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The Effects of a Computer-Aided Teleoperation Technology on Operator Workload and Performance of Concurrent Tasks

Monica M. Glumm
Francis W. Breitenbach
Jock O. Grynovicki

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Glumm, M.M.; Breitenbach, F.W.; Grynovicki, J.O.

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13. ABSTRACT *(Maximum 200 words)*

The feedback limited control system (FELICS) is a computer-aided teleoperation (CAT) technology that enables the remote operator to designate an extended path that the vehicle will automatically follow. This report describes the methodology and results of a study designed to quantify the effects of this technology on remote driving performance and operator workload in both single and dual task conditions. In the dual task condition, the operator's ability to detect and identify targets while driving was also measured. These data were compared with those obtained when the same vehicle was operated in the standard mode of remote driving.

The study was conducted on an indoor test course consisting of five segments: straight-aways, turns, serpentine, figure 8, and obstacle avoidance. Generally, for most segments of the course, greater speeds and fewer errors ($p < .001$) were achieved by subjects who drove the vehicle in the standard mode. In this mode, subjects rated the effort they expended as being less ($p < .05$) than did those subjects who operated the vehicle in the CAT mode. A significant relationship was found across driving modes between the distance traveled off the road and the subjects' assessment of their performance ($p < .05$). An association was also found between the subjects' level of frustration and the number of obstacles hit in the obstacle avoidance segment of the course ($p < .05$). When subjects were required to detect and identify targets while driving, driving speed in both modes decreased significantly ($p < .001$). In the CAT mode, the distance traveled off the road in turns and in the serpentine segments increased ($p < .05$), but driving error in the standard mode on these and other segments of the course was unaffected. Fewer targets were also correctly identified in the CAT mode than in the standard mode of remote operation.

In this report, the design of the specific CAT system being studied and problems generic to similar CAT systems and concepts are implicated in a discussion of the potential causes of these and other differences in performance found between the two modes of remote driving.

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Monica M. Glumm
Francis W. Breitenbach
Jock O. Grynovicki

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

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EXECUTIVE SUMMARY

The feedback limited control system (FELICS) is a computer-aided teleoperation (CAT) technology that enables the remote operator to designate an extended path that the vehicle will automatically follow. Theoretically, while the vehicle is following this path, the operator is provided a greater opportunity to perform another task or control another vehicle. The primary objective of the study described in this report was to quantify the effects of this technology on remote driving performance and operator workload for both single and dual task conditions. In the dual task condition, the operator's ability to detect and identify targets while driving was also measured. These data were compared with those obtained when the same vehicle was operated in the standard mode of remote driving.

The study was conducted on an indoor test course where driving speed and error are measured automatically. The course consists of five segments that include straightaways, right- and left-hand turns, serpentine, figure 8, and obstacle avoidance. For the first four segments of the course, the measure of driving error is the distance traveled off the roadway by one or more of the vehicle's wheels. For the last segment (obstacle avoidance), error is based on the number of obstacles hit.

During the study, each of 32 subjects was randomly assigned to one of two groups. One group was trained and tested in the CAT mode using FELICS; the second group was trained and tested in the standard mode of remote driving. Before training in remote driving, all subjects received training in target recognition and identification, as well as instruction in assessing their workload experience. During training in remote driving, each subject made consecutive runs through the test course in the assigned mode of operation until an asymptote had been attained in both driving speed and accuracy. The subject then completed two additional runs in which he or she received practice in performing the target identification and driving tasks concurrently. A total of six test runs was then performed in the assigned mode of remote driving. During three of these runs, the subject's only task was to drive the vehicle; during another three runs, the subject was required to perform the driving and target identification tasks concurrently.

In all course segments, in both the single and the dual task condition, significantly greater speeds ($p < .001$) were achieved during operations in the standard mode of remote driving. In this mode, by comparison to the CAT mode, fewer errors ($p < .001$) were recorded in all but the straightaway segment of the course where no differences were found between driving modes. In both modes, speed and errors differed among course segments ($p < .001$), and performance in the two modes on each segment followed similar trends. There were no differences between modes in the time to detect targets while driving, but a greater number of targets were correctly identified in the standard mode than in the CAT mode of remote operation ($p < .01$). Driving speed at the time these targets were detected was also higher in the standard mode than in the CAT mode of operation ($p < .001$). As might be expected, speed varied among course segments ($p < .001$), and an interaction was found between segment and driving mode ($p < .001$). In both modes, in the dual task condition, speed on straightaways decreased significantly ($p < .001$). In the CAT mode, the distance traveled off the roadway in turns and in the serpentine segments of the course increased ($p < .05$), but driving error in the standard mode on these and other segments of the course appeared to be unaffected by the introduction of a second task.

For course Segments 1 through 4, there was no indication of a relationship between work-load and driving speed in either mode of operation; however, a relationship was found between the subjects' ratings of their performance and the distance they traveled off the road. There also appeared to be an association between the subjects' level of frustration and the number of obstacles they hit in course Segment 5. In the standard mode, the subjects rated the effort they expended to achieve their level of performance as being less than did those subjects who operated the vehicle in the CAT mode. The subjects' assessment of their workload in the two driving modes followed similar trends in both task conditions. In both driving modes, the subjects' ratings of mental and temporal demands increased significantly in the dual task condition.

The significantly lower speeds attained in the CAT mode are believed to be largely attributable to a design feature that automatically reduces the speed of the vehicle in anticipation of turns to maintain vehicle stability. Inadequate vehicle reference information and difficulties in judging waypoint positioning with respect to road edges and obstacles on curves at distances are believed to be the major causes of operator error in this driving mode. In the CAT mode, frequent correction or redesignation of a previously plotted path may have contributed to an increase in the level of effort experienced by these subjects. The design and offset of the cursor from vehicle centerline created particular difficulties in the obstacle avoidance segment where differences in clearances to the left and right of the vehicle caused confusion, error, and noticeable frustration.

Correction of these problems may go a long way toward narrowing the large gap in performance between this CAT mode and the standard mode of remote driving. However, it is expected that operator perspective and ability to judge vehicle position with respect to road edges and obstacles at distances will remain a factor that may limit the length of the future path and the accuracy with which it is designated.

THE EFFECTS OF A COMPUTER-AIDED TELEOPERATION TECHNOLOGY ON OPERATOR WORKLOAD AND PERFORMANCE OF CONCURRENT TASKS

INTRODUCTION

In both the computer-aided and standard modes of remote driving, the operator's task is to designate the vehicle's path. In the standard mode, the operator maneuvers the vehicle through the scene displayed on a video monitor, providing continuous control input to which the vehicle responses in near real time. In the computer-aided mode, the operator plots an extended path within the driving scene which the vehicle will automatically follow. In this mode, while the vehicle is maneuvering along the designated path, the role of the driver is more that of a supervisor. During this interval in time, the remote driver monitors the progress of the vehicle and watches for any hazards that may not have been detectable from previous positions. This technique of remote driving theoretically offers a reduction in operator workload and potentially enables simultaneous control of another vehicle or the performance of another task. Additionally, in this mode, driver effectiveness may possibly be sustained at video update rates far below those required to control a vehicle in the standard mode of remote operation. This latter capability could result in significant reductions in communications bandwidth and could enhance vehicle survivability on the battlefield.

Although the concept of computer-aided teleoperation is not a new one, there has been little research that supports the anticipated benefits of the concept or that might assist in development of the technology that will. This report presents the results of a study which may provide insight into some of the design and training issues that challenge the developers of this concept--issues that must be resolved before some of the possible payoffs of this new technology can be realized.

This report focuses on a computer-aided teleoperation (CAT) technology called the feedback limited control system (FELICS). FELICS is a patented technology developed by AmDyne Corporation of Millersville, MD. An initial demonstrator was built under a Phase 1 Small Business Innovative Research (SBIR) contract with the Human Research & Engineering Directorate (HRED) of the U.S. Army Research Laboratory (ARL). Further development of this system was funded by the program manager-unmanned ground vehicles (PM-UGV) at Redstone Arsenal, Alabama. In support of the PM-UGV, ARL is conducting research to examine the effects of this technology on operator workload, performance, and ultimately, communications bandwidth requirements.

In 1986, the Jet Propulsion Laboratory (JPL) of the California Institute of Technology demonstrated a similar concept called computer-aided remote driving (CARD) (Holmes, Wilcox, Cameron, Cooper, & Salo, 1986). In this concept, the operator uses a three-axis joystick to move a three-dimensional (3-D) cursor within the driving scene presented on a 3-D video display[1]. The operator selects a point along the path using the cursor and activates a switch on the joystick, which indicates to the control station computer a linear path segment from a previously designated point to the current point. The operator continues to designate straight path segments in this manner until he or she is ready for the vehicle to traverse it. At this point, the operator inputs a command for the vehicle to proceed. When the vehicle reaches the end of the last segment plotted, it automatically stops. The operator may then designate another series of path segments.

By comparison with CARD, FELICS allows the operator to designate an extended curvilinear path using a two-axis joystick that controls the direction and steering of a cursor. The operator drives the cursor within the scene transmitted from a single video camera mounted on a pan-tilt mechanism on board the remote platform. As the cursor moves within the scene, it spawns waypoints in 1-meter intervals, indicating to the operator the path that the vehicle will follow. In the system being studied, a separate speed control lever allows the operator to select the maximum speed the vehicle can attain and puts the vehicle in motion. In FELICS, unlike CARD, while the vehicle is tracking the path just designated, the operator may choose to continue to plot a future path. While the vehicle is moving, the operator may also correct or change the future course of the vehicle by withdrawing waypoints and plotting new ones. The longer the path or the more waypoints plotted, the closer the vehicle is to attaining the maximum speed selected. However, to ensure vehicle stability, the speed of the vehicle is also determined by the straightness of the path that the operator has "drawn."

Both FELICS and CARD were demonstrated during the Office of the Secretary of Defense (OSD) UGV technology evaluation and exploitation demonstration (Demo 1) in the spring of 1992. CARD was implemented on a high mobility multipurpose wheeled vehicle (HMMWV) and FELICS on a commercial, all-terrain platform. Generally, path designation and execution using CARD was considered to be slower than using FELICS, and user interface was less convenient.

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[1] In more recent improvements in CARD, the 3-D cursor is a pseudo-image of a high mobility multipurpose wheeled vehicle (HMMWV), which changes in size and perspective. The joystick has been replaced with a 6-degree-of-freedom spaceball. Processing systems from Silicon Graphics provide a higher resolution 3-D scene.

The PM-UGV, planning further upgrades of FELICS, asked HRED of ARL to conduct an objective assessment of this technology to quantify its effects on remote driving performance and operator workload in both a single and a dual task condition. In the dual task condition, the operator's ability to detect and identify targets while driving was also measured. These data were compared with those obtained when the same vehicle was operated in the standard mode of remote driving. A reduction in the subjects' experiences of workload was expected to be reflected in an increase in the operators' ability to perform the driving and target identification tasks concurrently. The results of this investigation are presented in this report.

OBJECTIVE

The objective of this investigation was to measure and compare the effects of FELICS, a computer-aided teleoperation (CAT) technology, and the standard method of remote driving (i.e., full time soldier-in-the-loop teleoperation) on operator workload and performance of concurrent driving and target identification tasks.

The following questions were to be addressed in the comparison of these two methods of remote driving:

1. Would this CAT technology effect the expected reductions in the operators' experiences of workload?

2. Would this CAT technology enhance the operators' ability to perform the driving and target identification tasks concurrently?

3. What factors may have influenced any differences found in workload and performance between these two modes of remote operation?

METHOD

Subjects

A total of 32 military volunteers participated in this investigation. They ranged in age from 19 to 34 years with an average age of 25. The subjects were licensed drivers with 1 to 17 years of experience. All were screened to ensure that they met the physical qualifications of the target user group relative to color vision and visual acuity of 20/20 vision in one eye and at least 20/100 in the other eye (corrected or uncorrected). The military occupational specialties (MOSs) of the soldier participants included infantryman (11B and 11M), combat engineer (12B and 12F), artilleryman (13B), M1 tank crewman (19K), vehicle mechanic (63B), personnel administration specialist (75B), and motor vehicle operator (88M).

Apparatus

Research Platform

A four-wheel, electrical golf cart (Model X-444), built by E-Z-GO Division of Textron, Inc., served as the research platform (see Figure 1). The golf cart had been converted by the designer of FELICS, to enable operation in either of two modes, the CAT mode or the standard mode of remote driving. The vehicle was approximately 1.0 m (3.3 ft) wide by 2.6 m (8.6 ft) long and capable of attaining a maximum speed of approximately 18 kph (10 mph). Power was supplied by six 6-volt rechargeable batteries.

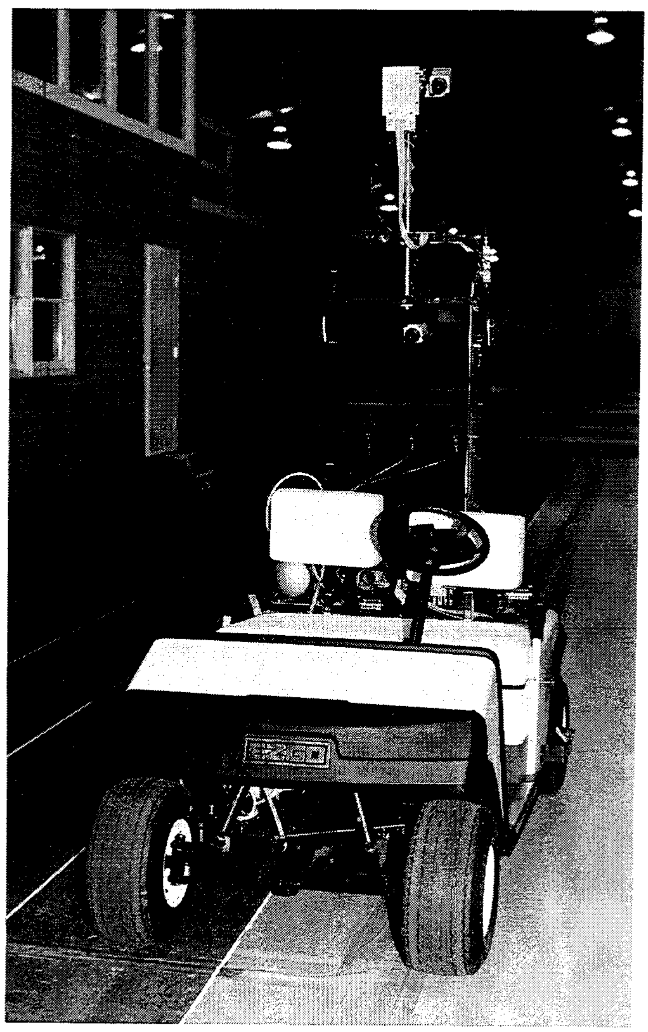

Figure 1. Research platform.

Remote Control Stations

The control station used for operations in the standard mode of remote driving is shown in Figure 2. This control station consisted of a steering wheel, brake, and accelerator pedal. In this driving mode, control functions are the same as those in the standard automobile; however, there is a noticeable delay between control input and vehicle response. This delay is primarily a function of actuator response time and is estimated to range between 250 and 500 milliseconds. Although the delay is prevalent in both modes of remote driving, it is transparent to the computer-aided teleoperator.

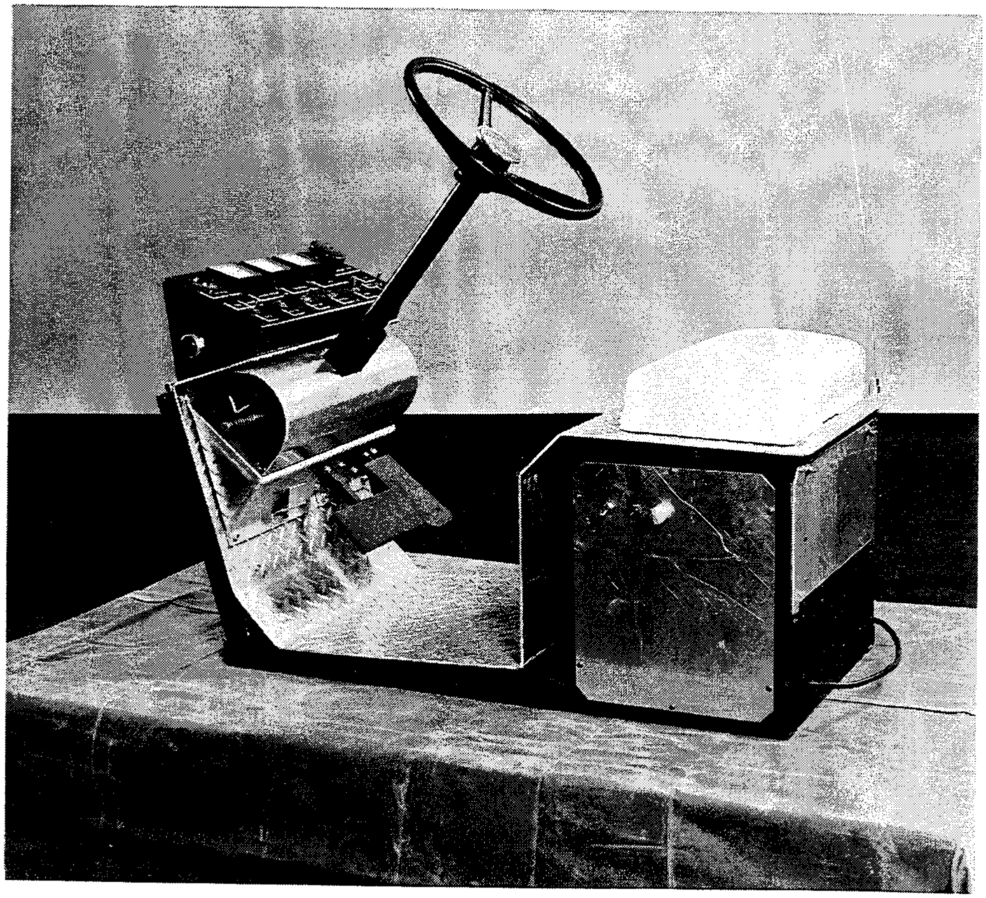

Figure 2. Standard remote driving controls.

Figure 3 shows a displacement joystick with knob that was used for operations in the CAT mode. This control design was selected during an earlier pilot study from two other candidate controllers, which included the standard controls and a two-axis force stick that was supplied by the contractor.

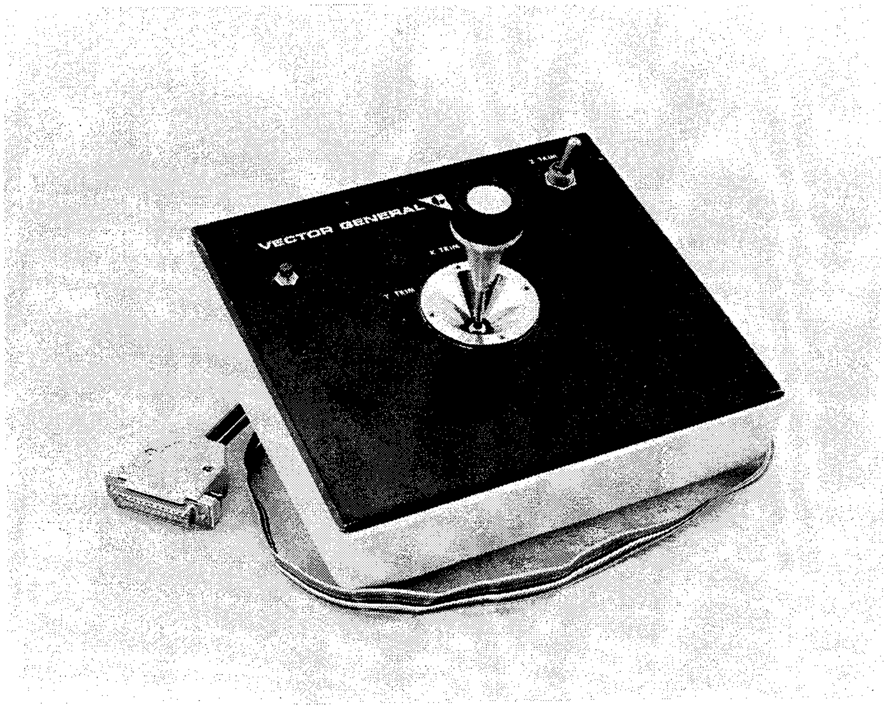

Figure 3. Computer-aided remote driving controls.

In the CAT mode, the joystick controls both direction and steering of the cursor that spawns the waypoints. A forward displacement of the joystick advances the cursor in the forward direction. Simultaneously turning the knob at the top of the joystick to either the left or right steers the cursor. A rearward displacement of the joystick enables the operator to withdraw some or all of the waypoints plotted. If all waypoints are withdrawn, the vehicle will be stopped.

In the CAT mode, a speed control lever determines the maximum speed that the vehicle can attain. The vehicle's ability to attain this maximum speed is also determined by the straightness and the length of the path (number of waypoints) that the operator has plotted. For this study, the speed control lever, located on a separate control box, was always set for maximum speed. The maximum number of waypoints that could be laid on the course at any one time was restricted to 15 by the contractor to minimize down-range and cross-range errors associated with vehicle execution of the designated path[2]. For each of the 15 waypoints attained, another could be plotted. Each pair of waypoints was 1 meter apart. Thus, the maximum length path that could be plotted at any one time was approximately 15 meters (49 ft).

Both the FELICS and standard remote control stations incorporated emergency stop buttons. These buttons would shut the system down if depressed.

[2]Down-range and cross-range errors at maximum distances from the vehicle were estimated by the designer of FELICS to be millimeters and thus, minimal.

Video Camera and Lens

The video camera used for each mode of operation was a 1/2-inch charged couple device (CCD) color camera (Model WV-CL352) with electronic iris manufactured by Panasonic®. In each driving mode, a 6-mm focal length lens, manufactured by COSMICAR®, provided the remote operator an approximate 55° horizontal and 43° vertical field of view (FOV). The resolution of the camera, lens, and display system was 20/200[3].

Given the distinct differences between the two remote driving techniques, it was not possible to select one camera position that would satisfy the operators' vision requirements in both modes without biasing operator performance in one or the other of these modes. Therefore, the camera used for operations in each of the two driving conditions was mounted at a different location on the vehicle.

For remote driving in the standard mode, the camera was centered laterally on the vehicle and fixed at an approximate 10° angle of depression, 1.7 m (5.5 ft) above the ground and 1.9 m (6.2 ft) toward the rear of the vehicle. At this position, the operator was provided a view of the edges of the vehicle's front fenders and the immediate environment through which the vehicle was traveling. This position was selected based on previous research by Glumm, Kilduff, Masley, and Grynovicki (in press).

The position of the remote camera used for operations in the CAT mode was the decision of the contractor who designed the system. In this mode, it was necessary that the camera pan and tilt to enable the operator to designate a future path. Greater camera height was also needed to provide the operator an overwatch perspective of the course for better estimation of waypoint positioning at distances. For this mode, the camera was located 2.5 m above the ground and 1.9 m to the rear of the vehicle. The camera was mounted on the left side of a pan-tilt mechanism which was centered laterally on the vehicle. Thus, in the CAT mode, both camera and cursor were offset from the centerline of the remote platform.

Driving Monitor

For both modes of operation, the video image was displayed to the subjects on a Sony TRINITRON® color monitor (Model PVM-1342Q) with 13-inch screen.

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[3]Measured using the Snellen visual acuity chart.

Target Detection Monitors

Three 20-inch color TV monitors manufactured by Panasonic® (Model 2082) displayed terrain scenes and targets. The three terrain scenes displayed on the three TV monitors formed a composite of "B" section of the Churchville test course. The targets to be superimposed on these terrain scenes included three Soviet vehicles (i.e., a T-72 tank, a BMP, and a Ural truck) and three U.S. systems (i.e., an M1 tank, an M2 Bradley, and a 5-ton truck). Figures 4 and 5 show the control station layout for each of the two remote driving modes.

Procedures

Indoor Test Course

The study was conducted in the joint Aberdeen Test Center (ATC)-ARL robotic test facility's indoor test course at Aberdeen Proving Ground, Maryland (see Figure 6). The course's black macadam roadway is 2.7 m (9 ft) wide and approximately 400 m (1/4 mile) long.

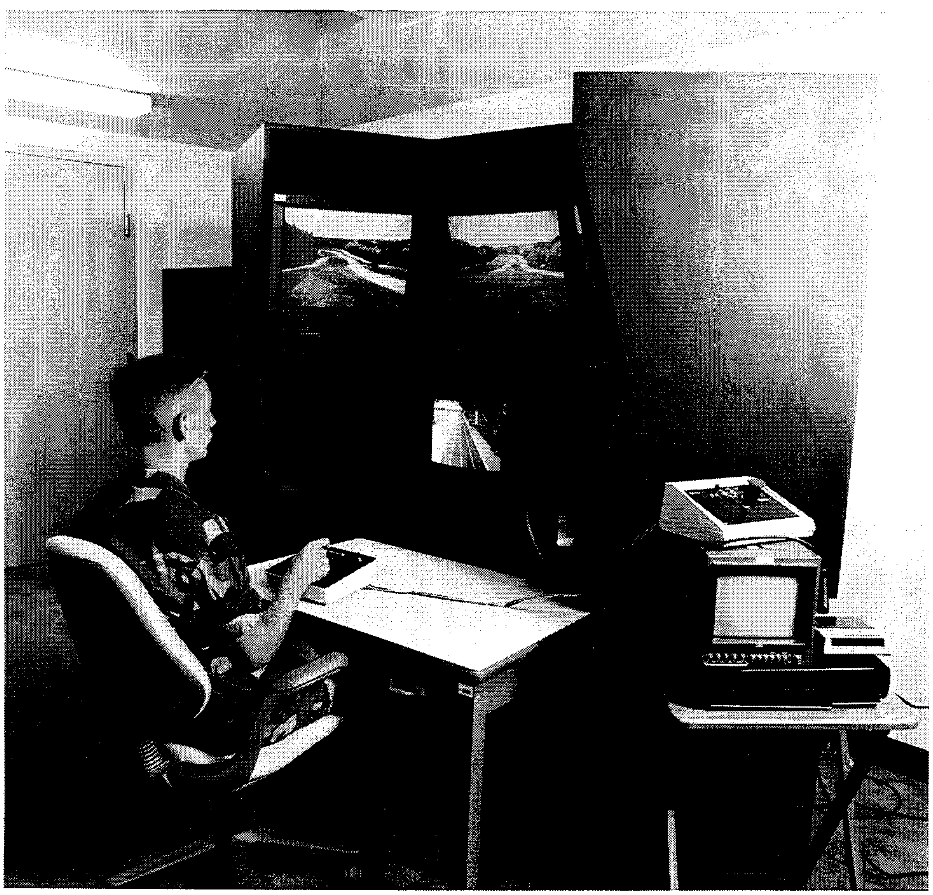

Figure 4. Control station layout for operation in the CAT mode.

Figure 5. Control station layout for operations in the standard mode.

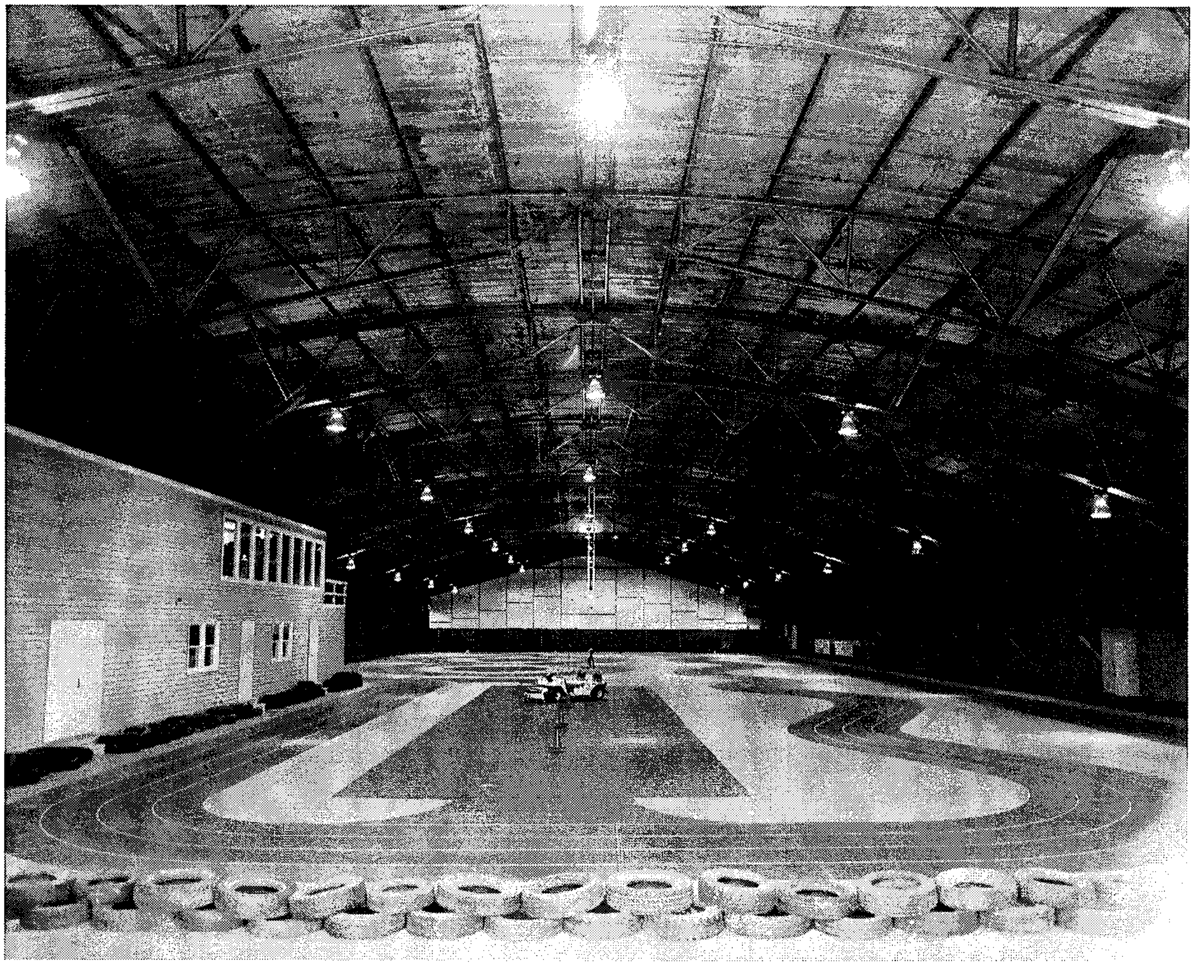

Figure 6. USAATC-ARL robotic test facility's indoor test course.

The area surrounding the road is painted a lighter shade to define path boundaries. The course consists of five segments that include straightaways, turns (right and left hand), serpentine, figure 8, and an obstacle avoidance segment. Three-dimensional cloth objects are hung at points along the roadway to represent trees and brush that would briefly obscure the remote operator's view of the road ahead. For the first four segments of the course, the measure of driving error is the distance traveled off the roadway by one or more of the vehicle's wheels. For the last segment (obstacle avoidance), error is based on the number of obstacles hit. Except for obstacles hit, driving speed and error are scored automatically, and summary statistics are available immediately after each run.

Measures of the deviation of the vehicle from the centerline of the road are used to compute the distance traveled off the road. This centerline, along with four other stripes, is affixed to the road's surface. Each stripe is approximately 1.3 cm (1/2 in.) wide. The stripes are spaced 68.5 cm (27 in.) apart and run parallel along the length of the course. A fluorescent light, video camera, and transmitter are mounted within a hood attached to the front of the vehicle. The fluorescent light illuminates the stripes on the road directly beneath the hood for the video camera. The video image of these stripes is transmitted to the data acquisition center for processing by two contrast trackers. These trackers lock onto the right edge of the right-most stripe in the FOV of the camera and compute the position of that stripe relative to the camera's horizontal FOV. Deviations from the centerline of the road are collected at a rate of 60 times a second.

The obstacle avoidance segment, positioned at the end of the course, is the last maneuver to be performed. In this segment the vehicle is driven between and around four traffic cones spaced approximately 4.9 m (16 ft) apart. The number of traffic cones hit is used to determine the level of accuracy for this segment. Failure to maneuver the vehicle between any two of the traffic cones is also counted as a hit.

A microswitch, positioned at the start of the course, senses the commencement of a run, and data collection is initiated automatically. Data collection is terminated in a similar manner. Microswitches are also positioned at the beginning and end of each course segment. If the vehicle temporarily strays off the course to a point where there are no stripes within the FOV of the camera, microswitches every 4.9 m (16 ft) within each segment identify the vehicle location upon its return and reintiate data collection. Vehicle speed is computed within each of these intervals based on time and distance traveled. The revolutions of a fifth wheel are converted into digital pulses that correspond to the actual distance traveled by the research platform.

Subject Screening and Pretest Questionnaires

An acuity test, at far and near distances, was administered to each of the 32 volunteers to ensure 20/20 vision in one eye and at least 20/100 in the other eye (corrected or uncorrected). This requirement was based on physical qualifications for visual acuity of the target user group. Subjects were also required to pass a color vision test. All subjects completed a questionnaire to obtain pertinent demographic and background information (see Appendix A).

Training

Each of the 32 subjects was randomly assigned to one of two groups. One group (Group A) was trained and tested in the CAT mode, and the other (Group B) was trained and tested in the standard mode of remote driving.

For both groups, the initial phase of the training included instruction about assessing their workload experience in accordance with the prescribed procedures of the subjective workload assessment technique selected: the National Aeronautics and Space Administration-task load index (NASA-TLX). In this technique, the subjects used rating scales to assess the mental, physical, and temporal demands they experienced in performing the task, the level of performance they believed they achieved, the effort they thought they expended to achieve this performance, and their feelings of frustration. Each of these workload factors is defined in Appendix B. All subjects received practice in assessing their workload throughout training in remote driving and target identification.

For each subject group or mode of operation, training in target identification preceded training in remote driving. Initially, during this period, the subject was shown 8x10 color photographs of the vehicles to be detected and identified. These vehicles included three Soviet, and three U.S. systems, which were defined as "enemy" and "friendly," respectively. Both the enemy and friendly vehicles consisted of one tank, one personnel carrier, and one truck. The subjects were trained to recognize design features and characteristics of each of the six systems. In preparation for the tasks they were to perform, the subjects were instructed to first acknowledge the presentation of a new vehicle by announcing "target" and then identify it by owner and type (e.g., "friendly tank" or "enemy truck"). The six photographs were shuffled and continually presented in a randomized order until the subject correctly identified each system by owner and type in three consecutive trials. At this point the subject was seated at the remote control console where he or she viewed target scenarios similar to those that would be presented during the test period. These scenarios were presented on the three TV monitors above the driving display. As during the initial training period, the subjects were required to first acknowledge the presence of the target and then identify it by owner and type. The primary purpose of this phase of training was to familiarize the subjects with the target identification task and to ensure that they understood the procedures to be followed during test. The subjects were required to correctly identify all targets detected in two consecutive target scenarios.

During training, all subjects were shown the same target scenarios in the same order. During test, each of the 16 subjects in Group A was shown different target scenarios. Each of the 16 subjects in Group B was shown the same target scenarios as his or her counterpart in Group A. During any given training or test scenario, a total of 18 targets was presented. Each of the six target types was presented once on each of the three target monitors in a randomized order. The location at which these targets appeared in the scene were also randomized. The size of the targets would vary based on their location. Each target was presented one at a time for a duration of 3 seconds. Target presentation was effected by microswitches every 4.9 m (16 ft) along the roadway of the test course. Except for the obstacle avoidance segment, an equal number of targets was presented in each course segment during each target scenario. In any given course segment, those switches that effected target presentation were varied among scenarios. A time-to-target presentation of 1 to 3 seconds was randomly generated when a designated switch was tripped by the wheels of the remote platform. One of the six target types would then appear at one of the six target locations on one of the three monitors in accordance with a pre-determined scenario on file in the computer. When the target was displayed, a counter was activated. When the subject detected and announced "target," the investigator immediately depressed a pushbutton that stopped the counter. Time to detect and vehicle speed at detection were stored. The subject was then required to identify the target by owner and type. The investigator compared the subject's response with the programmed scenario, noting whether the target was correctly identified. After 3 seconds, the target automatically disappeared from the screen.

After the subject had completed training in target identification, he or she was then trained to operate the vehicle in the driving mode that had been randomly assigned. During this period, the subjects were familiarized with the operation and response of the vehicle's controls and safety features. They were informed that driving speed and accuracy were of equal importance and were instructed to drive as fast as possible while keeping all four wheels on the roadway at all times. After each run through the course, the subjects were informed of their performance. Successive runs were made in the assigned mode of operation until an asymptote had been achieved in both driving speed and accuracy over all course segments. An asymptote was defined as less than a 0.5-kph difference in speed and 5-meter difference in distance traveled off the roadway among three consecutive runs.

After this phase in the training, subjects then received two practice trials in performing the tasks of remote driving and target identification concurrently.

Test

The design matrix for this experiment is shown in Figure 7. The study was a repeated measures design with driving mode a between-subjects factor and course segments and task conditions (single or dual tasks) within-subject factors. The independent variables were remote driving mode, task condition, and course segment. The dependent variables were driving speed and error, the percent of targets correctly identified, the time to detect these targets, and vehicle speed at detection. The measure of error for all course segments, except for obstacle avoidance (Segment 5), was the total distance traveled off the roadway by one or more wheels. The obstacle avoidance segment, positioned at the end of the course, was the last maneuver to be performed. These data were analyzed separately from data obtained on course Segments 1 through 4. The number of traffic cones hit was used to determine driving error for this latter segment.

The workload scores of each subject, as measured by the NASA-TLX, were used as covariates in the analyses of driving speed and error. Although workload could also be considered a dependent variable, its use as a covariate helped to reduce the influence of factors that could not be controlled in this experiment (e.g., driver skill level).

COURSE SEGMENTS		REMOTE DRIVING MODE			
		Computer-Aided Teleoperation (CAT)		Standard (STD)	
		Single (driving only)	Dual (driving and target ID)	Single (driving only)	Dual (driving and target ID)
1	Straightaway				
2	Turns (right- and left-hand)				
3	Serpentine				
4	Figure 8				
5	Obstacle Avoidance				

Figure 7. Design matrix.

During test, each subject performed a total of six runs in the assigned mode of remote driving. During three of these runs, the subject's only task was to drive the vehicle remotely. During the other three runs, the subjects were required to perform the remote driving and target identification task concurrently. The presentation of single and dual tasks for Groups A and B were counterbalanced (see Table 1). In those runs in which the subjects were required to perform two tasks concurrently, each of the 16 subjects assigned to Group A was shown three different target scenarios. Those subjects assigned to Group B were shown the same scenarios as their counterparts in Group A. After each run through the course, subjects were asked to assess their workload experience during that run.

Table 1

Order of Presentation of Single (1) and Dual Tasks (2) for Subject Groups A (CAT) and B (Standard)

Subject A (CAT)	Subject B (STD)	Order of presentation of single (1) and dual (2) tasks					
1	17	1	2	1	2	1	2
2	18	2	1	1	2	2	1
3	19	1	1	1	2	2	2
4	20	2	2	2	1	1	1
5	21	1	2	2	1	1	2
6	22	2	1	2	1	2	1
7	23	1	1	2	2	2	1
8	24	2	2	2	1	1	1
9	25	2	2	1	2	1	1
10	26	1	2	1	2	1	2
11	27	1	1	1	2	2	2
12	28	2	1	2	1	2	1
13	29	1	2	1	2	1	2
14	30	1	2	2	1	2	1
15	31	2	1	2	1	2	1
16	32	2	1	1	2	1	2

RESULTS

Error

Mean driving error (distance traveled off the road) on the first four segments of the course (see Appendix C) was subjected to an analysis of covariance (ANCOVA) with driving mode (STD versus CAT) as a between-subjects effect, and task conditions (single versus dual) and course segments as within-subject effects. As shown in Table 2, a significant main effect was found for driving mode, $F(1,29) = 21.6$, $p < .001$, with mean errors of .21 m and .77 m for the CAT and STD modes, respectively. This main effect was attributed to difficulties that drivers in the CAT mode experienced in judging waypoint positioning at distances from the vehicle. The ANCOVA also revealed a significant main effect for condition, $F(1, 29) = 4.34$, $p < .05$ with mean errors of .77 m and 1.01 m for the single and the dual task condition, respectively. This finding simply indicates that drivers commit more driving errors when required to perform a second task. The significant effect found for segment, $F(3, 90) = 7.86$, $p < .001$, is primarily attributed to the greater driving accuracy achieved on the less difficult straightaway segments of the course. More importantly, a significant interaction for segment and driving mode, $F(3, 90) = 7.66$, $p < .001$, is shown in Figure 8. This interaction is attributed to the lack of a difference in error between the STD and the CAT mode on straightaways as compared to the large differences in errors that occurred between these modes on the other segments of the course. All other effects failed to reach significance at the .05 level of confidence.

In the last segment of the course (obstacle avoidance) by contrast to the first four segments, the measure of driving error was the number of obstacles hit. Therefore, a separate ANCOVA was performed on this segment with driving mode and conditions as within effects. As shown in Table 3, the analysis revealed a significant main effect for driving mode, $F(1, 29) = 218.21$, $p < .001$, with a mean number of hits of .81 and 1.50 for the STD and CAT mode, respectively. This effect is attributed to the design of the cursor and its offset from the centerline of the vehicle, which caused difficulties in judging vehicle position with respect to obstacles. All other effects failed to reach significance at the .05 level.

Table 2

ANCOVA Results of Distance Traveled Off the Road on Course Segments 1 Through 4

Source	SS	df	MS	F	*p*
Driving Mode	309.35	1	309.35	21.60	.001**
Error 1	414.78	29*	14.30		
Condition	9.36	1	9.36	4.34	.046**
Condition X Driving Mode	2.39	1	2.39	1.11	.296
Error 2	62.63	29*	2.16		
Segment	161.13	3	53.71	7.86	.001**
Segment X Driving Mode	157.01	3	52.34	7.66	.001**
Error 3	615.30	90	6.83		
Segment X Condition	6.76	3	2.25	.71	.407
Segment X Condition X Driving Mode	10.97	3	3.66	1.14	.296
Error 4	290.21	90	3.21		

Workload factor	B	t-Value	*p*
Mental	-.00029	-.74747	.455
Physical	-.00029	-.46686	.641
Temporal	-.00033	-.71469	.475
Performance	*.00110*	*2.14836*	*.032***
Effort	-.00035	-.97956	.328
Frustration	-.00060	1.48896	.137

* Missing case.
** Statistically significant.

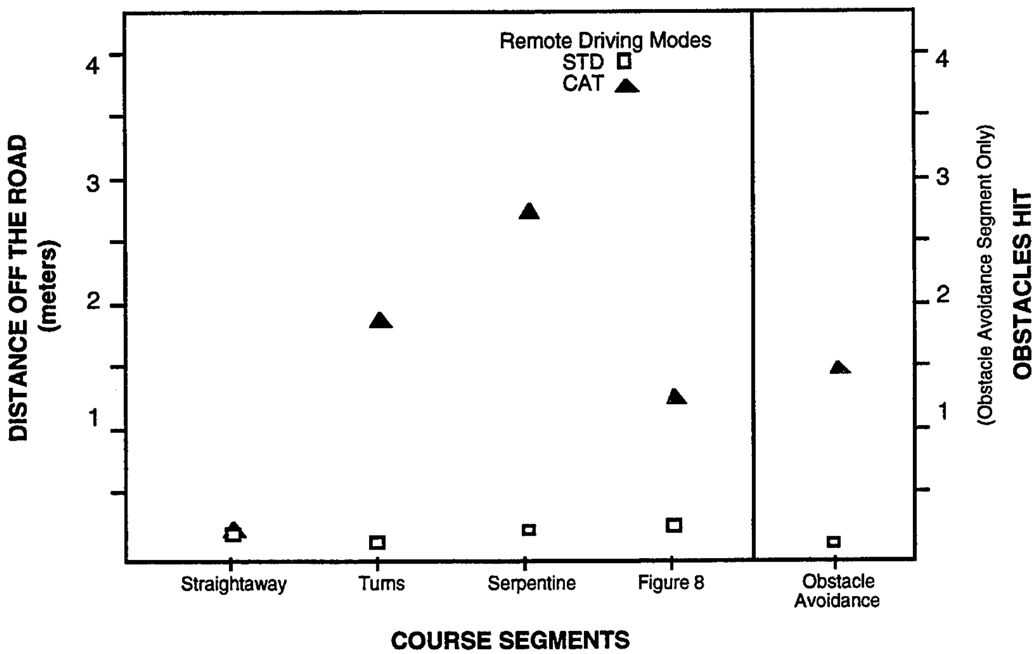

Figure 8. Mean driving error by remote driving mode and course segment averaged over task conditions.

Table 3

ANCOVA Results of Obstacles Hit for Course Segment 5
(natural log transformation used)

Source	SS	df	MS	F	*p*
Driving Mode	23.49	1	23.49	218.21	.001**
Error 1	2.58	29*	.11		
Condition	.09	1	.09	1.27	.270
Condition X Driving Mode	.17	1	.17	2.46	.130
Error 2	2.00	29*	.06		

Workload factor	B	t-Value	*p*
Mental	- .00065	-1.362	.176
Physical	- .00021	- .263	.793
Temporal	- .00054	- .929	.355
Performance	.00088	1.424	.157
Effort	.00027	.558	.578
Frustration	*.00119*	*2.460*	*.015***

* Missing case. ** Statistically significant.

Speed

Mean driving speed on the first four segments of the course was also subjected to an ANCOVA with driving mode (STD versus CAT) as a between-subjects effect, and task conditions (single versus dual) and course segments as within-subject effects. As shown in Table 4, a significant main effect was found for driving mode, $F(1,29) = 196.3$, $p < .001$, with mean speeds of 7.64 kph and 4.69 kph for the STD and CAT, respectively. This main effect was attributed to a design feature of CAT that automatically reduces the speed of the vehicle in anticipation of turns to maintain vehicle stability. The ANCOVA also revealed a significant main effect for conditions, $F(1, 29) = 25.3$, $p < .001$, with mean speeds of 6.36 kph and 5.96 kph for the single and the dual task conditions, respectively. This finding simply indicates that drivers drive more slowly when required to perform a second task. The significant effect found for segment, $F(3, 90) = 296.0$, $p < .001$, is primarily attributed to the greater speeds achieved on the straightaway segments of the course by comparison to any other course segment. Also, speeds in the turns were higher than those in the less predictable serpentine. More importantly, a significant interaction for segment and driving mode, $F(3, 90) = 27.81$, $p < .001$, is shown in Figure 9. This interaction is attributed to the somewhat smaller difference in speed between the STD and the CAT mode on straightaways as compared to the other segments of the course. All other effects failed to reach significance at the .05 level.

To be consistent with the analyses of error, a separate ANCOVA was performed on course Segment 5 (obstacle avoidance) with driving mode and conditions as within effects. As shown in Table 5, the analysis revealed a significant main effect for driving mode, $F(1, 29) = 72.35$, $p < .001$, with mean speeds of 5.21 kph and 3.10 kph for the STD and CAT mode, respectively. As in the analysis of speed on the first four segments of the course, this effect is attributed to a design feature of CAT that reduces the speed of the vehicle in anticipation of turns. All other effects failed to reach significance at the .05 level.

Table 4

ANCOVA Results of Speed on Course Segments 1 Through 4

Source	SS	df	MS	F	*p*
Driving Mode	1568.47	1	1586.47	196.30	.001**
Error 1	234.41	29*	8.08		
Condition	27.61	1	27.61	25.30	.001**
Condition X Driving Mode	.55	1	.55	.51	.540
Error 2	31.57	29*	1.09		
Segment	1078.10	3	359.00	296.00	.001**
Segment X Driving Mode	101.30	3	33.77	27.81	.001**
Error 3	109.29	90	1.21		
Segment X Condition	7.88	3	2.63	.38	.640
Segment X Condition X Driving Mode	.46	3	.15	.02	.970
Error 4	8.42	90	7.87		

Workload factor	B	t-Value	*p*
Mental	-.00208	-1.44829	.148
Physical	.00260	1.15136	.250
Temporal	.00191	1.13632	.256
Performance	.00152	.81061	.418
Effort	-.00041	-.31709	.751
Frustration	-.00010	-.07394	.941

* Missing case.
** Statistically significant.

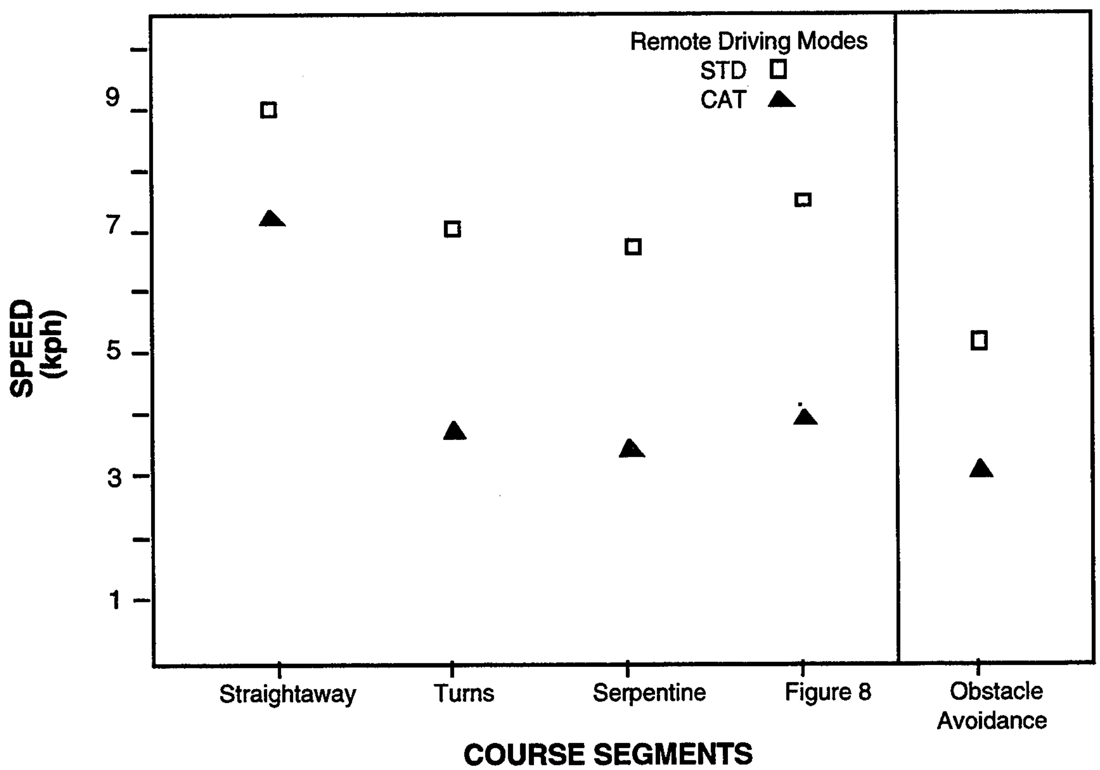

Figure 9. Mean driving speed by remote driving mode and course segment averaged over task conditions.

Table 5

ANCOVA Results of Speed on Course Segment 5

Source	SS	df	MS	F	*p*
Driving Mode	168.27	1	168.27	72.35	.001**
Error 1	5.82	29*	2.33		
Condition	.13	1	.13	74	.399
Condition X Driving Mode	.03	1	.03	.15	.702
Error 2	4.29	29*	.18		

Workload factor	B	t-Value	*p*
Mental	.00077	1.19849	.233
Physical	- .00145	-1.35230	.179
Temporal	- .00002	- .03581	.971
Performance	.00070	.84400	.400
Effort	- .00070	-1.08309	.281
Frustration	.00004	.06902	.945

* Missing case. ** Statistically significant.

Target Identification Performance

The mean number of targets correctly identified, the mean time to detect these targets, and mean driving speed at the time of their detection are provided in Appendix D. The mean number of targets correctly identified was subjected to a chi-square test with driving mode (STD versus CAT) a between-subjects effect and course segment a within-subject effect. As shown in Table 6, a significant main effect was found for driving mode, $x^2 = 8.28$, $p < .01$, with a mean number of correct identifications of 9.80 and 8.42 for the STD and CAT modes, respectively. This main effect may be attributed to a reduction in the amount of time that subjects in the CAT mode spent in target inspection to confirm their identity. All other effects failed to reach significance at the .05 level.

Table 6

Chi-square Test Results of Number of Targets Correctly Identified

Source	Chi-square	df	p
Driving mode	8.288	1	.01**
Segment	4.240	4	.64
Segment X driving mode	0.417	4	.98

** Statistically significant.

The mean time to detect those targets correctly identified, and the mean driving speed at the time these targets were detected, were each subjected to an analysis of variance (ANOVA) with driving mode (STD versus CAT) a between-subjects effect and course segment a within-subject effect. In the analysis of time to detect, as shown in Table 7, all effects failed to reach significance at the .05 level. However, as shown in Table 8, the results of the ANOVA for driving speed at the time these targets were detected revealed a significant main effect for driving mode, $F\ (1,30) = 106.2$, $p < .001$, with a mean speed of 6.21 kph and 3.97 kph for the STD and CAT modes, respectively. As might be expected, a significant main effect was also found for segment, $F\ (4) = 135.2$, $p < .001$, which once again is primarily attributed to the greater speeds achieved in the straightaway segments of the course by comparison to any other course segment. A significant interaction was also found for segment and driving mode, $F\ (4, 120) = 8.48$, $p <$

.001. This interaction is attributed to the somewhat smaller difference in speed between the STD and the CAT mode on straightaways as compared to the other segments of the course.

Table 7

ANOVA Results of Target Detection Time

Source	SS	df	MS	F	*p*
Driving Mode	.54	1	54	3.48	.078
Error 1	4.66	30	.16		
Segment	05	4	.01	.20	.084
Segment X Driving Mode	.09	4	.02	.50	.738
Error 2	5.55	120	.05		

Table 8

ANOVA Results of Vehicle Speed at Target Detection

Source	SS	df	MS	F	*p*
Driving Mode	200.80	1	200.80	106.22	.001**
Error 1	56.71	30	1.89		
Segment	244.88	4	61.22	135.20	.001**
Segment X Driving Mode	15.35	4	3.84	8.48	.001**
Error 2	54.34	120	.45		

** Statistically significant.

Workload

The results of the ANCOVAs for speed and error are also presented in Tables 2 through 5. These results show that there was no relationship between workload and driving speed in either mode of operation, but the subjects' ratings of their performance did appear to be influenced by the distance they traveled off the road, t = 2.148, $p < .05$. An association was also found between the subjects' level of frustration and the number of obstacles hit in the obstacle avoidance segment of the course, t = 2.460, $p < .05$.

A multiple analysis of variance (MANOVA) was performed to determine if there were differences in the subjects' ratings of workload demands between driving modes and task conditions. These ratings are provided in Table E-1 and illustrated in Figure E-1 of Appendix E. The results of the MANOVA based on the Wilks statistic shown in Table 9 indicate that in the standard mode, the subjects rated the effort they expended to achieve their level of performance as being less than did those subjects who operated the vehicle in the CAT mode, $F_{approx} = 4.42$, $p < .05$. The subjects' assessment of their workload in the two driving modes followed similar trends in both task conditions. In the dual task condition, the operators' ratings of mental ($F_{approx} = 9.52$, $p < .05$) and temporal ($F_{approx} = 4.80$, $p < .05$) demands increased significantly in both driving modes.

Table 9

MANOVA Results of Workload (approximate [univariate] F)

Source	SS	MS	F	*p*
Driving Mode				
Mental	110448.04	77268.25	1.4294	.241
Physical	5579.29	26970.09	.2068	.653
Temporal	6244.92	25210.51	.2477	.622
Performance	65084.50	28033.39	2.3216	.138
Effort	*374091.79*	*84542.63*	*4.4248*	*.044***
Frustration	126588.02	34704.82	3.6475	.066
Condition				
Mental	*52173.04*	*5474.81*	*9.5296*	*.004***
Physical	10428.25	6117.35	1.7047	.202
Temporal	*24187.63*	*5028.84*	*4.8097*	*.036***
Performance	159.50	1278.74	.1247	.726
Effort	1435.54	5679.40	.2527	.619
Frustration	7752.08	6392.08	1.2127	.280
ConditionX DrivingMode				
Mental	1328.25	5474.81	.2426	.626
Physical	263.67	6117.35	.0431	.837
Temporal	2234.50	5028.84	.4443	.510
Performance	940.75	1278.74	.7356	.398
Effort	4553.25	5679.40	.8017	.378
Frustration	752.08	6392.08	.1176	.734

** Statistically significant.

DISCUSSION

In this study, subjects in both driving modes experienced an increase in mental and temporal demands when they were required to perform a second task while driving. Contrary to hypothesis, this increase in workload in the dual task condition appeared to have relatively little affect on driving performance in the standard mode. In the CAT mode, however, driving errors on some segments of the course increased significantly. Fewer targets were also correctly identified in this mode than in the standard mode of remote operation. These findings may reflect differences in time-sharing efficiency between the two subject groups which to a great extent, as Wickens (1991) notes, are related to either differences in the automaticity of single-task skills or to time-sharing skills acquired through practice.

For many, the task of driving a standard automobile over known terrain is somewhat automatic when one arrives at his or her destination with no memory of the trip. Although not quite as automatic, remote driving in the standard mode shared more similarities with the on-board driving experience than did CAT. Commonalities in control design and operation and in the information provided in the driving scene, along with years of familiarization with on-board driving, may have facilitiated time sharing of tasks in the standard mode. Dissimilarities between the on-board driving experience and CAT may have caused some conflict. In the everyday operation of a motor vehicle, a driver engages in visual scanning and cognitive processing activities not unlike those involved in the detection and identification of targets. Wickens (1991) suggests that most learned time-sharing skills are probably specific to a given task combination, but one might also expect a transfer of these skills between some task combinations that are similar.

In this study, it was observed that subjects operating in the CAT mode adopted one of three different driving strategies. Some chose to maintain as many waypoints on the course as possible, regardless of segment difficulty, to maximize vehicle speed. It was not unusual for these subjects to plot extended paths down straightaways, around distant turns, and behind obstacles that obscured their view of the road ahead. A few of these subjects were consistently successful in these "blind" maneuvers, but most found it necessary to withdraw waypoints and replot the vehicle's path in attempts to correct for actual or perceived errors as viewed from new and closer camera perspectives. In some instances, as the camera panned around turns to accommodate designation of a future path, the operator was provided only a brief glimpse of previous errors in designation and impending deviations of the vehicle beyond road boundaries. At this point, attempts at total recovery from these errors were futile and cost time and vehicle speed.

Other subjects varied the length of the future path based on segment difficulty and their ability to discern the edges of the road at distances from the vehicle. Many of these operators, for example, maintained the maximum number of waypoints down straightaways, pausing at the end of these segments for the vehicle to approach a point at which its on-board camera captured a better perspective of the impending curve. The subjects would then plot a path only as far as they could see around the turn to ensure accurate positioning of waypoints with respect to the road's centerline. For the most part, these operators appeared to be more successful than those who opted to chance waypoint positioning at maximum distances, but errors in estimating the length of path that could be safely plotted still occurred.

In a third driving strategy, the subjects chose not to plot an extended path in any segment of the course. Rather, in this strategy, subjects were observed to maintain a relatively consistent number of waypoints forward of the vehicle, regardless of segment. Generally, the length of the path or the number of waypoints maintained represented less than half that allowed by the system. It was observed that many of the operators who employed this strategy maintained a fairly consistent speed through most segments of the course, having less need to correct for gross deviations off the road. In some instances, these subjects achieved overall course speeds that were greater than operators who adopted more aggressive strategies. The shorter the future path, however, the more closely this driving strategy resembled operations in the standard mode and the more familiar experience of on-board driving.

The results of this investigation show that those subjects who operated the vehicle in the standard mode attained greater speeds with fewer errors than did those subjects who operated the same vehicle in the CAT mode. The significantly lower speeds attained in the CAT mode are believed to be largely attributable to a design feature that automatically reduces the speed of the vehicle in anticipation of turns to maintain vehicle stability. Difficulties in judging waypoint positioning with respect to road edges and obstacles at distances are expected to be a major cause of errors. In many instances, subjects operating in the CAT mode were observed to redraw a path two to three times, to correct for actual or perceived errors in designation. This, too, may have contributed to reductions in vehicle speed and to the higher levels of effort experienced by subjects in this mode. The increase in errors in the dual task condition may not only reflect a decrease in the accuracy of designating the initial path but possibly a reduction in the speed and frequency at which deviations beyond road boundaries were detected and thus successfully corrected.

Problems in discerning the surface of the road and the spacing between obstacles and road edges at distances were compounded by uncertainties about the vehicle's position. In the standard mode, drivers were provided a view of the vehicle and ground proximate to the remote platform. In this mode, operators appeared to gauge with greater accuracy the position of vehicle's wheels with respect to road edges and confidently cut corners in turns in pursuit of the most efficient path through the course. In the CAT mode, however, a view of the vehicle could not be captured within the operator's visual field unless all waypoints were withdrawn and the vehicle stopped. In this mode, operators were forced to estimate vehicle location based on the position of the cursor and the waypoints it spawned. The design of the cursor, however, and its offset to the left of the centerline of the vehicle made such estimates difficult. The cursor did not resemble the remote platform in either size or shape and provided little information about the position of the vehicle's wheels with respect to road edges. Operators knew approximately where to position the cursor with respect to the centerline of the road so as to center the vehicle between the road's borders, but they remained uncertain about how far to the left or right of this point they could deviate without overshooting these borders. In the CAT mode, there was a greater tendency for operators to designate a path that closely conformed to the curvature of the road. Waypoints that appeared to deviate from this more reliable track were often withdrawn and the path redesignated. The design and offset of the cursor created particular difficulties in the obstacle avoidance segment of the course where differences in the clearances to the left and right of the vehicle were a major source of confusion and error. In this segment, operators underestimated clearances between the vehicle and traffic cones to the left of the remote platform, causing them to make wider turns around these obstacles. Limitations in the turning radius of the vehicle combined with operator overestimation of the clearance between the vehicle and traffic cones to the right of the remote platform resulted in obstacle hits. This, too, may have contributed to differences in vehicle speed between driving modes, as well as to the higher levels of effort experienced by these subjects.

CONCLUSIONS AND RECOMMENDATIONS

In both the standard and computer-aided mode of remote driving, the operator relies on visual information within the scene to select a safe and efficient path. As one might expect, deficits in information that may at times affect teleoperators' ability to judge the suitability of more immediate paths may have an even greater impact on their ability to assess the suitability of distant terrain and designate with accuracy the route selected. System resolution is not thought to have had a significant influence on driving error in the current assessment, but it is expected to be a factor during cross-country travel or when road edges and obstacles are not as well defined.

In this study, differences in driving performance between the two driving modes are believed to have been influenced by design characteristics of the specific CAT system assessed as well as by problems inherent to similar systems and concepts that rely on the remote operator's ability to see and thus accurately designate a suitable path at distances from the vehicle.

In the present assessment, one of the major causes of differences in speed between driving modes is a design feature that automatically reduces the speed of the vehicle in anticipation of future deviations from a straight line path. Although the designer of FELICS believes computer control of vehicle speed is necessary to maintain vehicle stability, it is recommended that the system be modified to provide the remote operator the option of assuming responsibility for such decisions, as tactics direct and terrain permits.

In this study, the design of the cursor for the CAT system and its offset from the centerline of the vehicle was a major source of confusion and error. It is recommended that the cursor be redesigned to accurately depict the size and perspective of the vehicle as the distance and the angle from which this cursor is viewed changes. The camera should either be centered laterally on the vehicle or corrections made in the programming so that the centerline of the cursor accurately denotes the centerline of the vehicle.

An increase in camera height may improve the operator's perspective of the future path, and a zoom capability may provide some help in detecting hazards and discerning road edges, but image stabilization then becomes a necessity. Sensors on board the remote platform may prove useful in providing information about terrain roughness or the proximity of obstacles and other hazards that may not have been detectable from previous positions. Such sensors may be deemed necessary when update rate and resolution are reduced to achieve a reduction in communications bandwidth. Nonetheless, operator perspective and the difficulties it may cause in judging vehicle position with respect to road edges and obstacles at distances will remain a factor that may limit the length of the future path and the accuracy with which it is designated.

In this study, those subjects who drove the vehicle in the CAT mode often likened it to playing a video game. Some subjects, who were accustomed to playing video games on a regular basis, indicated that it took some time to adjust to a different controller. They recommended the use of a joystick control with which video game enthusiasts are more familiar.

The need for additional training and practice is implied by differences in the workload demands perceived by subjects in the two modes of remote operation and the effects that these demands had or did not have on driving performance. However, solving the problems just described is expected to narrow the gap between performance in the two driving modes and to eventually demonstrate the benefits that perhaps only computer-aided teleoperation technology can offer in the area of bandwidth reduction.

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APPENDIX A

PRETEST (DEMOGRAPHIC) QUESTIONNAIRE

PRETEST (DEMOGRAPHIC) QUESTIONNAIRE

Please answer the following questions. The information you provide will be kept *<u>CONFIDENTIAL.</u>*

1. Name: ____
   Last First Middle Initial

2. Rank: __________________

3. Military Occupational Specialty (MOS): ________________

4. Time in Service: ______years

5. Age: ___________

6. Height: ___________

7. Weight: ___________

8. Are you left- or right-handed?

   Left-Handed [ ] Right-Handed [ ]

9. Do you wear eyeglasses or contacts?

   Yes [ ] No [ ]

10. How often do you play video or arcade games? *(Check one)*

    All the Time [ ]
    Often [ ]
    Sometimes [ ]
    Rarely [ ]
    Never [ ]

11. Have you ever been motion sick (for example: seasick, carsick, airsick, trainsick, etc.) ?

Yes [ ]   No [ ]

If YES, explain ____
____
____

12. How susceptible are you to motion sickness? *(Check one)*

Extremely [ ]
Very [ ]
Moderately [ ]
Minimally [ ]
Not at All [ ]

APPENDIX B

WORKLOAD RATING SCALE DEFINITIONS

7. SUBJECT INSTRUCTIONS: SOURCES-OF-WORKLOAD EVALUATION

Throughout this experiment the rating scales are used to assess your experiences in the different task conditions. Scales of this sort are extremely useful, but their utility suffers from the tendency people have to interpret them in individual ways. For example, some people feel that mental or temporal demands are the essential aspects of workload regardless of the effort they expended on a given task or the level of performance they achieved. Others feel that if they performed well the workload must have been low and if they performed badly it must have been high. Yet others feel that effort or feelings of frustration are the most important factors in workload; and so on. The results of previous studies have already found every conceivable pattern of values. In addition, the factors that create levels of workload differ depending on the task. For example, some tasks might be difficult because they must be completed very quickly. Others may seem easy or hard because of the intensity of mental or physical effort required. Yet others feel difficult because they cannot be performed well, no matter how much effort is expended.

The evaluation you are about to perform is a technique that has been developed by NASA to assess the relative importance of six factors in determining how much workload you experienced. The procedure is simple: You will be presented with a series of pairs of rating scale titles (for example, Effort vs. Mental Demands) and asked to choose which of the items was more important to your experience of workload in the task(s) that you just performed. Each pair of scale titles will appear on a separate card.

Circle the Scale Title that represents the more important contributor to workload for the specific task(s) you performed in this experiment.

After you have finished the entire series we will be able to use the pattern of your choices to create a weighted combination of the ratings from that task into a summary workload score. Please consider your choices carefully and make them consistent with how you used the rating scales during the particular task you were asked to evaluate. Don't think that there is any *correct* pattern; we are only interested in your opinions.

If you have any questions, please ask them now. Otherwise, start whenever you are ready. Thank you for your participation.

Appendix A.

RATING SCALE DEFINITIONS

Title	Endpoints	Descriptions
MENTAL DEMAND	*Low/High*	How much mental and perceptual activity was required (e.g., thinking, deciding, calculating, remembering, looking, searching, etc.)? Was the task easy or demanding, simple or complex, exacting or forgiving?
PHYSICAL DEMAND	*Low/High*	How much physical activity was required (e.g., pushing, pulling, turning, controlling, activating, etc.)? Was the task easy or demanding, slow or brisk, slack or strenuous, restful or laborious?
TEMPORAL DEMAND	*Low/High*	How much time pressure did you feel due to the rate or pace at which the tasks or task elements occurred? Was the pace slow and leisurely or rapid and frantic?
PERFORMANCE	*Perfect/Failure*	How successful do you think you were in accomplishing the goals of the task set by the experimenter (or yourself)? How satisfied were you with your performance in accomplishing these goals?
EFFORT	*Low/High*	How hard did you have to work (mentally and physically) to accomplish your level of performance?
FRUSTRATION LEVEL	*Low/High*	How insecure, discouraged, irritated, stressed and annoyed versus secure, gratified, content, relaxed and complacent did you feel during the task?

APPENDIX C

MEAN DRIVING SPEED AND ERROR BY DRIVING MODE AND COURSE SEGMENT FOR SINGLE AND DUAL TASK CONDITIONS

Table C-1

Mean Driving Speed and Error by Driving Mode and Course Segment for Single and Dual Task Conditions

		Speed (kph)						Error[a]					
		CAT			STD			CAT			STD		
Course segment		Single	Dual	$\bar{x}$	Single	Dual	$\bar{x}$	Single	Dual	$\bar{x}$	Single	Dual	$\bar{x}$
1 straightaway		7.69	6.93	7.31	9.41	8.69	9.05	.09	.43	.26	.12	.26	.19
2 turns	4.01	3.73	3.87	7.24	6.80	7.02	1.50	2.30	1.90	.09	.16	.12	
3 serpentine	3.66	3.47	3.57	6.97	6.71	6.84	2.47	3.06	2.76	.21	.28	.24	
4 figure 8	4.07	3.91	3.99	7.83	7.47	7.65	1.51	1.17	1.34	.20	.40	.30	
Overall $\bar{x}$	4.86	4.51	4.69	7.86	7.42	7.64	1.39	1.74	1.57	.16	.28	.21	
5 obstacle avoidance		3.08	3.12	3.10	5.19	5.22	5.21	1.60	1.40	1.50	.10	.15	.13

[a]For course Segments 1 through 4, distance traveled off the course is reported in meters (m). For course Segment 5, errors are reported in number of hits.

APPENDIX D

MEAN NUMBER OF TARGETS CORRECTLY IDENTIFIED, TARGET DETECTION TIME, AND VEHICLE SPEED AT TARGET DETECTION BY DRIVING MODE AND COURSE SEGMENT

Table D-1

Mean Number of Targets Correctly Identified, Target Detection Time, and Vehicle Speed at Target Detection by Driving Mode and Course Segment

Course segment	Number of targets correctly identified[a]		Detection time[b] (sec)		Vehicle speed at detection[b] (kph)	
	CAT	STD	CAT	STD	CAT	STD
1 straightaways	9.75	11.43	1.61	1.50	6.72	7.89
2 turns	9.93	11.31	1.58	1.45	3.05	5.78
3 serpentine	8.75	10.43	1.54	1.48	3.76	6.22
4 figure 8	9.68	10.81	1.63	1.44	3.71	6.59
5 obstacle avoidance	4.00	5.00	1.54	1.49	2.61	4.55
Mean	8.42	9.80	1.58	1.47	3.97	6.21

[a]The mean of the total number of targets correctly identified in three trials.
[b]For those targets correctly identified.

APPENDIX E

MEAN RATINGS OF WORKLOAD BY DRIVING MODE FOR SINGLE AND DUAL TASK CONDITIONS

MEAN RATINGS OF WORKLOAD BY DRIVING MODE FOR SINGLE AND DUAL TASK CONDITIONS

Table E-1

Mean Ratings of Workload[a] by Driving Mode for Single and Dual Task Conditions

Factor	Single		Dual	
	CAT	STD	CAT	STD
Mental demand	213	160	241	198
Physical demand	48	34	60	51
Temporal demand	84	89	100	118
Performance	111	78	117	76
Effort	229	131	226	146
Frustration	88	31	97	50
Overall rating	51	35	56	42

[a]Workload ratings for each factor were obtained by multiplying the raw rating by the weight given to that factor by the subject. The overall rating of workload is the sum of these adjusted ratings divided by 15, which is the sum of the weights.

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