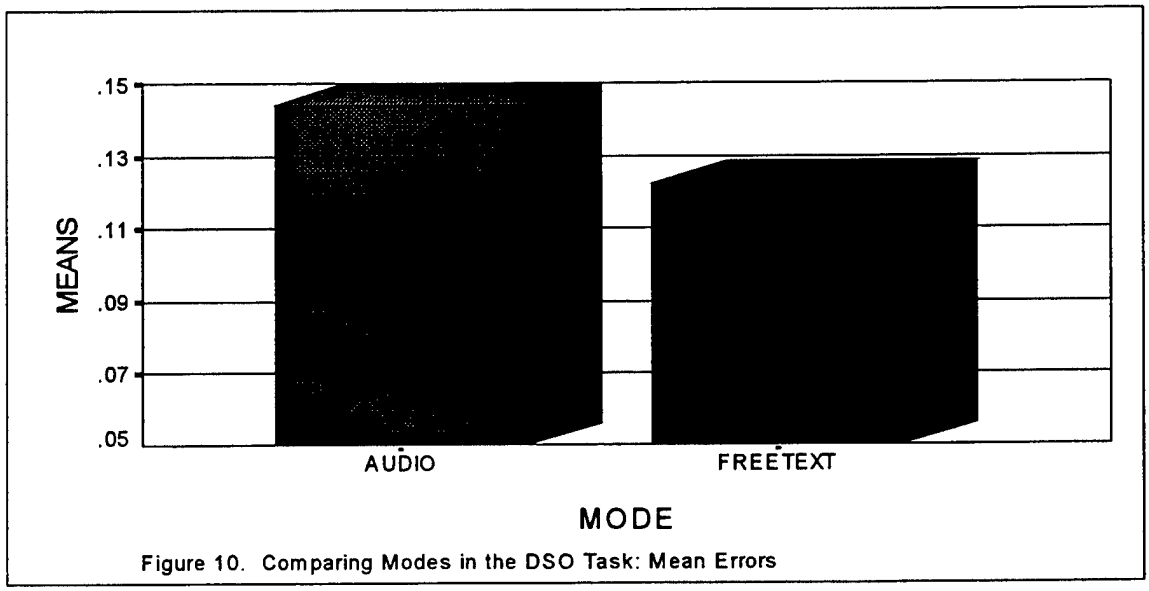

Figure 10. Comparing Modes in the DSO Task: Mean Errors

Examination of the correlations among the dependent measures (Appendix G, Table 2) showed no significant correlations ($p>0.05$) between any of the measures. As a consequence, each dependent measure was analyzed by a separate repeated measures MANOVA (Appendix G, Tables 3 through 6 for strokes,

time, error, and SWAT, respectively). The MANOVAs for strokes and time showed significant ($p<0.05$) main effects for mode. For time, the interaction between mode and threat was significant ($p<0.05$) but not for strokes ($p>0.05$). The main effects and the interaction for error and SWAT were not significant ($p>0.05$) with the exception of threat (not the focus here) and SWAT. Consequently, these two last dependent measures were dropped from further analysis. Further analysis focused on simple main effects for both strokes and time, even though the interaction for strokes was not significant, given that such analysis has proved useful. Figures 11 through 13 display the mean values under audio and freetext for the low (1 threat), medium (3 threats) and high (5 threats) conditions, respectively. Strokes remain higher under freetext for all threat conditions, but time is lower. Note that under the most difficult threat condition, the differences are less extreme than under the other conditions. Other measures of central tendency and dispersion are shown in Appendix G, Table 7. Figures 3 to 5 (Appendix G) display the median values for each threat condition. Positive skew is less pronounced compared to the OSO task.

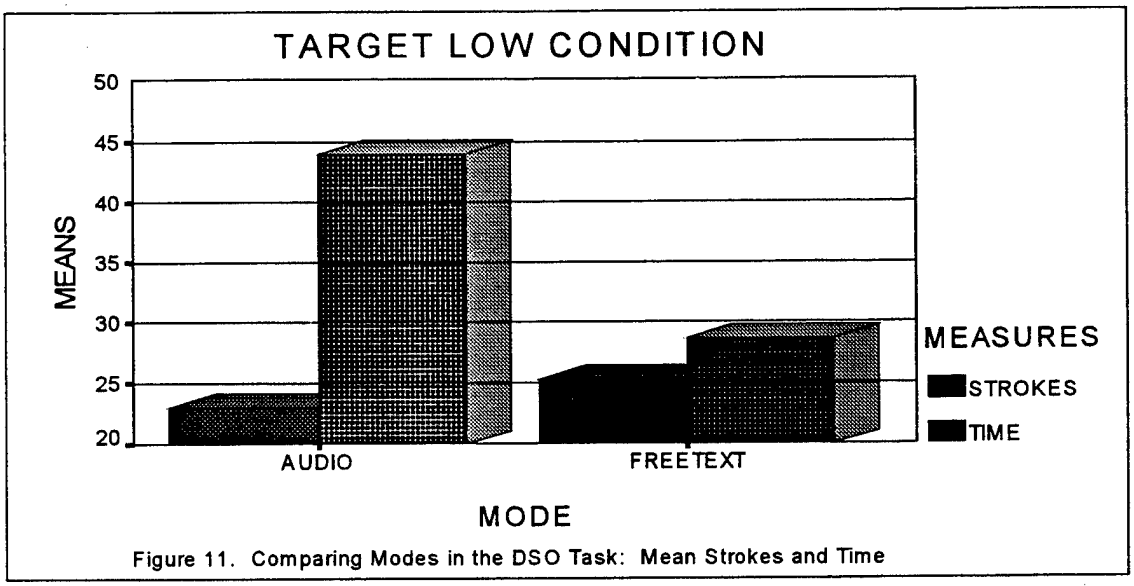

Figure 11. Comparing Modes in the DSO Task: Mean Strokes and Time

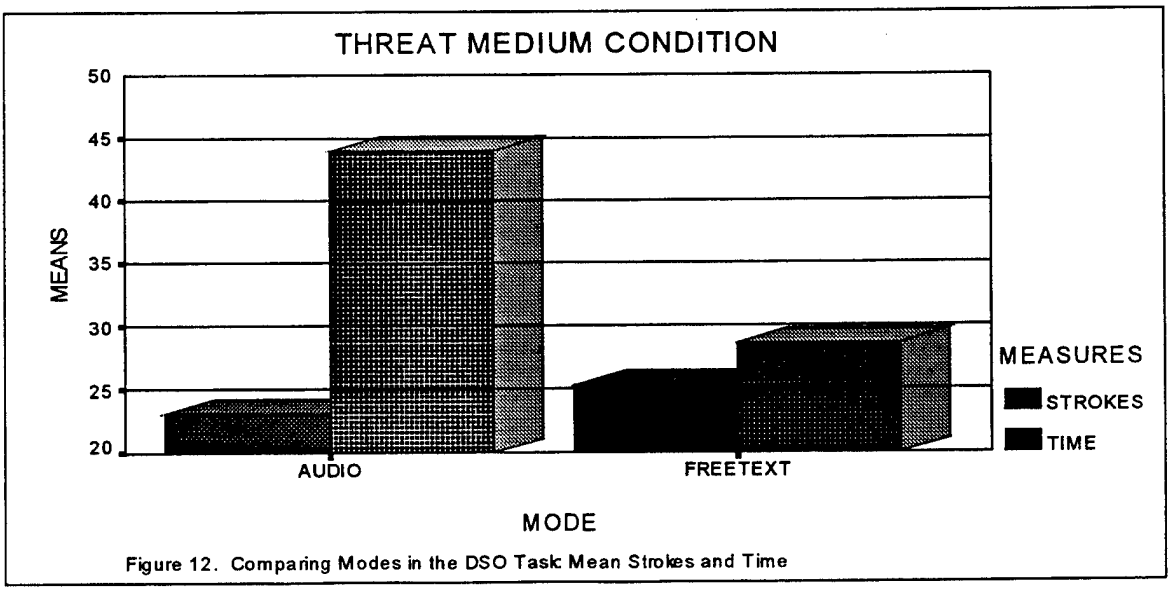

Figure 12. Comparing Modes in the DSO Task: Mean Strokes and Time

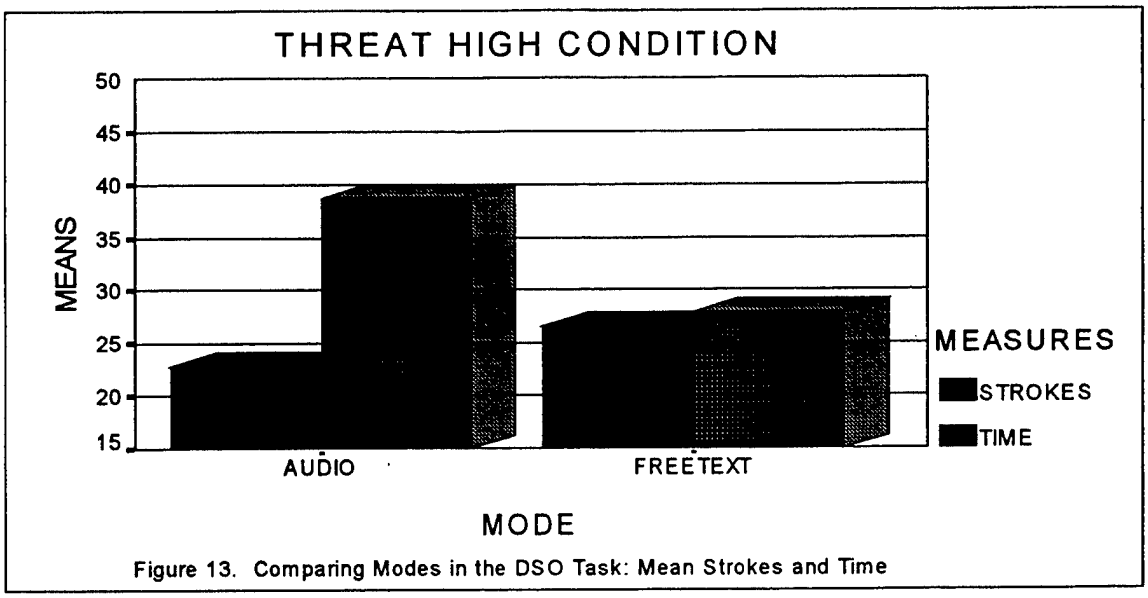

Figure 13. Comparing Modes in the DSO Task: Mean Strokes and Time

Since only two modes were tested in the DSO task, there is only one contrast, freetext minus audio. The eta-squared values for each threat condition and over all threat conditions are presented in Table 15. Note that while under all conditions the strength of the associations between the contrast and time are comparable to those in the OSO task, for strokes they are much higher. This is not, however, reflected in the mean differences in strokes between the two modes as shown in Table 16. Although still positive, the magnitude of the difference is less than in the OSO task, and the differences in time are also less. This is due to the compact nature of the DSO task requiring much less time and strokes to perform and, hence, less variance in the data. As in the OSO task, replications and an experience variable were found not to be significant ($p>0.05$) for main effects or interactions.

TABLE 15. COMPARING THE CONTRAST FREETEXT-AUDIO IN THE DSO TASK: ETA-SQUARED

**p<.01	THREAT CONDITION							
	LOW		MEDIUM		HIGH		OVERALL	
	MEASURE		MEASURE		MEASURE		MEASURE	
	STROKES	TIME	STROKES	TIME	STROKES	TIME	STROKES	TIME
SAMPLE	.7100**	.9570**	.6708**	.8267**	.7240**	.8982**	.8425**	.9441**
POPULATION ESTIMATE	.6795	.9524	.6361	.8085	.6950	.8875	.8265	.9384

TABLE 16. COMPARING THE CONTRAST FREETEXT-AUDIO IN THE DSO TASK: MEAN DIFFERENCES

**p<.01	THREAT CONDITION							
	LOW		MEDIUM		HIGH		OVERALL	
	MEASURE		MEASURE		MEASURE		MEASURE	
	STROKES	TIME	STROKES	TIME	STROKES	TIME	STROKES	TIME
MEAN DIFFERENCE	2.1818**	-15.3411**	3.3207**	-9.3272**	3.7363**	-10.7900**	3.0795**	-11.8190**
LOWER LIMIT 95% C.I.	1.9940	-17.6335	1.6814	-12.3358	2.1110	-13.3497	2.1414	-13.8453
UPPER LIMIT 95% C.I.	3.1643	-13.0486	4.9600	-6.3187	5.3617	-8.2303	4.0176	-9.7926

3.3 Subjective Data

In the post test questionnaire, the WSOs rank ordered the three modes (audio, freetext, integrated) based on their preference, i.e., the mode they liked best, the mode easiest to use, and the mode least likely to make errors. The integrated mode was ranked number one, unanimously, as the preferred method, followed by the freetext mode. The audio mode was ranked third. For the mode least likely to make errors, integrated was ranked first, followed by freetext, and audio was the most likely to make errors. Ten out of 11 WSOs ranked the integrated mode as the easiest to use, followed by the freetext mode, and the audio mode was ranked last. One WSO ranked the integrated mode easiest to use, followed by the audio mode, then the freetext mode.

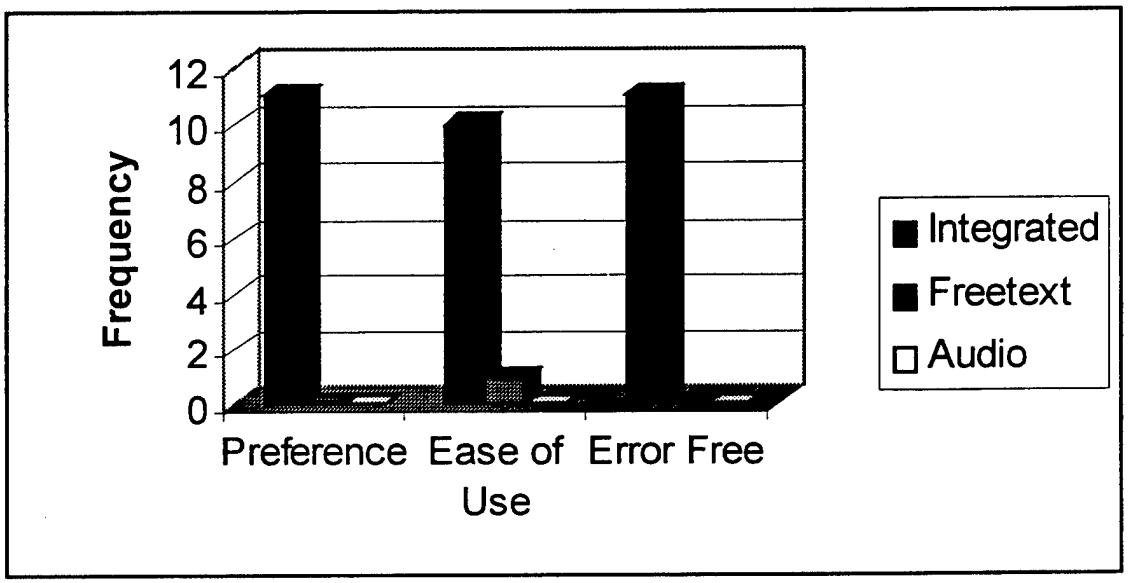

Figure 14. Rank Order Mode for Preference, Ease of Use and Error Free

The WSOs also rank ordered the two modes for the DSO task (audio and freetext). They unanimously ranked the freetext mode as the number one choice in terms of preference, ease of use, and least likely to make errors.

The Link 16 page designed to implement the integrated mode was moderately acceptable. Eight of the 11 WSOs responded to the question "Did they like the Link 16 page" more in a positive direction (4 slightly agreed, 2 moderately agreed and 2 strongly agreed). Three of the WSOs didn't like it. A suggestion to improve the page was to show only the data that was being changed, i.e., targets that were not a part of the FTM were included. Another suggestion was to provide the capability to accept or reject parts of the Link 16 message. There seemed to be some confusion as to what the "Link 16 page" was. Some of the related comments made suggestions for improving the FTM format thus suggesting that some WSOs were confusing the FTM area with the Link 16 page. Suggestions for improving the FTM format included numbering the target coordinates on the left for easier cross-check, and to display the whole message without needing to scroll.

To alert the WSO to the presence of a data link FTM, the words "Link 16" flashed at the bottom of the MFD page. Eight of 11 WSOs said the flashing message was sufficient to get their attention. However, it was suggested that it should be tied into the B-1 master caution system or CITS. Other suggestions were to

use bold or reverse video instead of flashing. One WSO preferred that the flashing be stopped once the FTM was displayed—he found the flashing to be distracting.

The questionnaire highlighted several data link design considerations for future designs:

1) Don't use prime data area to display the FTM
2) Use a separate full screen capability for the FTM
3) Display the FTM in its entirety so scrolling isn't required
4) Integrate the FTM controls into the system.

The WSO's recommendations for integrating Link 16 into the B-1 were:

1) The defensive, offensive and pilot stations all need Link 16 data
2) Replace existing MFDs/EDUs/VSDs with Liquid Crystal Displays (LCD) to provide a textual and graphics capability
3) Provide a beyond-line-of-sight data link capability
4) Replace the integrated keyboard (IKB) with a full alphanumeric keyboard
5) Integrate Link 16 into the B-1 from an Air Force-perspective, rather than as a B-1 only solution.

4. *DISCUSSION*

The primary purpose of this study was to evaluate the difference between the communication modes for WSO part tasks---three modes for the OSO task and two for the DSO task. The major tool used for this evaluation, repeated measures MANOVA transformed the four dependent measures: strokes per target or threat, time per target or threat, error per target or threat, and SWAT into contrasts or difference measures. These contrasts were freetext minus audio and integrated minus the average of the other two combined. For the OSO task, overall statistics for eta-squared and mean difference (derived from evaluating both contrasts) emphatically supported the integrated mode as the best environment in which the WSO can work. Eta-squared, a type of correlation between the difference measure and the original dependent measure(s), showed that the difference between the integrated mode and the average of the other two modes accounted for over 99% of the variance in strokes, more than 96% of the variance in time, 37% in errors, and 58% in SWAT. The corresponding percentages for freetext minus audio were 51% in strokes, 89.5% in time, less than 1 % in errors, and less than 15% in SWAT. By itself, eta-squared did not indicate the direction of the difference. The other statistic, mean difference, based on the univariate parameter estimates for each contrast favored the integrated mode over the other two. The difference between the integrated mode and the other two modes was over 11 times fewer strokes than the difference between freetext and audio. In fact, the freetext mode exhibited more strokes on average than in the audio mode. The time difference was twice as large when considering the integrated contrast versus the freetext/audio contrast. Integrated also showed 12 1/2 times less error (freetext and audio were about even in error overall) and a 4 1/2 times better SWAT rating.

Because of the interaction between mode and target, the focus of the analysis shifted to comparing the modes within each target condition. The strength of the association for the integrated contrast was consistently higher for each target condition when considering time and strokes. On the other hand, the effect of the difference between freetext and audio on strokes was only significant in the medium target condition, being about twice as strong as the low and high conditions. In addition, the effect on errors and on SWAT, although not significant, was several times greater in the high target condition, as opposed to the other two. The integrated contrast exhibited much greater consistency. This suggests an instability in measuring differences between freetext and audio that could be affected by subtle differences in an experimental environment or real world milieu.

The results for the integrated mode are more reliable with perhaps greater generalizability to the WSO population than the freetext/audio modes. Admittedly, some of this could be attributable to an artifact of the present study; i.e., the high target condition necessitated a longer FTM. Since the message area was limited to displaying only four lines simultaneously, the WSOs by necessity had to scroll the message up and down for both data entry and cross-check. This explains the increased number of strokes and would seem to have contributed to the increase in errors. This explanation is also supported in part by the subjective results; i.e., many WSOs stated their preference to see the message in its entirety.

Examining the mean differences demonstrated that the differences between contrasts held up for each target condition, namely, the difference between integrated and the other two modes being much greater than the difference between freetext and audio. However, interestingly, while within each contrast, the differences in SWAT ratings increased as would be expected when going from the low to high difficulty condition; just the opposite occurred for strokes, time and for the most part, errors. In other words, as evidenced by the general descriptive statistics, SWAT ratings became worse, as expected, but the number of strokes, amount of time, and number of errors decreased from the low to high conditions. This cannot be attributable to position effects---each condition appeared in each position an equal number of times and the replications variable was not significant ($p>0.05$). There was less skew; i.e., less extreme scores in the higher conditions, perhaps making the most difficult condition more representative of the greater population. In any event, the results support superior performance in the integrated mode. This performance was reinforced by the subjective data; i.e., the WSOs rank ordered the integrated mode as number one in terms of their preference, for ease of use, and as least likely to make errors.

The DSO results were less definitive. The differences between the contrasts were decidedly less than in the OSO task. This is attributed to the efficiency of the DSO task. All the data entry was accomplished on one page, the DOB page. The most difficult threat condition required more strokes for data entry but the organization of the DOB page makes for a relatively efficient method of data entry. Whether manually entering one set of threat coordinates, or five sets of threat coordinates, the task merely required entering more of like data on the same page. The freetext mode compared to audio mode was significantly lower in time but not for number of strokes. The number of errors and workload were not significantly different between the two modes.

Comparing the two tasks, the OSO task was much more complex and difficult than the DSO task. For example, between the two tasks, in the audio and freetext modes overall, the number of strokes and amount of time is more than doubled. Therefore, designing for the worst case, the biggest payoff will come with implementing the integrated mode for the OSO task; this task being the more onerous of the two. However, since the WSO is expected to function as both the OSO and DSO, equally sharing time between the two tasks, the type of data link interface implementation should be consistent for both the offensive and defensive stations.

5. *CONCLUSIONS/RECOMMENDATIONS*

The OSO data results, both objective and subjective, clearly demonstrate the superiority of the integrated mode as compared to the audio and freetext modes. In all areas, number of strokes, time, number of errors, and workload, the integrated mode was significantly better.

The DSO task results were not as consistent as the OSO results. The freetext mode, compared to audio mode, was significantly lower in time, but not for number of strokes. This effect was attributed to the compactness of the task. The number of errors and workload were not significantly different between the two modes.

The subjective data highlighted several design considerations. For the Link 16 page (automated the OSO retargeting task), suggestions for improving the page design were to show only the data being changed, provide a capability to accept or reject parts of the freetext message, and stop flashing the alert message once the freetext message was acknowledged. Future data link design considerations are: 1) Don't use prime data areas to display FTM, 2) Use a separate full screen capability for the FTM, 3) Display the FTM in its entirety so scrolling isn't necessary, and 4) Integrate the FTM controls into the system.

The WSOs recommendations for integrating Link 16 into the B-1 are:

1) The defensive, offensive and pilot stations all need Link 16 data
2) Replace existing MFDs/EDUs/VSDs with Liquid Crystal Displays (LCD) to provide a textual and graphics capability
3) Provide a beyond-line-of-sight data link capability
4) Replace the integrated keyboard (IKB) with a full alphanumeric keyboard
5) Integrate Link 16 into the B-1 from an Air Force-perspective rather than as a B-1 only solution.

Since the OSO task is clearly more complex and the more difficult of the two tasks, the offensive station is primary in shaping recommendations for a B-1 data link interface design. Designing for the worst case, the biggest payoff will come with implementing the integrated mode for the OSO task. The type of data link implementation should be consistent for both the offensive and defensive stations. Therefore, based on these study results, the integrated mode is recommended as the most beneficial design from a performance and user acceptance perspective.

Future studies should address the design details for an integrated approach. This study evaluated interface issues; it was not a hardware evaluation. The post-test questionnaire clearly stated the WSOs areas of concern with this study's interface design and provided some recommendations for what they would like to see in a future data link hardware design.

6. *BIBLIOGRAPHY*

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APPENDIX A

INTELLIGIBILITY WORD LISTS

SHEET 5B

1. seek
2. din
3. kill
4. beat
5. fed
6. tip
7. pin
8. ban
9. beat
10. gang
11. came
12. day
13. tang
14. wick
15. peace
16. rig
17. foil
18. puff
19. rust
20. safe
21. path
22. sass
23. fin
24. lake
25. paw
26. math
27. nest
28. took
29. case
30. bark
31. tent
32. not
33. sup
34. run
35. hop
36. tear
37. sin
38. bit
39. cut
40. bill
41. cold
42. win
43. heap
44. page
45. peel
46. buck
47. ten
48. sale
49. raze
50. dud

Generated by Air Force Research Laboratory,
Wright-Patterson AFB

APPENDIX A

INTELLIGIBILITY WORD LIST

SHEET 6B

1. kin
2. dip
3. heave
4. beat
5. peach
6. bad
7. lake
8. lark
9. sun
10. seed
11. went
12. cave
13. cud
14. vest
15. hang
16. tin
17. pay
18. dill
19. sit
20. kit
21. pace
22. pale
23. sum
24. beach
25. rate
26. pen
27. teak
28. wed
29. tan
30. told
31. shop
32. sane
33. not
34. sass
35. pack
36. pub
37. keel
38. mat
39. dun
40. will
41. bug
42. book
43. came
44. fib
45. sick
46. just
47. pig
48. pip
49. raw
50. boil

APPENDIX B

Target Data

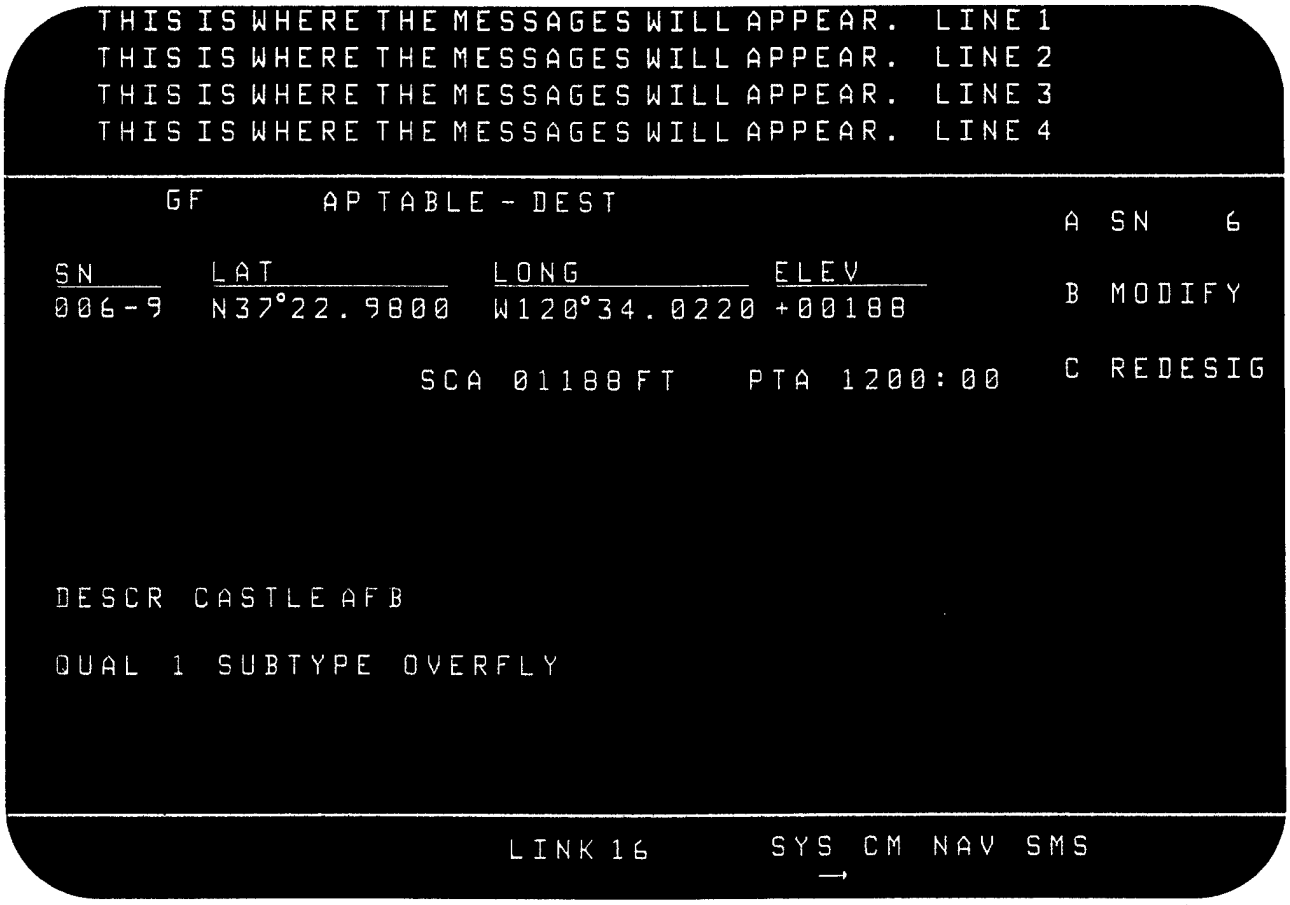
MISSION	MSN REF. #	TARGET GROUP	DIFFICULTY LEVEL
A	#15	30.9	1 – 1 TARGET 2 – 3 TARGETS 3 – 5 TARGETS
B	#14	20.9	1 – 1 TARGET 2 – 3 TARGETS 3 – 5 TARGETS
C	#32	60.9	1 – 1 TARGET 2 – 3 TARGETS 3 – 5 TARGETS
D	#12	30.9	1 – 1 TARGET 2 – 3 TARGETS 3 – 5 TARGETS

Threat Data

MISSION	MISSION #	THREAT GROUP	DIFFICULTY LEVEL
A	M15.APT	SA-7 SA-3 & SA-10 SA-9 & SA-10	1 – 1 THREAT 2 – 3 THREATS 3 – 5 THREATS
B	M14.APT	SA-10 SA-3, SA-9 & SA-10 SA-3 & SA-7	1 – 1 THREAT 2 – 3 THREATS 3 – 5 THREATS
C	M32.APT	SA-7 SA-3 & SA-10 SA-3, SA-7, SA-9 & SA-10	1 – 1 THREAT 2 – 3 THREATS 3 – 5 THREATS
D	M12.APT	SA-3 SA7, SA-9 SA-3, SA7, SA-9 & SA-10	1 – 1 THREAT 2 – 3 THREATS 3 – 5 THREATS

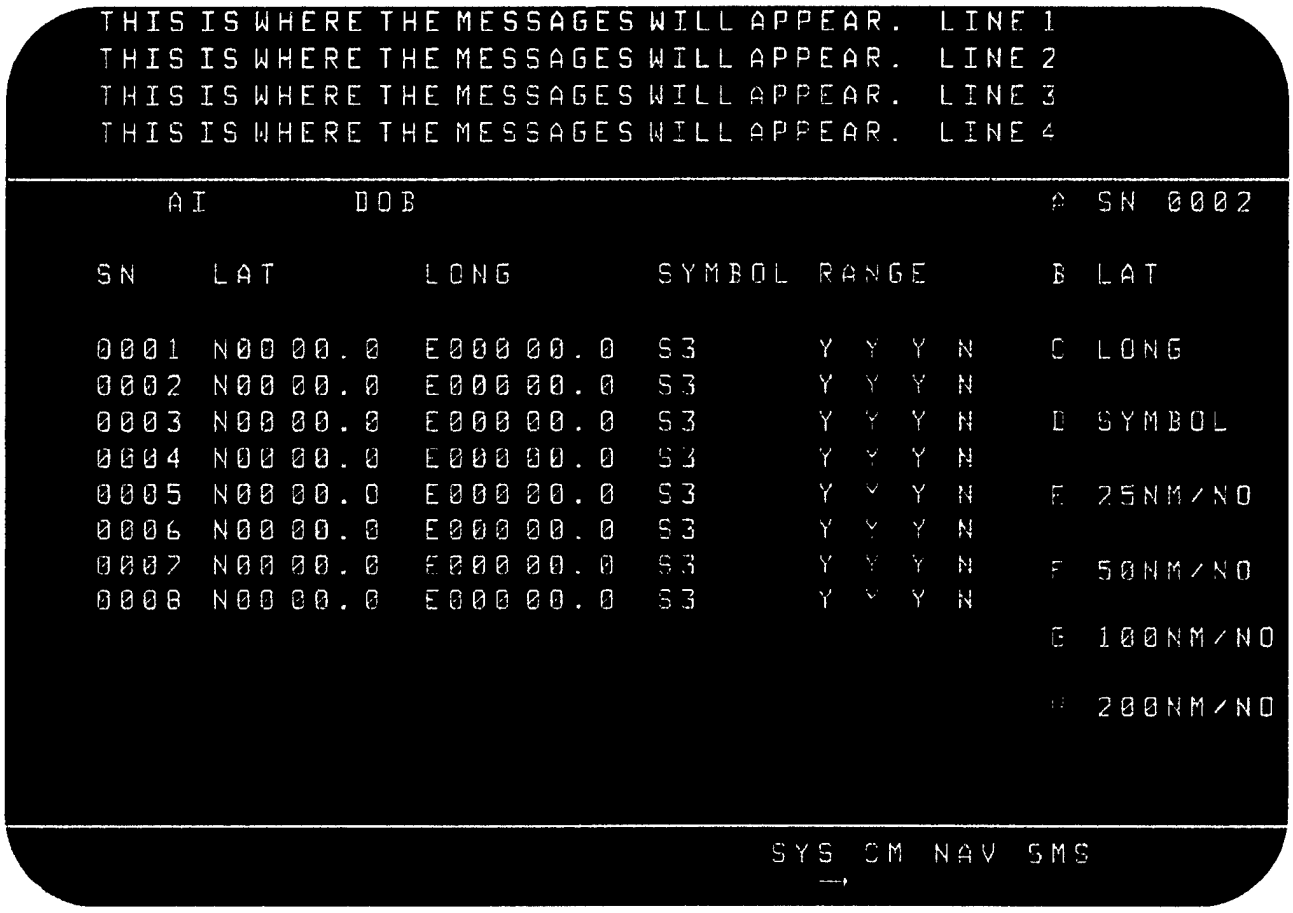
APPENDIX C

Link 16 Page



APPENDIX D

Defensive Order of Battle Page



APPENDIX E

Randomized Order of Presentation

OSO TASK						
SUBJECT #	MODE OF PRESENTATION					
1	V	F	I	V	F	I
2	F	I	V	F	I	V
3	I	V	F	I	V	F
4	I	F	V	I	V	F
5	F	V	I	F	V	I
6	V	I	F	V	I	F
7	V	I	F	V	I	F
8	I	F	V	I	F	V
9	F	V	I	F	V	I
10	F	I	V	F	I	V
11	I	V	F	I	V	F
12	V	F	I	V	F	I

Note: Subject #12 did not appear as scheduled—this order was not tested

DSO TASK				
SUBJECT #	MODE OF PRESENTATION			
1	V	V	F	F
2	F	V	V	F
3	V	F	V	F
4	F	F	V	V
5	V	F	F	V
6	F	V	F	V
7	F	F	V	V
8	V	F	F	V
9	F	V	F	V
10	V	V	F	F
11	F	V	V	F
12	V	F	V	F

V – AUDIO (VOICE)
F – FREETEXT MESSAGE
I – INTEGRATED

Note: Odd subject numbers did OSO task first; even subject numbers did DSO task first. Subject #12 did not appear when scheduled—this order was not tested

APPENDIX F

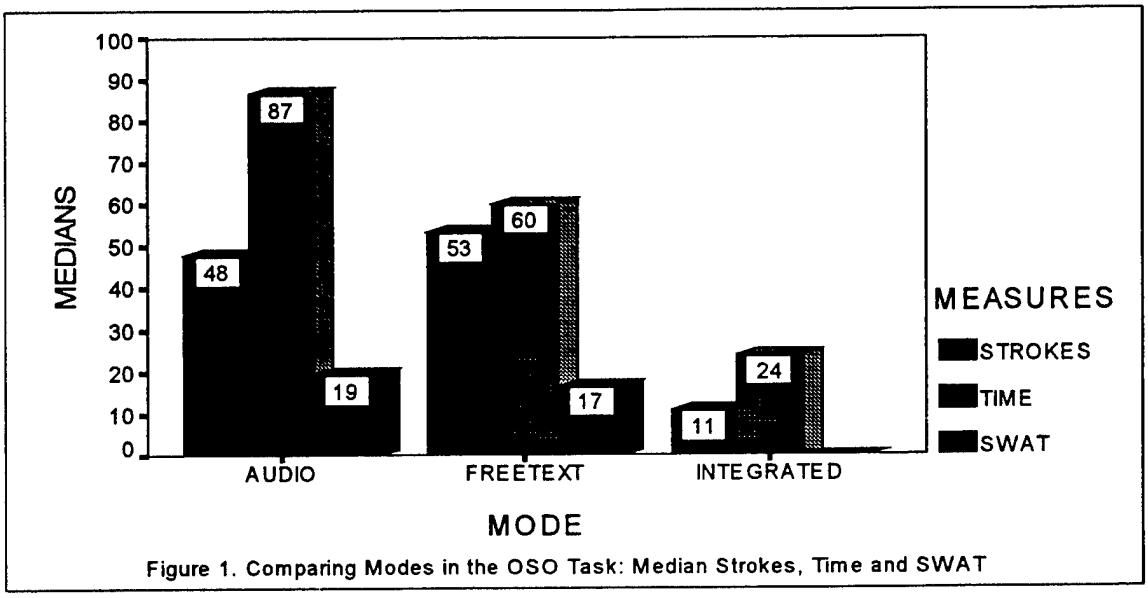


Figure 1. Comparing Modes in the OSO Task: Median Strokes, Time and SWAT

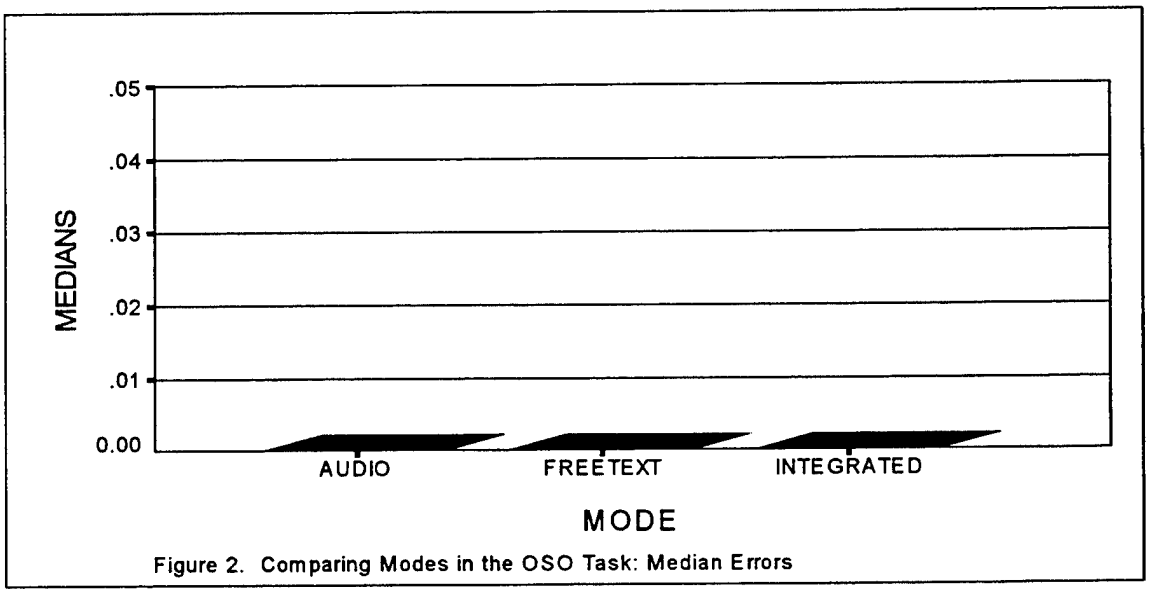


Figure 2. Comparing Modes in the OSO Task: Median Errors

APPENDIX F

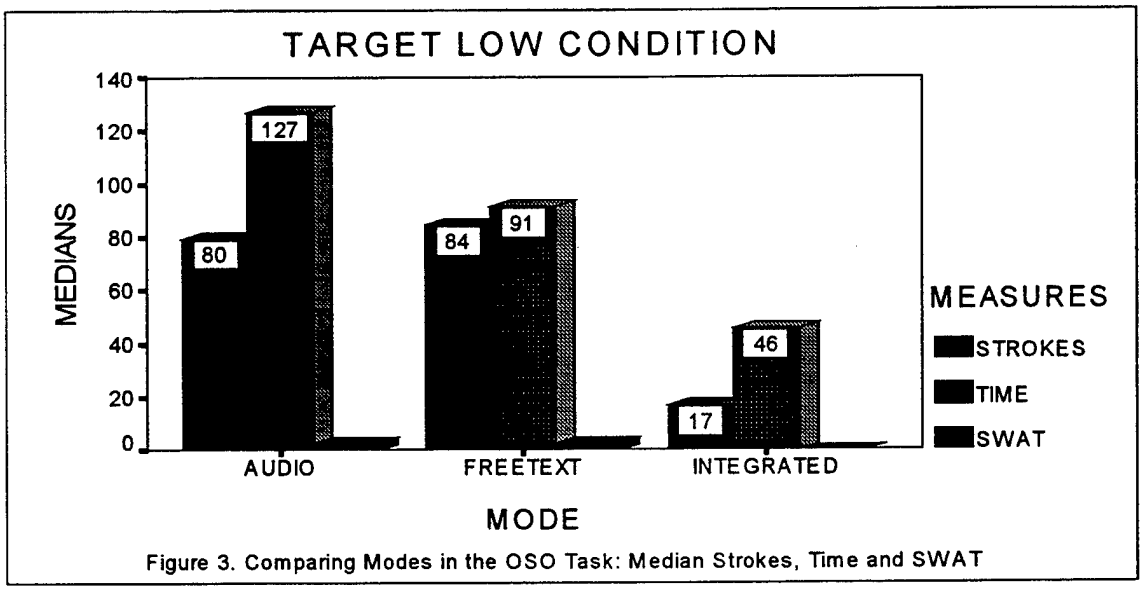


Figure 3. Comparing Modes in the OSO Task: Median Strokes, Time and SWAT

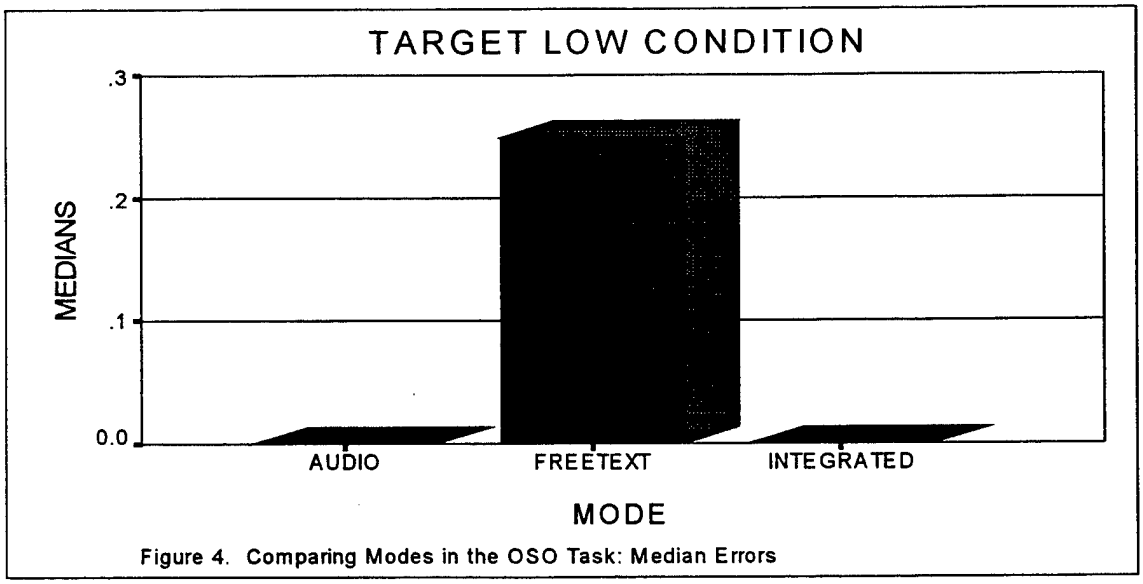


Figure 4. Comparing Modes in the OSO Task: Median Errors

APPENDIX F

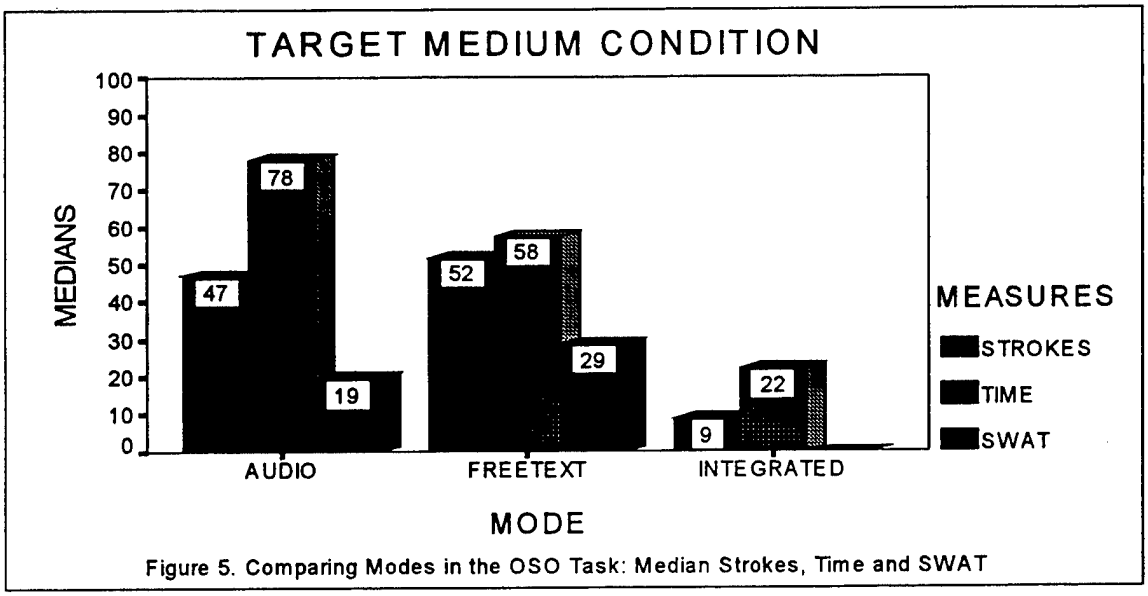


Figure 5. Comparing Modes in the OSO Task: Median Strokes, Time and SWAT

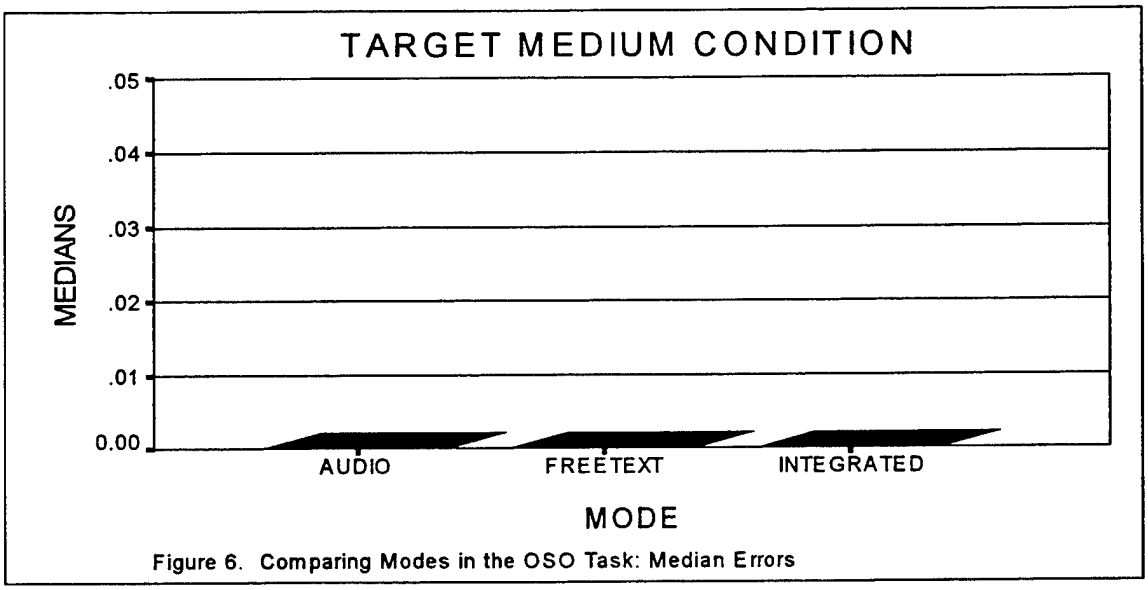


Figure 6. Comparing Modes in the OSO Task: Median Errors

APPENIX F

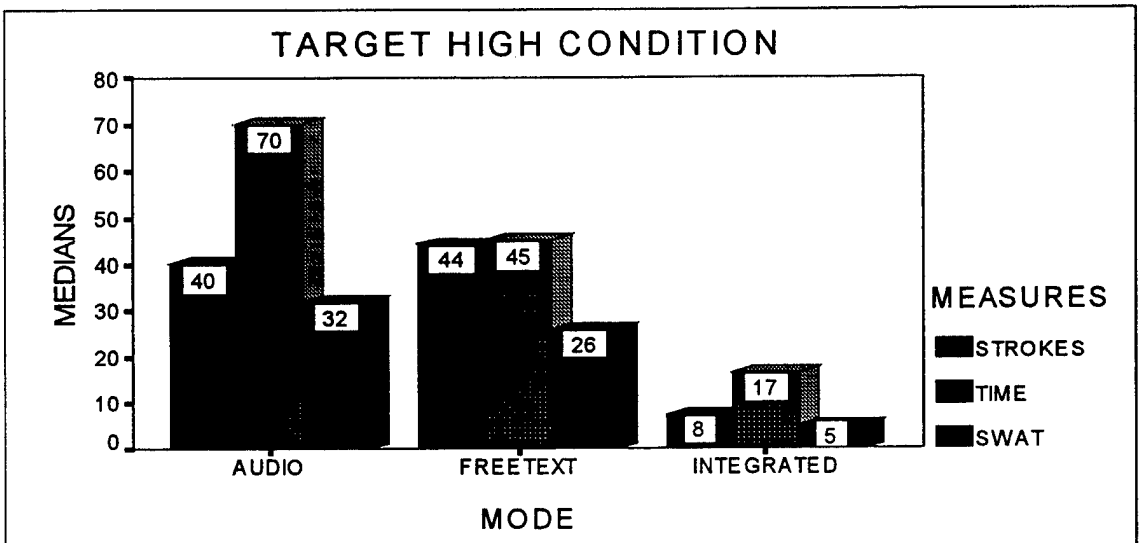


Figure 7. Comparing Modes in the OSO Task: Median Strokes, Time and SWAT

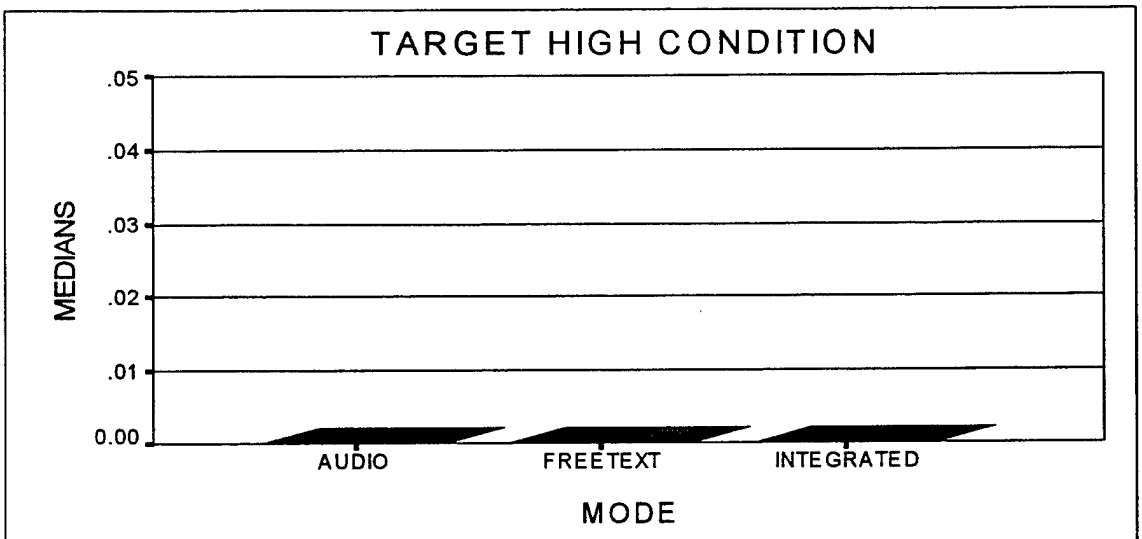


Figure 8. Comparing Modes in the OSO Task: Median Errors

APPENDIX F

TABLE 1. OVERALL INDICES OF CENTRAL TENDENCY AND DISPERSION
OSO TASK

	MODE		
	AUDIO	FREETEXT	INTEGRATED
STROKES			
Mean	57.817	61.884	13.269
Std Deviation	18.727	18.446	7.302
Median	47.750	53.250	10.950
Percentile 25	43.450	47.950	7.550
Percentile 75	77.000	83.250	15.750
Mode	37.700	53.250	7.500
Range	61.300	56.950	24.500
Minimum	37.700	41.300	6.000
Maximum	99.000	98.250	30.500
TIME			
Mean	96.921	69.379	28.889
Std Deviation	32.793	26.848	14.128
Median	86.879	60.101	24.084
Percentile 25	70.346	48.117	17.991
Percentile 75	122.508	82.998	41.545
Mode	56.404	37.459	12.478
Range	116.941	104.666	44.867
Minimum	56.404	37.459	12.478
Maximum	173.345	142.125	57.345
ERRORS			
Mean	.193	.209	.000
Std Deviation	.347	.388	.000
Median	.000	.000	.000
Percentile 25	.000	.000	.000
Percentile 75	.250	.250	.000
Mode	.000	.000	.000
Range	1.250	1.500	.000
Minimum	.000	.000	.000
Maximum	1.250	1.500	.000
SWAT			
Mean	26.357	22.195	5.542
Std Deviation	23.853	18.517	7.370
Median	19.400	16.700	.000
Percentile 25	7.700	5.400	.000
Percentile 75	46.800	37.800	11.550
Mode	.000	.000	.000
Range	74.775	58.050	20.950
Minimum	.000	.000	.000
Maximum	74.775	58.050	20.950

APPENDIX F

TABLE 2. OVERALL CORRELATION COEFFICIENTS
OSO TASK

	TIME	ERRORS	SWAT
STROKES	.8932	.5168	.1787
	(99)	(99)	(99)
	P= .000	P= .000	P= .077
TIME		.5024	.1140
		(99)	(99)
		P= .000	P= .261
ERRORS			.1179
			(99)
			P= .245

APPENDIX F

TABLE 3. OVERALL REPEATED MEASURES MANOVA
DEPENDENT MEASURES: STROKES, TIME AND ERROR
OSO TASK

Tests involving 'MODE' Within-Subject Effect.

EFFECT .. MODE
Multivariate Tests of Significance (S = 1, M = 2 , N = 1 1/2)

Test Name	Value	Exact F	Hypoth. DF	Error DF	Sig. of F
Pillais	.99790	395.22973	6.00	5.00	.000
Hotellings	474.27568	395.22973	6.00	5.00	.000
Wilks	.00210	395.22973	6.00	5.00	.000
Roys	.99790				

Note.. F statistics are exact.

Tests involving 'TARGET' Within-Subject Effect.

EFFECT .. TARGET
Multivariate Tests of Significance (S = 1, M = 2 , N = 1 1/2)

Test Name	Value	Exact F	Hypoth. DF	Error DF	Sig. of F
Pillais	.99599	206.96160	6.00	5.00	.000
Hotellings	248.35392	206.96160	6.00	5.00	.000
Wilks	.00401	206.96160	6.00	5.00	.000
Roys	.99599				

Note.. F statistics are exact.

Tests involving 'MODE BY TARGET' Within-Subject Effect.

EFFECT .. MODE BY TARGET
AVERAGED Multivariate Tests of Significance (S = 3, M = 0, N = 18)

Test Name	Value	Approx. F	Hypoth. DF	Error DF	Sig. of F
Pillais	1.40084	8.75985	12.00	120.00	.000
Hotellings	9.49238	29.00449	12.00	110.00	.000
Wilks	.05314	17.07553	12.00	100.83	.000
Roys	.89525				

APPENDIX F

TABLE 4. OVERALL REPEATED MEASURES MANOVA
DEPENDENT MEASURE: SWAT
OSO TASK

EFFECT .. MODE
Multivariate Tests of Significance (S = 1, M = 0, N = 3 1/2)

Test Name	Value	Exact F	Hypoth. DF	Error DF	Sig. of F
Pillais	.61151	7.08339	2.00	9.00	.014
Hotellings	1.57409	7.08339	2.00	9.00	.014
Wilks	.38849	7.08339	2.00	9.00	.014
Roys	.61151				

Note.. F statistics are exact.

EFFECT .. TARGET
Multivariate Tests of Significance (S = 1, M = 0, N = 3 1/2)

Test Name	Value	Exact F	Hypoth. DF	Error DF	Sig. of F
Pillais	.77213	15.24839	2.00	9.00	.001
Hotellings	3.38853	15.24839	2.00	9.00	.001
Wilks	.22787	15.24839	2.00	9.00	.001
Roys	.77213				

Note.. F statistics are exact.

EFFECT .. MODE BY TARGET
Multivariate Tests of Significance (S = 1, M = 1 , N = 2 1/2)

Test Name	Value	Exact F	Hypoth. DF	Error DF	Sig. of F
Pillais	.73962	4.97087	4.00	7.00	.032
Hotellings	2.84049	4.97087	4.00	7.00	.032
Wilks	.26038	4.97087	4.00	7.00	.032
Roys	.73962				

Note.. F statistics are exact.

APPENDIX F

TABLE 5. INDICES OF CENTRAL TENDENCY AND DISPERSION
FOR EACH TARGET CONDITION
OSO TASK

	TARGET							
	LOW				MEDIUM			
	MODE			Total	MODE			Total
	AUDIO	FREETEXT	INTEGRATED		AUDIO	FREETEXT	INTEGRATED	
STROKES								
Mean	81.909	86.432	20.727	63.023	48.795	53.470	10.765	37.677
Std Deviation	8.405	5.046	6.843	31.154	5.854	4.613	4.976	20.057
Median	79.500	84.250	17.000	79.250	46.917	51.833	8.833	46.917
Percentile 25	77.000	83.250	15.000	27.750	45.250	50.750	7.500	11.667
Percentile 75	81.500	89.250	27.750	84.000	53.167	56.333	11.667	51.833
Mode	74.500	83.250	13.250	13.250	46.917	53.250	7.500	7.500
Range	24.500	19.000	17.250	85.750	19.000	13.750	17.417	56.000
Minimum	74.500	79.250	13.250	13.250	42.750	48.250	6.000	6.000
Maximum	99.000	98.250	30.500	99.000	61.750	62.000	23.417	62.000
TIME								
Mean	136.526	99.932	44.749	93.736	83.010	58.844	24.536	55.463
Std Deviation	19.007	21.062	9.003	41.765	15.338	12.810	10.103	27.391
Median	127.060	91.140	45.620	91.140	78.074	57.604	21.877	57.604
Percentile 25	122.508	82.945	39.875	52.703	68.837	48.366	17.991	25.293
Percentile 75	154.230	118.818	52.703	126.503	92.998	62.754	25.293	76.619
Mode	112.378	77.460	28.838	28.838	63.398	44.280	16.457	16.457
Range	60.968	64.665	28.508	144.508	46.839	47.837	35.403	93.781
Minimum	112.378	77.460	28.838	28.838	63.398	44.280	16.457	16.457
Maximum	173.345	142.125	57.345	173.345	110.238	92.117	51.859	110.238
ERRORS								
Mean	.364	.409	.000	.258	.083	.159	.000	.081
Std Deviation	.517	.539	.000	.457	.149	.322	.000	.209
Median	.000	.250	.000	.000	.000	.000	.000	.000
Percentile 25	.000	.000	.000	.000	.000	.000	.000	.000
Percentile 75	1.000	.750	.000	.250	.083	.250	.000	.000
Mode	.000	.000	.000	.000	.000	.000	.000	.000
Range	1.250	1.500	.000	1.500	.417	1.000	.000	1.000
Minimum	.000	.000	.000	.000	.000	.000	.000	.000
Maximum	1.250	1.500	.000	1.500	.417	1.000	.000	1.000
SWAT								
Mean	13.339	11.457	2.982	9.259	27.573	23.189	5.727	18.830
Std Deviation	19.352	15.558	5.104	14.891	22.572	15.334	8.391	18.615
Median	2.700	2.700	.000	.000	19.400	28.650	.000	11.550
Percentile 25	.000	.000	.000	.000	9.250	9.250	.000	2.700
Percentile 75	20.600	16.700	6.550	14.650	46.800	36.225	14.400	33.425
Mode	.000	.000	.000	.000	46.800	11.550	.000	.000
Range	52.725	41.650	15.700	52.725	64.575	44.100	20.950	64.575
Minimum	.000	.000	.000	.000	.000	2.700	.000	.000
Maximum	52.725	41.650	15.700	52.725	64.575	46.800	20.950	64.575

APPENDIX F

TABLE 5 (CONTINUED)

TARGET

HIGH

	MODE			Total
	AUDIO	FREETEXT	INTEGRATED	
STROKES				
Mean	42.745	45.750	8.314	32.270
Std Deviation	6.285	3.870	1.987	17.769
Median	40.300	44.450	7.550	40.300
Percentile 25	38.500	42.800	6.800	8.800
Percentile 75	44.300	47.950	8.800	44.450
Mode	37.700	41.300	8.800	8.800
Range	20.700	13.100	6.200	51.750
Minimum	37.700	41.300	6.650	6.650
Maximum	58.400	54.400	12.850	58.400
TIME				
Mean	71.228	49.360	17.381	45.990
Std Deviation	13.429	10.450	3.523	24.465
Median	70.346	45.195	16.578	45.195
Percentile 25	60.666	42.725	14.677	19.040
Percentile 75	77.064	54.159	19.040	61.213
Mode	56.404	37.459	12.478	12.478
Range	44.287	36.097	11.606	88.212
Minimum	56.404	37.459	12.478	12.478
Maximum	100.690	73.556	24.084	100.690
ERRORS				
Mean	.132	.059	.000	.064
Std Deviation	.218	.122	.000	.150
Median	.000	.000	.000	.000
Percentile 25	.000	.000	.000	.000
Percentile 75	.250	.050	.000	.000
Mode	.000	.000	.000	.000
Range	.700	.350	.000	.700
Minimum	.000	.000	.000	.000
Maximum	.700	.350	.000	.700
SWAT				
Mean	38.159	31.939	7.918	26.005
Std Deviation	24.400	19.688	7.995	22.416
Median	32.125	26.200	5.150	19.550
Percentile 25	15.800	10.800	.000	8.100
Percentile 75	68.225	50.475	15.400	47.575
Mode	7.700	3.850	.000	.000
Range	67.075	54.200	19.550	74.775
Minimum	7.700	3.850	.000	.000
Maximum	74.775	58.050	19.550	74.775

APPENDIX G

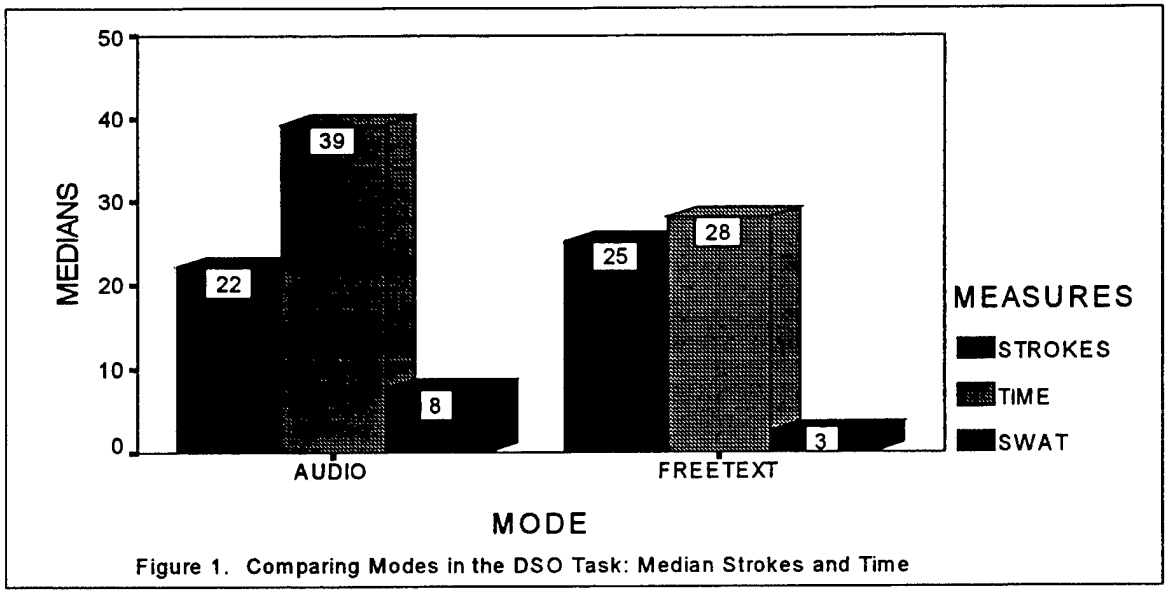


Figure 1. Comparing Modes in the DSO Task: Median Strokes and Time

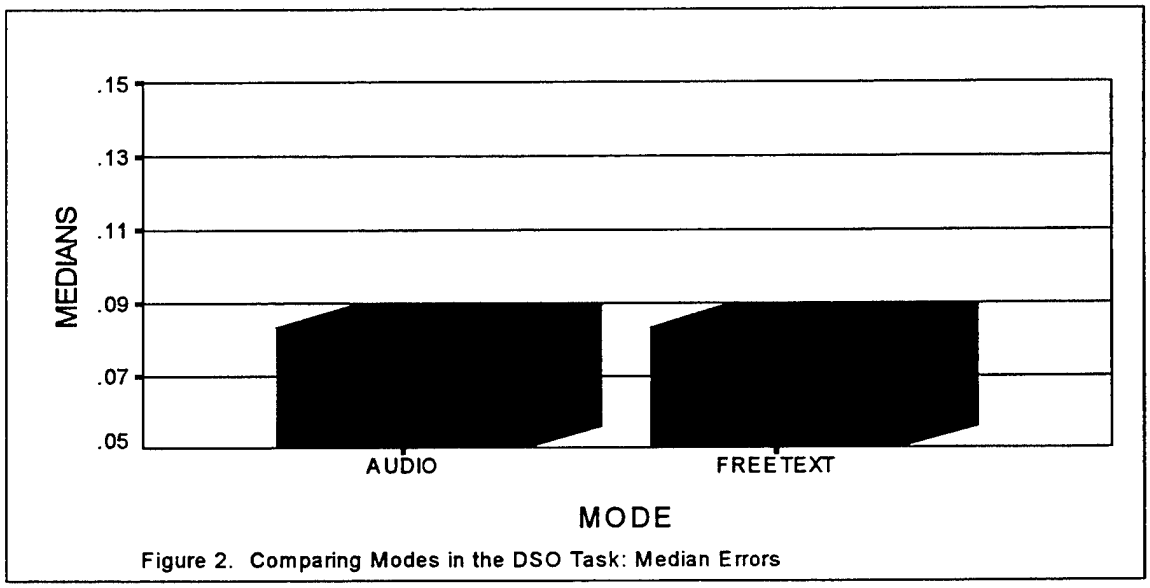


Figure 2. Comparing Modes in the DSO Task: Median Errors

APPENDIX G

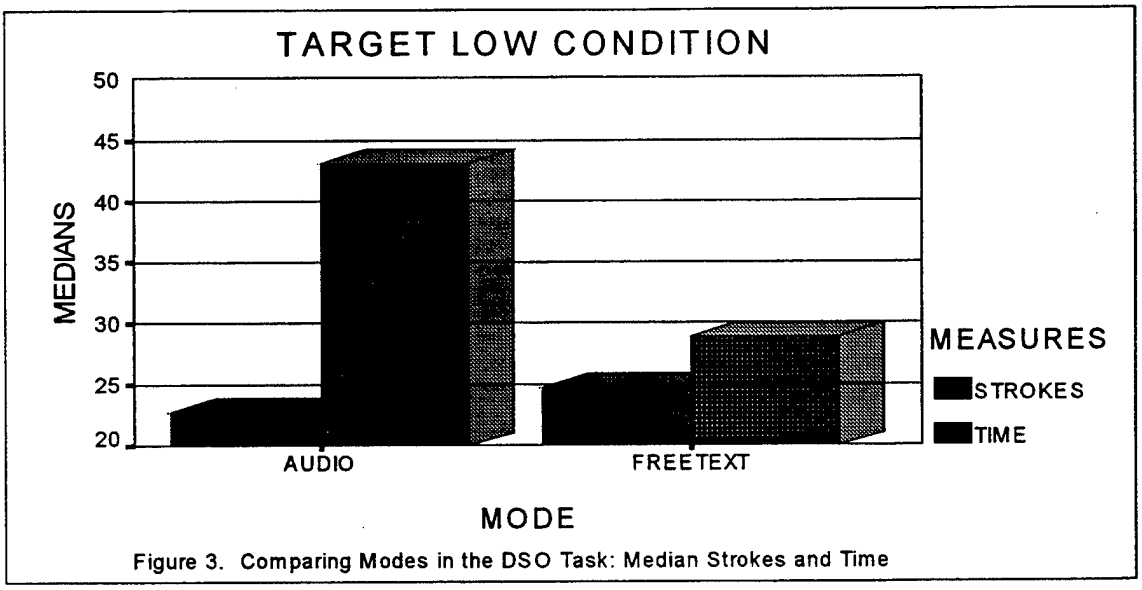


Figure 3. Comparing Modes in the DSO Task: Median Strokes and Time

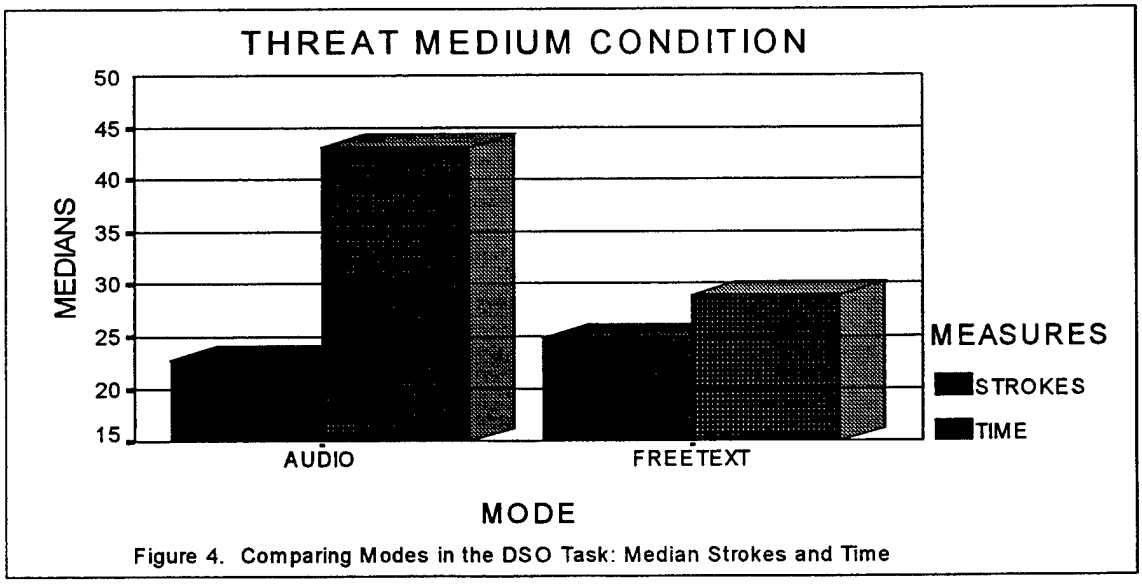


Figure 4. Comparing Modes in the DSO Task: Median Strokes and Time

APPENDIX G

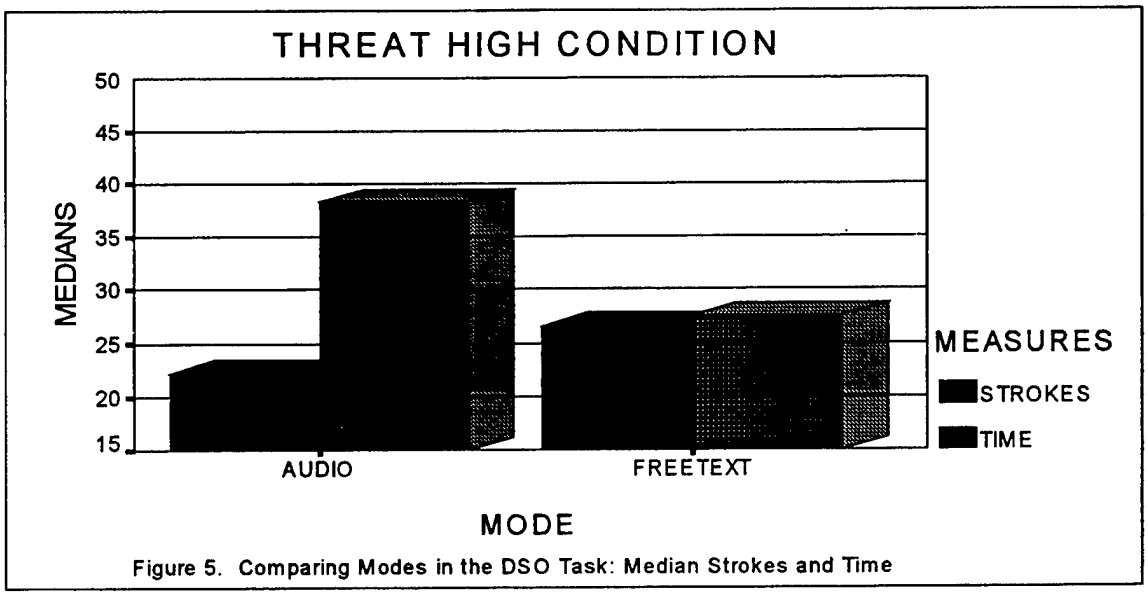


Figure 5. Comparing Modes in the DSO Task: Median Strokes and Time

APPENDIX G

TABLE 1. OVERALL INDICES OF CENTRAL TENDENCY AND DISPERSION
DSO TASK

	MODE	
	AUDIO	FREETEXT
STROKES		
Mean	22.68	25.76
Std Deviation	1.94	2.58
Median	22.20	25.25
Percentile 25	21.25	23.58
Percentile 75	23.67	26.55
Mode	21.00	23.50
Range	8.50	10.20
Minimum	20.50	21.80
Maximum	29.00	32.00
ERRORS		
Mean	.14	.12
Std Deviation	.21	.17
Median	.08	.08
Percentile 25	.00	.00
Percentile 75	.25	.20
Mode	.00	.00
Range	.95	.83
Minimum	.00	.00
Maximum	.95	.83
TIME		
Mean	39.83	28.01
Std Deviation	6.03	6.03
Median	39.40	28.10
Percentile 25	36.35	24.29
Percentile 75	43.19	31.33
Mode	27.92	17.73
Range	26.97	20.87
Minimum	27.92	17.73
Maximum	54.89	38.60
SWAT		
Mean	17.33	10.69
Std Deviation	20.90	14.80
Median	7.70	2.70
Percentile 25	.00	.00
Percentile 75	30.78	19.65
Mode	.00	.00
Range	65.80	54.55
Minimum	.00	.00
Maximum	65.80	54.55

APPENDIX G

TABLE 2. OVERALL CORRELATION COEFFICIENTS
DSO TASK

	TIME	ERRORS	SWAT
STROKES	-.1140	.2384	-.1285
	(66)	(66)	(66)
	P= .362	P= .054	P= .304
TIME		.1379	-.1182
		(66)	(66)
		P= .270	P= .344
ERRORS			-.1075
			(66)
			P= .390

APPENDIX G

TABLE 3. OVERALL REPEATED MEASURES MANOVA
DEPENDENT MEASURE: STROKES
DSO TASK

Tests involving 'MODE' Within-Subject Effect.

[mode has only two levels--same as averaged univariate test]

Source of Variation	SS	DF	MS	F	Sig of F
WITHIN+RESIDUAL	29.25	10	2.93		
MODE	156.49	1	156.49	53.50	.000

EFFECT .. THREAT
Multivariate Tests of Significance (S = 1, M = 0, N = 3 1/2)

Test Name	Value	Exact F	Hypoth. DF	Error DF	Sig. of F
Pillais	.19077	1.06083	2.00	9.00	.386
Hotellings	.23574	1.06083	2.00	9.00	.386
Wilks	.80923	1.06083	2.00	9.00	.386
Roys	.19077				

Note.. F statistics are exact.

EFFECT .. MODE BY THREAT
Multivariate Tests of Significance (S = 1, M = 0, N = 3 1/2)

Test Name	Value	Exact F	Hypoth. DF	Error DF	Sig. of F
Pillais	.38438	2.80972	2.00	9.00	.113
Hotellings	.62438	2.80972	2.00	9.00	.113
Wilks	.61562	2.80972	2.00	9.00	.113
Roys	.38438				

Note.. F statistics are exact.

APPENDIX G

TABLE 4. OVERALL REPEATED MEASURES MANOVA
DEPENDENT MEASURE: TIME
DSO TASK

Tests involving 'MODE' Within-Subject Effect.

[mode has only two levels--same as averaged univariate test]

Source of Variation	SS	DF	MS	F	Sig of F
WITHIN+RESIDUAL	136.48	10	13.65		
MODE	2305.05	1	2305.05	168.90	.000

EFFECT .. THREAT
Multivariate Tests of Significance (S = 1, M = 0, N = 3 1/2)

Test Name	Value	Exact F	Hypoth. DF	Error DF	Sig. of F
Pillais	.64851	8.30270	2.00	9.00	.009
Hotellings	1.84504	8.30270	2.00	9.00	.009
Wilks	.35149	8.30270	2.00	9.00	.009
Roys	.64851				

Note.. F statistics are exact.

EFFECT .. MODE BY THREAT
Multivariate Tests of Significance (S = 1, M = 0, N = 3 1/2)

Test Name	Value	Exact F	Hypoth. DF	Error DF	Sig. of F
Pillais	.59609	6.64097	2.00	9.00	.017
Hotellings	1.47577	6.64097	2.00	9.00	.017
Wilks	.40391	6.64097	2.00	9.00	.017
Roys	.59609				

Note.. F statistics are exact.

APPENDIX G.

TABLE 5. OVERALL REPEATED MEASURES MANOVA
DEPENDENT MEASURE: ERRORS
DSO TASK

Tests involving 'MODE' Within-Subject Effect.

[mode has only two levels--same as averaged univariate test]

Source of Variation	SS	DF	MS	F	Sig of F
WITHIN+RESIDUAL	.10	10	.01		
MODE	.01	1	.01	.85	.378

EFFECT .. THREAT
Multivariate Tests of Significance (S = 1, M = 0, N = 3 1/2)

Test Name	Value	Exact F	Hypoth. DF	Error DF	Sig. of F
Pillais	.29740	1.90474	2.00	9.00	.204
Hotellings	.42328	1.90474	2.00	9.00	.204
Wilks	.70260	1.90474	2.00	9.00	.204
Roys	.29740				

Note.. F statistics are exact.

EFFECT .. MODE BY THREAT
Multivariate Tests of Significance (S = 1, M = 0, N = 3 1/2)

Test Name	Value	Exact F	Hypoth. DF	Error DF	Sig. of F
Pillais	.28815	1.82157	2.00	9.00	.217
Hotellings	.40479	1.82157	2.00	9.00	.217
Wilks	.71185	1.82157	2.00	9.00	.217
Roys	.28815				

Note.. F statistics are exact.

APPENDIX G

TABLE 6. OVERALL REPEATED MEASURES MANOVA
DEPENDENT MEASURE: SWAT
DSO TASK

Tests involving 'MODE' Within-Subject Effect.

[mode has only two levels--same as averaged univariate test]

Source of Variation	SS	DF	MS	F	Sig of F
WITHIN+RESIDUAL	2164.61	10	216.46		
MODE	726.74	1	726.74	3.36	.097

EFFECT .. THREAT
Multivariate Tests of Significance (S = 1, M = 0, N = 3 1/2)

Test Name	Value	Exact F	Hypoth. DF	Error DF	Sig. of F
Pillais	.69131	10.07752	2.00	9.00	.005
Hotellings	2.23945	10.07752	2.00	9.00	.005
Wilks	.30869	10.07752	2.00	9.00	.005
Roys	.69131				

Note.. F statistics are exact.

EFFECT .. MODE BY THREAT
Multivariate Tests of Significance (S = 1, M = 0, N = 3 1/2)

Test Name	Value	Exact F	Hypoth. DF	Error DF	Sig. of F
Pillais	.22734	1.32406	2.00	9.00	.313
Hotellings	.29423	1.32406	2.00	9.00	.313
Wilks	.77266	1.32406	2.00	9.00	.313
Roys	.22734				

Note.. F statistics are exact.

APPENDIX G

TABLE 7. INDICES OF CENTRAL TENDENCY AND DISPERSION
FOR EACH THREAT CONDITION
DSO TASK

	THREAT							
	LOW			MEDIUM			HIGH	
	MODE		Total	MODE		Total	MODE	
	AUDIO	FREETEXT		AUDIO	FREETEXT		AUDIO	FREETEXT
STROKES								
Mean	23.09	25.27	24.18	22.15	25.47	23.81	22.79	26.53
Std Deviation	2.30	2.44	2.57	1.51	2.81	2.78	1.99	2.54
Median	22.75	24.75	23.63	21.83	24.11	23.29	22.20	26.55
Percentile 25	21.50	23.50	22.75	21.00	23.42	21.83	21.05	24.85
Percentile 75	24.00	25.50	25.25	23.17	26.33	25.50	24.65	28.75
Mode	21.00	23.50	23.50	20.50	22.83	22.83	20.55	26.55
Range	8.00	8.50	11.00	5.00	8.25	10.58	5.35	8.05
Minimum	21.00	23.50	21.00	20.50	22.83	20.50	20.55	21.80
Maximum	29.00	32.00	32.00	25.50	31.08	31.08	25.90	29.85
TIME								
Mean	44.01	28.67	36.34	36.78	27.46	32.12	38.70	27.91
Std Deviation	6.30	5.33	9.70	4.27	6.37	7.13	5.26	6.81
Median	43.10	28.92	36.32	37.40	27.95	33.27	38.24	27.49
Percentile 25	39.68	24.81	28.92	33.03	21.92	27.95	36.35	23.72
Percentile 75	49.82	30.65	43.10	39.62	33.52	37.40	43.19	34.05
Mode	35.50	19.02	19.02	28.42	18.01	18.01	27.92	17.73
Range	19.39	19.42	35.87	15.26	18.51	25.67	18.90	20.87
Minimum	35.50	19.02	19.02	28.42	18.01	18.01	27.92	17.73
Maximum	54.89	38.44	54.89	43.68	36.52	43.68	46.82	38.60
ERRORS								
Mean	.07	.07	.07	.11	.19	.15	.26	.11
Std Deviation	.16	.12	.14	.12	.25	.20	.27	.09
Median	.00	.00	.00	.08	.08	.08	.20	.15
Percentile 25	.00	.00	.00	.00	.00	.00	.10	.00
Percentile 75	.00	.25	.00	.25	.33	.25	.40	.20
Mode	.00	.00	.00	.00	.08	.08	.00	.00
Range	.50	.25	.50	.33	.83	.83	.95	.25
Minimum	.00	.00	.00	.00	.00	.00	.00	.00
Maximum	.50	.25	.50	.33	.83	.83	.95	.25
SWAT								
Mean	5.59	.49	3.04	16.69	11.74	14.21	29.71	19.84
Std Deviation	12.67	1.09	9.15	20.16	15.91	17.90	22.59	15.46
Median	.00	.00	.00	7.85	2.70	6.63	29.93	19.65
Percentile 25	.00	.00	.00	2.70	.00	.00	10.40	5.15
Percentile 75	5.40	.00	2.70	30.78	22.25	22.25	47.75	28.65
Mode	.00	.00	.00	.00	.00	.00	.00	.00
Range	42.95	2.70	42.95	58.43	46.80	58.43	65.80	54.55
Minimum	.00	.00	.00	.00	.00	.00	.00	.00
Maximum	42.95	2.70	42.95	58.43	46.80	58.43	65.80	54.55

APPENDIX G

TABLE 7 (CONTINUED)

	THREAT
	HIGH
	Total
STROKES	
Mean	24.66
Std Deviation	2.94
Median	24.75
Percentile 25	21.80
Percentile 75	26.55
Mode	26.55
Range	9.30
Minimum	20.55
Maximum	29.85
TIME	
Mean	33.31
Std Deviation	8.11
Median	35.21
Percentile 25	27.49
Percentile 75	38.60
Mode	17.73
Range	29.08
Minimum	17.73
Maximum	46.82
ERRORS	
Mean	.18
Std Deviation	.21
Median	.15
Percentile 25	.00
Percentile 75	.20
Mode	.00
Range	.95
Minimum	.00
Maximum	.95
SWAT	
Mean	24.78
Std Deviation	19.55
Median	23.66
Percentile 25	10.40
Percentile 75	33.80
Mode	.00
Range	65.80
Minimum	.00
Maximum	65.80