ARMY RESEARCH LABORATORY

An Analysis of Teleoperation Workload in Various Sensory Feedback Modes

David R. Scribner

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AN ANALYSIS OF TELEOPERATION WORKLOAD IN VARIOUS SENSORY FEEDBACK MODES

David R. Scribner

September 1996

APPROVED: ____________________
ROBIN L. KEESEE
Director, Human Research &
Engineering Directorate

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U.S. ARMY RESEARCH LABORATORY

Aberdeen Proving Ground, Maryland

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INTRODUCTION

The Teleoperated Interface Research Team of the Soldier-Systems Control Branch, Human Research and Engineering Directorate (HRED) of the U.S. Army Research Laboratory (ARL) has been involved with state-of-the-art teleoperated vehicles and control systems of various types for scientific study and performance enhancement. One objective of the research program at ARL is to survey all possible sensory feedback modes and to analyze them for their sensory immersion value, as reflected in performance measures of speed, error rate, control frequency response, and other stress, workload, and preference measures. ARL is currently the lead entity in the Army that is examining the optimization of teleoperator performance.

The different feedback modes available for study are stereovision (allowing true depth perception), binaural feedback from microphones on the teleoperated vehicle, color vision, expanded field of view (FOV), and simulated force feedback. Other modes such as low data rate (foveal windowing, reduced frame rate, reduced resolution, etc.), low bandwidth audio (sub-woofer frequencies), and the use of helmet-mounted displays are being examined as well but are not part of the scope of this paper.

The impetus for modeling different sensory feedback modes related to teleoperation began with the examination of manpower-based system evaluation aid (MAN-SEVAL), one of the hardware and manpower (HARDMAN) III software modules. HARDMAN III was a major development effort of the Army Research Institute's (ARI) System Research Laboratory and is now part of ARL (HRED). MAN-SEVAL is part of the HARDMAN III Government-owned software, which consists of a set of automated aids to assist analysts in conducting human factors assessments, including manpower, personnel, and training. MAN-SEVAL is a stochastic modeling environment that performs workload assessment analyses and manpower maintenance analyses. The workload analysis is the area of interest for this paper.

It appeared that MAN-SEVAL was capable of being used separately from the rest of the software modules as a modeling tool. The ability to define functions (groups of related tasks), tasks, workload (visual, cognitive, psychomotor, and auditory), and task times allowed the layout and examination of a workload and performance (time) model of the basic teleoperated driving task. It was realized that the tasks and workload could be altered, based on projected effect of different sensory feedback modes. Therefore, work began to attempt to capture, in

MAN-SEVAL, the workload associated with different sensory feedback modes. The workload associated with each (or a combination) of the feedback modes is seen to be an inverse relationship to performance in teleoperated driving. In other words, if the workload for a particular feedback mode is high, then the performance in that feedback mode will tend to improve. The performance of teleoperated tasks is the main research focus in the Teleoperated Interface Research Team at ARL.

The following is a list of the models built in the MAN-SEVAL modeling environment:

On-board driving model (baseline)

<u>Teleoperated modes (different sensory feedback)</u>

Low level (narrow FOV, monoscopic viewing, no audio or force feedback)
Binaural feedback
Simulated force feedback (in steering device)
Wide FOV (165º)
Stereoscopic vision
All feedback (combined)

The recent increases in quantity and quality of sensory feedback modes are to allow the operator to drive at higher speeds and during off-road conditions. These technical challenges were identified after Office of the Secretary of Defense demonstration of state-of-the-art robotics technology (OSD DEMO I) as critical teleoperator performance hurdles. The challenge to developing good teleoperated systems is the basic driving task, essential to the delivery or placement of the mission package; reconnaissance, surveillance, and target acquisition (RSTA); chemical detection; weapon system; or otherwise.

ARL is currently pursuing a research effort during which the sensory feedback modes will be examined to determine monetary cost, bandwidth transmission requirements, and operator performance changes. However, before this research effort, ARL's focus involved modeling the feedback modes and the resultant workload outcomes to form the beginnings of a predictive set of models with which to project performance changes as technologies impact the teleoperated system.

The purpose of this report is three-fold:

1. Define the functions and tasks of the teleoperated driver,

2. Assess the teleoperator's driving workload during conditions of varying sensory feedback, and

3. Provide a possible prediction tool for the impact of technology on teleoperation performance. Discussion will also encompass recommendations for further modeling development.

TELEOPERATED DRIVING MODEL ANALYSIS

Identification of Teleoperated Driving Functions and Tasks

Tasks are defined as the smallest single work units, depending upon the fidelity of the model, which are "mapped out" in order to understand a task network. Functions are related groups of tasks that are required to complete a part of the overall job. Driving functions (groups of related tasks) were identified through a task analysis of teleoperated driving tasks with the cooperation of resident ARL subject matter experts (SMEs) in the area of teleoperated driving and operations. The functions were then separated into discrete tasks (or relatively basic elements of work) that were required to complete the associated functions. All functions were sequenced according to logical flow as were all tasks associated with the functions. Task times were collected from a combination of interviews with ARL SMEs and the timing of simulated events as executed normally in driving operations. Note. Dummy functions or tasks are those non-data-generating functions or tasks incorporated into a network to maintain proper structure.

The following teleoperated driving functions were identified:

- Move to area of operations (dummy function)
- Conduct surveillance (of driving scene)
- Monitor vehicle instruments
- Monitor vehicle status
- Perform self-recovery
- Nothing happens (dummy function)
- Steer vehicle
- Power vehicle

Table 1 is a detailed list of the functions and tasks identified to complete a generic teleoperated driving task. Dummy functions or dummy tasks are those which were included but have no data to be processed or generated, they are there for the formation of the model structure only.

It was determined that the tasks in Table 1 had to be represented to a "deep" enough level to be sensitive enough to and reflect possible changes in mission task times and workload levels influenced by different technologies in the ARL teleoperated high mobility multipurpose wheeled vehicle (HMMWV). The next step in the process was to "move" the function and task data into the MAN-SEVAL environment.

Table 1

Functions and Tasks to Complete a Generic Teleoperated Driving Task

Functions	Tasks
Move to area of operations	Dummy function
Conduct surveillance	Conduct surveillance (dummy task) Detection of status change Alerted by external source Type of change? Course (dummy task) Is course in FOV? Course not in FOV Alter vehicle orientation Course in FOV Search (dummy task) Visual (dummy task) Look up Look down Look left Look right Auditory Dummy ID course? Does ID course Does not ID course On course Not on course Consult navigational aid ID potential obstacles and hazards? Does ID hazards Does not ID hazards Hazard immediate threat? Immediate threat, alter course Not immediate threat
Monitor vehicle instruments	Monitor Instruments (dummy task) Frequent (dummy task) Infrequent (dummy task) Monitor speedometer Monitor tachometer Monitor fuel level Monitor oil pressure Monitor engine temperature

Table 1 (continued)

	Monitor battery voltage
	Verify normal range
	Normal range
	Not normal range
	Stop vehicle and monitor
Monitor vehicle status	Monitor vehicle status (dummy task)
	Monitor vehicle pitch
	Monitor vehicle roll
	Vehicle attitude in normal range?
	Normal range
	Not normal range
	Stop vehicle and correct vehicle attitude
	Monitor engine speed
	Engine speed in normal operation?
	Normal
	Not normal
	Slow or stop vehicle and check
	Monitor ground surface
	Ground surface suitable for travel?
	Suitable
	Not suitable
	Change course (dummy task)
Perform self-recovery	Perform self-recovery
	Need to change direction?
	Change needed
	Look to sides and estimate correction
	Change not needed
	Need to reverse direction?
	Reverse needed
	Look to rear, back up
	Change direction
	Reverse not needed
	Proceed
Nothing happens	(dummy function)
Steer vehicle	Steer vehicle (dummy task)
	Steer right
	Steer left
	Hold straight
	Let steering self-center
	Verify center position
	Verify steering control action

Table 1 (continued)

Power vehicle	Power vehicle (dummy task) Accelerator (dummy task) Apply accelerator Hold accelerator Release accelerator Verify accelerator action Brake (dummy task) Apply brake Hold brake Release brake Verify brake action

MAN-SEVAL Modeling

This section describes how MAN-SEVAL is used. A description of all the steps required to build, run, and analyze models built in MAN-SEVAL follows, but first, a little bit about the major components of the modeling software is presented.

MAN-SEVAL was used to assess workload of the teleoperated driving task. The MAN-SEVAL workload assessment aid integrates two essential technologies, Micro Saint software simulation and the McCracken-Aldrich workload assessment methodology. Micro Saint (built by Micro Analysis & Design) is used to build and execute task network models that simulate operational procedures. Each task within the network is assigned to an operator. The McCracken-Aldrich workload assessment methodology is used to assess the visual, auditory, cognitive, and psychomotor workload components for each crew member. Each task is assigned a scaled value for each of the four workload components. When the simulation is run, the guard’s workload is traced over time and then graphed. The model allows easy identification of high or low workload periods. The McCracken-Aldrich workload scales are presented in Appendix A of this report.

The steps for conducting a MAN-SEVAL workload analysis are as follow:

1. Define Conditions. The conditions during which the teleoperated driving mission will be performed are documented.

2. Develop Function List. All possible functions that the teleoperator may perform are listed. They are normally placed in sequence as they would be performed during actual operations.

3. Develop Task List. All possible tasks that the teleoperator may be required to perform are listed and sequenced as they would be completed during actual operations.

4. Identify Crew Positions. The driver is the only position listed.

5. Assign Tasks to Jobs. Two things are done here. All crew members capable of performing each task are identified, and then each task is assigned to one specific crew member. In this analysis, all tasks were assigned to the teleoperated driver.

6. Define Performance Parameters. Several things are done here. All tasks are assigned a most likely and a fastest time. Each task is then assigned workload scale values for visual, auditory, cognitive, and psychomotor workload channels. The workload scale values are derived from the McCracken-Aldrich workload assessment methodology. Finally, a high workload level is mathematically defined by the user.

7. Execute Simulation Run. Using Micro Saint, the task network simulation mode is run.

8. Analyze Results. Workload graphs depicting each crew member's workload in each workload channel are developed over time. High workload tasks are displayed and can be reallocated to other crew members automatically or manually when possible. Summary reports (e.g., percentage of time a high workload condition is experienced for each crew member) are also available.

Estimating Variance of Model Workloads

For each model developed, workload level and task time estimates were collected from HRED SMEs and from estimated scaling by using the descriptors of different workload channel tasks as described in the McCracken-Aldrich workload scale residing in the MAN-SEVAL software.

It is especially important to note that the workload scalings in the McCracken-Aldrich workload rating system are comprised of 8 points from 0 through 7, each with a different interval spacing. These workload ratings are established as interval data and have been validated by leading workload experts.

The workload levels for each channel were identified and set for the first model built or the low level feedback teleoperation model. Then, each task in each function was evaluated for a potential in workload reduction, based on the sensory feedback being examined. If the task was identified as one being affected by the sensory feedback technology, the workload level was adjusted accordlingly, either up or down each individual scale. The actual workload levels are listed in Appendix B. It is equally important that the reader understand that the workload adjustments in each model and the resultant output data be treated as an ordinal relationship. This will be mentioned again further in this report. The potential problem with the use of MAN-SEVAL is the forced usage of specific scale ratings, so that if a task were presumed to become easier, the next lower workload value may have been scaled lower in that subscale. Workload adjustments are subjective in nature and do not carry the confidence of true physiological workload data collection.

Data Generation of Different Sensory Feedback Modes

Data were generated from multiple runs of each sensory feedback model. Each model was run a total of 30 iterations. The criterion for accepting model output for each execution was that the overall task time be within one standard deviation (SD) of actual mean test course completion times for that mode of operation (i.e., on board or teleoperated). The mean course completion times were 3 and 6 minutes for on-board and teleoperated runs, respectively. Data for each workload channel were collected in the form of mean workload.

Each model was run six times (30 iterations per run) to collect workload information. Workload channel data were collected at 1/5-second intervals, as output in MAN-SEVAL, thus producing between 850 and 1800 data points for each workload channel, for each run.

DATA ANALYSIS

Mean workload values for iterative model runs were used as the final data that were examined to determine if any differences existed among the data. A one-way analysis of variance (ANOVA), with an F test was used to determine if there were any significant differences among the seven different models run for each of four workload channels (visual, auditory, cognitive, and psychomotor), as well as overall workload, which was the sum of all workload channels. A Scheffé post hoc test was used to determine if mean differences were significant between all teleoperated models where significance dictated.

RESULTS

Note. Before the results of these data are reviewed, it is important to consider the results of the on-board versus teleoperated means in the following data sets if nonsignificant differences occur. This is so because of the differences between on-board driving and teleoperated driving.

A nonsignificant result is one in which there is marked similarity between the workload of that teleoperated feedback and on-board driving, which is desirable. However, among teleoperated means, significant differences are important to note. Additionally, when data (workload means) are plotted or depicted graphically, the lesser workload condition is desired.

The results of data analysis for overall workload are presented in Tables 2 through 5.

Table 2

F Test for Overall Workload

Source	df	SS	s2	F ratio	Critical F value	Prob. F
Between	6	515.39	85.89	9.89	2.38 (.05)	.0000
Within	35	303.73	8.67		3.38 (.01)	
Total	41	819.13				

Table 3

Multiple Range Tests: Scheffé Test With Significance Level .05

		Group						
		1	6	7	2	5	4	3
(On-board)	1|							
(Wide FOV)	6|							
(All feedback)	7|							
(Low level)	2|	*						
(stereovision)	5|	*						
(force fdbk)	4|	*						
(binaural)	3|	*	*					

The difference between two means is significant if
MEAN(J)-MEAN(I) >= 2.0831 * RANGE * SQRT(1/N(I) + 1/N(J))
with the following value(s) for RANGE: 5.33

*Indicates significant differences

Table 4

Descriptive Statistics for All Groups, Overall Workload

Group	n	Mean	Deviation	Minimum	Maximum
On-board	6	31.30	1.07	30.00	32.65
Low level	6	39.18	3.21	33.11	42.69
Binaural	6	42.34	2.54	38.49	45.86
Force Fdbk	6	40.37	2.64	36.42	44.35
Stereo	6	39.77	3.75	33.59	42.80
Wide FOV	6	34.97	1.54	33.01	36.49
All Fdbk	6	36.18	4.40	28.89	41.81

Table 5

Homogeneous Subsets for Overall Workload

Subset 1	1,6,7
Subset 2	6,7,2,5,4
Subset 3	7,2,5,4,3

The overall mean workload comparisons and homogeneous groups for all feedback modes are graphically depicted in Figure 1.

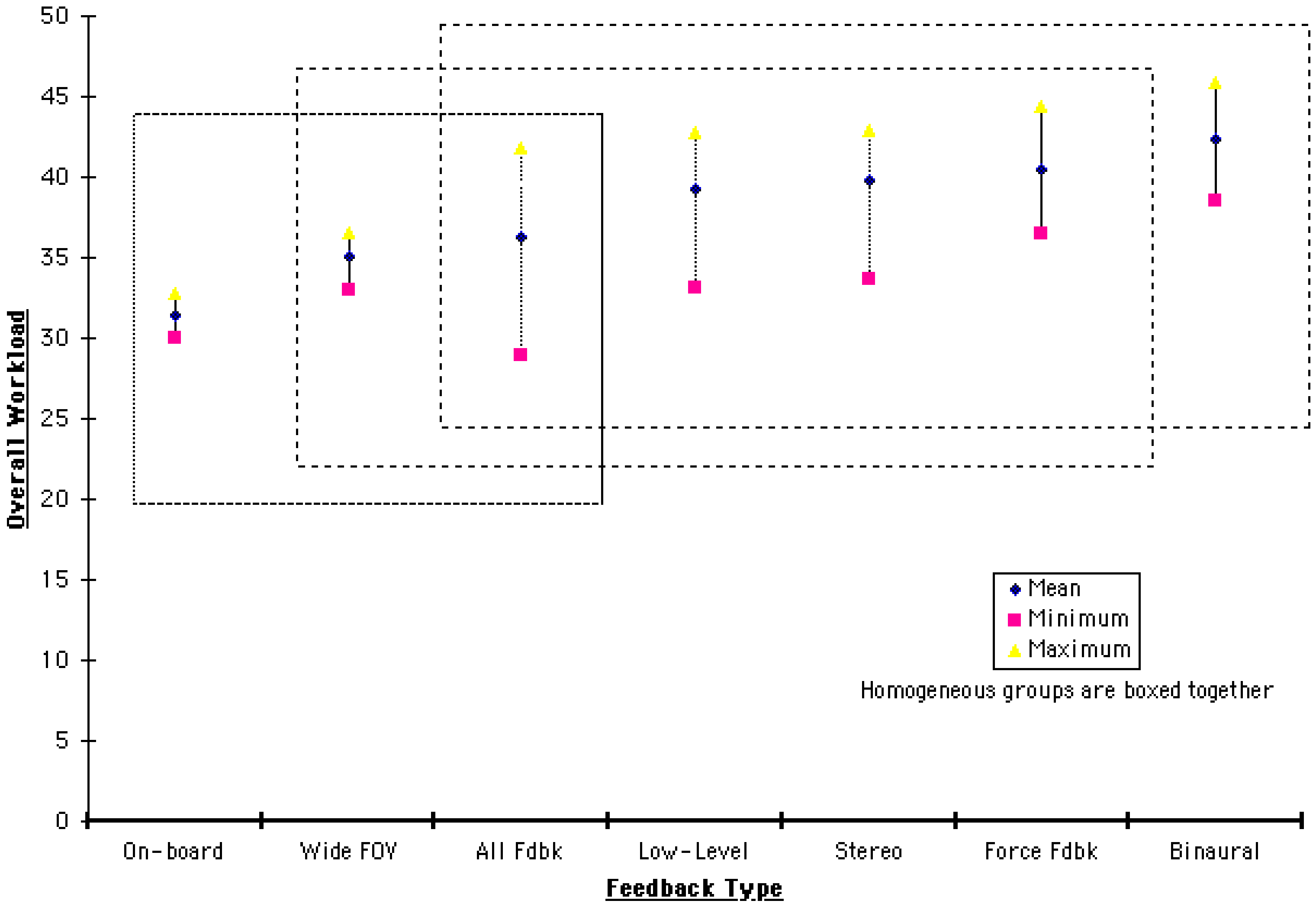

Figure 1. Mean and range values for overall work load with homogeneous grouping.

The results of data analysis for visual workload are presented in Tables 6 through 9.

Table 6

F Test for Visual Workload

Source	df	SS	s2	F ratio	Critical F value	Prob. F
Between	6	114.65	19.10	9.15	2.38 (.05)	.0000
Within	35	73.05	2.08		3.38 (.01)	
Total	41	187.71				

Table 7

Scheffé Test With Significance Level .05, Visual Workload

		Group						
		1	7	6	5	3	2	4
(On-board)	1|							
(All feedback)	7|							
(Wide FOV)	6|							
(binaural)	5|	*						
(low level)	3|	*						
(force fdbk)	2|	*						
(Stereo)	4|	*	*					

The difference between two means is significant if
MEAN(J)-MEAN(I) >= 1.02 * RANGE * SQRT(1/N(I) + 1/N(J))
with the following value(s) for RANGE: 5.33

*Indicates significant differences

Table 8

Descriptive Statistics for All Groups, Visual Workload

Group	n	Mean	Deviation	Minimum	Maximum
On-board	6	12.11	.50	11.38	12.95
Low level	6	17.02	1.98	13.14	18.76
Binaural	6	15.62	.72	14.56	16.54
Force fdbk	6	17.29	1.50	14.42	18.57
Stereo	6	15.50	1.83	12.88	17.32
Wide FOV	6	15.02	.69	13.94	15.62
All fdbk	6	13.94	1.93	11.31	16.07

Table 9

Homogeneous Subsets for Visual Workload

Subset 1	1,7,6
Subset 2	7,6,5,3,2
Subset 3	6,5,3,2,4

The visual workload comparisons and homogeneous groups for all feedback modes are graphically depicted in Figure 2.

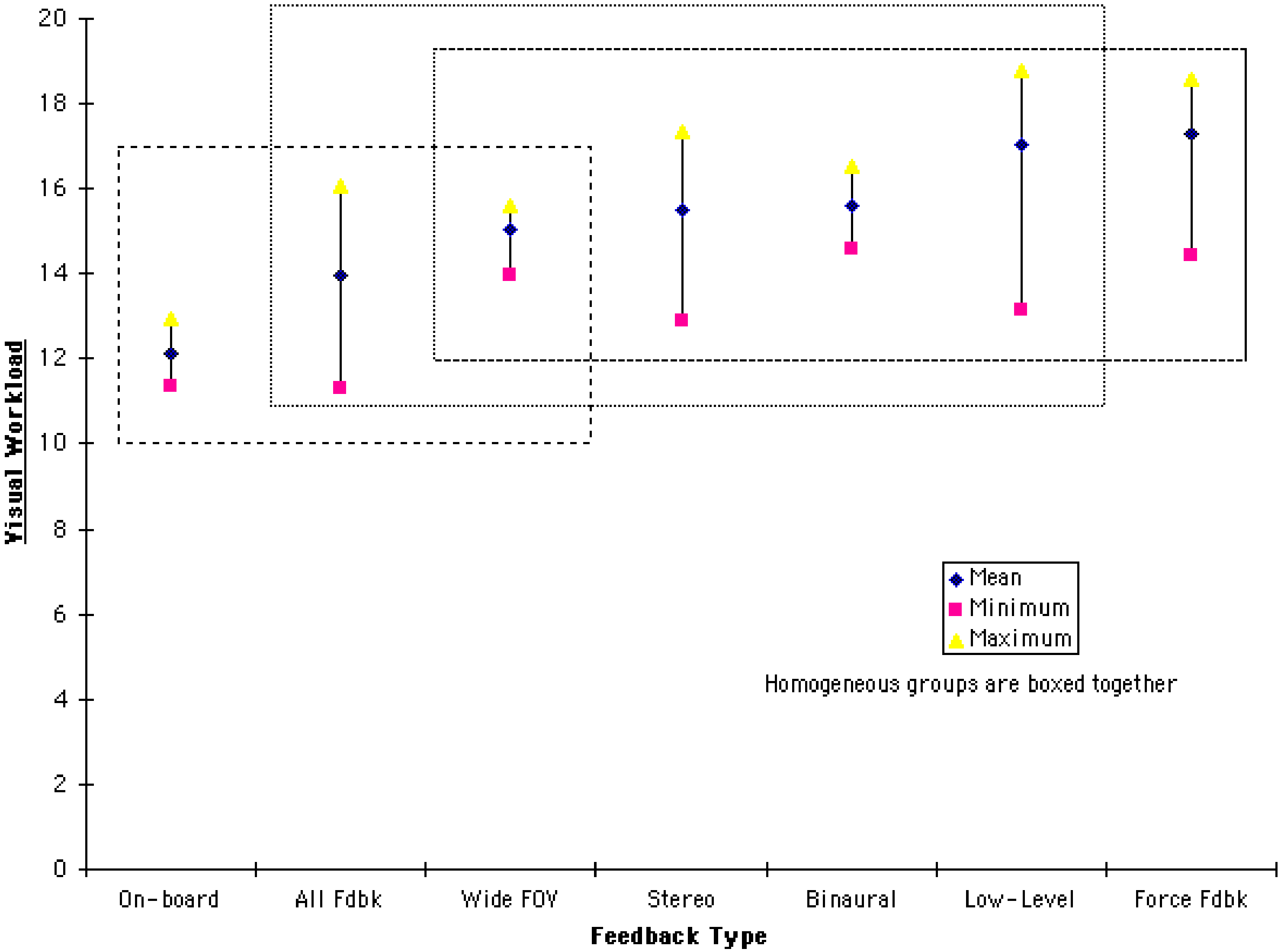

Figure 2. Mean and range values for visual work load with homogeneous grouping.

The results of data analysis for auditory workload are presented in Tables 10 through 13.

Table 10

F Test for Auditory Workload

Source	df	SS	s2	F ratio	Critical F value	Prob. F
Between	6	75.88	12.64	106.24	2.38 (.05)	.0000
Within	35	4.16	.11		3.38 (.01)	
Total	41	80.05				

Table 11

Scheffé Test With Significance Level .05, Auditory Workload

		Group 2	4	5	6	1	7	3
(force fdbk)	2							
(Stereo)	4							
(binaural)	5							
(Wide FOV)	6							
(On-board)	1							
(All feedback)	7							
(low level)	3	*	*	*	*	*	*	

The difference between two means is significant if
MEAN(J)-MEAN(I) >= .24 * RANGE * SQRT(1/N(I) + 1/N(J))
with the following value(s) for RANGE: 5.33

*Indicates significant differences

Table 12

Descriptive Statistics for All Groups, Auditory Workload

Group	n	Mean	Deviation	Minimum	Maximum
On-board	6	1.38	.15	1.28	1.68
Low level	6	1.00	.00	1.00	1.00
Binaural	6	4.95	.87	3.80	6.22
Force fdbk	6	1.00	.00	1.00	1.00
Stereo	6	1.00	.00	1.00	1.00
Wide FOV	6	1.00	.00	1.00	1.00
All fdbk	6	1.00	.18	1.43	1.95

Table 13

Homogeneous Subsets for Auditory Workload

Subset 1	2,4,5,6,1
Subset 2	3

The auditory workload comparisons and homogeneous groups for all feedback modes are graphically depicted in Figure 3.

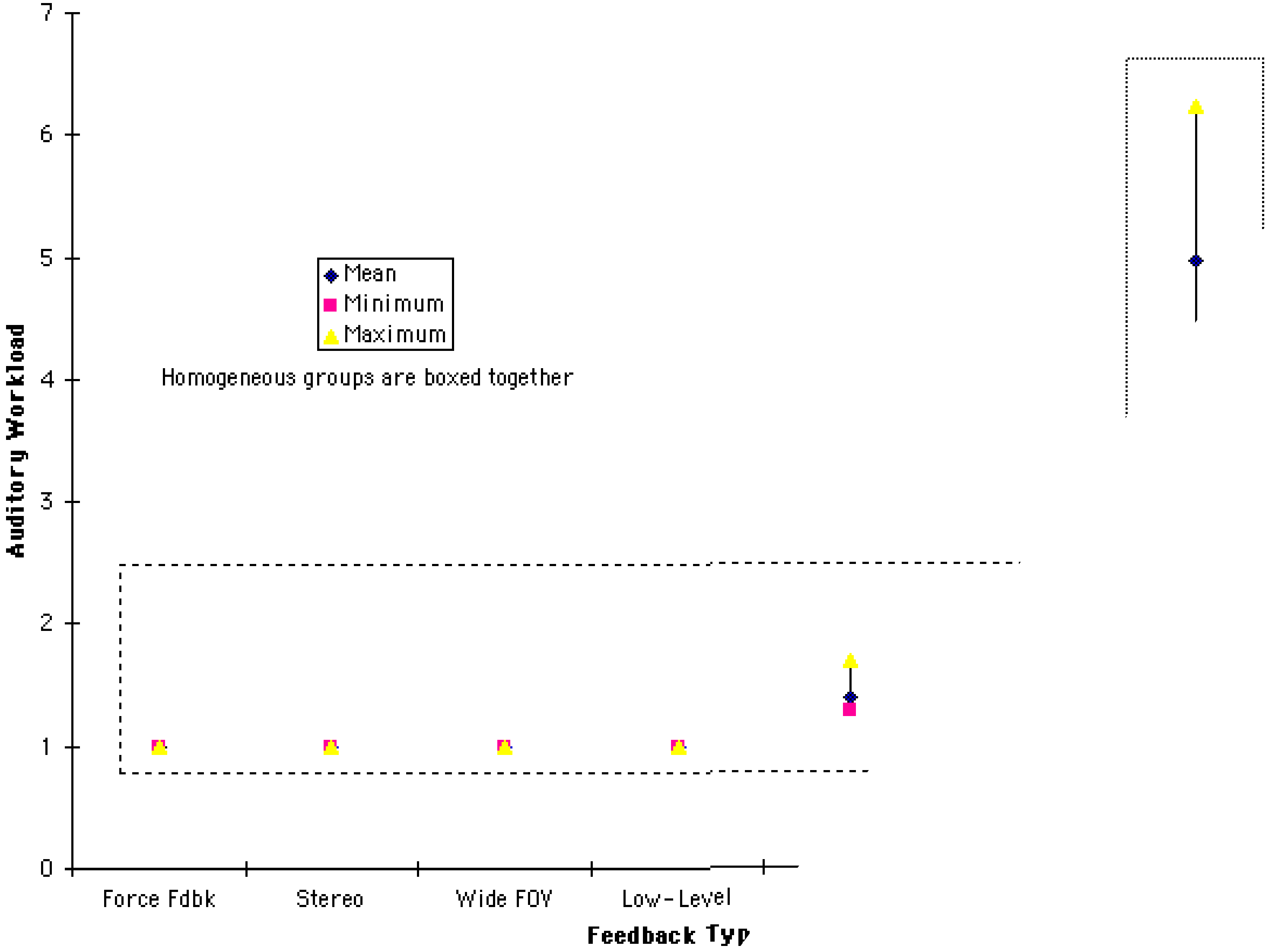

Figure 3. Mean and range values for auditory work load with homogeneous grouping.

The results of data analysis for cognitive workload are presented in Tables 14 through 17.

Table 14

F Test for Cognitive Workload

Source	df	SS	s2	F ratio	Critical F value	Prob. F
Between	6	226.20	37.70	29.73	2.38 (.05)	.0000
Within	35	44.37	1.26		3.38 (.01)	
Total	41	270.57				

Table 15

Scheffé Test With Significance Level .05, Cognitive Workload

		Group						
		1	6	7	3	4	2	5
(On-board)	1|							
(Wide FOV)	6|	*						
(All feedback)	7|	*						
(Low level)	3|	*	*					
(stereovision)	4|	*	*					
(force fdbk)	2|	*	*					
(binaural)	5|	*	*	*				

The difference between two means is significant if
MEAN(J)-MEAN(I) >= .79 * RANGE * SQRT(1/N(I) + 1/N(J))
with the following value(s) for RANGE: 5.33

*Indicates significant differences

Table 16

Descriptive Statistics for All Groups, Cognitive Workload

Group	n	Mean	Deviation	Minimum	Maximum
On-board	6	9.39	.54	8.89	10.34
Low level	6	15.49	.73	14.69	16.81
Binaural	6	14.63	1.14	12.82	15.89
Force fdbk	6	15.11	.91	14.16	16.79
Stereo	6	16.85	1.77	13.86	18.17
Wide FOV	6	12.01	.58	11.49	12.85
All fdbk	6	13.15	1.55	10.70	14.83

Table 17

Homogeneous Subsets for Cognitive Workload

Subset 1	1
Subset 2	6,7
Subset 3	7,3,4,2
Subset 4	3,4,2,5

The cognitive workload comparisons and homogeneous groups for all feedback modes are graphically depicted in Figure 4.

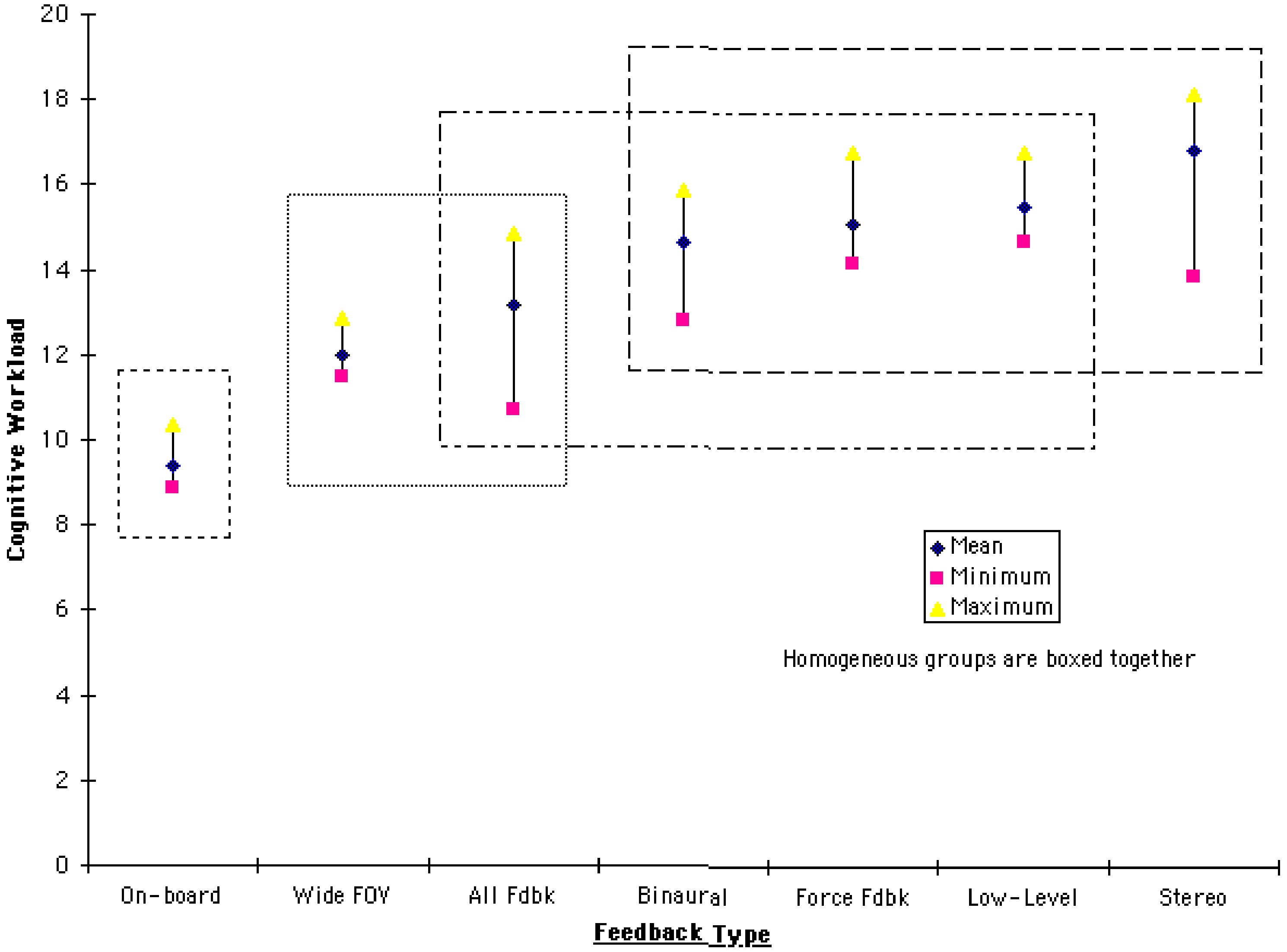

Figure 4. Mean and range values for cognitive work load with homogeneous grouping.

The results of data analysis for psychomotor workload are presented in Tables 18 through 21.

Table 18

F Test for Psychomotor Workload

Source	df	SS	s2	F ratio	Critical F value	Prob. F
Between	6	114.65	19.10	9.15	2.38 (.05)	.0000
Within	35	73.05	2.08		3.38 (.01)	
Total	41	187.71				

Table 19

Scheffé Test With Significance Level .05, Psychomotor Workload

	Group	2	5	6	4	3	7	1
(force fdbk)	2							
(binaural)	5							
(Wide FOV)	6							
(Stereo)	4							
(low level)	3							
(All feedback)	7	*						
(On-board)	1	*	*					

The difference between two means is significant if
MEAN(J)-MEAN(I) >= .52 * RANGE * SQRT(1/N(I) + 1/N(J))
with the following value(s) for RANGE: 5.33

*Indicates significant differences

Table 20

Descriptive Statistics for All Groups, Psychomotor Workload

Group	n	Mean	Deviation	Minimum	Maximum
On-board	6	8.41	.10	8.28	8.60
Low-Level	6	5.66	.73	4.27	6.41
Binaural	6	7.13	.54	6.57	8.13
Force Fdbk	6	6.97	.88	5.93	7.97
Stereo	6	6.41	.47	5.85	7.30
Wide FOV	6	6.96	.69	5.85	8.03
All Fdbk	6	7.37	1.25	5.42	9.05

Table 21

Homogeneous Subsets for Psychomotor Workload

Subset 1	2,5,6,4,3
Subset 2	5,6,4,3,7
Subset 3	6,4,3,7,1

The psychomotor workload comparisons and homogeneous groups for all feedback modes are graphically depicted in Figure 5.

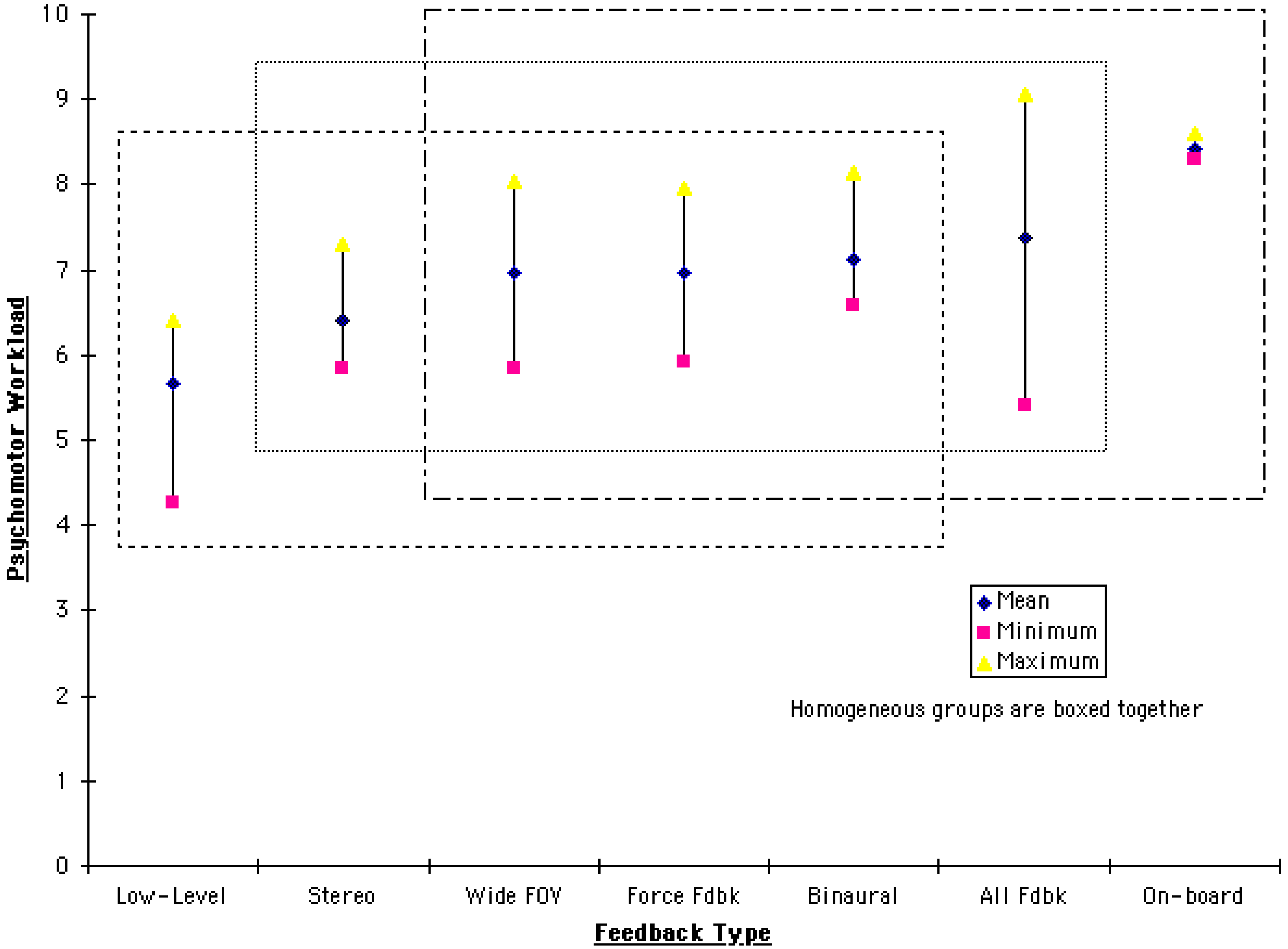

Figure 5. Mean and range values for psychomotor work load with homogeneous grouping.

The results of data analysis for number of on-going tasks workload are presented in Tables 22 through 25.

Table 22

F Test for Number of On-going Tasks Workload

Source	df	SS	s2	F ratio	Critical F value	Prob. F
Between	6	2.07	.34	4.51	2.38 (.05)	.0095
Within	35	1.07	.07		3.38 (.01)	
Total	41	3.14				

Table 23

Scheffé Test With Significance Level .05, Number of On-going Tasks Workload

		Group						
		6	2	3	5	4	1	7
(Wide FOV)	6|							
(force fdbk)	2|							
(low level)	3|							
(binaural)	5|							
(Stereo)	4|							
(On-board)	1|							
(All feedback)	7|	*						

The difference between two means is significant if
MEAN(J)-MEAN(I) >= .19 * RANGE * SQRT(1/N(I) + 1/N(J))
with the following value(s) for RANGE: 5.85

*Indicates significant differences

Table 24

Descriptive Statistics for All Groups, Number of On-going Tasks Workload

Group	n	Mean	Deviation	Minimum	Maximum
On-board	6	5.19	.01	5.18	5.21
Low level	6	4.64	.16	4.54	4.83
Binaural	6	4.80	.16	4.65	4.97
Force fdbk	6	4.95	.22	4.69	5.09
Stereo	6	4.88	.48	4.40	5.37
Wide FOV	6	4.60	.36	4.18	4.85
All fdbk	6	5.57	.26	5.30	5.82

Table 25

Homogeneous Subsets for Number of On-going Tasks Workload

Subset 1	6,2,3,5,4
Subset 2	2,3,5,4,1,7

The visual workload comparisons and homogeneous groups for all feedback modes are graphically depicted in Figure 6.

F Tests

F tests revealed significant differences for all workload channels, including overall workload and number of on-going tasks. All ANOVAs yielded F ratios that were significant to the .01 α level. The Scheffé Test was used to perform group mean post hoc comparisons:

Post Hoc Analysis

For overall workload, the Scheffé Test showed that *on-board* was significantly different from *low level, stereo, force feedback* and *binaural* to the .05 level. *Wide field of view* was also was significantly different from *binaural* to the .05 level. *On-board, wide FOV,* and *all feedback* conditions were not statistically different from each other, and were identified as a homogeneous group, where the highest and lowest means are not significantly different.

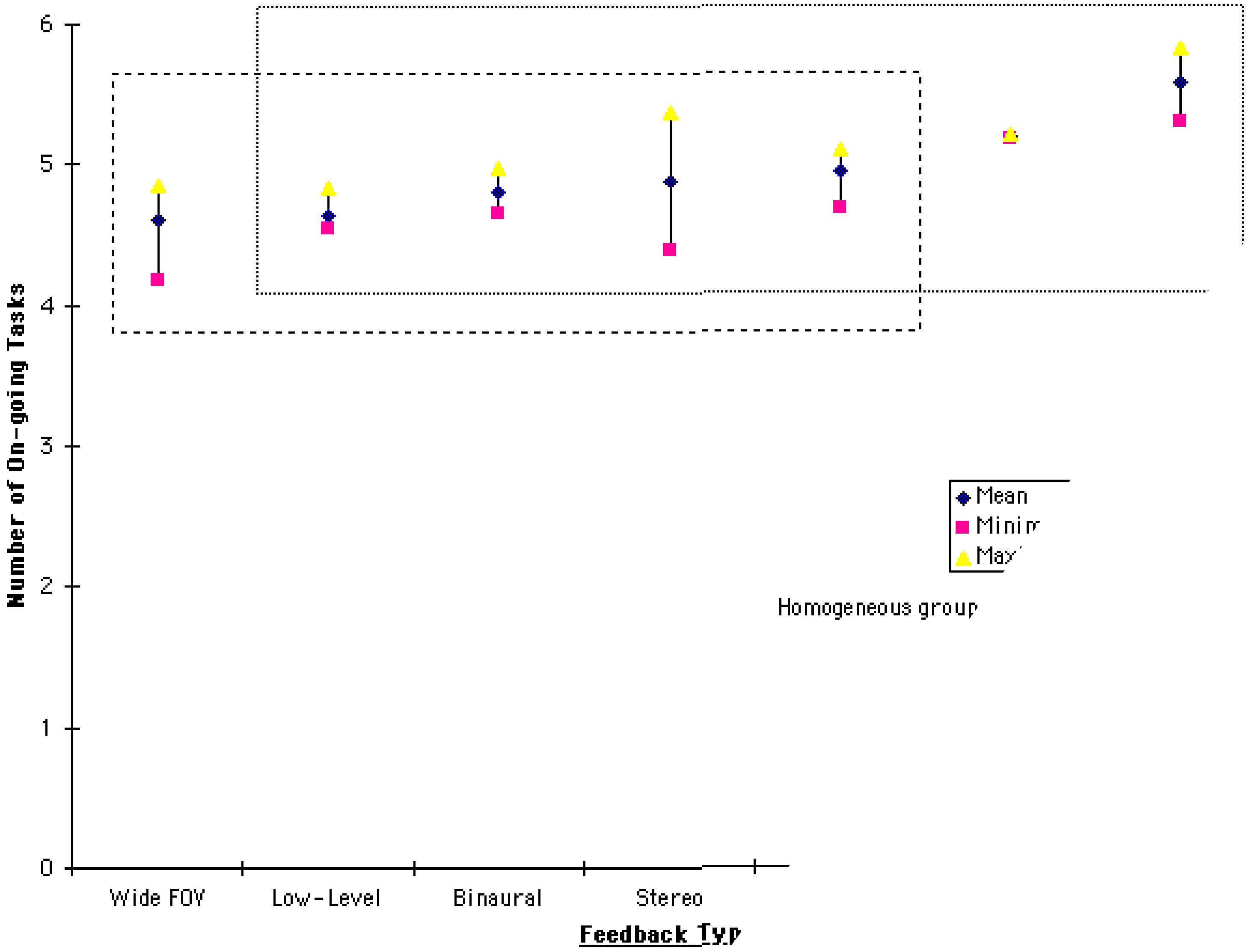

Figure 6. Mean and range values for number of on-going tasks with homogeneous grouping.

For visual workload, the Scheffé Test showed that *on-board* was significantly different from *low level, stereo, force feedback,* and *binaural* to the .05 level. *All feedback* was also was significantly different from *force feedback* to the .05 level. *On-board, wide FOV,* and *all feedback* conditions <u>were not</u> statistically different from each other and were identified as a homogeneous group, in which the highest and lowest means are not significantly different.

For auditory workload, the Scheffé Test showed that *binaural feedback* was significantly different from all other conditions to the .05 level.

For cognitive workload, the Scheffé Test showed that *on-board* was significantly different from all other conditions to the .05 level. *Wide field of view* was also was significantly different from *binaural, force feedback, low level,* and *stereo* to the .05 level. Additionally, *all feedback* was significantly different from *stereo* to the .05 level. *Wide FOV* and *all feedback* conditions <u>were not</u> statistically different from each other and were identified as a homogeneous group, in which the highest and lowest means are not significantly different. *On-board* was identified as a single homogeneous group.

For psychomotor workload, the Scheffé Test showed that *low level* was significantly different from *all feedback* and *on-board* to the .05 level. *Stereo* was also was significantly different from *on-board* to the .05 level. *On-board, binaural, force feedback,* and *wide field of view* conditions <u>were not</u> statistically different from each other and were identified as a homogeneous group, in which the highest and lowest means are not significantly different.

For number of on-going tasks, the Scheffé Test showed that *wide field of view* was significantly different from *all feedback* to the .05 level. *All feedback, on-board, force feedback, stereo, binaural,* and *low level* conditions <u>were not</u> statistically different from each other and were identified as a homogeneous group, in which the highest and lowest means are not significantly different.

CONCLUSIONS

Upon examination of the F Test results and the post hoc mean comparisons of the different model group means, it can be seen that a definite trend occurred in the data. It appears that the data for *wide FOV* and the *all feedback* models were similar to those of *on-board* driving with respect to overall and visual workload. Additionally, *wide FOV* and *all feedback* were significantly different from the other teleoperated feedback (binaural, force feedback, low level, and stereo), even though different from on-board data for cognitive workload. The best evidence of this is seen by examining the graphical representations of the data (see Figures 1 through 6).

The reason for the similarities of the modeled data among *on-board, wide FOV,* and *all feedback* models appears to be because of the number of tasks that are affected by the feedback. The feedback qualities of the modeled conditions are similar because of the task workload similarity. Using the *on-board* model as a baseline comparison, *wide FOV* and *all feedback* data seem to be worth examining through the use of further modeling and model validation via field data collection during teleoperated driving conditions.

The author believes that the utility of the *wide FOV* and of course, the *all feedback* models, is for the most part, supported by the relevant scientific literature. The *all feedback* model is of particular concern for future modeling efforts because of the potentially strong effect of combining all possible feedback modes.

The author further believes that the modeled combination of all feedback modes, except for binaural (auditory) feedback, would have yielded stronger results beyond those reflected for *wide field of view* and *all feedback* combined. This hypothesized effect is expected because of the relatively high overall workload seen in the binaural feedback condition.

In the future, factorial analysis of the effects of different combinations of sensory feedback modes will benefit those teleoperated systems developers looking for the right mix of sensory feedback, for the particular task needs of the system. It is believed that in order to learn more about the interaction effects of all feedback scenarios, a factorial design or a specially selected set of feedback combinations for workload comparison should be tried in the future.

Overall, the confidence in the "generality" of the overall workload data is high, because of the examination of workload for each operator task and the common sense approach to sensory feedback modes. However, specific workload data to be used for the purpose of equipment design or fabrication would be foolhardy without model validation through the comparison of real workload data.

RECOMMENDATIONS FOR FURTHER RESEARCH AND DEVELOPMENT

A. Collect real task times from soldiers in the user population.

To enhance the fidelity of the models herein and in the future, it is suggested that task times to be included in the MAN-SEVAL models be collected from a large pool of actual system users. The task times from the larger pool of real users should prove to be more stable estimates. A current ARL effort with the project manager of unmanned ground vehicles (PMUGV) will accomplish this.

B. Verify the workload ratings of teleoperated tasks in MAN-SEVAL.

A truer method of estimating workload from different types of tasks should be included in the McCracken-Aldrich workload scales. A listing of all teleoperated tasks as they relate precisely to the workload scales should be developed for future modeling. Presently, tasks must be identified and a similar but not exact task is given in the workload scales. This would require the consultation of a workload expert.

C. Performing Maintenance and RSTA mission modeling.

RSTA should be examined in future modeling efforts to provide a more complete approach to the area of teleoperated mission and payload operation.

Additionally, it has been suggested that a maintenance workload and task time model be developed along with mission-oriented clothing restrictions as variations of the maintenance models (mission-oriented protective posture [MOPP] and arctic clothing). This will be performed in the near future by ARL to support PMUGV efforts.

D. Develop a common workload measure for data transfer from experimental to modeling environments.

Compare any experimental data findings with modeled predictions to determine if the modeling effort established in this report can be validated or verified. This may also encompass the use of a workload rating system such as the National Aeronautics and Space Administration (NASA) task load index (TLX) or other measures to successfully capture the four channels of workload as used in MAN-SEVAL. NASA TLX data can be transformed into “overall workload” data. However, there is no direct or standardized workload format. Such a format is needed to transfer common workload measures from the experimental situation into the modeling situation.

An effort to begin investigation in this area, which will be fostered by a Phase II small business innovative research (SBIR) contract, is progressing at ARL.

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APPENDIX A

MCCRACKEN-ALDRICH WORKLOAD SCALES

MCCRACKEN-ALDRICH WORKLOAD SCALES

McCracken-Aldrich Scale Values

Scale Value	**Descriptor**	**Scale**
0.0	No Visual Activity	Visual
1.0	Visually Register/Detect (detect occurrence of image)	
3.7	Visually Discriminate (detect visual difference)	
4.0	Visually Inspect/Check (discrete inspection/static condition)	
5.0	Visually Locate/Align (selective orientation)	
5.4	Visually Track/Follow (maintain orientation)	
5.9	Visually Read (symbol)	
7.0	Visually Scan/Search/Monitor (continuous/serial inspection, multiple conditions)	
0.0	No Cognitive Activity	Cognitive
1.0	Automatic (simple association)	
1.2	Alternative selection	
3.7	Sign/Signal Recognition	
4.6	Evaluation/Judgment (consider single aspect)	
5.3	Encoding/Decoding, Recall	
6.8	Evaluation/Judgment (consider several aspects)	
7.0	Estimation, Calculation, Conversion	
0.0	No Auditory Activity	Auditory
1.0	Detect/Register Sound (detect occurrence of sound)	
2.0	Orient to Sound (general orientation/attention)	
4.2	Orient to Sound (selective orientation/attention)	
4.3	Verify Auditory Feedback (detect occurrence of anticipated sound)	
4.9	Interpret Semantic Content (speech)	
6.6	Discriminate Sound Characteristics (detect auditory differences)	
7.0	Interpret Sound Patterns (pulse rates, etc.)	
0.0	No Psychomotor Activity	Psychomotor
1.0	Speech	
2.2	Discrete Actuation (button, toggle, trigger)	
2.6	Continuous Adjustive (flight control, sensor control)	
4.6	Manipulative	
5.8	Discrete Adjustive (rotary, vertical thumb wheel, lever position)	
6.5	Symbolic Production (writing)	
7.0	Serial Discrete Manipulation (keyboard entries)	

APPENDIX B

WORKLOAD BREAKDOWN BY SENSORY FEEDBACK TYPE

WORKLOAD BREAKDOWN BY SENSORY FEEDBACK TYPE

Key:
OB - On-Board Driving LL - Low Level Feedback BI - Binaural Feedback
FF - Force Feedback ST - Stereo Vision WF - Wide Field of View
AF - All Feedback Combined

Note. In the following tables, blank data spaces signify data from the Low Level Feedback condition that did not change as a result of the sensory feedback mode.

Function 1: **Move to Area of Operations (dummy function)**

Function 2: **Conduct Surveillance**

Tasks:

1. Conduct Surveillance (dummy)

2. Detection of Status Change

	LL	OB	BI	FF	ST	WF	AF
AUD							
COG	4.6	3.7					4.6
PSYM							
VIS	3.7	1					3.7
Most Likely Time to Complete (s)	1.5	1.0				1.2	1.2
Fastest Time to Compete (s)	1.2	.6				1.0	1.0

3. Alerted by External Source

	LL	OB	BI	FF	ST	WF	AF
AUD			4.7				4.7
COG	4.6	3.7	3.7				3.7
PSYM							
VIS	5	3.7	5				5
Most Likely Time to Complete (s)	1.2	1.0					1.2
Fastest Time to Compete (s)	1.0	.6					1.0

4. Type of Change (dummy)
5. Course (dummy)
6. Is Course in FOV?

	LL	OB	BI	FF	ST	WF	AF
AUD							
COG	6.8	3.7			6.8	4.6	4.6
PSYM							
VIS	7	3.7			5	5.4	5
Most Likely Time to Complete (s)	1.2	1.0			1.0		1.0
Fastest Time to Compete (s)	1.0	.6			.9		.9

7. Course Not in FOV

	LL	OB	BI	FF	ST	WF	AF
AUD							
COG	6.8	3.7			6.8	4.6	4.6
PSYM							
VIS	7	3.7			5	5.4	5
Most Likely Time to Complete (s)	1.5	1.0			1.2	1.0	1.0
Fastest Time to Compete (s)	1.2	.6			1.0	.9	.9

8. Alter Vehicle Orientation

	LL	OB	BI	FF	ST	WF	AF
AUD							
COG	6.8	3.7				5.3	5.3
PSYM	2.6	1				2.6	2.6
VIS	5.4	3.7				5.4	5.4
Most Likely Time to Complete (s)	4.8	2.5					4.8
Fastest Time to Compete (s)	2.5	1.0					2.5

9. Course in FOV (dummy)
10. Search (dummy)
11. Visual (dummy)

12. Look Up

	LL	OB	BI	FF	ST	WF	AF
AUD							
COG	6.8	3.7			5.3	4.6	4.6
PSYM	1	1			1	1	1
VIS	7	3.7			5.9	5.4	5.4
Most Likely Time to Complete (s)	1.5	1.0			1.2	1.0	1.0
Fastest Time to Compete (s)	1.2	.6			1.0	.9	.9

13. Look Down

	LL	OB	BI	FF	ST	WF	AF
AUD							
COG	6.8	3.7			5.3	4.6	4.6
PSYM	1	1			1	1	1
VIS	7	3.7			5.9	5.4	5.4
Most Likely Time to Complete (s)	1.5	1.0			1.2	1.0	1.0
Fastest Time to Compete (s)	1.2	.6			1.0	.9	.9

14. Look Left

	LL	OB	BI	FF	ST	WF	AF
AUD							
COG	6.8	3.7			5.3	4.6	4.6
PSYM	1	1			1	1	1
VIS	7	3.7			5.9	5.4	5.4
Most Likely Time to Complete (s)	1.5	1.0			1.2	1.0	1.0
Fastest Time to Compete (s)	1.2	.6			1.0	.9	.9

15. Look Right

	LL	OB	BI	FF	ST	WF	AF
AUD							
COG	6.8	3.7			5.3	4.6	4.6
PSYM	1	1			1	1	1
VIS	7	3.7			5.9	5.4	5.4
Most Likely Time to Complete (s)	1.5	1.0			1.2	1.0	1.0
Fastest Time to Compete (s)	1.2	.6			1.0	.9	.9

16. Auditory

	LL	OB	BI	FF	ST	WF	AF
AUD			2				2
COG			1				1
PSYM							
VIS							
Most Likely Time to Complete (s)	1.2	1.0					1.2
Fastest Time to Compete (s)	1.0	.6					1.0

17. Dummy

18. ID Course?	LL	OB	BI	FF	ST	WF	AF
AUD							
COG	6.8	3.7			5.3	4.6	4.6
PSYM							
VIS	5	3.7			5	5.4	5
Most Likely Time to Complete (s)	1.5	1.0			1.2	1.0	1.0
Fastest Time to Compete (s)	1.2	.6			1.0	.9	.9

19. Does ID Course	LL	OB	BI	FF	ST	WF	AF
AUD							
COG	6.8	3.7			4.6	4.6	4.6
PSYM							
VIS	5	3.7			5	5.4	5
Most Likely Time to Complete (s)	1.5	1.0			1.2	1.0	1.0
Fastest Time to Compete (s)	1.2	.6			1.0	.9	.9

20. Does Not ID Course	LL	OB	BI	FF	ST	WF	AF
AUD							
COG	6.8	3.7			4.6	4.6	4.6
PSYM							
VIS	5	3.7			5	5.4	5
Most Likely Time to Complete (s)	1.5	1.0			1.2	1.0	1.0
Fastest Time to Compete (s)	1.2	.6			1.0	.9	.9

21. On Course	LL	OB	BI	FF	ST	WF	AF
AUD							
COG							
PSYM							
VIS							
Most Likely Time to Complete (s)	1.5	1.0			1.2	1.0	1.0
Fastest Time to Compete (s)	1.2	.6			1.0	.9	.9

22. Not on Course	LL	OB	BI	FF	ST	WF	AF
AUD							
COG	6.8	3.7			4.6		4.6
PSYM							
VIS	5.4	3.7			5.4		5.4
Most Likely Time to Complete (s)	1.5	1.0			1.2	1.0	1.0
Fastest Time to Compete (s)	1.2	.6			1.0	.9	.9

23. Consult Navigational Aid	LL	OB	BI	FF	ST	WF	AF
AUD							
COG	7	3.7					7
PSYM							
VIS	7	7					7
Most Likely Time to Complete (s)	1.2	1.0					1.2
Fastest Time to Compete (s)	1.0	.6					1.0

24. ID Potential Obstacles/Hazards?	LL	OB	BI	FF	ST	WF	AF
AUD			2				2
COG	6.8	3.7	6.8		4.6		4.6
PSYM							
VIS	7	5.9	5.4		5.9		5.9
Most Likely Time to Complete (s)	1.5	1.0			1.2		1.2
Fastest Time to Compete (s)	1.2	.6			1.0		1.0

25. Does ID Hazards		LL	OB	BI	FF	ST	WF	AF
	AUD			2				2
	COG	6.8	3.7	6.8		4.6		4.6
	PSYM							
	VIS	7	5.9	5.4		5.9		5.4
Most Likely Time to Complete (s)		1.5	1.0			1.2		1,2
Fastest Time to Compete (s)		1.2	.6			1.0		1.0

26. Does Not ID Hazards		LL	OB	BI	FF	ST	WF	AF
	AUD			2				2
	COG	6.8	3.7	6.8		4.6		4.6
	PSYM							
	VIS	7	5.9	5.4		5.9		5.4
Most Likely Time to Complete (s)		1.5	1.0			1.2		1.2
Fastest Time to Compete (s)		1.2	.6			1.0		1.0

27. Hazard Immediate Threat?		LL	OB	BI	FF	ST	WF	AF
	AUD			2				2
	COG	6.8	3.7	6.8		4.6		4.6
	PSYM							
	VIS	7	5.9	5.4		5.9		5.4
Most Likely Time to Complete (s)		1.2	1.0			1.0		1.0
Fastest Time to Compete (s)		1.0	.6			.9		.9

28. Immediate Threat, Alter Course		LL	OB	BI	FF	ST	WF	AF
	AUD			2				2
	COG	7	3.7	4.6				4.6
	PSYM	2.6	2.6	2.6				2.6
	VIS							
Most Likely Time to Complete (s)		3.5	1.8					3.5
Fastest Time to Compete (s)		1.5	.9					1.5

29. Not Immediate Threat		LL	OB	BI	FF	ST	WF	AF
	AUD			2				2
	COG	7	3.7	4.6				4.6
	PSYM							
	VIS							

Function 3: Monitor Vehicle Instruments

Tasks:

1. Monitor Instruments (dummy)
2. Frequent (dummy)
3. Infrequent (dummy)

4. Monitor Speedometer		LL	OB	BI	FF	ST	WF	AF
	AUD							
	COG	5.3						5.3
	PSYM							
	VIS	4						4

5. Monitor Tachometer		LL	OB	BI	FF	ST	WF	AF
	AUD							
	COG	5.3						5.3
	PSYM							
	VIS	4						4

6. Monitor Fuel Level		LL	OB	BI	FF	ST	WF	AF
	AUD							
	COG	4.6						4.6
	PSYM							
	VIS	4						4

7. Monitor Oil Pressure		LL	OB	BI	FF	ST	WF	AF
	AUD							
	COG	4.6						4.6
	PSYM							
	VIS	4						4

8. Monitor Engine Temperature		LL	OB	BI	FF	ST	WF	AF
	AUD							
	COG	4.6						4.6
	PSYM							
	VIS	4						4

9. Monitor Battery Voltage		LL	OB	BI	FF	ST	WF	AF
	AUD							
	COG	4.6						4.6
	PSYM							
	VIS	4						4

10. Verify Normal Range		LL	OB	BI	FF	ST	WF	AF
	AUD							
	COG	4.6						4.6
	PSYM							
	VIS	4						4

11. Normal Range		LL	OB	BI	FF	ST	WF	AF
	AUD							
	COG	4.6						4.6
	PSYM							
	VIS	4						4

12. Not Normal Range		LL	OB	BI	FF	ST	WF	AF
	AUD							
	COG	4.6						4.6
	PSYM							
	VIS	4						4

13. Stop Vehicle and Monitor		LL	OB	BI	FF	ST	WF	AF
	AUD							
	COG	1.2	1.2					1.2
	PSYM	2.2						2.2
	VIS	7.0	3.7					7.0
Most Likely Time to Complete (s)		10.0	5.0					10.0
Fastest Time to Compete (s)		7.0	1.8					7.0

Function 4: Monitor Vehicle Status

Tasks:

1. Monitor Vehicle Status (dummy)

2. Monitor Vehicle Pitch

	LL	OB	BI	FF	ST	WF	AF
AUD							
COG	6.8	1				4.6	4.6
PSYM							
VIS	5	3.7				5	5
Most Likely Time to Complete (s)	1.8	1.0				1.3	1.3
Fastest Time to Compete (s)	1.2	.6				1.0	1.0

3. Monitor Vehicle Roll

	LL	OB	BI	FF	ST	WF	AF
AUD							
COG	6.8	1				4.6	4.6
PSYM							
VIS	5	3.7				5	5
Most Likely Time to Complete (s)	1.8	1.0				1.3	1.3
Fastest Time to Compete (s)	1.2	.6				1.0	1.0

4. Vehicle Attitude in Normal Range?

	LL	OB	BI	FF	ST	WF	AF
AUD							
COG	6.8	1				4.6	4.6
PSYM							
VIS	5	3.7				5	5
Most Likely Time to Complete (s)	2.4	1.0					2.4
Fastest Time to Compete (s)	1.2	.6					1.2

5. Normal

	LL	OB	BI	FF	ST	WF	AF
AUD		4.3	1				1
COG	4.6	4.6	4.6				4.6
PSYM							
VIS	5.9	5.9	5.9				5.9
Most Likely Time to Complete (s)	1.6	1.0					1.6
Fastest Time to Compete (s)	1.2	.6					1.2

6. Not Normal

	LL	OB	BI	FF	ST	WF	AF
AUD		4.3	1				1
COG	4.6	4.6	4.6				4.6
PSYM							
VIS	5.9	5.9	5.9				5.9
Most Likely Time to Complete (s)	1.6	1.0					1.6
Fastest Time to Compete (s)	1.2	.6					1.2

7. Stop Vehicle, Correct Vehicle Attitude

	LL	OB	BI	FF	ST	WF	AF
AUD							
COG	6.8	4.6					6.8
PSYM	2.6	2.6					2.6
VIS	5.4	3.7					5.4
Most Likely Time to Complete (s)	18.0	12.0					18.0
Fastest Time to Compete (s)	15.0	6.0					15.0

8. Monitor Engine Speed		LL	OB	BI	FF	ST	WF	AF
	AUD		4.3	1				1
	COG	3.7	3.7	3.7				3.7
	PSYM							
	VIS	5.9	5.9	5.9				5.9
Most Likely Time to Complete (s)		1.6	1.0	1.2				1.2
Fastest Time to Compete (s)		1.2	.6	1.0				1.0

9. Engine Speed in Normal Operation?		LL	OB	BI	FF	ST	WF	AF
	AUD		4.3	1				1
	COG	4.6	3.7					4.6
	PSYM							
	VIS	5.9	5.9					5.9
Most Likely Time to Complete (s)		1.6	1.0	1.2				1.2
Fastest Time to Compete (s)		1.2	.6	1.0				1.0

10. Normal		LL	OB	BI	FF	ST	WF	AF
	AUD		4.3	1				1
	COG	4.6	4.6	4.6				4.6
	PSYM							
	VIS	5.9	5.9	5.9				5.9
Most Likely Time to Complete (s)		1.6	1.0	1.2				1.2
Fastest Time to Compete (s)		1.2	.6	1.0				1.0

11. Not Normal		LL	OB	BI	FF	ST	WF	AF
	AUD		4.3	1				1
	COG	4.6	4.6	4.6				4.6
	PSYM							
	VIS	5.9	5.9	5.9				5.9
Most Likely Time to Complete (s)		1.6	1.0	1.2				1.2
Fastest Time to Compete (s)		1.2	.6	1.0				1.0

12. Slow or Stop Vehicle and Check		LL	OB	BI	FF	ST	WF	AF
	AUD							
	COG	1.2						1.2
	PSYM	2.6						2.6
	VIS							

13. Monitor Ground Surface		LL	OB	BI	FF	ST	WF	AF
	AUD		4.3	4.3				4.3
	COG	3.7	3.7	3.7				3.7
	PSYM							
	VIS	4	3.7	5				4
Most Likely Time to Complete (s)		1.6		1.2			1.0	1.0
Fastest Time to Compete (s)		1.2		1.0			.9	.9

14. Ground Surface Suitable for Travel?		LL	OB	BI	FF	ST	WF	AF
	AUD		4.3	4.3				4.3
	COG	6.8	3.7	4.6		5.3		4.6
	PSYM							
	VIS	4	3.7	4		4		4
Most Likely Time to Complete (s)		1.6		1.2			1.0	1.0
Fastest Time to Compete (s)		1.2		1.0			.9	.9

15. Suitable

	LL	OB	BI	FF	ST	WF	AF
AUD		4.3	4.3				4.3
COG	6.8	3.7	4.6		5.3		4.6
PSYM							
VIS	4	3.7	4		4		4
Most Likely Time to Complete (s)	1.6		1.2			1.0	1.0
Fastest Time to Compete (s)	1.2		1.0			.9	.9

16. Not Suitable

	LL	OB	BI	FF	ST	WF	AF
AUD		4.3	4.3				4.3
COG	6.8	3.7	4.6		5.3		4.6
PSYM							
VIS	4	3.7	4		4		4
Most Likely Time to Complete (s)	1.6		1.2			1.0	1.0
Fastest Time to Compete (s)	1.2		1.0			.9	.9

17. Change Course

	LL	OB	BI	FF	ST	WF	AF
AUD							
COG	1	1					1
PSYM	2.6	2.6					2.6
VIS	5.4	3.7					5.4
Most Likely Time to Complete (s)	3.0	1.5					3.0
Fastest Time to Compete (s)	1.2	1					1.2

18. (dummy)

Function 5: Perform Self Recovery

Tasks:

1. Perform Self-Recovery

	LL	OB	BI	FF	ST	WF	AF
AUD							
COG	6.8	3.7				4.6	4.6
PSYM	4.6	2.6					2.6
VIS	7	5				5.4	5.4

2. Need to Change Direction?

	LL	OB	BI	FF	ST	WF	AF
AUD							
COG	7	3.7			5.3	4.6	4.6
PSYM							
VIS	7	5			5.4	7	5.4
Most Likely Time to Complete (s)	1.8	1.0			1.2		1.2
Fastest Time to Compete (s)	1.2	.6			1.0		1.0

3. Change Needed (dummy)

4. Look to Sides Estimate Correction

	LL	OB	BI	FF	ST	WF	AF
AUD							
COG	6.8	3.7			5.3	4.6	4.6
PSYM	1	1			1	1	1
VIS	7	5			5.4	7	5.4
Most Likely Time to Complete (s)	1.4	1.0			1.0		1.0
Fastest Time to Compete (s)	1.25	.6			.9		.9

5. Change Not Needed		LL	OB	BI	FF	ST	WF	AF
	AUD							
	COG	1.2						1.2
	PSYM							
	VIS							
Most Likely Time to Complete (s)		1.8	1.0					1.8
Fastest Time to Compete (s)		1.2	.6					1.2

6. Need to Reverse Direction?		LL	OB	BI	FF	ST	WF	AF
	AUD							
	COG	1.2						1.2
	PSYM							
	VIS							
Most Likely Time to Complete (s)		1.2	1.0					1.2
Fastest Time to Compete (s)		1.2	.6					1.2

7. Reverse Needed		LL	OB	BI	FF	ST	WF	AF
	AUD							
	COG	1.2						1.2
	PSYM							
	VIS							
Most Likely Time to Complete (s)		1.2	1.0					1.2
Fastest Time to Compete (s)		1.2	.6					1.2

8. Look to Rear, Back-up		LL	OB	BI	FF	ST	WF	AF
	AUD							
	COG	6.8	3.7			5.3		5.3
	PSYM	2.6						2.6
	VIS	7	5			5.4		5.4
Most Likely Time to Complete (s)		14.0	6.0				10.0	10.0
Fastest Time to Compete (s)		8.0	3.0				5.0	5.0

9. Change Direction		LL	OB	BI	FF	ST	WF	AF
	AUD							
	COG	1.2						1.2
	PSYM	2.6						2.6
	VIS							
Most Likely Time to Complete (s)		4.2	2.0				3.0	3.0
Fastest Time to Compete (s)		2.0	.9				1.5	1.5

10. Reverse Not Needed		LL	OB	BI	FF	ST	WF	AF
	AUD							
	COG	1.2						1.2
	PSYM							
	VIS							
Most Likely Time to Complete (s)		1.2	1.0					1.2
Fastest Time to Compete (s)		1.0	.6					1.0

11. Proceed (dummy)

Function 6: Nothing Happens (dummy)

Function 7: Steer Vehicle

Tasks:

1. Steer Vehicle (dummy)

2. Steer Right		LL	OB	BI	FF	ST	WF	AF
	AUD							
	COG	1	1		1		1	1
	PSYM	2.6	2.6		2.6		2.6	2.6
	VIS	5.4	3.7		4		5	4
Most Likely Time to Complete (s)		1.3			1.0			1.0
Fastest Time to Compete (s)		.95			.8			.8

3. Steer Left		LL	OB	BI	FF	ST	WF	AF
	AUD							
	COG	1	1		1		1	1
	PSYM	2.6	2.6		2.6		2.6	2.6
	VIS	5.4	3.7		4		5	4
Most Likely Time to Complete (s)		1.3			1.0			1.0
Fastest Time to Compete (s)		.95			.8			.8

4. Hold Straight		LL	OB	BI	FF	ST	WF	AF
	AUD							
	COG	1	1		1			1
	PSYM	2.6	2.6		2.6			2.6
	VIS	5.4	3.7		4			4
Most Likely Time to Complete (s)		1.3			1.0			1.0
Fastest Time to Compete (s)		.95			.8			.8

5. Let Steering Self-Center		LL	OB	BI	FF	ST	WF	AF
	AUD							
	COG							
	PSYM	1			1			1
	VIS	1			4			4
Most Likely Time to Complete (s)		1.3			1.0			1.0
Fastest Time to Compete (s)		.95			.8			.8

6. Verify Center Position		LL	OB	BI	FF	ST	WF	AF
	AUD							
	COG	6.8	1		6.8		4.6	4.6
	PSYM							
	VIS	5.4	3.7		4		5	4
Most Likely Time to Complete (s)		2.5			1.0		1.5	1.0
Fastest Time to Compete (s)		1.2			.8		1.2	.8

7. Verify Steering Control Action		LL	OB	BI	FF	ST	WF	AF
	AUD							
	COG	4.6	1				4.6	4.6
	PSYM							
	VIS	5.4	3.7				5	5
Most Likely Time to Complete (s)		2.0	1.2				1.2	
Fastest Time to Compete (s)		1.2	1.0				1.0	

Function 8: Power Vehicle

Tasks:

1. Power Vehicle (dummy)

2. Accelerator (dummy)

3. Apply Accelerator

	LL	OB	BI	FF	ST	WF	AF
AUD							
COG	1						1
PSYM	2.6						2.6
VIS	1						1
Most Likely Time to Complete (s)	1.3	1.2					1.3
Fastest Time to Compete (s)	1.0	.6					1.0

4. Hold Accelerator

	LL	OB	BI	FF	ST	WF	AF
AUD							
COG	1						1
PSYM	2.6						2.6
VIS	1						1
Most Likely Time to Complete (s)	1.3	1.2					1.3
Fastest Time to Compete (s)	1.0	.6					1.0

5. Let Off Accelerator

	LL	OB	BI	FF	ST	WF	AF
AUD							
COG	1						1
PSYM	2.6						2.6
VIS	1						1
Most Likely Time to Complete (s)	1.3	1.2					1.3
Fastest Time to Compete (s)	1.0	.6					1.0

6. Verify Accelerator Action

	LL	OB	BI	FF	ST	WF	AF
AUD		4.3	1				1
COG	4.6	1	3.7				3.7
PSYM							
VIS	3.7	3.7	3.7				3.7
Most Likely Time to Complete (s)	1.3		1.0				1.0
Fastest Time to Compete (s)	.95		.8				.8

7. Brake (dummy)

Most Likely Time to Complete (s)	1.3	1.2
Fastest Time to Compete (s)	1.0	.6

8. Apply Brake

	LL	OB	BI	FF	ST	WF	AF
AUD							
COG	1						1
PSYM	2.6						2.6
VIS	1						1
Most Likely Time to Complete (s)	1.3	1.2					1.3
Fastest Time to Compete (s)	1.0	.6					1.0

9. Hold Brake		LL	OB	BI	FF	ST	WF	AF
	AUD							
	COG	1						1
	PSYM	2.6						2.6
	VIS	1					1	
Most Likely Time to Complete (s)		1.3	1.2					1.3
Fastest Time to Compete (s)		1.0	.6					1.0

10. Let Off Brake		LL	OB	BI	FF	ST	WF	AF
	AUD							
	COG	1						1
	PSYM	2.6						2.6
	VIS	1					1	
Most Likely Time to Complete (s)		1.3	1.2					1.3
Fastest Time to Compete (s)		1.0	.6					1.0

11. Verify Brake Action		LL	OB	BI	FF	ST	WF	AF
	AUD		4.3	1				1
	COG	4.6	1	3.7				3.7
	PSYM							
	VIS	3.7	3.7	3.7				3.7
Most Likely Time to Complete (s)		1.3	1.0					1.3
Fastest Time to Compete (s)		.95	.8					.8

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13. ABSTRACT *(Maximum 200 words)*

Recent quality increases of sensory feedback for teleoperation are allowing greater sensory immersion for the teleoperator. High speed and off-road driving conditions are critical teleoperator performance hurdles. The primary challenge to the development of good teleoperated systems is the basic driving task essential to the delivery of a mission package. The Human Research and Engineering Directorate of the U.S. Army Research Laboratory is involved with the advance of sensory feedback technologies in teleoperated systems and examines the effect of these technologies on teleoperator performance. Several driving models reflecting different sensory feedback modes were built in MAN-SEVAL, a module of HARDMAN III. Seven models were built in all, including one baseline model of on-board driving. The six other models consisted of low level feedback, binaural feedback, force feedback, stereovision, wide field of view, and all teleoperated feedback combined. These models have identical functional and task flow structures; however, task workloads were altered in each model, based upon the impact of the sensory feedback technology. The purpose of this effort was to 1) define the functions and tasks of the teleoperated driver, 2) formulate teleoperated driving models to assess the teleoperator's driving workload during varying sensory feedback conditions, and 3) develop a prediction tool for the impact of technology on teleoperator workload. Iterative model executions provided data that yielded significant differences between on-board and teleoperated workload as well as among workload for teleoperated models only.

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