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USES OF COMPUTER-ASSISTED INSTRUCTION IN DEVELOPING PSYCHOMOTOR SKILLS RELATED TO HEAVY MACHINE OPERATION

by

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A study was performed to determine the relative effectiveness of different formats of computer-assisted instruction (CAI) in teaching a psychomotor performance task. A control group combining male and female subjects received instruction based on the study of written materials and unstructured practice sessions on a heavy transmission gear-shifting task. No significant differences were found between male and female performance patterns and learning abilities under control conditions. →

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Two experimental groups, both restricted to males, were trained under similar practice conditions with the addition of computer monitoring of performance and feedback of supplemental information to the students. One group received terminal feedback of numerical performance quality scores following each trial. The other group received continuous feedback of an analytic display (a display of nominal roadspeed against elapsed time in the form of an X-Y plot) concurrent with each trial. Both experimental groups were tested for retention of skills after transitioning to a non-feedback performance environment. Both forms of computer-assisted instruction proved to be significantly superior to the control teaching procedure.

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INTRODUCTION

Many systems of programmed instruction involving computer interaction with students have been developed for training intellectual skills. The skills involved in machinery operation are not purely intellectual, but rather psychomotor. These skills include the coordination of relatively independent muscle systems, precision in manipulative control, translation of visual input into motor output, and the continuous integration of sensory information concerning machine functions into motor output. These psychomotor and tracking skills are quite different from the intellectual material that is usually taught by CAI techniques.

Examination of the literature on CAI indicates that when it is incorporated in simulator training of psychomotor skills, it is generally utilized as a means of controlling an iterative training sequence. CAI is generally not utilized to give subjects immediate feedback of psychomotor output parameters. When a subject's performance is compared to an established criterion or model, it is done to determine if the subject has satisfactorily completed the training program (Rigney, Morrison, Williams, and Towne, 1973; Rigney, Towne, and Morrison, 1975; Feurzeig, Cohen-Lukas, and Schiff, 1975; Faconti, Mortimer, and Simpson, 1970; Charles, Johnsons, and Swink, 1973; and Caro, 1973).

This information is not often used to indicate the "goodness of fit" of a student performance model relative to an ideal model. Feedback of information indicating the relationship of a student's performance to a control model can serve to improve the subject's performance. Holding (1965) sites the beneficial use of such performance feedback for training air to air gunnery skills as well as a variety of other psychomotor skills.

Kelley (1968) discussed the effectiveness of augmented displays and controls, such as quickened and predictor displays, when they are used in operational environments. Such displays and controls allowed subjects to predict how their control actions approximated those necessary to achieve the system goals. Hence, the subjects were able to compare their performance models against a control or ideal model. Real-time feedback methods are limited in their application in operational systems. There are many situations where such displays and controls cannot be used because extraneous environmental factors are too numerous. In a simulator the extraneous factors are controlled, which makes it possible to establish a control model for virtually an unlimited number of variations in the simulator's operation. Augmented displays and controls much like those suggested by Kelley (1968) can effectively be developed for training on virtually any motor performance task. Implementing such displays should result in improved

performance on the simulator, but may also reduce the transfer of this training to operational situations where the special displays and controls are replaced with conventional operating equipment.

The advantage of using such displays in simulation training lies in the immediate matching of the motor actions of the subject's operational models with the control model. The problem with using such real-time feedback in training was considered in an outline by Holding (1965) of training considerations related to handling knowledge of results.

Holding (1965) first established a distinction between intrinsic and artificial knowledge of results. Artificial knowledge was defined as any score, display, or message that was used in training, but did not appear in the operating environment of the device whose function was being learned. Ultimately, each trainee must learn to perform the task under actual operating conditions; that is with intrinsic knowledge of results only, if the training skills are to be generalizable. A transition from artificial to intrinsic cues should be provided as part of any training routine in which artificial knowledge is used.

Holding (1965) made a further distinction between concurrent and terminal feedback of artificial cues, and considered terminal feedback to be superior on a number of grounds. Concurrent feedback tended to inhibit the transition to intrinsic cue monitoring, since the student's

attention was largely devoted to the concurrent display. However, the case was not simple. Concurrent feedback such as that in augmented displays may offer the best possibility for initially guiding the student's motor output into an approximation of the desired coordinated output pattern, and can be considered to be a means of securing a forced response rather than a channel for the communication of information. Furthermore, when concurrent feedback is intermittent, it takes on many of the characteristics of terminal feedback.

In this study, the performance of subjects on a psychomotor task was examined after they had received simulator training using intrinsic feedback only; intrinsic plus terminal artificial feedback; or intrinsic feedback plus a combination of terminal and concurrent artificial feedback.

METHODS

SUBJECTS

Subjects for this study were sixty paid volunteers from the student population at the University of South Dakota at Vermillion. All subjects were screened for 20/30 corrected vision, and had driven manual transmission cars.

Because of the difficulty of evaluating training procedures with a repeated measures design, we used independent and non-overlapping experimental and control groups. Subjects were assigned to one group or another in the order in which they volunteered for the study. Table 1 gives a description of the different groups.

The groups did not differ significantly in age or stated experience in handling manual transmission vehicles. This equality of stated experience applied to the female control group as well as to the three male groups. Since there is a fair exposure to machinery-handling for college-age females in the rural South Dakota environment, the female subject pool may have contained a biased sample of individual volunteers, weighted in favor of persons with such experience when compared to the national average.

All subjects were given identical briefings and instructions (see Appendix A), and all were told they were participating in a computer teaching experiment. The experimenters were aware of the subjects' status as being either

Table 1
Subject Ages Within Groups

	Sample Size	Age Range	Mean Age
Male Control Group	15	19-27	20.8
Female Control Group	15	18-28	20.4
Terminal Feedback Group	15	19-29	21.0
Graphic Feedback Group	15	18-24	19.7

experimental or control. However, there was no indication that any contamination of results followed from this lack of a double blind procedure.

APPARATUS

A heavy truck transmission and gear shifting mechanism was used as a test bed for different formats of computer-student interaction. This task was chosen because of the ease with which a wide range of different computer instruction techniques could be associated with it, and because it was generally representative of a large family of man-machine interactions involving foot and hand control of rotating machinery.

The training apparatus consisted of an actual transmission unit, clutch assembly, and throttle control. The transmission was driven by a variable speed electric motor controlled by the throttle pedal through a pedal operated clutch. The student's right hand operated a direct-link shift lever through a six slot plus neutral pattern. Nominal engine RPM values and MPH road speeds were displayed to the student on a video screen using horizontal bar-type scales. No attempt was made to simulate the larger visual input of an actual operating environment. The same RPM and MPH displays were used whenever intrinsic feedback was utilized.

The information monitored by the computer included input and output shaft rotation rates nominally equivalent to RPM and MPH, respectively. The position of the throttle

and clutch pedals and the gear shift lever was detected by potentiometers and magnetic reed switches and fed into the computer to be compared with a stored model of ideal performance. Each of the five analog parameters being monitored was digitally sampled at one-hundred samples/second, but only ten samples/second were actually stored in the computer memory for further reference. The simulator was controlled by a DEC PCP8-E computer system, with 32K of 12 bit core memory. For a full description of the computer system and description of the minimum system required to operate the simulator see Appendix F.

TASK AND TEST CONDITIONS

The performance required of the student was to reach an indicated 55 MPH road speed in exactly 22 seconds with the greatest possible degree of "smoothness" while shifting through all the gears. The passage of 22 seconds was indicated by a buzzer, and smoothness was defined in terms of maintaining equal increments of acceleration over time during the shifting sequences.

CONTROL CONDITION

The control condition for learning this task without computer mediated feedback involved reading a manual, taking a quiz on the contents of the manual, further study of the manual until a criterion quiz score was reached, and a thirty minute practice session on the device involving

twenty 4-shift sequences. Under the control condition, subjects received only RPM and speed displays (intrinsic feedback) and received no performance feedback after each trial (terminal feedback). Since the computer display unit was used to present MPH and RPM data in this "control" condition (see Figure 1), and since the computer was also used to demonstrate the desired twenty-two second execution interval, students in the control group could believably be told to consider themselves part of a "computer education" experiment, even though no actual feedback of individual performance parameters was involved. All feedback in the control condition was intrinsic.

EXPERIMENTAL CONDITIONS

Two experimental groups were run, each receiving a different form of performance feedback. Each experimental condition was similar to the control condition in that the participants first studied the instruction manual until a criterion test score was reached. The same demand scheduling of twenty 4-shift sequences were used.

The experimental treatment differed from the control treatment in that different types of supplementary feedback were provided for each of the two experimental groups to supplement or replace the intrinsic feedback available in the control groups. Descriptions of the two treatments follow.

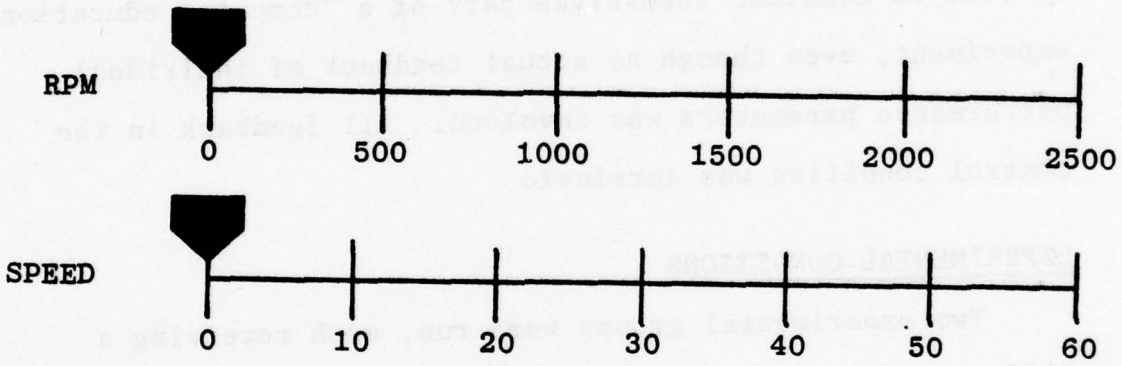

Figure 1
Instrumentation Displayed During All
Intrinsic Real-Time Feedback Conditions.

Numerical, Terminal Feedback (Terminal Group)

Two numerical scores were calculated. A "smoothness" score was based on a sum-of-squares deviation of actual acceleration from the desired acceleration profile. This smoothness of acceleration score was scaled in arbitrary units from 0 to 100, zero representing a perfect score. A time-off-target score was based on the elapsed time between the start of the run and the first point at which a 55 MPH indicated road speed was reached, minus the 22 second target interval. This value was scaled in seconds and tenths. These primary performance scores were displayed to the student at the end of each single trial. A composite score and an historic record of scores for earlier trials was also displayed.

Figure 2 shows an example of the display seen by a subject on the eighth of twenty trials. These subjects received intrinsic feedback only during the trial itself. Using the performance score feedback, the subject could see at once the relative success of particular performance attempts, and could immediately see the effect of any modification or variation of their performance tactics. The subject could also immediately see if progress was being made in both a short term and a long term sense. Most importantly, if a single successful run was made, the subject was aware of this at once while the proprioceptive sensations of the performance were still reasonably immediate, accessible, and reproducible.

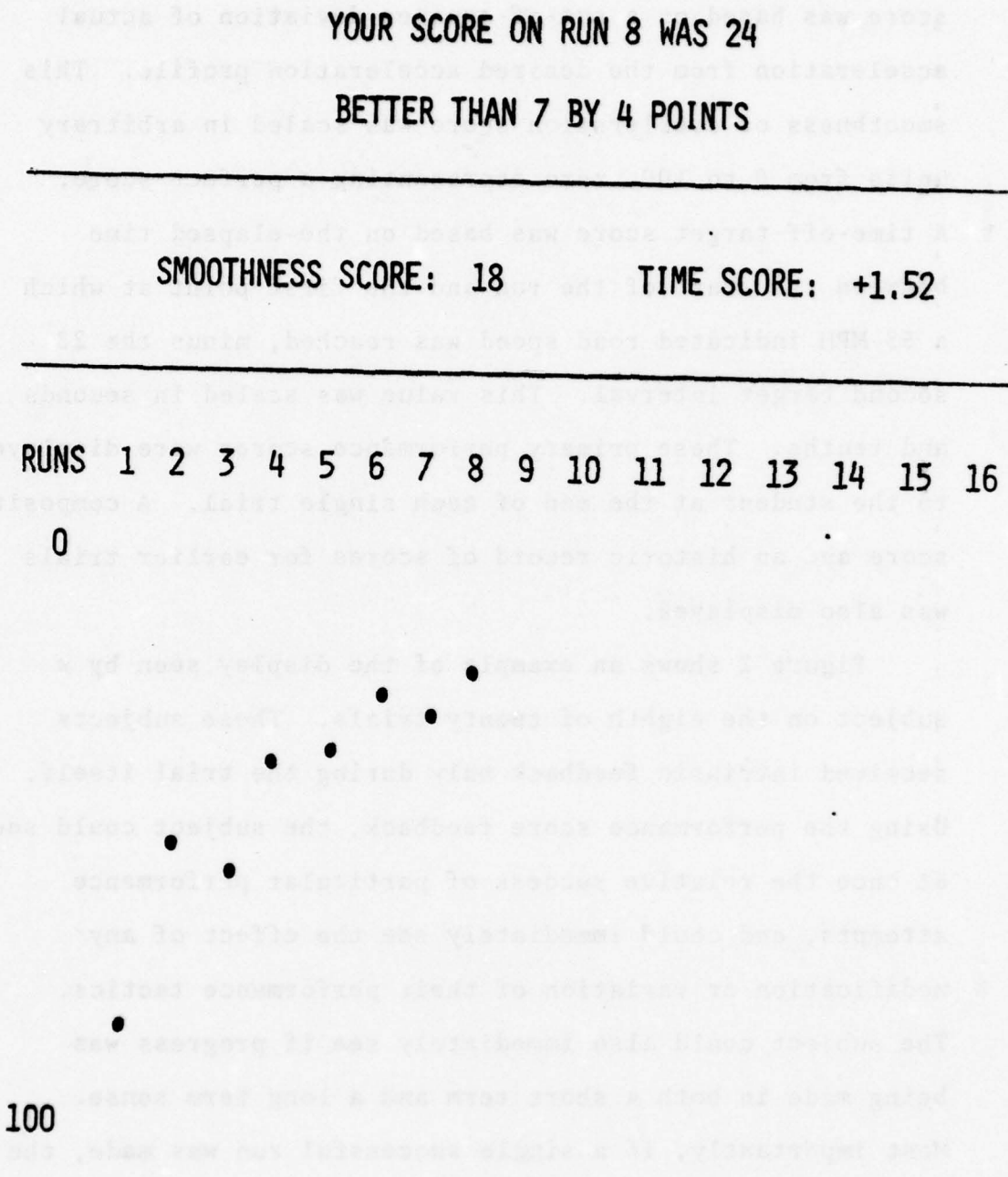

Figure 2
Terminal Feedback Condition--Feedback on Eighth Trial.

Analytic, Graphic Feedback (Graphic Group)

Students trained by this method received feedback in real-time, concurrent with the actual gear-shifting performance. At the onset of each training trial, the student was presented with a display showing the plot of road speed against time as generated by an ideal performance. This display constituted a "track" to be followed during the trial. The student's task was to match his performance with this command model. The student's actual performance was represented on the display as a dotted line evolving with time and superimposed on the command track. An example of such a display is shown in Figure 3.

Using this type of feedback, the student saw at once when a given shift execution diverged from the desired acceleration pattern, and could time his subsequent clutch and throttle operations accordingly. In order to effect a transition from the concurrent artificial training sessions to the intrinsic operation of the simulator, the following training sequence was utilized: For the first eight trials, the graphic feedback was displayed both concurrently and terminally; for the second eight trials, the real-time feedback was all intrinsic and the graphic display was shown only as terminal feedback.

In order to test the transfer of training from feedback to non-feedback conditions, the final four trials were conducted for both experimental groups under intrinsic

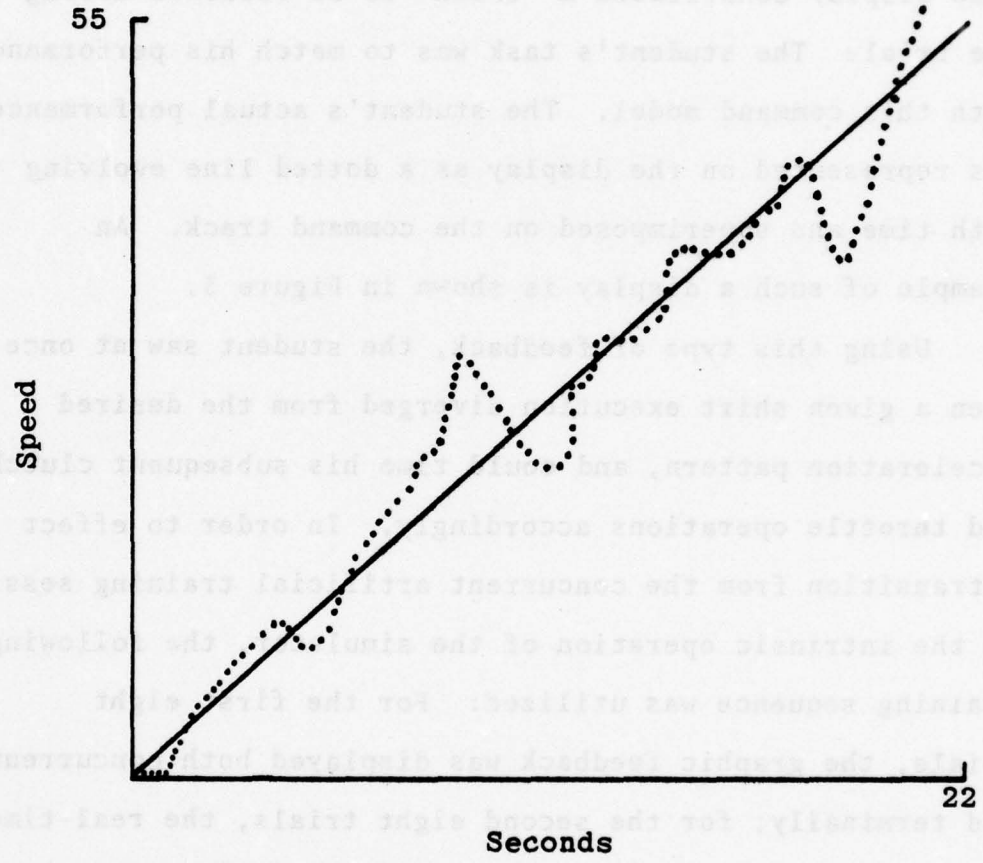

Figure 3
Graphic Performance Feedback.

feedback alone. Comparisons between control and experimental groups were based on their scores on these final four of twenty trials. Prior to these four trials, both experimental and control groups had identical exposure to written instructions and actual practice time. The only difference in procedure between the experimental and control groups was the availability of supplemental CAI feedback during practice trials one to sixteen for the experimental groups. Table 2 summarizes the treatment given to each group.

MEASURES

A variety of measures were taken on subjects' performance on the apparatus, including clutch depression time, time spent in each gear, RPM and speed across time and many more. For the purpose of determining the relative proficiency of the control and experimental groups, only two measures were used.

1. Time-Off-Target: Actual time to reach 55 MPH - 22 seconds (target time).
2. Smoothness: The mean squared deviation from the regression line calculated for that trial.

These two measures were utilized because they were defined as criteria for good performance in all training sessions. The more specific measures such as clutch depression time, time in each gear, etc., were not as appropriate for evaluating systems performance since they were only measures of subsystem performance and were not defined in terms of good or bad systems performance.

Table 2
Performance Feedback During Test Sessions

	Trials					
	1-8		9-16		17-20	
	Real-Time	Terminal	Real-Time	Terminal	Real-Time	Terminal
CONTROL GROUPS	Intrinsic Feedback	None	Intrinsic Feedback	None	Intrinsic Feedback	None
TERMINAL FEEDBACK GROUP	Intrinsic Feedback	Performance Summary Scores	Intrinsic Feedback	Performance Summary Scores	Intrinsic Feedback	None
GRAPHIC FEEDBACK GROUP	Graphic Feedback	Graphic Feedback	Intrinsic Feedback	Graphic Feedback	Intrinsic Feedback	None

RESULTS

No significant difference was found in the time-off-target measure (see Figures 4, 5, and 6; and Tables 3 and 4). Smoothness score means and deviations for the sum of the last four trials are presented in Figure 7 for the control and experimental groups.

No significant differences between male and female control groups existed, so the subjects from these two groups were pooled. Only the last four trials were used to test the effectiveness of the training method, because they were the only sessions where all groups received intrinsic real-time feedback without terminal feedback. After the initial six trials, MS scores only showed slight improvement with practice for both experimental and control groups. In examination of the control group's MS scores, Figure 8 shows that high quality scores were as likely to occur early in the sequence as later, and the occurrence of a single high quality trial did not predict an increased likelihood of a high score on the immediately following trial.

A one-way analysis of variance (Table 5) of MS scores indicated a p value of .035. Both the terminal and the graphic feedback conditions produced significantly better scores than the control condition but did not differ significantly between each other (see Table 6).

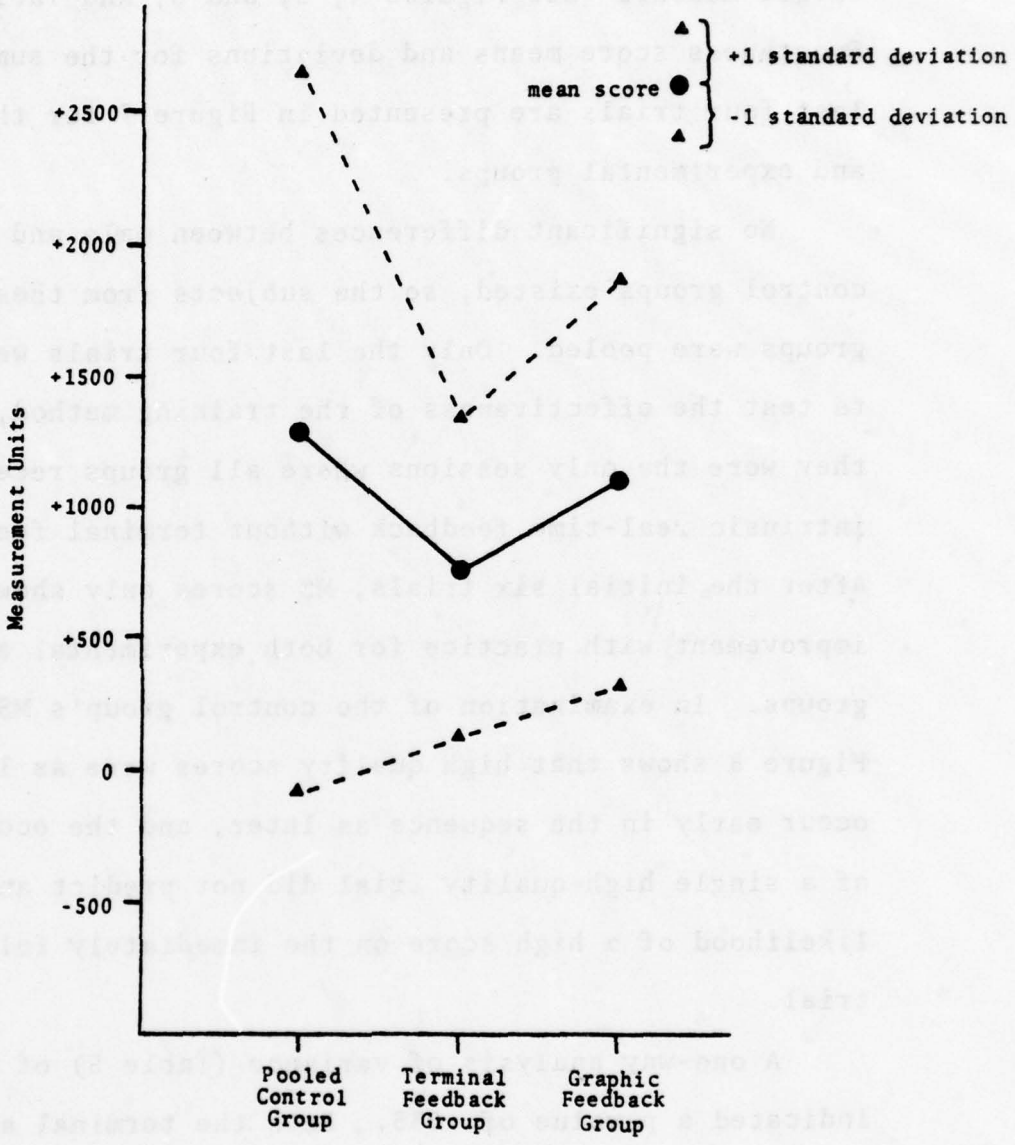

Figure 4
Control and Experimental Groups Time-off-Target Absolute Error for the Sum of Trials 17-20.

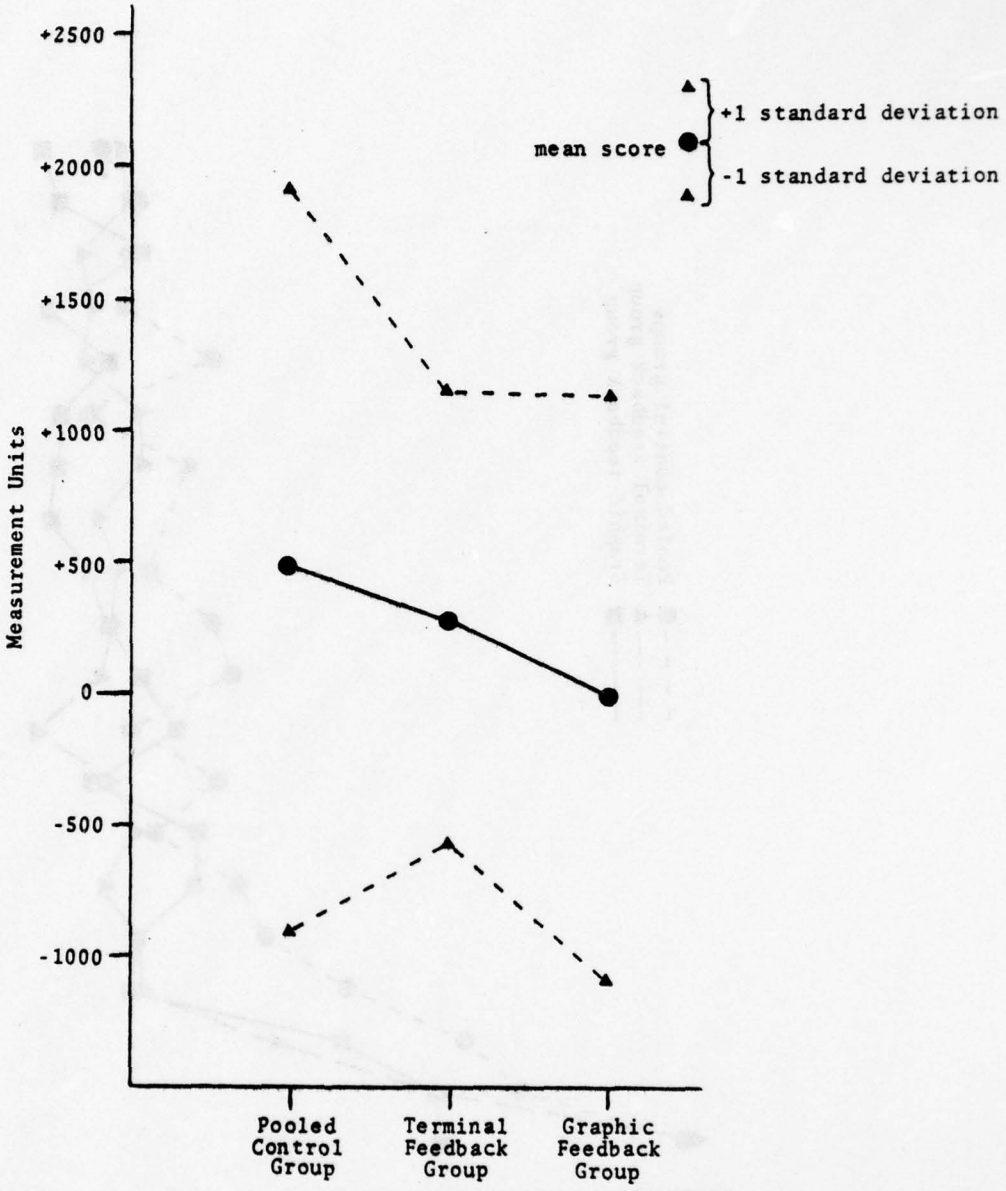

Figure 5
Control and Experimental Groups Time-off-Target Constant Error for the Sum of Trials 17-20.

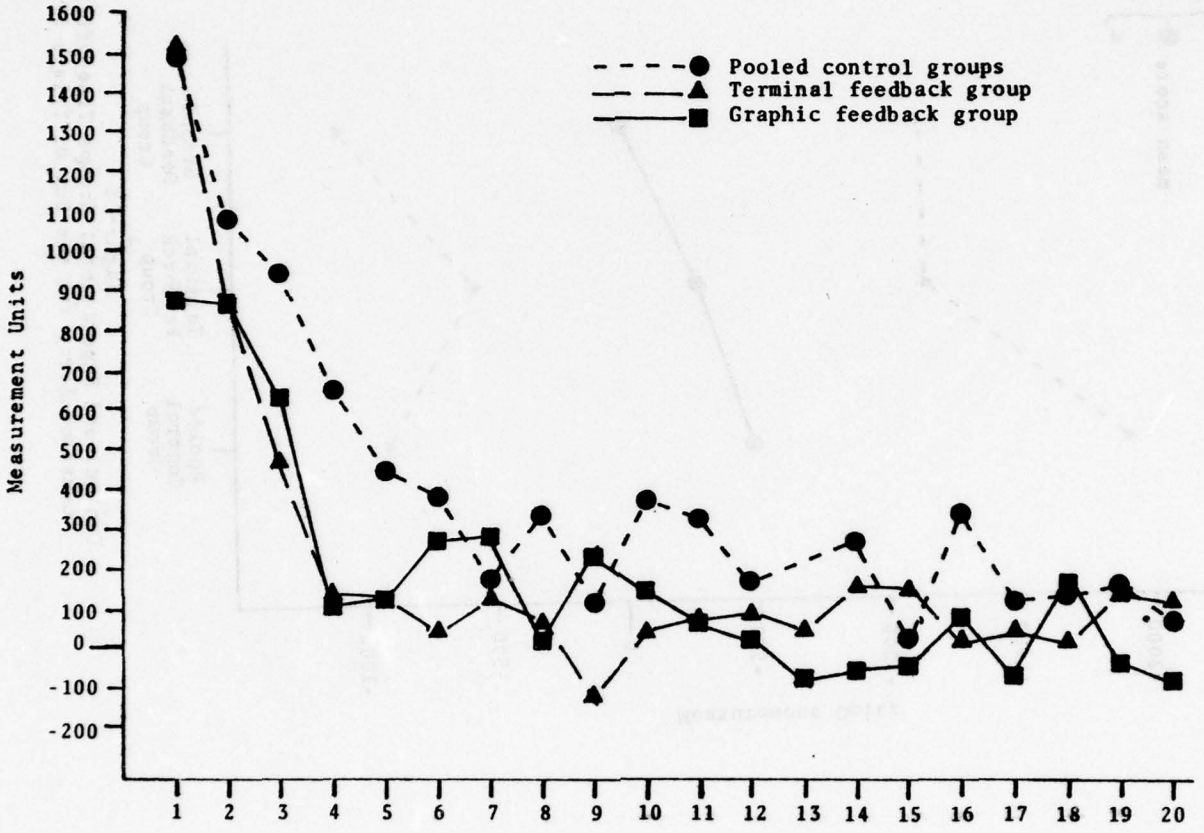

Figure 6
Control and Experimental Groups Time-off-Target
Constant Error for Trials 1-20.

Table 3
One-Way Analysis of Variance on
Time-off-target Absolute Error
Scores for Trials 17-20.*

Source	df	MS	F	p
Conditions	3	1492145.	1.25	.295
Within	57	1196961.		
TOTAL	59			

*sum of each subject's Absolute Error scores for trials 17 through 20.

Table 4
One-Way Analysis of Variance on
Time-off-target Constant Error
Scores for Trials 17-20.*

Source	df	MS	F	p
Conditions	3	1193776.	.81	.448
Within	57			
TOTAL	59			

*sum of each subject's scores for trials 17 through 20.

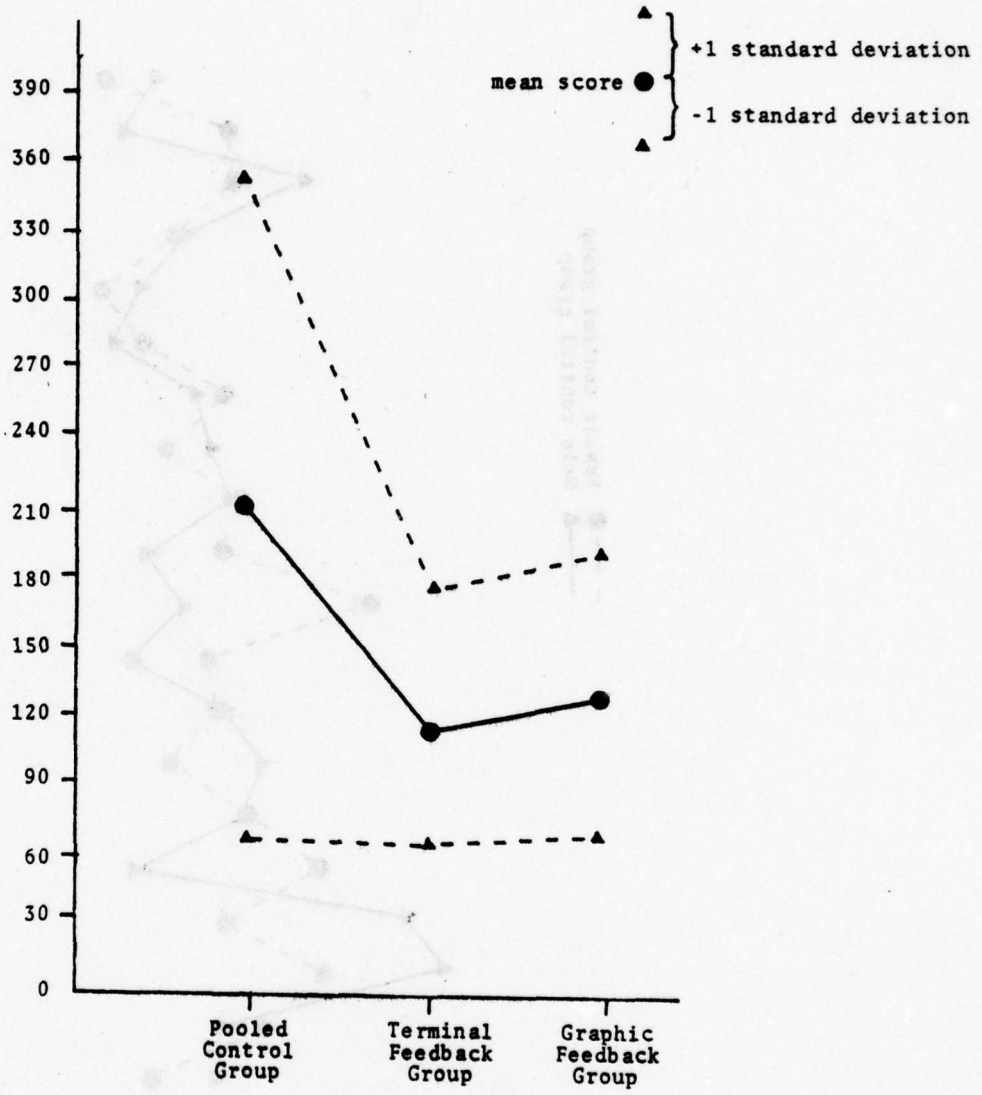

Figure 7
Control and Experimental Groups Smoothness (MS) Scores for the Sum of Trials 17-20.

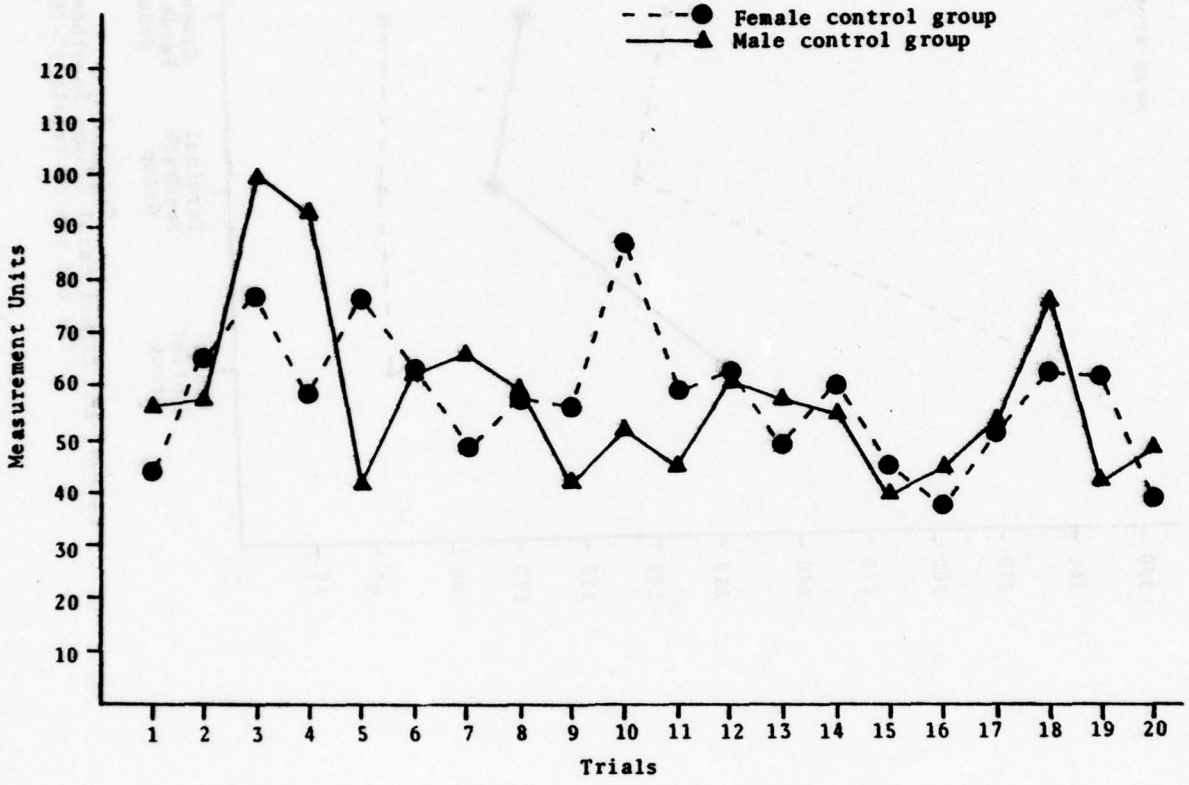

Figure 8
Male and Female Control Groups Smoothness (MS) Scores for Trials 1-20.

Table 5
One-Way Analysis of Variance on
Smoothness (MS) Scores
for Trials 17-20.*

Source	df	MS	F	p
Conditions	2	66098.188	4.70	.013
Within	57	14072.590		
TOTAL	59			

*sum of each subject's trials 17 through 20.

Table 6
Duncan Multiple Range Test on
Smoothness (MS) Scores
for Trials 17-20.

	Control	Graphic	Terminal
Control	-----		
Graphic	83.661*	-----	
Terminal	102.247*	18.586	-----

*probability less than .05

When performance during the training trials (1-16) are examined (Figure 9), it is apparent that the initial performance improvement in MS scores took place in the first block of eight trials and that by the end of this block the two experimental groups were superior to the control group. It is important to note that during trials 1-8, subjects in the graphic feedback group received real-time graphic feedback. However, on the second eight trials (9-16), subjects in the graphic feedback group received only intrinsic real-time feedback which resulted in decrement in performance that was not compensated for until the test sessions 17-20. An analysis of variance run on data for trials 9-16 (Table 7) showed that a significant difference existed among the three groups. The Duncan Multiple Range Test (Table 8) indicated that this difference was not between the control and the graphic feedback or the graphic and terminal feedback groups, but between control and terminal feedback groups (see Figure 10), the terminal feedback scores being significantly superior ($p < .05$) between trials 9-16.

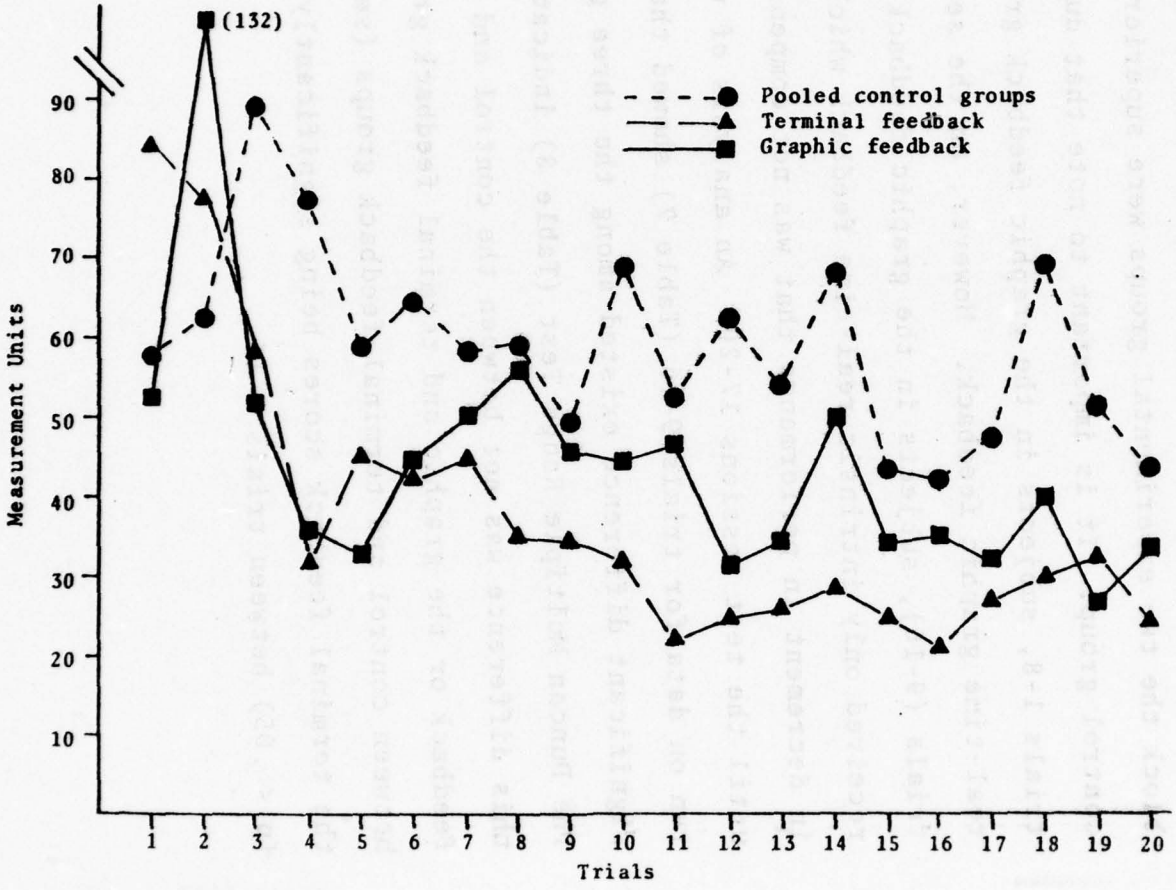

Figure 9
Control and Experimental Groups Smoothness (MS) Scores for Trials 1-20.

Table 7
One-Way Analysis of Variance on
Smoothness (MS) Scores
for Trials 9-16.*

Source	df	MS	F	p
Conditions	2	235797.000	7.01	.002
Within	57	33646.473		
TOTAL	59			

*sum of each subject's trials 9 through 16.

Table 8
Duncan Multiple Range Test on
Smoothness (MS) Scores
for Trials 9-16.

	Control	Graphic	Terminal
Control	-----		
Graphic	107.337	-----	
Terminal	213.764*	106.427	-----

*probability less than .05

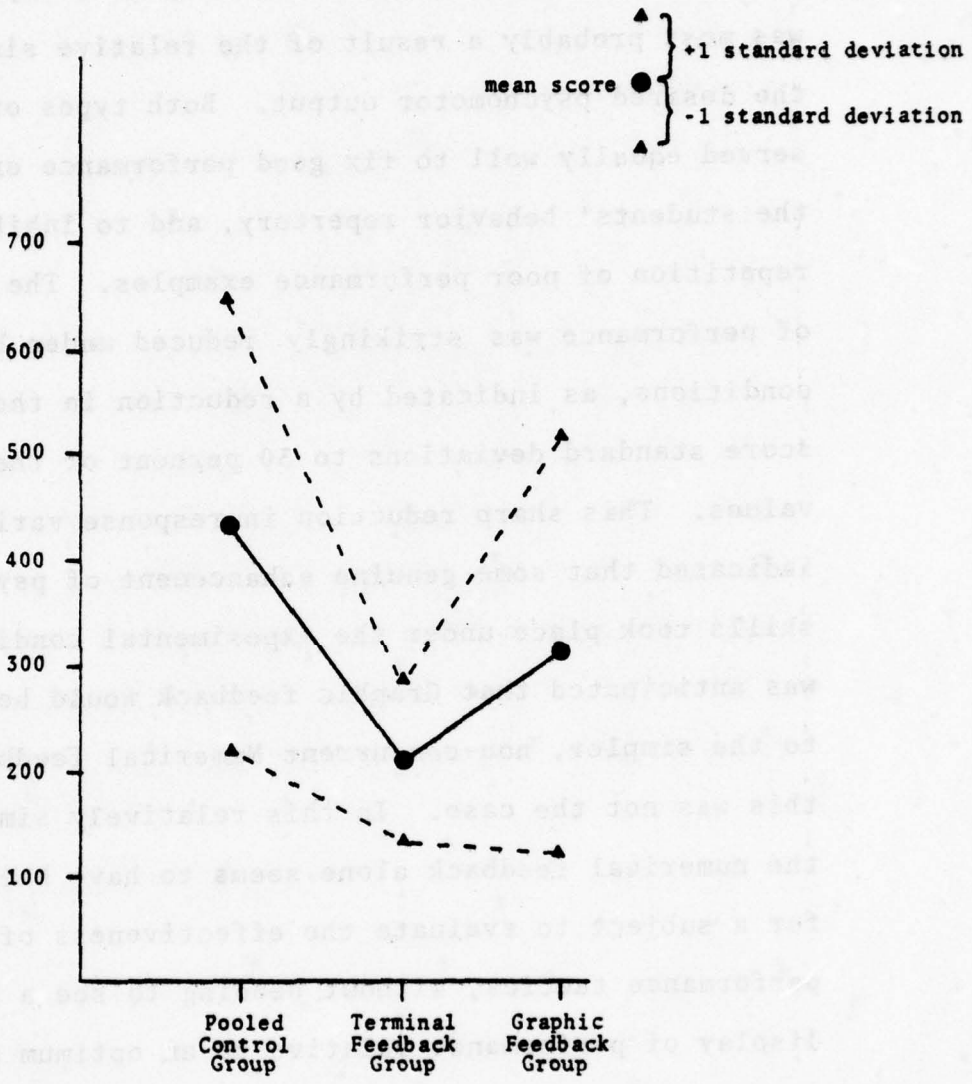

Figure 10
Control and Experimental Groups Smoothness (MS) Scores for the Sum of Trials 9-16.

DISCUSSION

The lack of any experimental differentiation between Terminal Numerical feedback and Graphic Analytic feedback was most probably a result of the relative simplicity of the desired psychomotor output. Both types of feedback served equally well to fix good performance examples in the students' behavior repertory, and to inhibit the repetition of poor performance examples. The variability of performance was strikingly reduced under both experimental conditions, as indicated by a reduction in the smoothness score standard deviations to 30 percent of the control group values. This sharp reduction in response variability also indicated that some genuine enhancement of psychomotor skills took place under the experimental conditions. It was anticipated that Graphic feedback would be superior to the simpler, non-concurrent Numerical feedback, but this was not the case. In this relatively simple task, the numerical feedback alone seems to have been sufficient for a subject to evaluate the effectiveness of various performance tactics, without needing to see a graphic display of performance relative to an optimum performance track. The fact that subjects in the Graphic feedback group did not perform better than the Terminal feedback group, even during the first eight trials, suggests that this is true. To be effective in shaping new performance skills, a command display must be superior to the performance

on the apparatus without the real-time aid. Otherwise, there is no point in adding artificial feedback, since subjects must eventually depend completely on intrinsic feedback.

It may be that with tasks requiring more precision of motor output, the analytic display format would have some training advantage over simpler terminal feedback of numerical scores. The subjects in this study, in all groups, exhibited considerable flexibility in performance output. Few of them demonstrated the rigidity of an inadequate motor output that often characterizes poor psychomotor performance. An evaluation of individual subject records indicated that both feedback formats were of some use in removing bad performance habits that might otherwise be intractable to most training procedures. It is felt that in both cost and effectiveness, a CAI system of psychomotor instruction could be a match for many one-to-one instruction procedures involving close supervision, and would be superior to almost any classroom environment with unsupervised practice.

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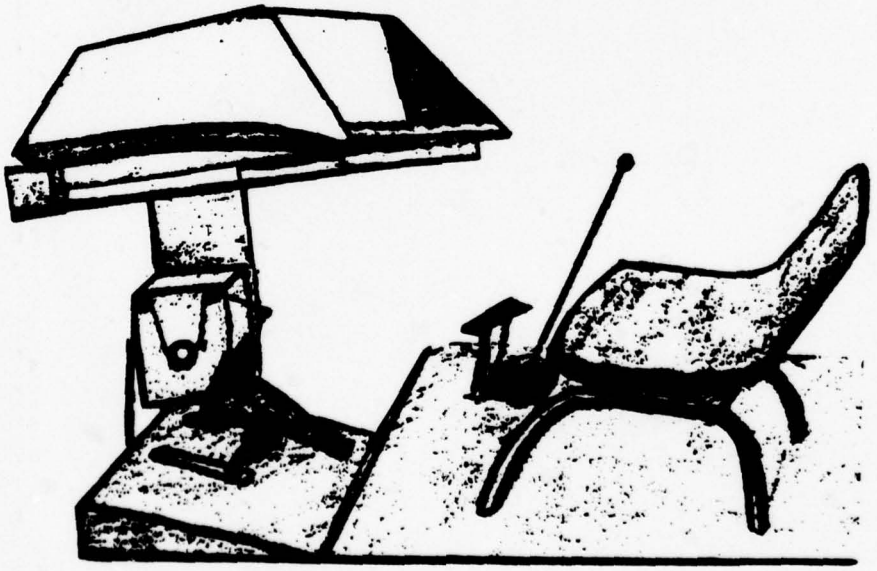
APPENDIX A

Operations Manual

OPERATIONS MANUAL

The driving simulator that you will be working with in this study operates much like a normal 4 speed manually operated car or truck. Your task will be to learn how to control the simulator in such a way that road speed (as indicated by a speedometer) increases gradually with as little difference as possible in the rate of speed increase in different gears. At the same time you should attempt to have as small a drop in speed as possible when you shift from one gear to another. The simulator responds very much like a car or truck moving up a gradually sloping hill. For this reason the speed will tend to drop quite quickly if the clutch is left disengaged for very long periods of time.



Performance Requirements

You will be required to shift through the gears--1st to 2nd to 3rd to 4th--while trying to accomplish two objectives.

1. Increase the speed slowly and steadily from 0 to 55 mph with as little fluctuation in this steady increase in speed as possible.

2. This steady increase should be planned so that the time interval between 0 mph to 55 mph is as close to 22 seconds as possible.

Reaching 55 mph before or after 22 seconds will not be considered perfect performance. However, if you make it to 55 mph just at 22 seconds, but do not maintain a steady increase in speed you also will be considered to have fallen short of perfect performance. The ideal performance on the task then is one where a gradual steady increase in speed will result in obtaining 55 mph just when 22 seconds has elapsed. Unless the speed increase is steady, hitting 55 mph right on time will be of small value. If the ideal performance is plotted on a graph, it looks much like that shown in Figure 1.

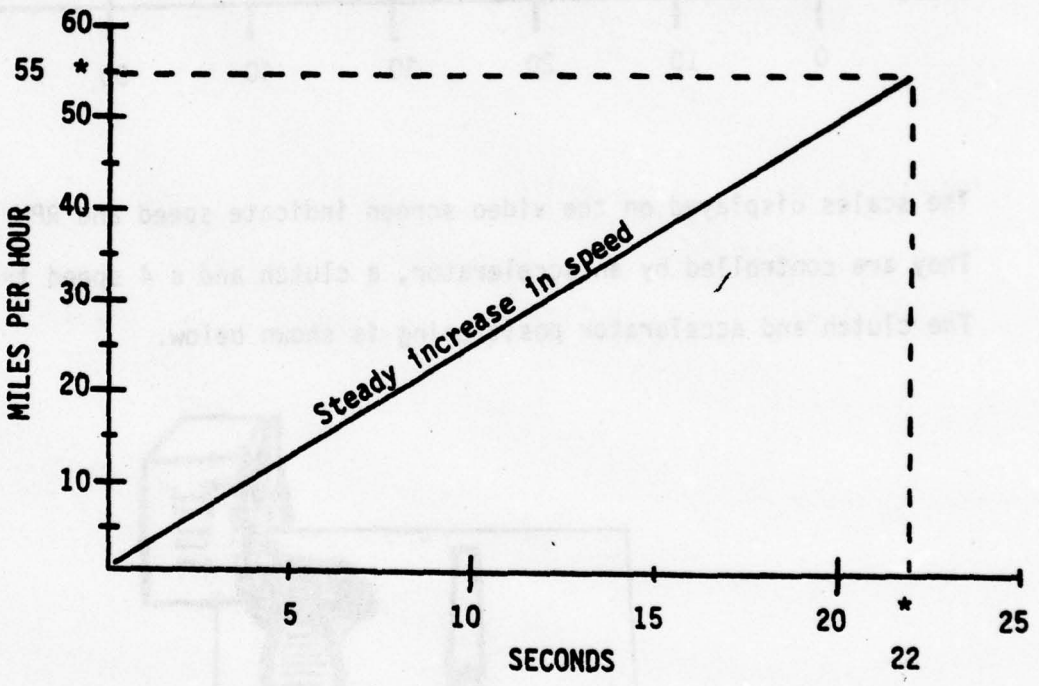


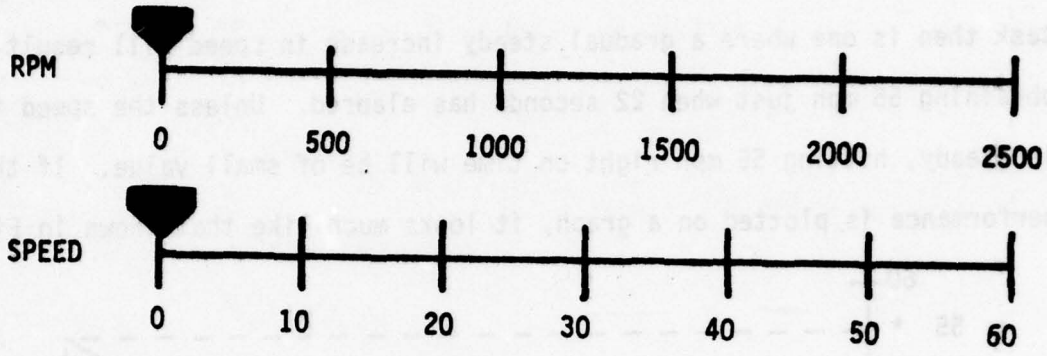
Figure 1

Ideal Performance

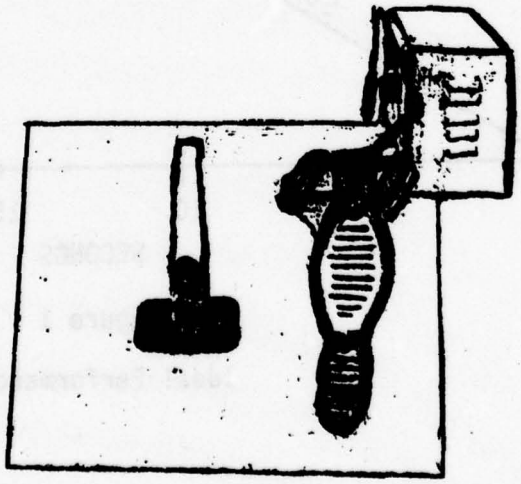
The speed is marked on the left side from 0 to 60 mph and the time is marked across the bottom. The line moving from the zero point to the right is a measure of the speed that you should be traveling at any time during a shifting session. Be sure to note that the increase in speed is gradual and that at no time does the rate of increase change.

Instruments and Controls

A speedometer (indicating road speed) and a tachometer (indicating engine speed) will be displayed on a video screen directly in front of the seat in the simulator.

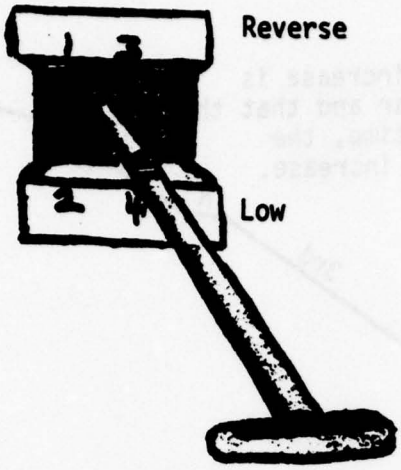


The scales displayed on the video screen indicate speed and RPM scales. They are controlled by an accelerator, a clutch and a 4 speed transmission. The clutch and accelerator positioning is shown below.



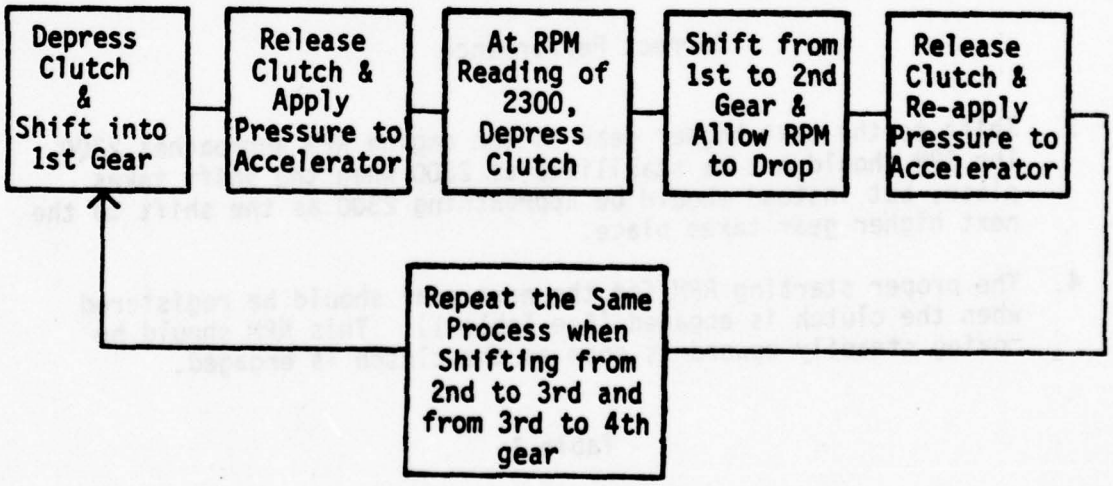
clutch pedal accelerator pedal

The shift pattern is the standard 4 speed shift pattern.



Reverse and Low will not be used for this study. only 1st, 2nd, 3rd, and 4th will be used.

In order to shift from one gear to another in a manual transmission, the clutch pedal must be depressed, the shift must be made from one gear to the next and then the clutch pedal must be released. The proper sequence of events is then as follows:



How to Achieve a Steady Increase in Speed

1. Make the increase in speed within each gear as steady as possible. Also make the rate of speed increase in all gears as close to the same as possible.

2. Make the shifting time as small as possible.

Study Figure 2 closely.

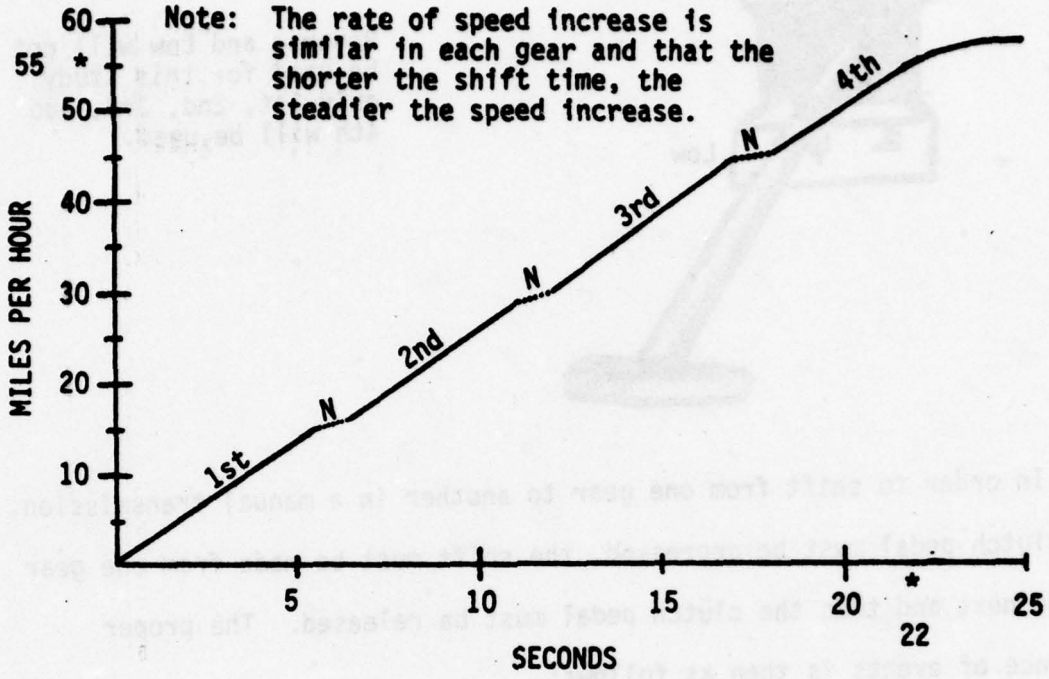


Figure 2

Correct Performance

3. Shift to the next higher gear as the engine RPM approaches 2300. The RPM should not be stabilized at 2300 when the shift takes place, but instead should be approaching 2300 as the shift to the next higher gear takes place.

4. The proper starting RPM for the next gear should be registered when the clutch is engaged (See Table 1). This RPM should be moving steadily upward as soon as the clutch is engaged.

Table 1

Gear	Starting RPM	Shifting RPM
1st	500	2300
2nd	1250	2300
3rd	1250	2300
4th	1750	2400

Figure 3 below shows the increase in RPM in the same way that earlier tables showed increase in speed. Note that the RPM reading does not stabilize at a specific RPM before you shift. The RPM should be increasing until the shift takes place. Also the RPM should begin to increase again right when the clutch is engaged.

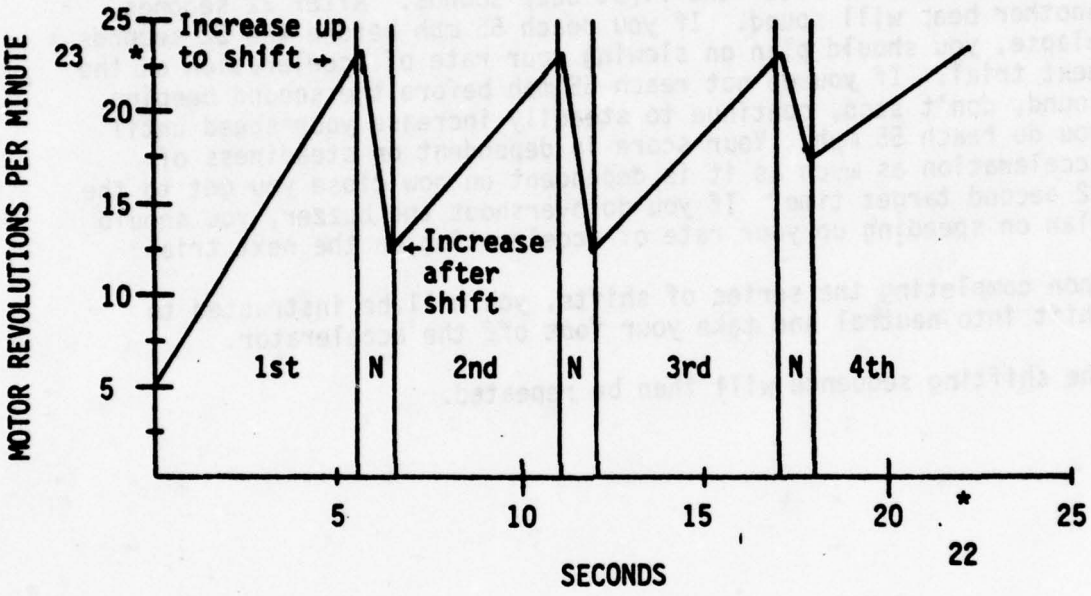


Figure.3

CORRECT RPM CONTROL

Training Procedure

1. While sitting in the simulator, experiment with the gears so you are familiar with their location.

2. You will then be instructed, via the video screen, to depress the clutch, shift into first gear and allow the motor to idle.

3. When you hear a beeping sound you are to shift through the gears from 1st to 4th as smoothly as possible, attempting to reach 55 mph 22 seconds after the first beep sounds. After 22 seconds, another beep will sound. If you reach 55 mph before the 22 seconds elapse, you should plan on slowing your rate of acceleration on the next trial. If you do not reach 55 mph before the second beeping sound, don't stop, continue to steadily increase your speed until you do reach 55 mph. Your score is dependent on steadiness of acceleration as much as it is dependent on how close you get to the 22 second target time. If you do overshoot the buzzer, you should plan on speeding up your rate of acceleration on the next trial.

4. Upon completing the series of shifts, you will be instructed to shift into neutral and take your foot off the accelerator.

5. The shifting sequence will then be repeated.

Operations Manual Exam

1. When the target time designated to reach 55 mph is reached it will be signaled by:

   a. a flashing light.
   b. a shutdown of the display.
   c. a beeping sound.
   d. the word TIME printed across the display.
   e. it will not be signaled.

2. It is recommended that when shifting out of 1st, 2nd, and 3rd gears that the rpm:

   a. have a stable reading of 1750 rpm.
   b. have a stable reading of 1250 rpm.
   c. have a stable reading of 2300 rpm.
   d. be moving toward 1750 rpm.
   e. be moving toward 2300 rpm.

3. All of the actions listed below will help in achieving good performance on the shifting task except one. Which alternative will help the least in obtaining good systems performance?

   a. keep the speed increase within each gear as steady as possible.
   b. accelerate quickly and smoothly in each gear.
   c. keep the shift time as small as possible.
   d. keep the rate of speed increase in each gear the same.
   e. be accelerating in each gear up until the time the shift takes place.

4. Upon engaging the clutch in 2nd or 3rd gear, the rpms should be at:

   a. 1250 rpm and climbing.
   b. 2300 rpm and climbing.
   c. 1750 rpm and climbing.
   d. a steady 1250 rpm.
   e. a steady 1750 rpm.

5. Upon engaging the clutch in 4th gear the rpm reading should be at:

   a. 1250 rpm and climbing.
   b. 2300 rpm and climbing.
   c. 1750 rpm and climbing.
   d. a steady 1250 rpm.
   e. a steady 1750.

6. The ideal time required to get from 0 mph to 55 mph for this test is:

   a. 18 seconds
   b. 20 seconds.
   c. 22 seconds
   d. 24 seconds
   e. 26 seconds

7. If you do not reach 55 mph in the desired time period you should:

   a. stop acceleration at once.
   b. continue to accelerate smoothly until you reach 55 mph.
   c. just push the accelerator pedal to the floor.
   d. hold the speed steady at the speed you obtained on the trial before passing the desired time period.
   e. there is nothing in particular that you should do.

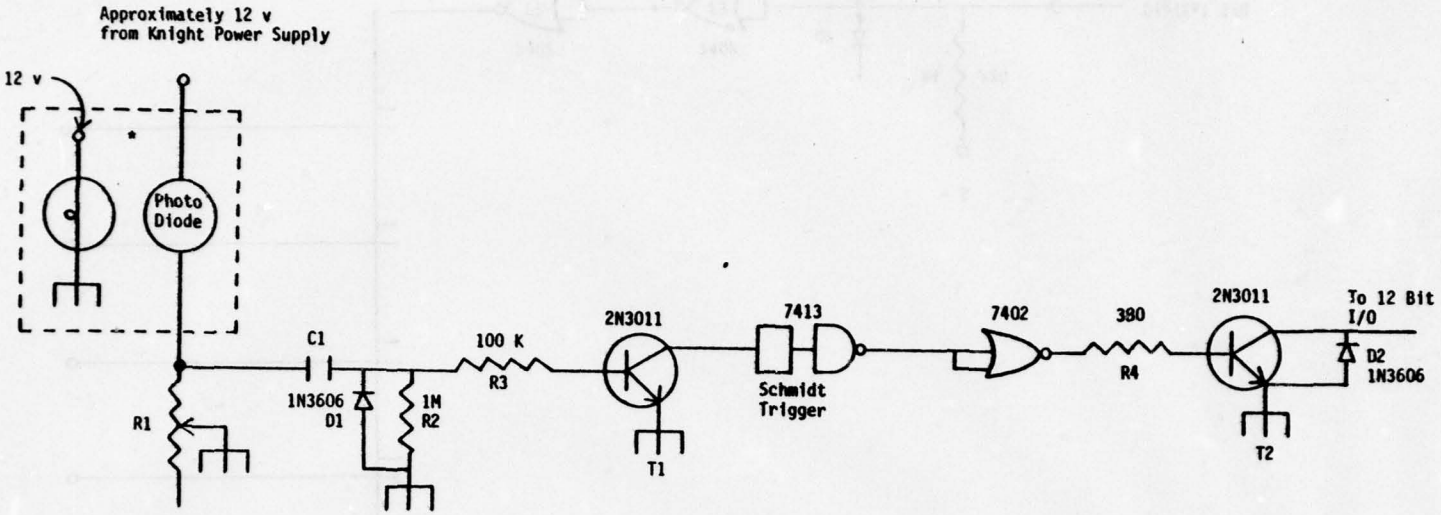
APPENDIX B

Apparatus Hardware and Sensors

Apparatus Hardware and Sensors

Schematic 1 is representative of the RPM and speed sensors. The intermittent light causes resistance changes in the photo-diode, which produces a fluctuating voltage at the top of the R1. This signal is capacitor coupled by C1 to remove the offset from ϕ, and D1 clamps negative spikes. T1 provides current sinking capability to switch the Schmidt Trigger (7413), which produces a TTL square wave. The 7402, R4, T2, and D2 provide a standard cable driving circuit to enter the 12 bit I/0.

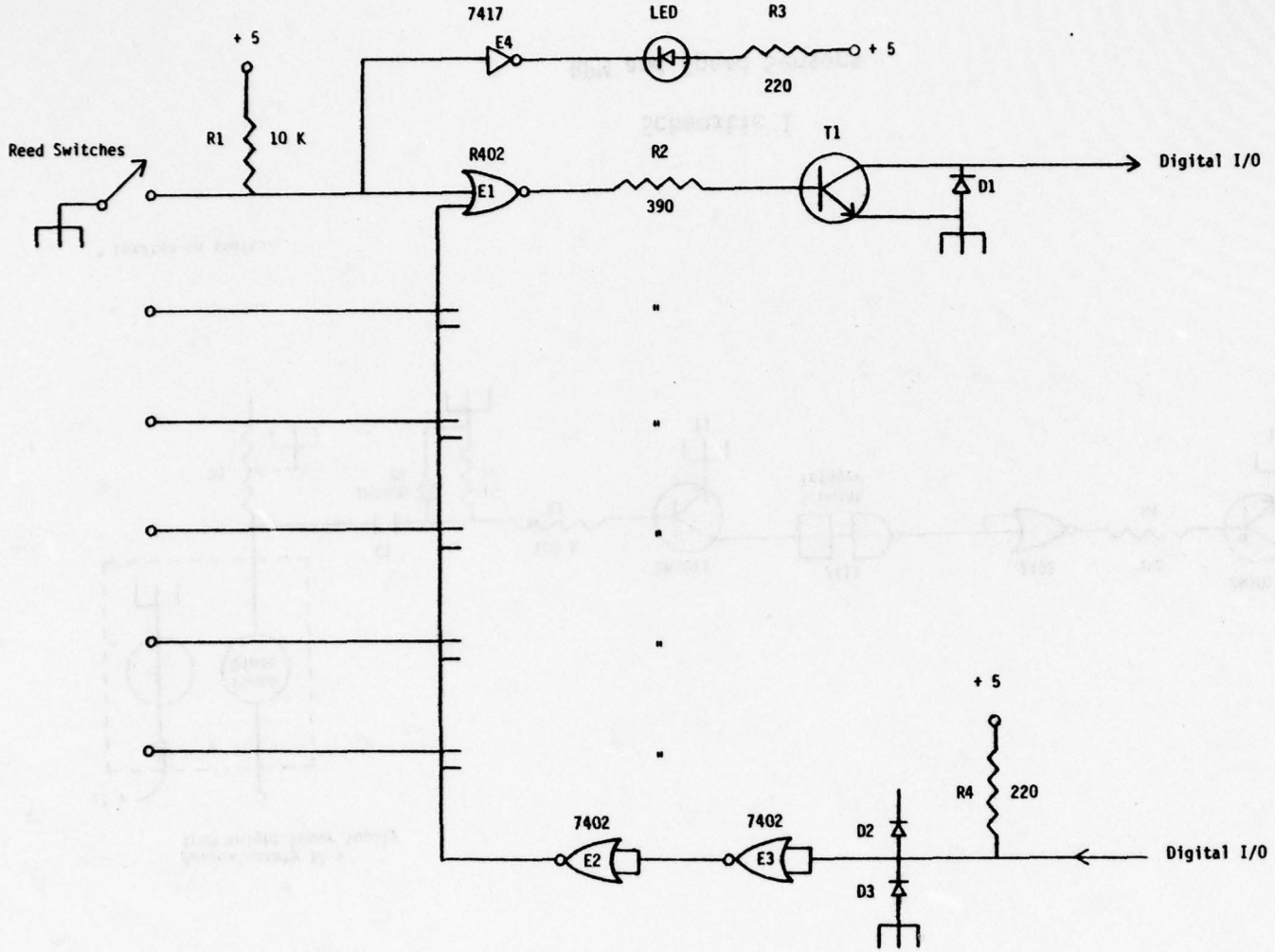
Schematic 2 shows the circuit for sensing the shift position. The reed switches mounted around the gear shift cause the input to E1 to go to ground when they are closed. R1 holds the input high when the switch is open. To read the shift position, a pulse is transmitted from the 12 bit I/0. This pulse is received and inverted by the R4, D2, D3, E3, E2 circuit, and is used to strobe the six gates monitoring the reed switches. R2, T1, and D1 complete the driving circuit which connects to the digital I/0. E4, LED, and R3 provide a monitoring circuit to use in adjusting the positions of the reed switches.



* Located on shafts

Schematic 1

RPM and Speed Sensors



Schematic 2

Shift Position Sensors

APPENDIX C

Hierarchical Instruction Set

Hierarchical Instruction Set

The Human Factors Laboratory has done some pilot work in developing a CAI program that utilizes a hierarchical instruction format consisting of summary data, discrete error messages and real-time command modeling. An example of this instruction format is shown in the following flowcharts.

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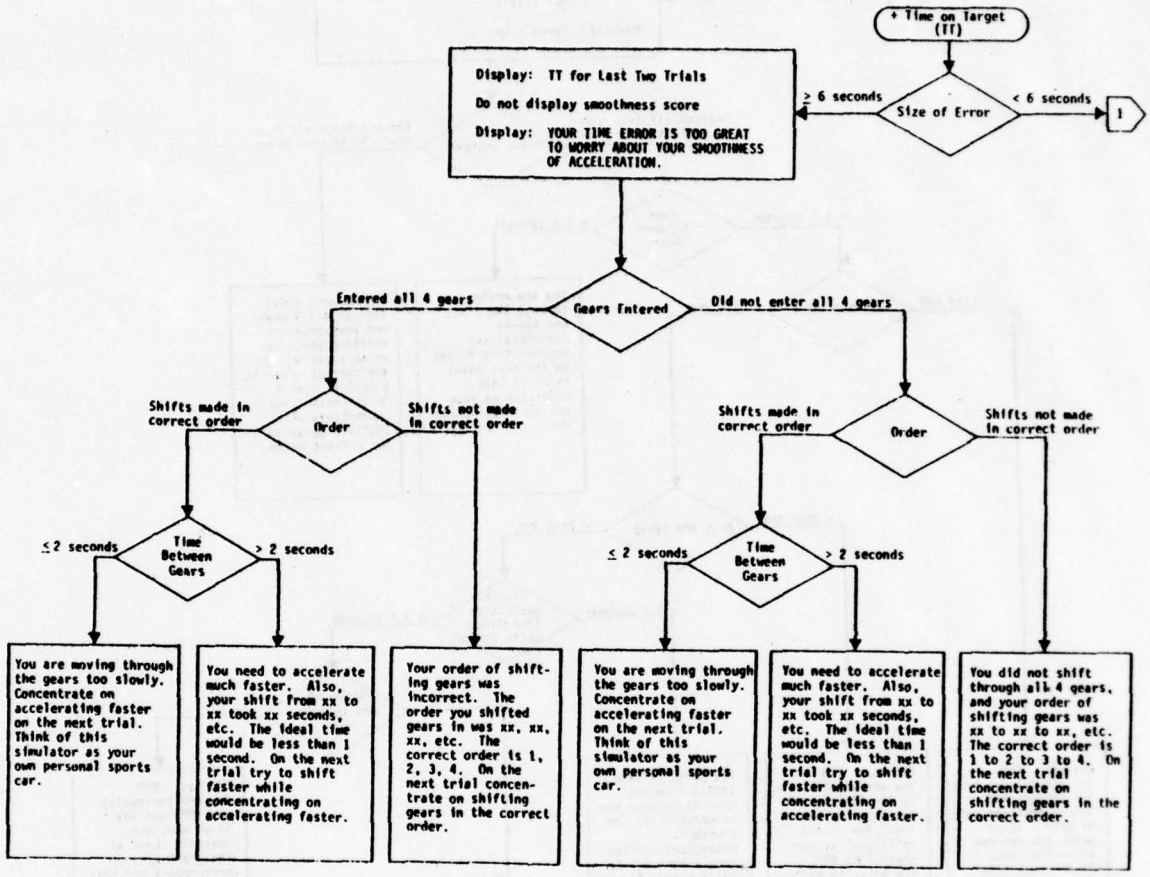

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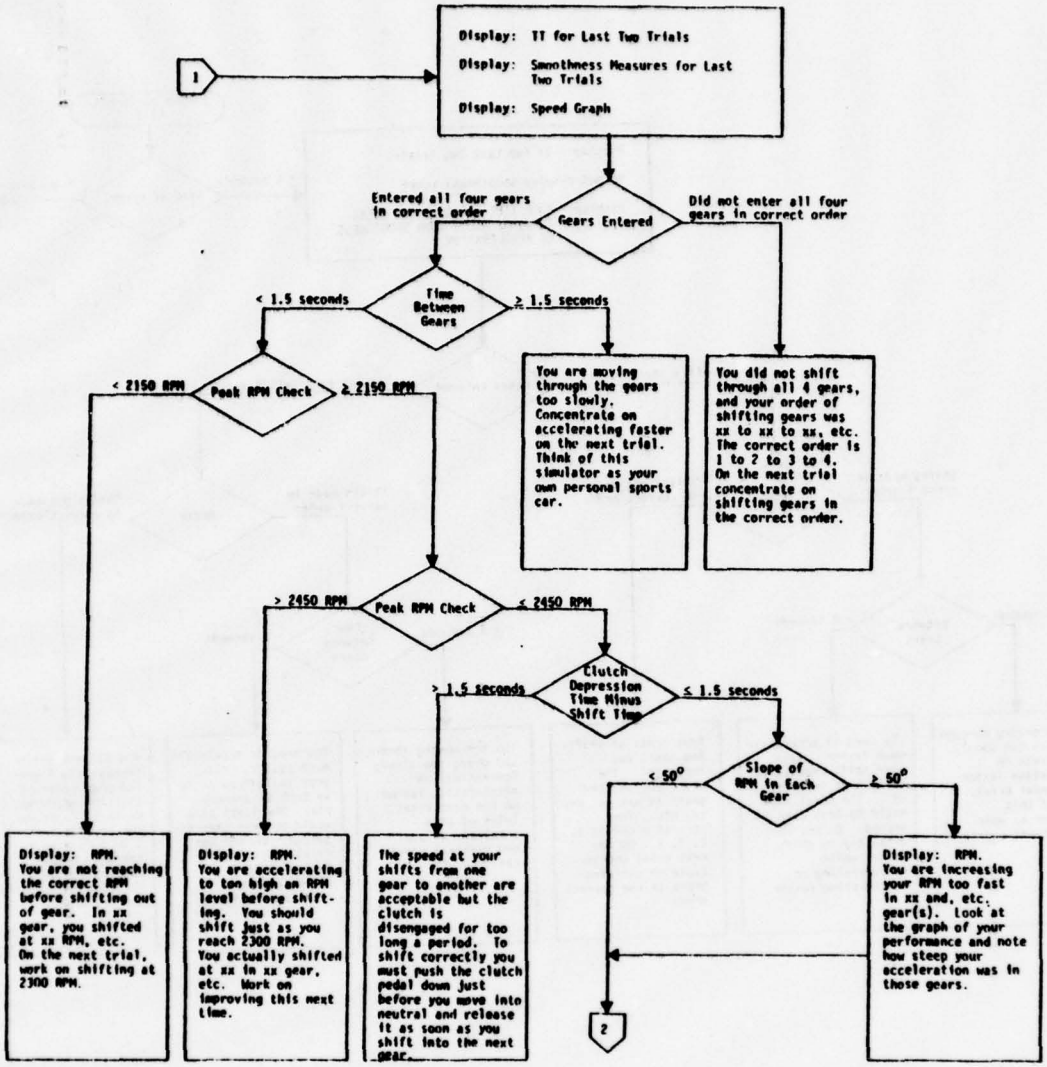

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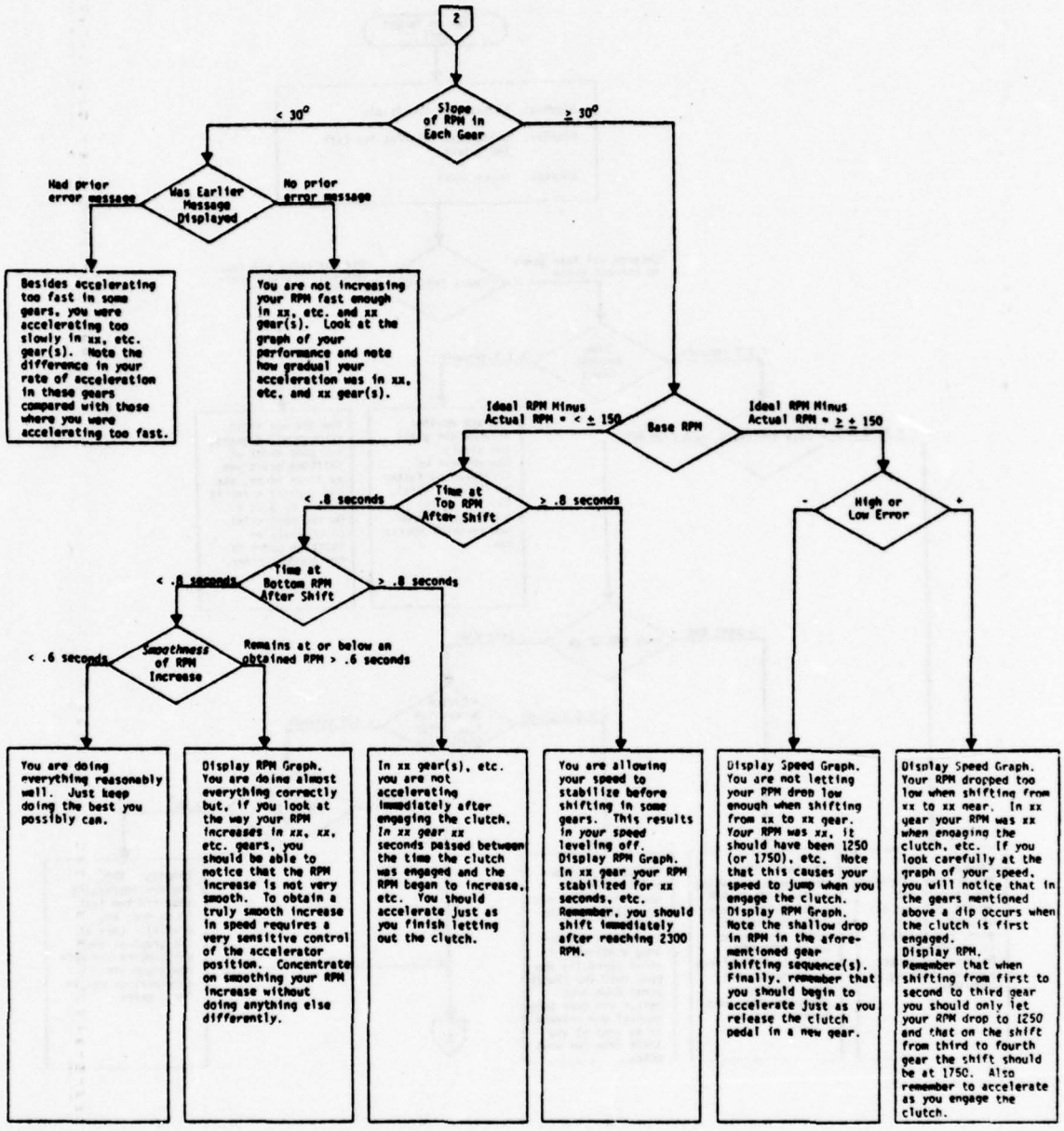

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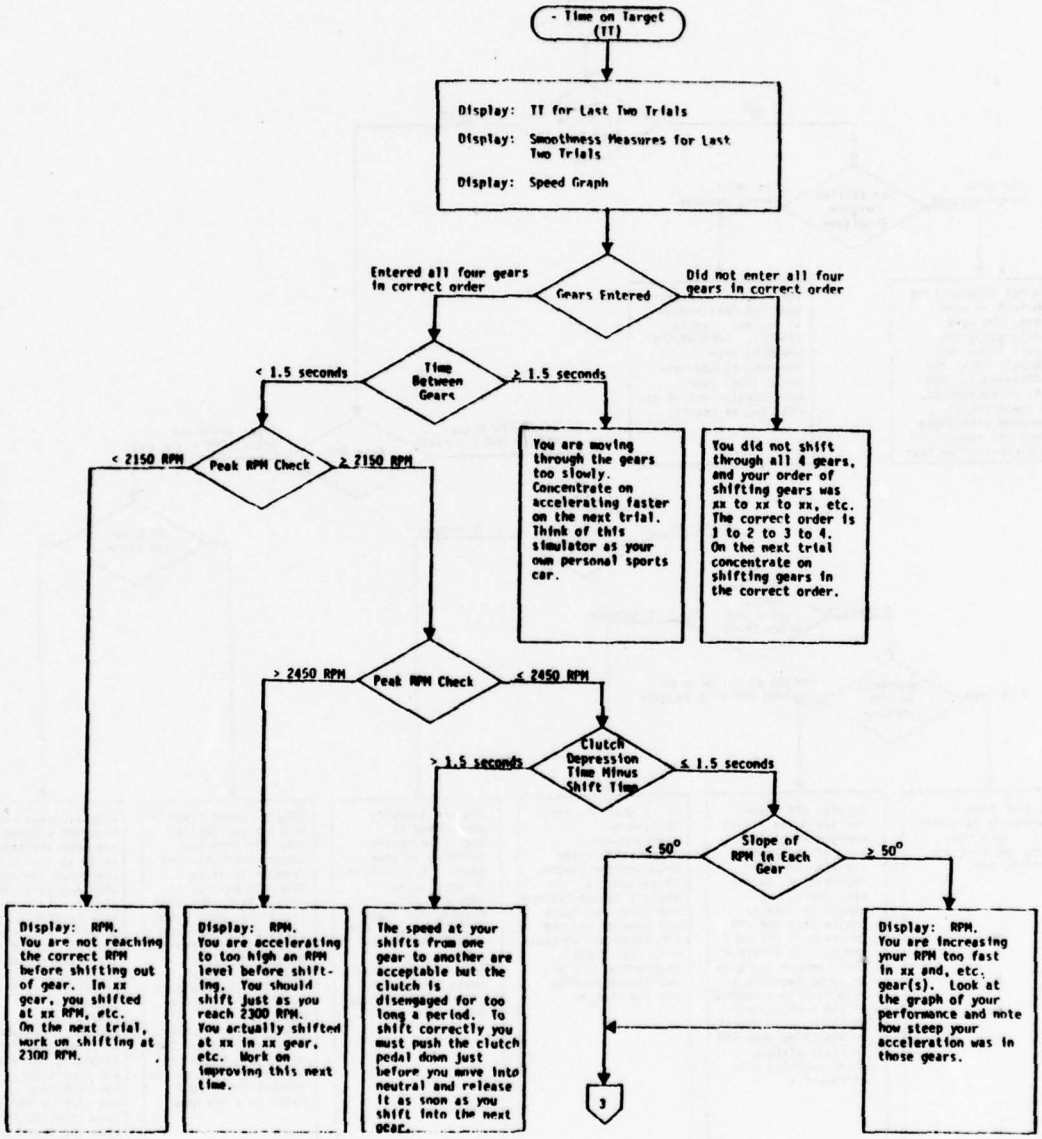

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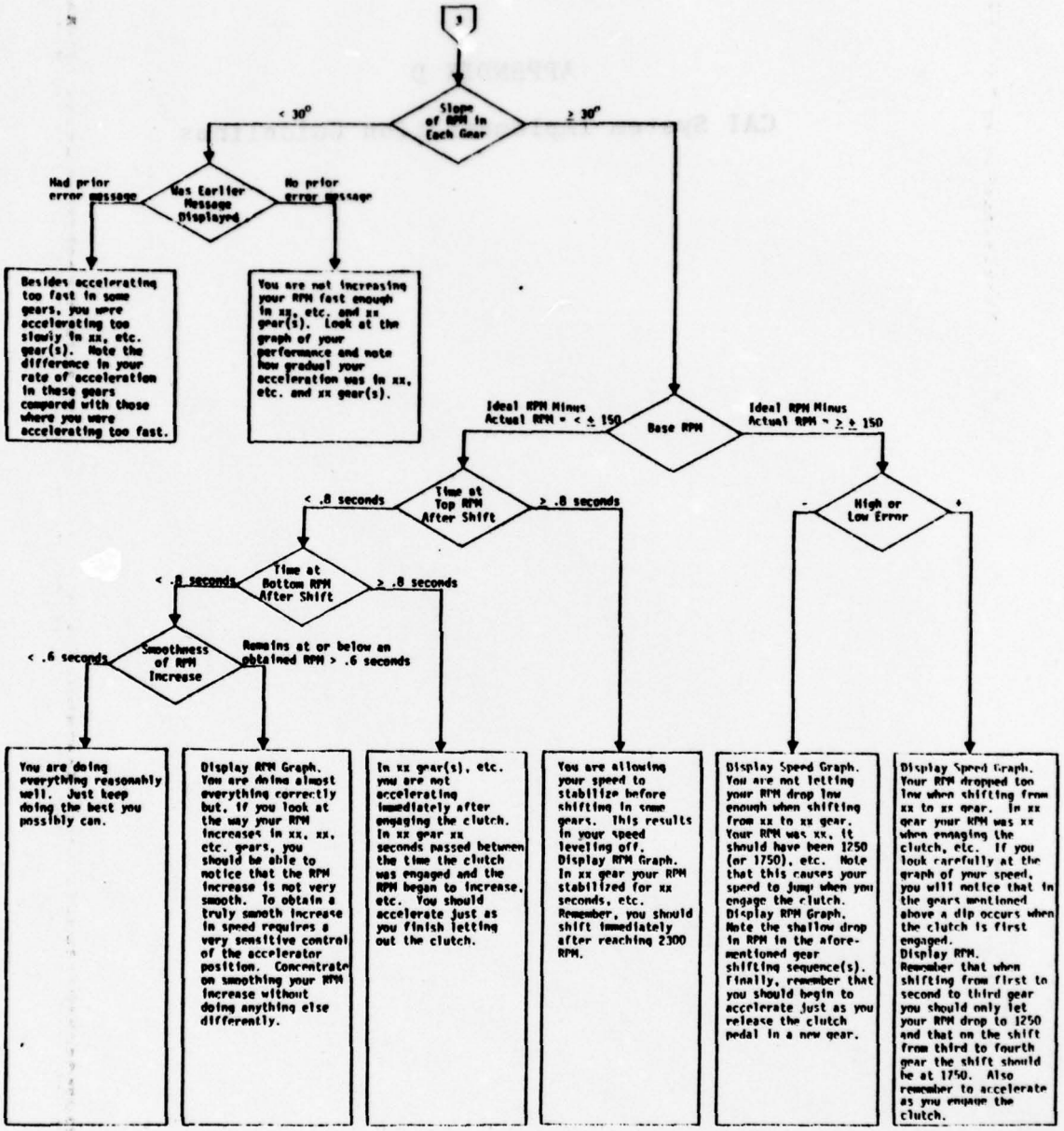


APPENDIX D

CAI System Implementation Guidelines

CAI System Implementation Guidelines

It is a complex process to program a specific inventory of interactions between the computer, the student, and the machinery the student is learning to control. We identified six areas in which formal decisions have to be made concerning the details of such interactions.

1. Selection of information to be monitored by the computer. The application of computer feedback techniques to psychomotor training requires a variety of sensors, or "instrumentation," attached to the device whose operation is being learned. This instrumentation communicates two different types of data to the computer:

   a. Information referring to operator's motor output. Sensors on the controls operated by the student can detect the position of the controls, the pressures and torques exerted on the controls, and the rate and range of change in these values. By analyzing these data, it is possible to determine the actual manipulation of the controls by the student-operator.

   b. Information referring to the dynamic condition of the mechanical system being operated. Sensors on various operating elements of the system can detect such values as RPM of rotating components, internal pressures in hydraulic components, and other kinetic forces indicating the actual internal operating conditions of mechanical devices.

   Either or both of these sets of data can be used to provide feedback concerning his performance to the trainee.

2. Selection of information to be presented to the student operator. Information may be fed back by computer as either a visual display on a TV type screen or as some form of acoustic display. The contents of any of these displays may be generally characterized as being one or another of these three types:

a. Numerical scores, which may represent a value of a single dimension of performance quality, or may be weighted composite indices of several dimensions of performance quality.

b. Analytic displays, which may combine one or more performance variables in a graphic display against time, or as a function of other variables.

c. Error messages, which contain English language statements describing deviations of control outputs or system conditions from the nominal ideal model.

Although displays of extraordinary complexity can be arranged, the most useful ones are generally those plotting some single motor output function or system condition against time.

3. Selection of the rate and timing of feedback to the student. If tasks are relatively brief, a single display may be presented once at each completion of a discrete event. With tasks of substantial duration, the feedback may include static displays presented at discrete intervals, or as a continuously changing display. In either case, the best rate for updating displays had to be experimentally determined.

   Any display occurring during the performance of a psychomotor task constitutes an additional workload, competing for attention with other task elements and profoundly changing the nature of the task being performed. The presence of a continuously updated display may add elements of a tracking task to a performance situation that otherwise would not include a tracking requirement.

4. Selection of the complexity and style of messages, scores and displays. In the case of error messages, the complexity of vocabulary and grammar must be adjusted to the educational level of the individuals being instructed. Numerical scores must be scaled to an optimal number of discrete steps and significant digits.

5. Provision may be made for storage of any of the parameters generated during the instruction process. This would include records of operator output, system condition and also the array of feedback

displays and scores actually presented to the student. If such data are stored over a long series of trials, the student may be offered supplemental feedback showing the rate and direction of progress made over the series. Information can also be presented to the student in terms of his relationship to larger populations, such as centile or Z-scores.

6. Some provision should also be included for testing the transfer of the student's newly acquired performance capabilities from the feedback to non-feedback conditions.

APPENDIX E

Discussion of the Present Study in Terms of Operant Conditioning Theory

Discussion of the Present Study in Terms of Operant Conditioning Theory

Computer-assisted instruction represents an attempt to organize the process of teaching in terms of what is known about human learning. One set of basic principles which are relevant to this process are those of B. F. Skinner, which emphasize the importance of immediate reinforcement, gradual progression or shaping of responses, the maximization of the probability of success, and the minimization of behavioral inhibition due to punishment. While none of our training procedures were incompatible with these principles, there was a substantial divergence of emphasis between what we did and what might be expected in terms of a traditional, operant conditioning oriented training program.

a. Learning to do the job correctly was presumed to be its own reward. No attempt was made to introduce the continuous stream of praise or other secondary reinforcements which are often associated with cognitive CAI.

b. The student was presumed to be sufficiently alert and competent to shape his own motor output to closer and closer approximations of the ideal performance model if the model, his own output, and the points of difference between them were numerically or graphically displayed. No attempt was made to establish a reinforcement pattern for progressive improvement in performance other than the knowledge of results.

c. Where extraordinarily complex performance is called for; such as genuinely independent movement of two limbs, or coordinated movements in several dimensions, a more formal "shaping" procedure may be desirable. This may also be

desirable in cases where the activity to be performed is quite different from any motor output patterns likely to pre-exist in the average student's behavior repertory. Shaping procedures may easily be programmed into a CAI psychomotor training system. In terms of our present system, the addition of a shaping option would call for creating and storing a series of ideal performance models with progressively stricter demands on accuracy of timing and control, and changing the reference model used as the students become more proficient.

d. The presentation of error messages has some of the characteristics of a punishment, or an aversive conditioning process. This may frustrate or inhibit poor students, and may tend to depress the flexibility of their behavioral responses. This danger should be minimized by programming certain constraints into the system of error-message presentation. The messages should be organized into a hierarchy of importance, and only one or two presented to a student in any given trial. In addition, each error message should be followed by an opportunity to practice and correct the error separately from the integrated performance pattern being taught, if at all possible, and the correction should be immediately reinforced with some type of praise, even if the integrated performance score does not show any immediate improvement.

Reference: Skinner, B. F., The Technology of Teaching. Appleton-Century-Crofts: New York, 1968.

APPENDIX F

Description of the Computer System

Description of the Computer System

The following is a list of the parts of the Human Factors Laboratory computer system that are utilized in the operation on the simulator.

Following this is a listing of a minimum system necessary to operate the simulator providing some alterations in the software are made.

Current Components Utilized in the Current System

From Digital Equipment Company:		Price*
PDP8E-AE	Rack Mountable 8K system: Computer, 8K Core Memory and Teletype Control (rack mountable, slides included). Unit consists of: 1 KK8-E Central Processor 1 MC8-EJ 8K Core Memory and Memory Extention Control 1 KC8-EA Programmer's Console 1 KL8-E Console Teletype Control 1 Combination Power Supply, Chassis and OMNIBUS with 20 Quad Bus Slots	$ 5,650
MR8-EC	256 Word OS/8 ROM for TD8-E systems	800
DK8-EP	Real-time Clock, Programmable	810
VT8-EA	High-speed Alphanumeric and Graphics Video Display Terminal and Control (with 64 character line buffer, upper case 5 x 7 dot matrix 60 Hz).	2,050
TD8-EM	OMNIBUS DECtape Control and Dual DECtape Drive. Data transfer via programmed I/0. Max 4 TD8-E Controls per system (rack mountable).	5,000
AH04	Sample and Hold Option	300
AD01-AP	10-Bit Analog-to-Digital Conversion System up to 32 channels. Gains are programmable up to +10 volts (channels are implemented with the A124 option)	2,400
KE8-E	Extended Arithmetic Element (EAE)	1,080

Non-Digital Equipment Company Equipment:		Price*
	LP8 Tally Line Printer and Controller (200 lines per minute)	$ 5,500
	24 K of Plessy Core	4,500
	TOTAL COST OF EQUIPMENT USED	$33,635

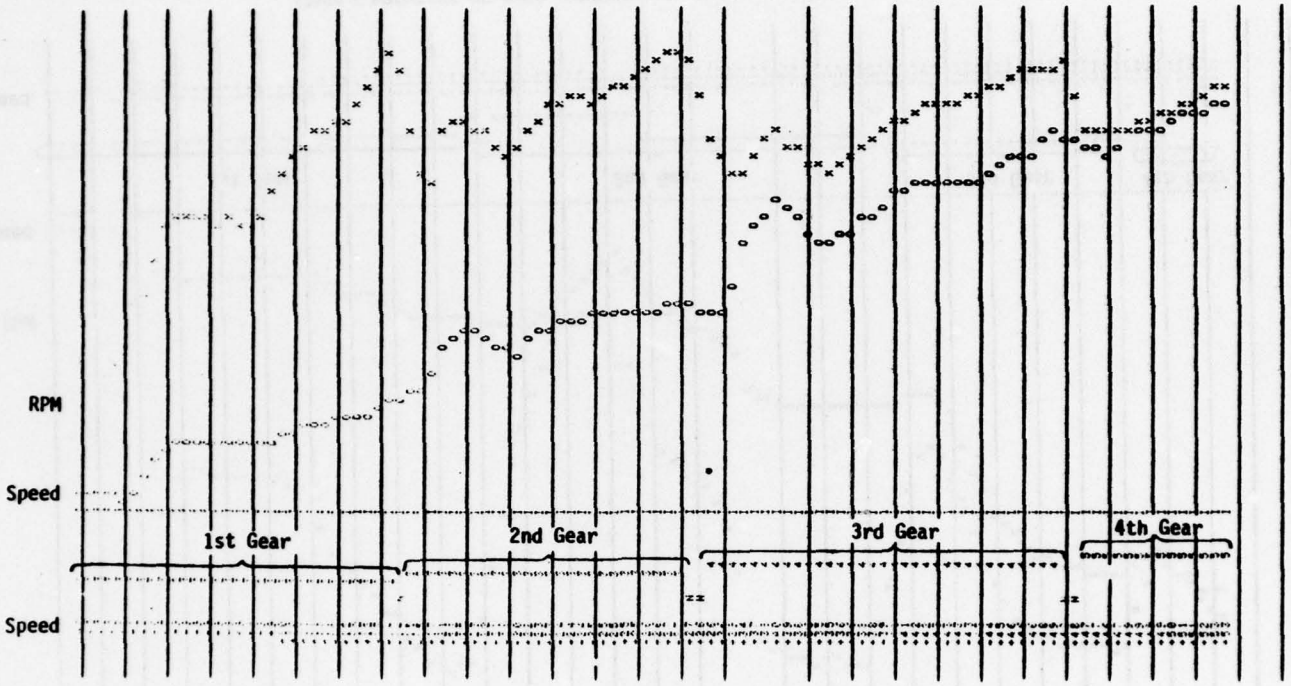
Minimum System Required to Operate Simulator (with software alterations)

PDP8E-AE	Base System	$ 5,650
VT8-EA	Video Display	2,050
KA8-E	Extender Interface for Positive I/O Device	250
DR8-EA	12 Bit Buffered I/O	500
DK8-EP	Real-Time Clock, Programmable Clock	810
AD01-AD	10-Bit Analog-to-Digital Conversion	2,400
LT33-DC	ASR33 Synchronous Read and Punch, Friction Feed	1,620
LP8	Tally Line Printer and Controller	5,500
	TOTAL COST OF MINIMUM OPERATING EQUIPMENT	$18,780

* Prices are the costs at the time of purchase (approximately 1973).

APPENDIX G

Sample of Computer Printout Showing Storage Format and Graphic Representation of Data Collected During a Single 22 Second Trial Involving Three Shift Points

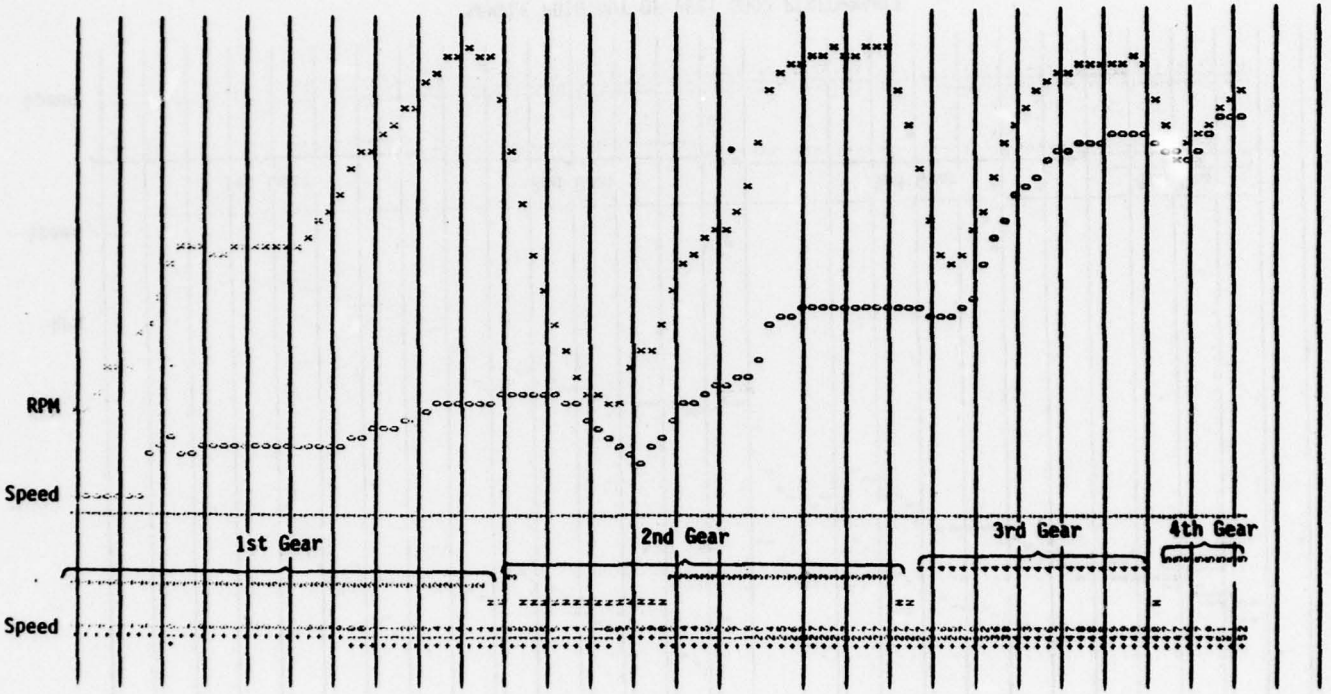


SAMPLE PRINTOUT OF VERY GOOD PERFORMANCE

Time Off Target* = +.40 seconds
Smoothness Score (Mean Square Error) = 4.37

---

* Time Off Target = Actual time to reach 55 mph - 22 seconds.

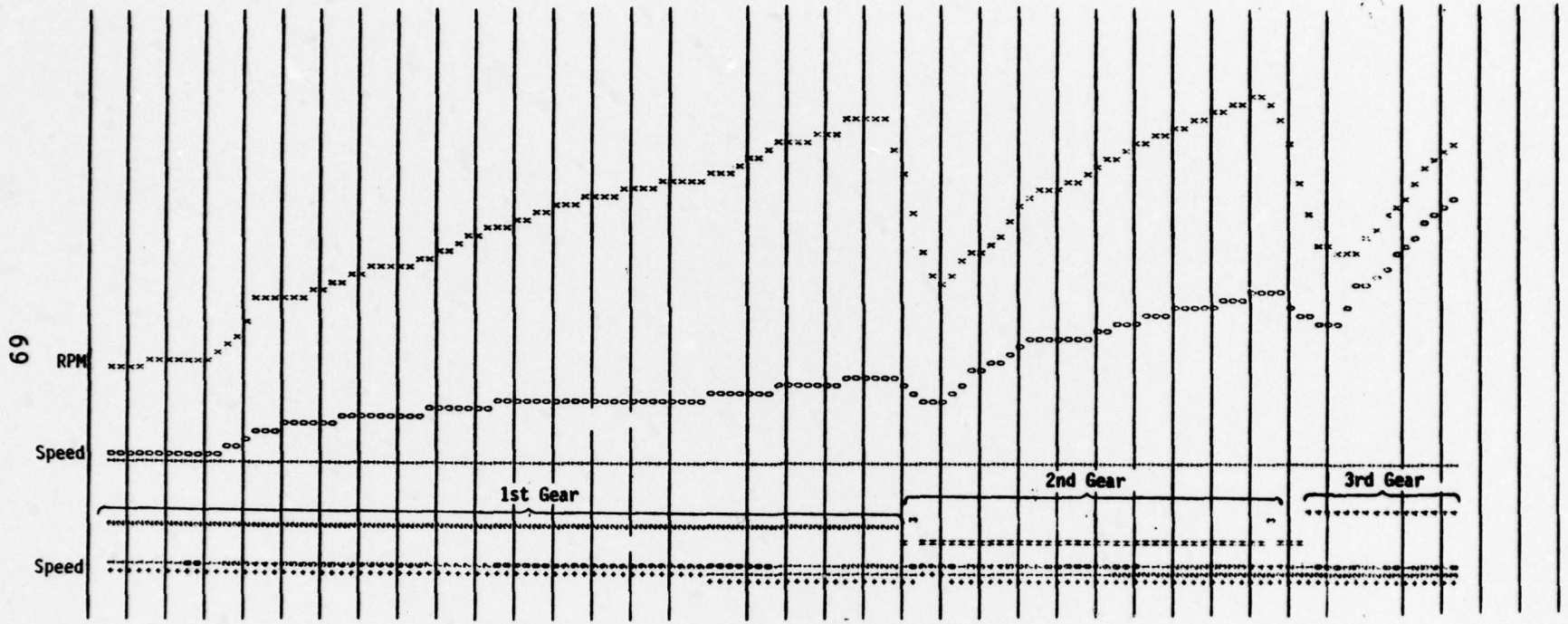


SAMPLE PRINTOUT OF POOR PERFORMANCE DUE TO UNSTEADY ACCELERATION

Time Off Target* = +.06 seconds
Smoothness Score (Mean Square Error) = 74.18

---

* Time Off Target = Actual time to reach 55 mph - 22 seconds.



SAMPLE PRINTOUT OF POOR PERFORMANCE DUE TO A LOW RATE OF ACCELERATION

Time Off Target* = 18.00 seconds (estimated time)**
Smoothness Score (Mean Square Error) = 58.25

---

* Time Off Target = Actual time to reach 55 mph - 22 seconds.
** Trial is terminated after 28 seconds and the time required to get to 55 mph is estimated.