DESIGN CONSIDERATIONS OF A COMBINED BRAKE-ACCELERATOR PEDAL SYSTEM

by

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INTRODUCTION

Driving an auto is a complex and demanding task, involving the highest stakes of life, limb and money. Yet, almost everybody thinks that he is able to drive, and, in fact, 96 million persons in this country are licensed to do so. Even those who cringe in terror at the sound of a home bench saw will slide under the steering wheel and pull into the onrushing traffic with aplomb - often without looking to see if the way is clear.

The statistics of the rate of accidents on an American road in a car show that a traffic death occurs every ten minutes and an injury every nineteen seconds. The automotive death rate is over 50,000 per year; this can be dramatized as "In 1966, 10 times more deaths than Vietnam or 500,000 deaths since 1954." For every death there are many injuries; in 1966, there were more than 50,000 deaths and over 190,000 injuries. In addition to the suffering and sorrow from death or injury, there is the dollar; $10 billion of them in 1966 (NSC, 1967).

Just as the accidents occur from Key West to Seattle, during summer and winter, on express ways and waysides, in compact and competition cars, with sober teenagers and tight senior citizens, the solution must be many faced.

The problem is complex indeed, but needs to be solved. A careful analysis is needed so that remedies can be suggested.

Which part of the Man-Machine-Environment System is most fruitful to improve? A simile is the danger of falls into an open manhole.

You can put a cover on it (engineering design), teach people to walk around it (selection and training) or put up signs "Don't step in holes" (motivation). Design is the most effective but what should be designed? Man? Environment? or Machine?

Although we are on the threshold of breaking the genetic code, we are far from exercising any control on human characteristics - except perhaps by training. Basically, the ability of human beings to use various devices depends on their psychomotor abilities and anthropometric characteristics (McCormick, 1964). An annual expenditure of a billion dollars spread over a hundred million drivers is only $10 per driver per year. It is not expected that much benefit can occur from this amount of direct training. The same amount spend on advertising may be more beneficial.

Designing new roads is an expensive and time consuming job, and leaves thousands of miles of existing roads. Especially serious is the problem of city streets with their obscuring structures. Interstate highway construction costs are 0.5 to 3 million dollars a mile depending on location and other factors. Taking a conservative estimate of the interstate highway construction costs as a million dollars a mile, one billion dollars would change a thousand miles of the 3.5 million miles of existing public highways. Moreover, an effective design of the roads has not yet been determined. Recently, Henry Ford II* said ". . . new highway construction is not the only solution to urban traffic problems. Modern traffic engineering methods and technology have enormous potential. Today, no American city has a really modern traffic

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*Speech - New Orleans - July, 1966.

control system. Except for a few experimental installations, expressways have no traffic control system at all." Thus neither the man nor the environment is easy to modify.

However, in America, automobiles have high turnover. The estimated half life of cars in the United States is five years; that is, five years from now more than half the cars on the roads in the U.S. will be manufactured after today. Since the number of cars on the road is increasing every day, it would be beneficial to modify the design as early as possible. Thus the new cars would offer not only changes in style, but also improved safety. Economically, at 8 million American cars sold per year, one billion dollars would allow $125 per automobile or approximately 5 to 7% of the cost of an average automobile. Therefore, the modification of the automobile seems the most cost-effective approach.

Increased safety and comfort in cars may be introduced by innovation of the controls. The design of the brake system may be improved to facilitate the ease of stopping. It may be desirable to include also instrument warning lights to alert drivers to such dangers as doors that are ajar or tires that are low on air or brake linings that are worn.

One of the parameters which affects safety is the permissible margin of error. The greater this margin, the less the chance of an accident or less the severity of accident. This margin is dependent upon design. One parameter of the design is the time between the decision of the controller and the reaction of the machine. The quickness with which the driver can react to any situation is a very important factor in driving - especially at high speeds.

It is assumed that a shorter reaction time will increase the permissible margin of error and thus greater time will be available to control the automobile to attain a specified condition. In other words, the car can be driven at higher speeds with equal safety or maintain the same speed with increased safety; which option the driver will select is unknown. However, no data are available to prove that with faster reaction time there is less chance of occurance of an accident. The tests for accident records furnished (Greenshields, 1936) on 284 drivers indicate that slow reaction time may have little to do with accident frequency.

If any of the factors can be so controlled that their time of execution is reduced, the reaction time will be decreased. A study on a brake-reaction time testing machine shows the following trends for 50,000 average motorists (Olmstead, 1936):

(i) The fast-reacting motorist has a tendency to drive at higher speeds than slow-reacting motorists. This tends to nullify the advantage that fast-reacting motorists should have over slow-reacting motorists in case they are required to stop.

(ii) An average motorist will decrease his reaction time during the first four years of driving, but after four years of driving there is no further improvement.

(iii) Age is one of the factors which has a tendency to increase reaction time, since with increase in age there is the natural tendency to lose both mental and physical coordination which is reflected in reaction time.

(iv) The average motorist probably drives with a feeling of false security, as it was revealed from this study that the average motorist drives without a thorough understanding of the factors involved in safe driving.

The brief interval between sensing a stimulus and starting to do something in response to the stimulus is called "reaction time."

i Sensing time: the time required to sense a signal. It is a function of the properties of the signal (size, intensity, duration).

ii Decision time: the time required to complete the neurological process of selection of the correct response to the presented stimulus. It is a function of decision complexity (complexity of the decision to be made, amount of practice).

iii Response time: the time required to respond to a signal. It is a function of the complexity of response (force, displacement, precision requirements).

Sensing time and decision time together are referred to as response latency while response time is akin to movement time. If any of these factors can be controlled so that their time of execution is reduced, the reaction time will be decreased.

Sensing time is of the order of a few hundredths of a second. The mode used for sensing the presented signal affects this time. Although the sensing time varies with the different senses, differences in the lag in hearing, touch and sight are small and probably insignificant. The comparison, however, is not very meaningful as the sensing time is known to depend upon the signal characteristics such as size of source, intensity, duration and location, etc. The larger the size of the visual signal, the faster, to some limiting value, will be the sensing time. Similarly, with an increase in the intensity of a signal, the sensing time will be faster. Sensing time will be faster to visual signals that strike the center rather than the periphery of the eye (Teichner, 1954).

The reaction time for combined signals (two or more signals simultaneously) is not faster than for the one signal giving the fastest reaction time (Teichner, 1954).

There is also variation in the reaction time among individual people, and with any one person, from one time to another. These differences tend to increase as the task becomes more difficult or exacting and as the conditions of work become more adverse. Thus, the extent of variation in reaction time depends on the particular environmental conditions as well as persons involved (Woodworth and Schlosberg, 1954).

Response (movement) time does not seem to have any correlation with response latency (Slater - Hammel, 1952; Pierson, 1956; Henry, 1961). It does, however, depend upon factors such as movement complexity and, obviously, distance to move, precision of movement, etc. It is of the order of a tenth of a second for very simple tasks but increases to a second or even more for complex tasks (such as precise positioning of levers) (Morgan et. al., 1963).

Reaction time between hands and feet is slightly different for simple tasks; it takes about 20% longer to respond with the feet than with the hands. Response with the preferred limb (for example, the right hand for right handed people) is about 3% faster than with the non-preferred limb (Teichner, 1954). So, if the control should be selected on the basis of speed of activation, the order of selection for right-handed operators should be the right hand, left hand, right foot, and left foot.

PREVIOUS WORK

Some formal studies on the man-machine aspects of a foot pedal have been advanced by Trumbo and Schneider (1963), and McCormick (1964). Their main consideration was the reaction movement time during the continuous operation of different types of pedals, i.e. the subjects were told to depress and release the pedal as many times as they could during an interval of three to four minutes. Obviously this is not the type of action one may be expected to perform while driving an automobile, but, as a useful and common result of these experiments, it was found the most effective and least fatiguing pedal design placed the fulcrum under the heel, as opposed to a fulcrum at the top or in the middle. Ayoub and Trombley (1967) used reaction time to a visual stimulus and a time of travel to a fixed stop. The optimal position for the fulcrum, with the load attached at the ball of the foot, is at the heel because it results in the minimum time of motion. This result was in agreement with the findings of Trumbo and Schneider (1963). They also recommended that the optimal foot-tibia angle should be from 78 to 96 degrees; however, 84 degrees is the preferred angle. This was predicated on the femur being horizontal, to reduce the constriction of blood flow by the edge of the operator's chair.

Versace (1966) at the Human Factors Department at the Ford Motor Company conducted some preliminary studies of dual brake-accelerator devices on automobiles but failed to show any "unusual advantage" over the conventional two pedal system.

One type of "one-pedal control" of a car has been developed by Humphrey, Inc., (1968). In this method, various degrees of braking are accomplished by simply letting up on the accelerator pedal. In this system, three distinct braking zones are provided: an upper proportional braking zone, a middle neutral or coasting zone, and a lower acceleration zone. However, this design has the limitation that the driver has to keep his foot constantly on the pedal. If, due to fatigue or some other reason, he removes his foot from the pedal, the car will come to a panic stop.

Several designs of dual action brake pedal mechanisms have been resting in the files of the United States Patent Office since the early twenties, but, to the author's knowledge, no experimental evaluation of reaction times has been done on dual - pedal systems except at Kansas State University.

To explore the potentials of a dual pedal on automobiles, a series of six experiments was conducted at Kansas State University. The first three of these experiments have been described in detail by Konz and Daccarrett (1967). The next three experiments are described in detail by Kalra (1968).

Experiment One brought out the interesting facts that, for drivers experienced in the existing right-foot system, both braking with the hands resting on the brake control and braking with the left foot resting on the braking control were significantly faster than the existing system. The improvement of approximately 0.2 second is equivalent to nine feet (1/2 a car length) at 30 miles per hour.

Experiment Two was conducted to find the reaction time on an integrated control pedal designed by Winkleman. One hundred twenty one visitors to an Engineering Open House volunteered their services; of the 121, 11 had also participated in Experiment One. The average time for these 11 subjects when using the right foot in Experiment One was 0.62 sec.; the 0.41 sec. when using the integrated control was significantly ($p < .01$) lower when it was tested with a Wilcoxon Matched-Pairs Test. Although a direct comparison between controls could not be made for all 121 subjects, it seemed likely that the average savings of 0.21 sec. enjoyed by the 11 would also be enjoyed by the other 110 since the average time on the integrated control for the 110 was .41 sec. also.

Experiment Three was performed to compare an American Automobile Association (AAA) reaction timer and the Winkleman integrated pedal. The American Automobile Association (AAA) reaction timer, a "black box" of the conventional system, had a "clutch" pedal, a "brake" pedal, an "accelerator," signal lights and a timing mechanism. Twenty five university faculty and students were used as subjects. It was observed that the 0.29 sec. when using the left foot was significantly ($p < .05$) less than the 0.36 sec. of the integrated control and the 0.36 sec. was significantly less than the 0.45 sec. when using the right foot.

Conditions in the laboratory are far from conditions on highways. So Experiment Four was conducted by mounting the control in a 1960 Rambler with automatic transmission. The integrated control was tested on a highway against the conventional accelerator and brake pedal. Sixteen subjects drove two miles along a two lane highway without intersections with one control and then drove back with the other control in place. Average reaction time with conventional brake and accelerator was 0.57 sec. The integrated control, with mean reaction time of 0.47 sec. was significantly faster ($p < .01$). An increase of .11 seconds in the highway condition over the laboratory condition was noted in the actuation time with both the integrated and conventional controls.

In Experiment Five, the reaction times were tested for the AAA reaction timer, a parked 1960 Rambler equipped with automatic transmission, and an integrated brake and accelerator pedal mounted on a test box. The integrated brake pedal with a reaction time of 0.323 seconds was found to be significantly faster ($p < .01$) than both the AAA reaction timer (0.482 sec.) and the 1960 Rambler conventional (0.432 sec.). The integrated brake pedal had the minimum learning effect.

Experiment Six was run to check the effect of varying some of the parameters in the design of the integrated pedal. More specifically, referring to the sketch (Fig. 1 and 2) of the integrated control, the optimum values of l and L, the respective distances from the heel of the pedal of the brake shaft and the accelerator shaft were sought. The criterion was the minimum reaction time. No specific values of these variables or any combinations of them were better than others. In other words, it can be said that the criterion of least reaction time does not act as a constraint in the tested range of pivot distances from the heel of the pedal. The above conclusion is significant for designers, since it provides a fairly wide working range to select the values of these variables on criteria of more mechanical nature.

Problem

Experiment Seven was run to investigate the effects of varying some of

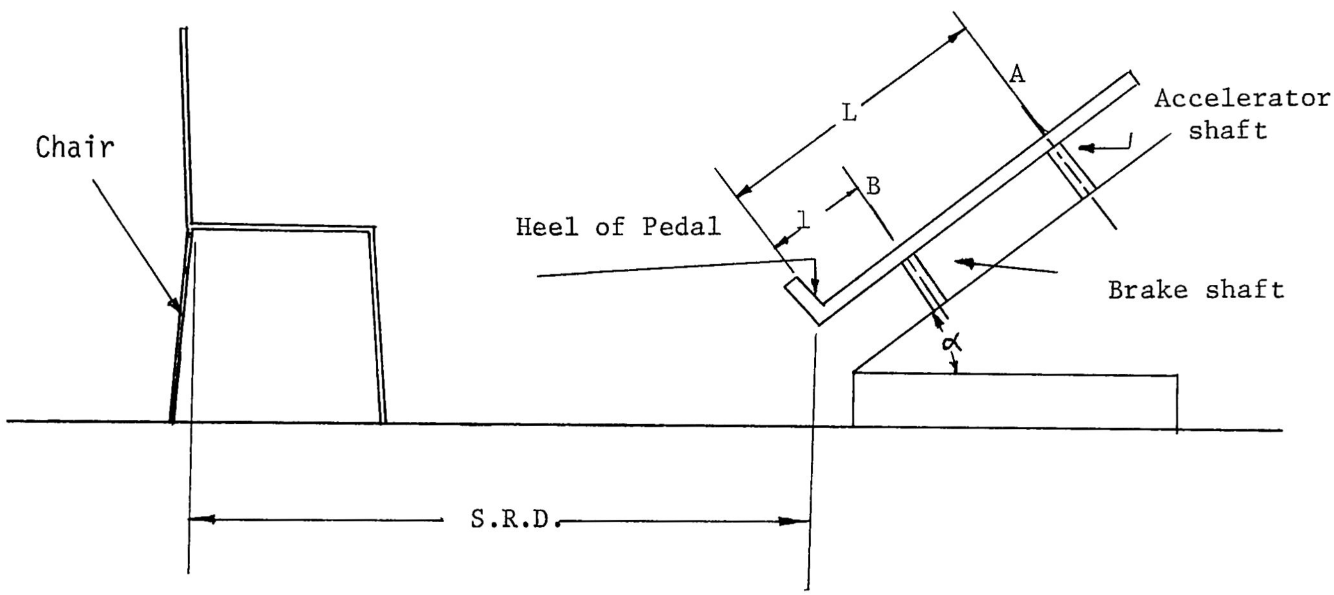


Fig. 1. Sketch of integrated control showing the variables (A, B, α, S.R.D.) in Experiment Seven as well as the variables (L, 1) of Experiment Six

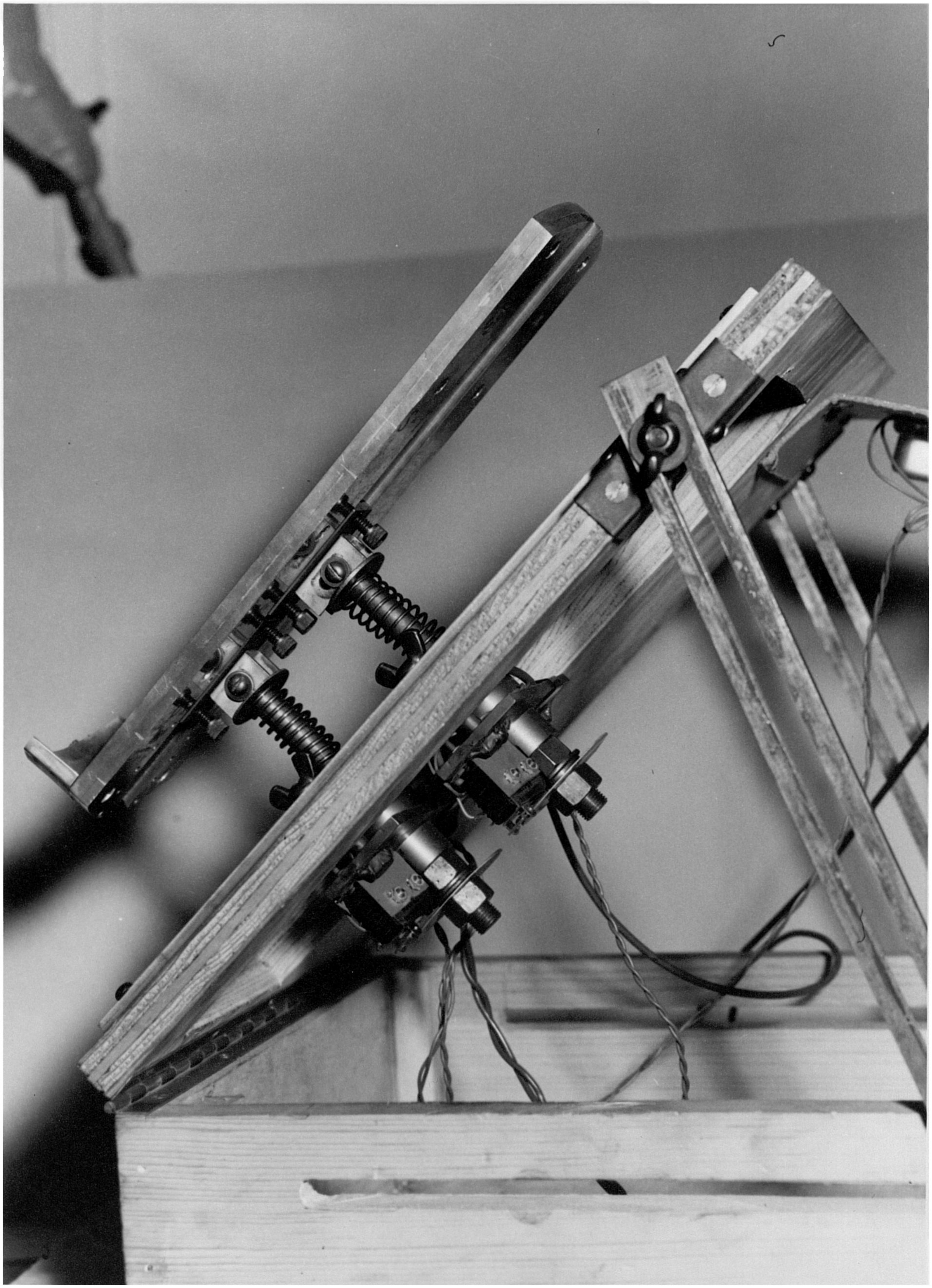


Fig. 2. A side view of the integrated brake-accelerator pedal.

the parameters in the design of the integrated pedal. In this experiment, the variables investigated were (i) force required to press the pedal in the forward (accelerator) direction (A), (ii) force in the backward (brake) direction (B), (iii) inclination of the foot pedal with the floor (α), and (iv) distance of the driver from the brake pedal in terms of seat reference distance (S.R.D.).

METHOD

Experimental Arrangement

The experimental set up is shown in Fig. 3 and is similar to that of Kalra (1968). The elements of the set up (referring to Fig. 3) were:

A. Chair

B. Integrated brake/accelerator pedal test box

C. Actuation indicator bulb

D. 1/100 second reaction timer

E. 60 watt lamp covered with red cellophane

F. Control switch

G. D.C. power

The design considerations in the selection of different parameters are given in Appendix 1.

The distances of the two shafts (Fig. 1) from the heel of the pedal were kept fixed at 4.5 and 7.5 inches from the heel although these distances seem to have no significant effect on the reaction time

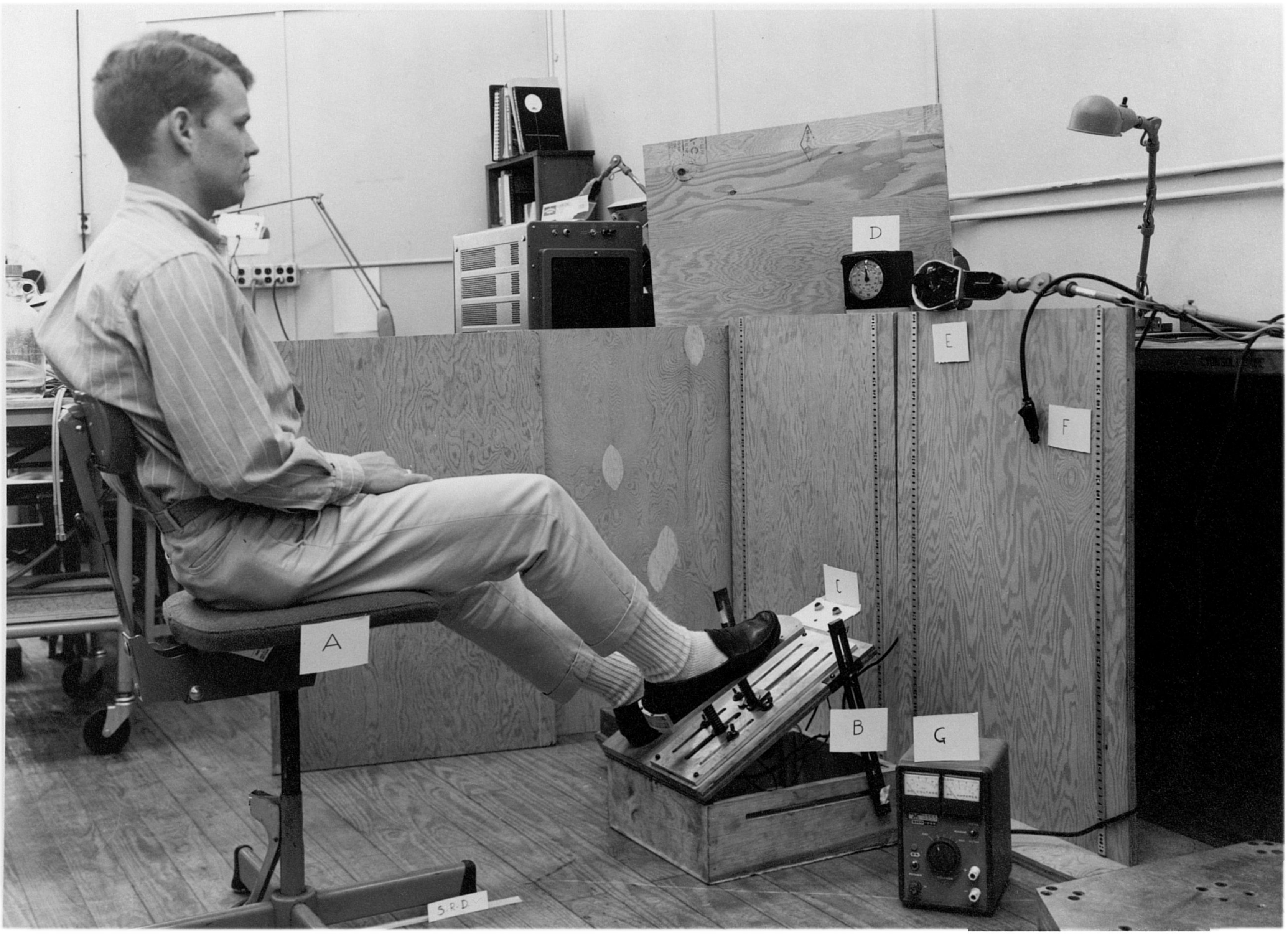


Fig. 3. Experimental set-up of the integrated brake-accelerator pedal

(Kalra, 1968). The foreshaft (A) acted as a fulcrum when the pedal was pressed in the rearward direction and the rear shaft (B) acted as a fulcrum when the pedal is pressed in the forward direction. The forward and backward motions are used for accelerating and braking the car respectively.

The two shafts were connected to two cut-out switches which were connected to the two "actuation indicator bulbs," one green and one red. A D. C. Power supply (8-10 volts) was used to pass current through the switches and bulbs. The bulbs were off when no control was in operation. When the foreshaft of the pedal was depressed, the green bulb came on, and when the foreshaft was released and the rear depressed, no light was on. But when both the shafts were depressed, the red bulb came on and a buzzer sounded, indicating that both the controls were simultaneously on.

A "reaction timer" was connected through an operating switch to both the rear shaft relay switch and the 60 watt lamp. The control switch had a dual purpose role, one being to turn on the 60 watt lamp and the second to reset the reaction timer to zero position after the reaction for one trial had been recorded. The reaction timer was electrically connected through the rear shaft cut-out switch and was stopped as soon as the rear shaft (brake) was depressed by 1/16 inch.

A biomechanic chair was used. The seat height was adjusted to about 15.7 inches above the heel of the pedal for both men and women drivers. (McFarland, R. A., Stoudt, H. W., Damon, A., 1966).

A red cellophane covering on the 60 watt lamp was provided to simulate the tail light of a car.

Design of the Experiment

A searching technique called EVOP (EVolutionary Operation of Processes) (Box and Hunter, 1959) was used for finding the optimum values of A, B, α, and S.R.D. In the choice of the data analysis technique, there are three considerations: mathematics, strategy, and analysis. From a mathematical efficiency viewpoint, EVOP and Analysis of Variance (ANOVA) are equivalent. The basic advantage of EVOP is from an experimental strategy viewpoint and ease of understanding by people not sophisticated in statistics rather than any statistical advantage. The EVOP technique emphasizes, to the experimenter, the effect of interactions. It also avoids "overkill" in that once an effect is found to be significant, the experiment stops and new values of the parameter are investigated. It is an example of Bayesian or step-by-step decision making.

The EVOP technique, primarily designed for production processes, calculates a response surface and determines the values of the parameters. Two essential features of the evolutionary processes are:

i Variation

ii Selection of favorable variants

The levels of the parameters are changed in small levels, such that, due to the changes, the path of steepest ascent (descent) can be approximated to move toward the maximum (minimum). Before any change is made in the variables, the process is run for a number of cycles at one level of the variables. Then the response surface is determined, and new changes introduced so as to lead to the maximum. The 'evolution' thus is a step-by-step process - each change representing a new step and with the direction of the step so selected as to lead to the maximum.

In EVOP a single performance of a complete set of operating conditions is called a cycle and the repeated running through of a cycle of operating conditions is called a phase. A new phase of EVOP begins when new conditions are explored, involving different levels of the same variables or different variables.

A 2^3 factorial design with a center point shown in the Fig. 4 was used for this experiment. Since the calculation forms are not available for four variables, only three factors were studied at a time. The variables selected were: Force required to depress the accelerator (A), force required to depress the brake (B), inclination of the pedal surface with the floor (α), and Seat Reference Distance (S.R.D.) Various other parameters that might be studied are: size of the pedal, seat height in relation to pedal, etc. The specific values selected for different parameters have been shown in Fig. 6 for phase I giving ten points for the experiment. A data recording sheet (See Appendix II) was designed to record the data.

Subjects

Four paid subjects, all male, each having at least four years

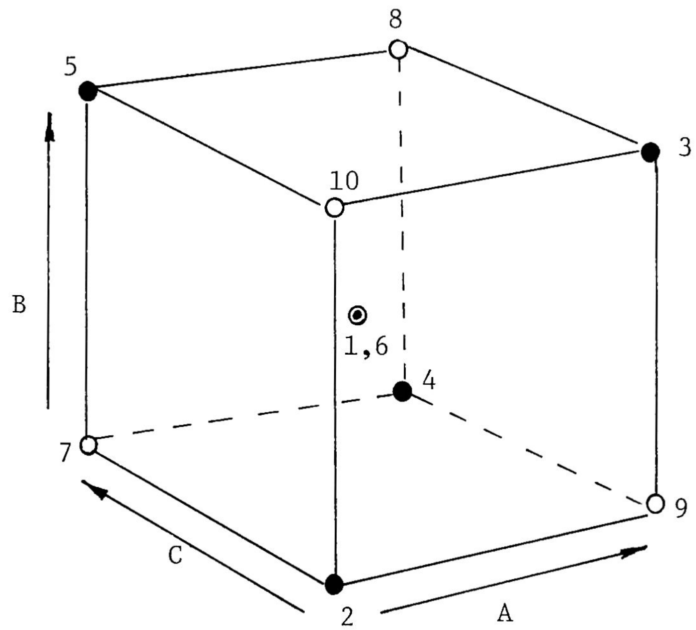


Fig. 4. Sketch showing a 2^3 factorial design with a center point.

○ indicates five trials of Block I of the cycle.

● indicates five trials of Block II of the cycle.

of driving experience were used. The average age was twenty three and the average years of driving experience was five. Height range was 5'7" to 6'0" with an average of 5'9". The same four subjects were run in all the phases in order to minimize subject effects.

Sequence

In Experiments Five and Six, the effect of learning for 100 trials per subject on the integrated brake pedal was found to be negligible. Hence it was concluded that learning within a set of 100 trials for a particular cycle would not have any appreciable effect on reaction time. Therefore the sequence of the first subject was varied so as to reduce the effort of changing the experimental apparatus. The sequence of the subject two was the mirror image of subject one's. Subject three followed a different sequence from one and the sequence of subject four was the mirror image of the subject three. The sequences were varied in each phase.

Experimental Procedure

The accelerator pedal inclination varies from one model of a car to another and was found to range from 45 to 65 degrees in the six different models checked -- Model T Ford, Volvo, Chevrolet, Corvair, Chrysler, and Pontiac. In the experiment the combined brake pedal device inclination was varied from a 20° angle to 50°.

The seat reference distance (S.R.D.), the distance between the heel of the pedal and the intersection point of the seat surface with the back rest surface of the seat, was varied from 35 to 60% of the subject's height. The distance was changed by shifting the chair, keeping the brake pedal at a fixed place.

The two springs, the brake spring being 2.44 inches long with a spring constant of 66.67 pounds/unit inch and the accelerator spring being 2.56 inches long with a spring constant of 10.42 pounds/unit inch were calibrated in the laboratory for different loads (Fig. 5). The forces to depress the accelerator and brake pedal were changed by introducing or removing horseshoe shape washers in between the springs. This, in fact, is equivalent to changing the springs. Since there was a linear correlation of the amount of deflection and the compression in the springs, .06 inches thick horseshoe plates were made for a step increase of four pounds in the brake spring compression. Similarly .192 inches thick horseshoe plates were made for the step change of two pounds in the accelerator force. In this way force on the accelerator was varied from four to eight pounds in steps of two pounds, and in the brake was varied from 13 to 25 pounds in steps of four pounds.

The 60 watt lamp covered with red cellophane was fixed at a height of three feet above the ground and about 5 feet away in front of the subject's eyes. Since the chair was moved instead of the brake pedal, relative distance between the chair and lamp was not

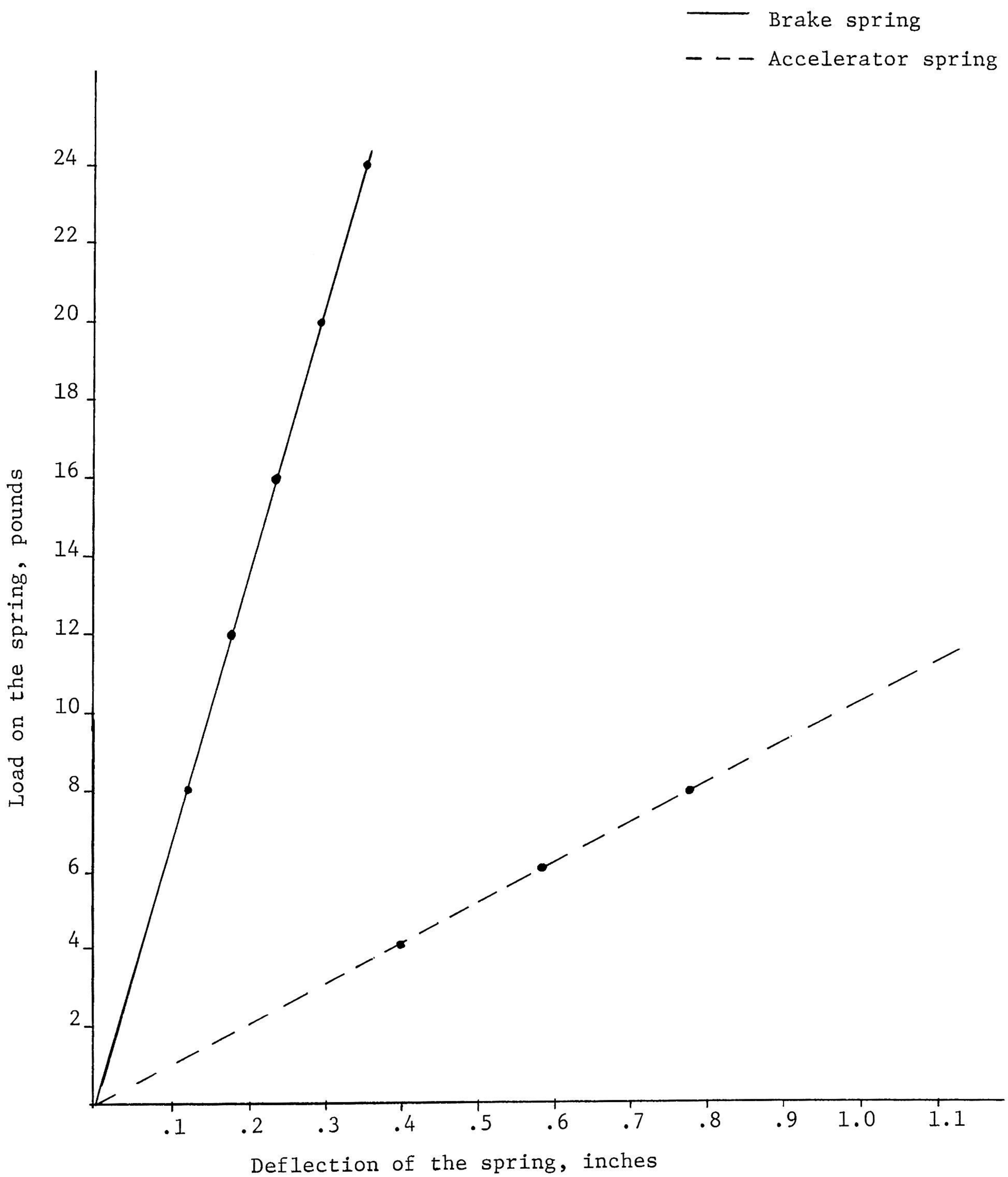


Fig. 5. Relationship of the deflection and load on the springs.

constant for varying distances of S.R.D. and subjects.

Before starting the experiment, personal data of the subjects; namely, name, sex, height, age, and years of driving experience were recorded. The subject was told the purpose of the experiment. He was told to hold the pedal with the accelerator in a depressed position and look at the red lamp in front. When the lamp came on, he was to release the accelerator and press the brake shaft.

In the initial condition of the depressed accelerator, it was made certain by the experimenter that both the controls were not in the depressed condition. If both the controls were pressed simultaneously after the presentation of the stimulus, the buzzer sounded, and hence the data was disregarded. The author feels that, in an actual system, the driver should be informed when he is pressing both the accelerator and brake. It may be even desirable to automatically disengage one mode if a certain percent of the other mode is actuated. The subjects were given about three to five practice trials at each condition. Ten replications were made for each condition before changing to the next one.

A time between the stimuli of 5 seconds or more is sufficient to prevent treating the stimuli as one stimulus (Welford, 1960), so the time between the two stimuli was kept about 5 to 10 seconds. This time between two successive stimuli was also sufficient to prevent the anticipative response to a signal about to occur (Morgan <u>et al</u>., 1963). During the period when the conditions were changed the subject was not doing anything, so no separate rest period was given.

The experiment was held in the Human Engineering Laboratory of Industrial Engineering Department at Kansas State University. The experiment was run in six phases. The values of the parameters for each phase were selected from the previous phase in the direction of the steepest descent during the previous phase until the minimum was reached.

RESULTS

Phase I

The parameters of Seat Reference Distance (SRD), Angle of Inclination (α), and Brake Force (B) were selected for study in Phase I. See points 1 through 10 respectively in Fig. 6 (a). The accelerator force was kept constant at six pounds in this phase. Reaction time for the first four subjects are summarized in Table 1. The times, given in thousandths of a second (milliseconds), are the mean times per trial based on the 10 readings taken at each point for each subject.

Three variable EVOP was used to evaluate the significance of the main effects (S.R.D., α, B) and the interaction effects (S.R.D. X α, S.R.D. X B, α X B). Running averages, Yi's (i identifying the conditions 1, 2, ... 10), were calculated from the mean times for each subject. A single cycle is broken into two blocks of five runs each as indicated by the open and filled circles as shown in Fig. 4. The estimate, E_1, E_2, ... E_7, of the indicated combinations of main effects and interactions are calculated as follows:

$$E_1 = (\text{S.R.D.} - \alpha \times B) \text{ effect} = 1/2\ (Y_3 + Y_4 - Y_2 - Y_5)$$

$$E_2 = (\alpha - \text{S.R.D.} \times B) \text{ effect} = 1/2\ (Y_3 + Y_5 - Y_2 - Y_4)$$

$$E_3 = (- B + \text{S.R.D.} \times \alpha) \text{ effect} = 1/2\ (Y_2 + Y_3 - Y_4 - Y_5)$$

$$E_5 = (\text{S.R.D.} + \alpha \times B) \text{ effect} = 1/2\ (Y_8 + Y_9 - Y_7 - Y_{10})$$

$$E_6 = (\alpha + \text{S.R.D.} \times B) \text{ effect} = 1/2\ (Y_8 + Y_{10} - Y_7 - Y_9)$$

$$E_7 = (B + \text{S.R.D.} \times \alpha) \text{ effect} = 1/2\ (Y_7 + Y_8 - Y_9 - Y_{10})$$

Now, from the combined information of Block I and Block II, main effects and interactions were calculated as follows:

$$\text{S.R.D. effect} = 1/2\ (E_5 + E_1)$$

$$B \text{ effect} = 1/2\ (E_6 + E_2)$$

$$\alpha \text{ effect} = 1/2\ (E_7 - E_3)$$

$$\text{S.R.D.} \times B \text{ interaction} = 1/2\ (E_7 + E_3)$$

$$\text{S.R.D.} \times \alpha \text{ interaction} = 1/2\ (E_6 - E_2)$$

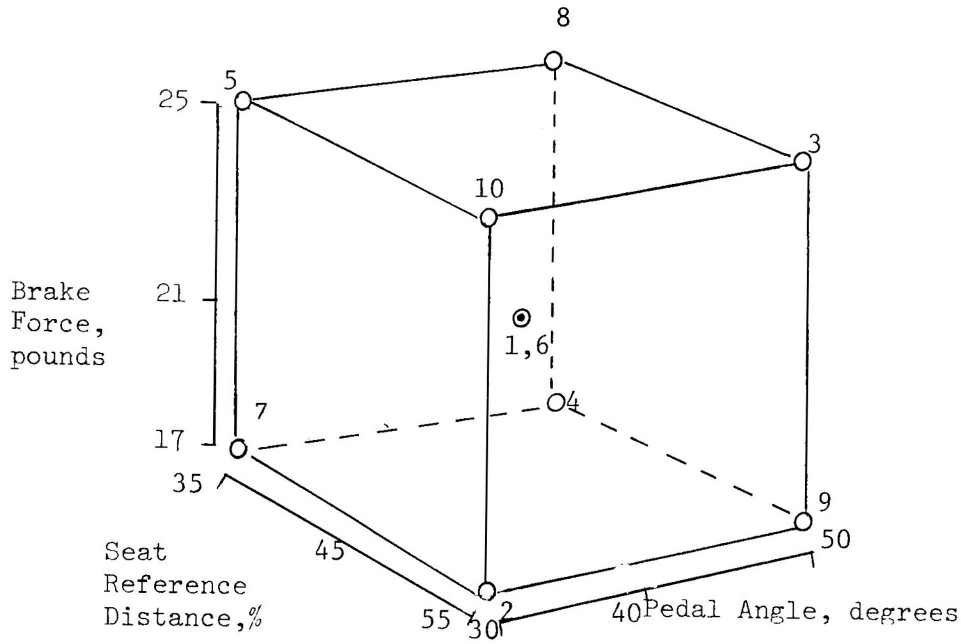
$$\alpha \times B \text{ interaction} = 1/2\ (E_5 - E_1)$$

Sample calculations for two successive cycles illustrating the use of EVOP in calculating Yi's, the main effects (S.R.D., B, and α)

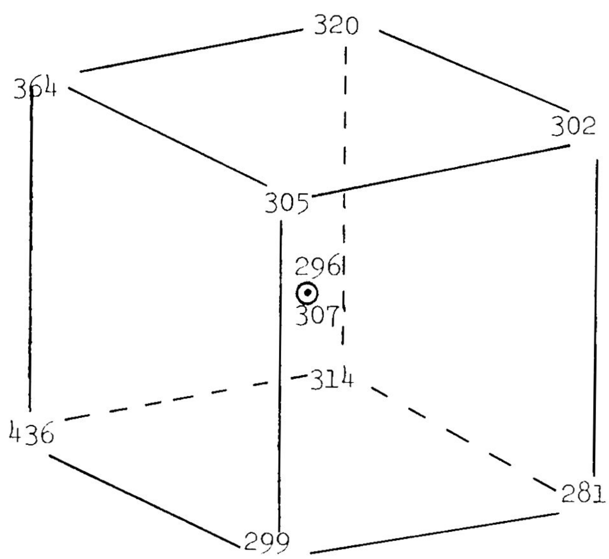
and their interaction effects and the 95% error limits for these effects are given in Appendix III. The calculation form is that given by George Box and Stuart Hunter (1959).

The results of calculations after each cycle of Phase I are consolidated in Table 2. The 95% error limits are shown.

As seen from Table 2, the main effects of S.R.D. and α, as well as their interaction, S.R.D. x α, had a significant effect on the reaction time at the completion of Phase I. There was no significant effect of B or interactions B x α and B x S.R.D. In other words, the response surface was not affected by the change of brake force at the 95% confidence level. However, the response surface descended with an increase in S.R.D., and ascended with an increase of angle of inclination of the pedal. Looking at reaction times of Table 1, higher response times are indicated in the region of points 4, 5, 7, and 8. In other words, reaction times were higher with increasing values of α and decreasing values of S.R.D. At the end of Phase I, the variation of the response surface at 95% error limits was 0 ± 25 milliseconds. A four way analysis of variance was also used to analyze the data, omitting the data of the center points. Again, the main effects of S.R.D. and pedal angle and their interaction effects were significant. Table 3. The analysis of variance brings out that effect of S.R.D. is more statistically significant than pedal angle. But the EVOP points out that pedal angle effect is more prominent than S.R.D. This brings out an interesting comment that what may be more statistically significant need not be the most prominent effect. The tendency of those not sophisti-



(a)Cycle of Variants



(b) Mean reaction time(milliseconds) after 4 cycles (accelerator force constant @6 pounds).

Fig.6. Pattern of variants and results for three variables for phase I.

Table 1

Mean Reaction Time (milliseconds) of Ten Trials in Phase I

Subject	"Point" 1	2	3	4	5	6	7	8	9	10	Average
G.P.	304	332	271	280	391**	323	381	282	258*	331	315
S.S.	272*	279	290	326	296	294	459**	325	274	294	311
S.W.	323	311	343	360	373	292*	427**	373	315	326	344
S.M.	285	272	302	281	396	318	477**	298	277	271*	318
Average	296	299	302	312	364	306	426	320	281	306	322

* Subject's min. mean time for his ten points (row min.)
** Subject's max. mean time for his ten points (row max.)

Table 2

Consolidated Main Effects and 95% Error Limits (Phase I)

Cycle No.	Cumulative Effects S.R.D.	B	α	S.R.D. x B	S.R.D. x α	B x α	95% Error Limits
2	-57.1*	-13.6	51.4*	21.1	-21.4	-24.4	$\pm$ 39.4
3	-41.9*	- 8.9	54.1*	20.8	-21.6	-23.3	$\pm$ 28.5
4	-47.0*	- 9.8	61.8*	22.7	-36.2*	-23.6	$\pm$ 24.7

* Significant effects

Table 3

Analysis of Variance of Reaction Time at Phase I

Source	df	MS	F
S.R.D.	1	29950	41.0**
Pedal angle (α)	1	18097	7.9*
Brake force (B)	1	674	1.1
Subjects (S)	3	2505	-
S.R.D. X α	1	10842	4.9*
S.R.D. X B	1	4211	1.9
α X B	1	4349	2.0
S.R.D. X S	3	730	-
S X B	3	604	-
S X α	3	2292	-
S.R.D. X α X B	1	2193	2.2
Residual	12	98	
Total	31		

$^{**}p < .01$

$^{*}p < .05$

cated in analysis of variance is to assume that the source of variation that is the most significant is the most important. EVOP directly presents the useful information that the surface varies ± 25 milliseconds by chance; the 47 and 62 milliseconds are therefore important.

There is another advantage of EVOP in that the error term is based on 40 observations whereas in the analysis of variance it is based on only 32 observations because no centerpoints are used. Hence, the use of centerpoints in the EVOP:

(i) Gives more error information

(ii) Gives a better subjective "feel" to persons looking at the response surface and departure from the response surface.

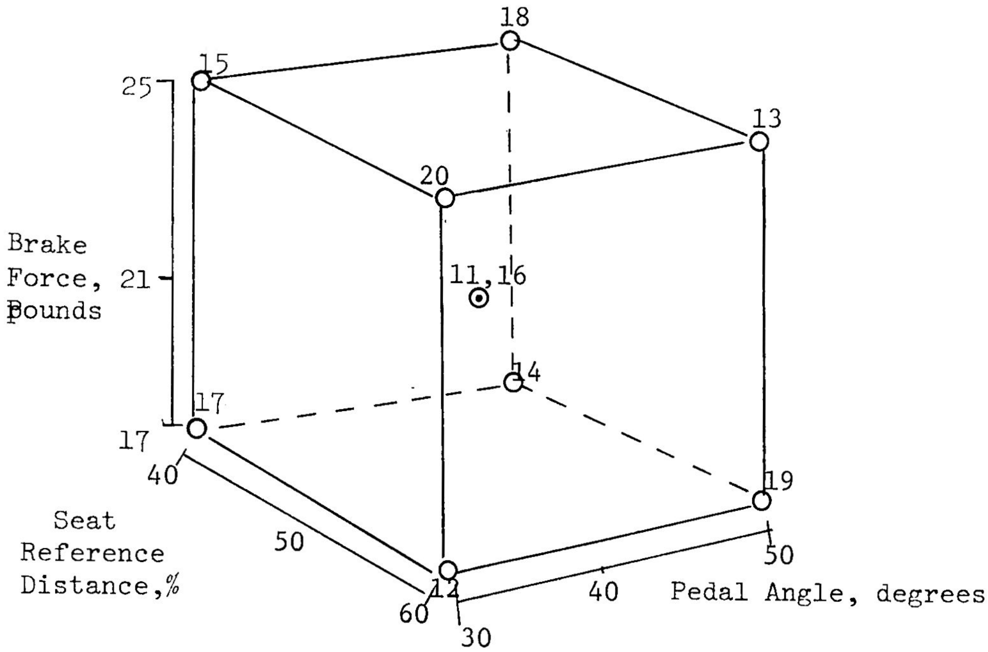
(iii) Gives information on the repeatability of the data since point one and six are the same.

Phase II

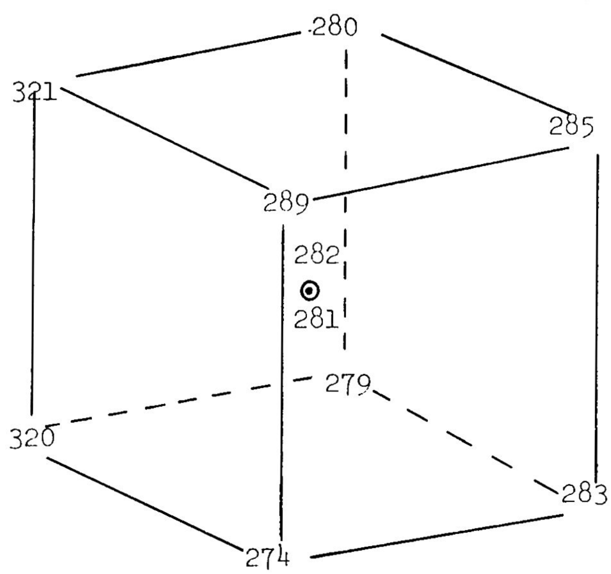
It was felt that the S.R.D. as 35% of the subject's height was uncomfortable so it was decided to change the S.R.D. to 40-50-60 from 35-45-55 and keep the other variables the same.

The new values of the variables selected are shown in Fig. 7(a). The results of mean reaction time for the ten points after 4 cycles are shown in Fig. 7(b). The mean times per cycle are tabulated in Table 4.

Table 5 shows the cumulative effects and 95% error limits for various effects. The main effect of S.R.D. and the interaction of S.R.D. x α were found significant. Even though the α effect was not significant at the 95% level, the angle of inclination did influence the



(a) Cycle of variants



(b) Mean reaction time (milliseconds) after 4 cycles (accelerator force constant@ 6 pounds).

Fig. 7. Pattern of variants and results for three variables for phase II.

Table 4

Mean Reaction Time (milliseconds) of Ten Trials in Phase II

Subject	"Point" 11	12	13	14	15	16	17	18	19	20	Average
G.P.	249	223*	282	251	301	250	339**	255	255	230	264
S.W.	299	283	317**	266*	307	294	311	286	279	312	295
S.S.	274	271	248*	282	300**	264	295	265	278	268	275
S.M.	307	320	293*	318	377**	316	336	314	319	348	325
Average	282	274	285	279	321	281	320	280	283	290	290

* Subject's min. mean time for his ten points (row min.)

** Subject's max. mean time for his ten points (row max.)

Table 5

Consolidated Main Effects and 95% Error Limits (Phase II)

Cycle No.	Cumulative Effects S.R.D.	B	α	S.R.D.x B	S.R.D.xα	B xα	95% Error Limits
2	-14.4	10.4	16.9	11.9	-35.6*	-14.9	$\pm$ 24.7
3	-14.7	3.2	17.7	3.8	-20.7*	- 8.1	$\pm$ 19.3
4	-19.6*	4.8	17.3	- 3.3	-21.6*	- 3.9	$\pm$ 18.2

* Significant effects

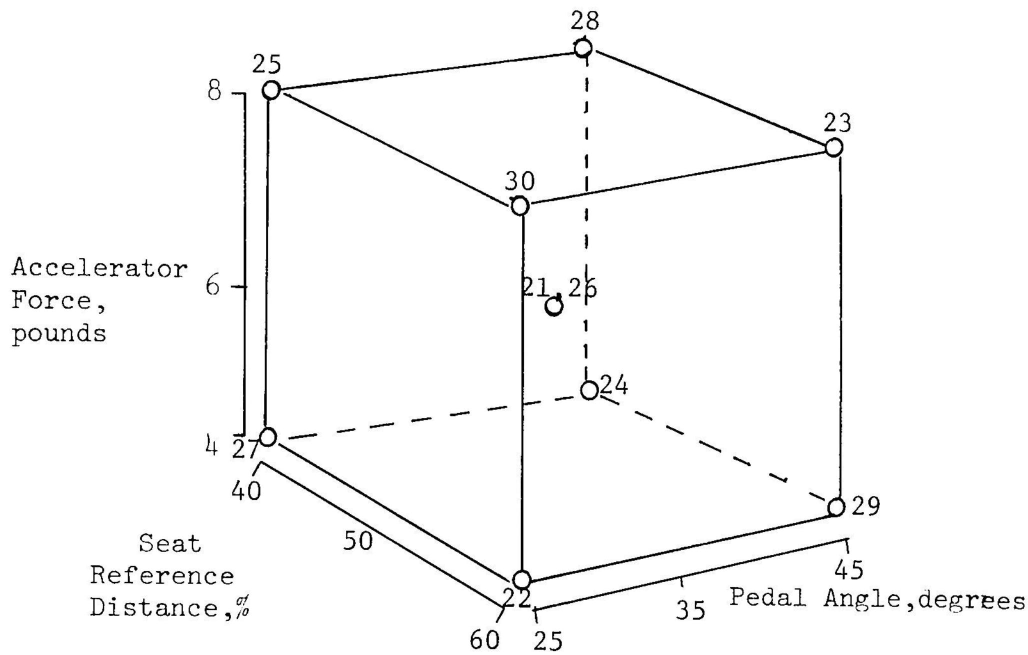
reaction time appreciably. These results proved again the trend of an increase of reaction time with decrease in S.R.D. and increase of α. Brake force and its interaction with the other two variables was very small, so it was decided to eliminate B and include accelerator force (A) as a variable in the next phase.

Phase III

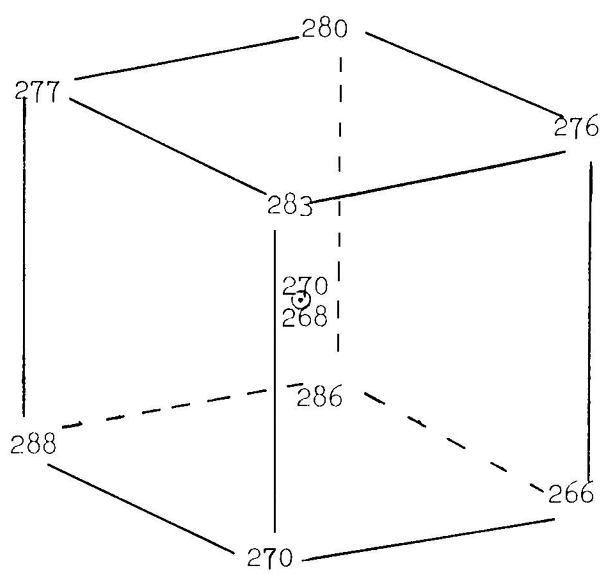
The new set of variables selected are shown in Fig. 8(a). The values of the α were set at 25°-35°-45°. S.R.D. was kept the same as that of Phase II (40-50-60) and the accelerator force (A) was set at 4-6-8. The results are shown in Fig. 8(b). The mean times per subject are tabulated in Table 6. Table 7 shows the cumulative effects and 95% error limits for various effects. The interaction of A x α was found significant. There was a trend of an increase in reaction time with decrease in S.R.D. and increase in A at large values of S.R.D. However, there was decrease in reaction time with an increase in A at small values of S.R.D. Even here accelerator force (A) had little effect on performance as compared to S.R.D. and α.

Phase IV

The new set of variables selected are shown in Fig. 9(a). The range of S.R.D. was decreased to 40-47.5-55. The values of α were decreased to 20°-27.5°-35°. The values of the A were kept the same as that of Phase III (4-6-8). The value of B was kept constant at 17 pounds, the same as that of Phase III.



(a) Cycle of variants



(b) Mean reaction time (milliseconds) after 4 cycles(brake force constant @17 pounds).

Fig. 8. Pattern of variants and results for three variables for phase III.

Table 6

Mean Reaction Time (milliseconds) of Ten Trials in Phase III

Reaction Time (1/1000 Sec)

Subject	"Point" 31	32	33	34	35	36	37	38	39	40	Average
G.P.	235	243	249	258	248	236	278**	229*	244	232	245
S.S.	261*	269	277	308**	272	270	293	308**	266	299	282
S.W.	262	271	268	262	258*	263	284**	263	259	262	265
S.M.	303	296*	310	317	329	304	298	320	296*	339**	311
Average	265	270	276	286	277	268	288	280	266	283	276

* Subject's min. mean time for his ten points (row min.)

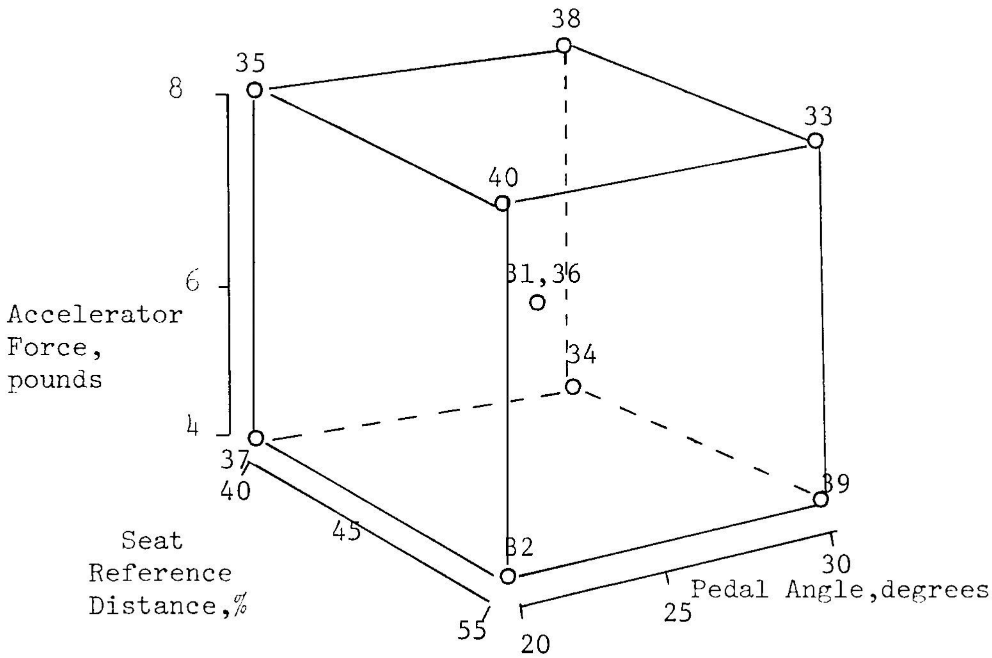
** Subject's max. mean time for his ten points (row max.)

Table 7

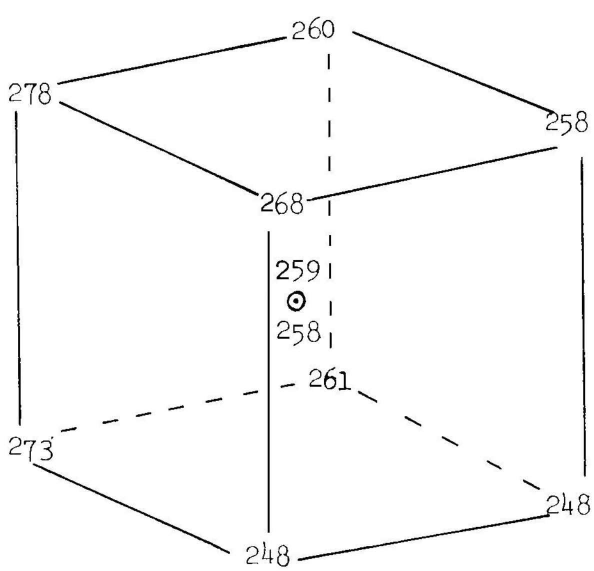
Consolidated Main Effects and 95% Error Limits (Phase III)

Cycle No.	Cumulative Effects S.R.D.	A	α	S.R.D.x A	S.R.D.x α	A x α	95% Error Limits
2	0.9	-5.9	14.6*	2.1	2.6	-14.6*	$\pm$ 13.6
3	-1.5	-5.8	10.2*	5.4	0.7	-11.7*	$\pm$ 9.2
4	-2.5	2.5	8.2	1.2	2.0	-10.0 *	$\pm$ 9.6

* Significant effects



(a) Cycle of variants



(b) Mean reaction time (milliseconds) after 4 cycles(brake force @17 pounds).

Fig. 9. Pattern of variants and results for three variables for phase IV.

Table 8

Mean Reaction Time (milliseconds) of Ten Trials in Phase IV

"Point"

Subject	41	42	43	44	45	46	47	48	49	50	Average
S.M.	285	247*	285	305	308**	279	294	298	284	301	289
S.W.	261	234*	248	254	283	253	286**	255	249	260	258
G.P.	217	224	225	208	244**	222	227	217	205*	230	222
S.S.	271	286**	272	277	278	277	285	271	254**	279	275
Average	259	248	258	261	278	258	273	260	248	268	261

* Subject's min. mean time for his ten points (row min.)

** Subject's max. mean time for his ten points (row max.)

Table 9

Consolidated Main Effects and 95% Error Limits (Phase IV)

Cycle No.	Cumulative Effects						95% Error Limits
	S.R.D.	A	α	S.R.D.xA	S.R.D.xα	A x α	
2	5.5	15.5*	22.0*	-18.5*	-5.0	-12.0*	± 10.7
3	- 5.4	11.6*	22.9*	-13.1*	-11.4*	- 8.4	± 8.4
4	- 8.7*	11.4*	15.6*	-7.6	- 8.7*	- 6.3	± 8.6

*Significant effects

The mean times per subject are tabulated in Table 8. Table 9 shows the cumulative effects and 95% error limits for various effects. The results are shown in Fig. 9(b). Table 9 reveals that there was significant effect of all the three main effects; only the S.R.D. x α interaction, however, was significant. This time there was an increase in reaction time with decrease in S.R.D., increase in α, and increase in A separately and jointly. The minimum value of A was already 4 pounds; there was little scope to reduce the value of A still further for the satisfactory operation of the system. Hence it was decided not to reconsider A as a variable in the next phase. To eliminate the effect of A, points 35 and 37, 32 and 40, 31 and 36, 34 and 38, and 33 and 39 were combined together and their mean time are shown in Fig. 10. If we eliminate the effect of A and B we find that points 2 and 10 together are overlapping with 34 and 38, respectively. These points, in common in phases I, II, and IV are shown in Fig. 10. Comparing the values revealed that there was some learning effect.

Phase V

The next set of variables selected are shown in Fig. 11(a). B was varied instead of A. The values of B were 13-17-21 pounds. Similarly, S.R.D. values were 45-50-55 instead of the 40-47.5-55% of Phase IV. α was 20-27.5-35 as in Phase IV and the value of A was kept constant at 6 pounds.

The mean times per subject are tabulated in Table 10. The results

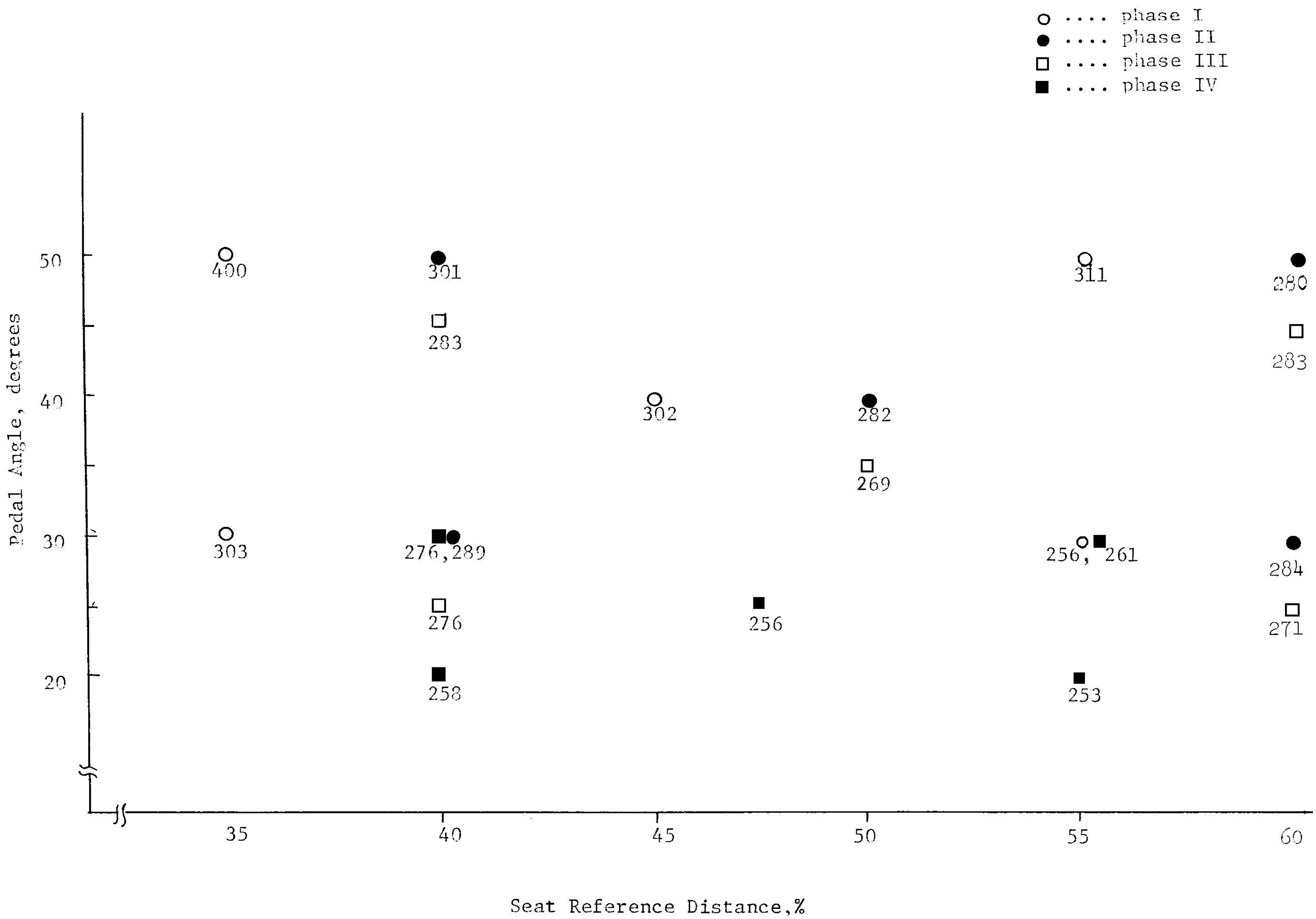
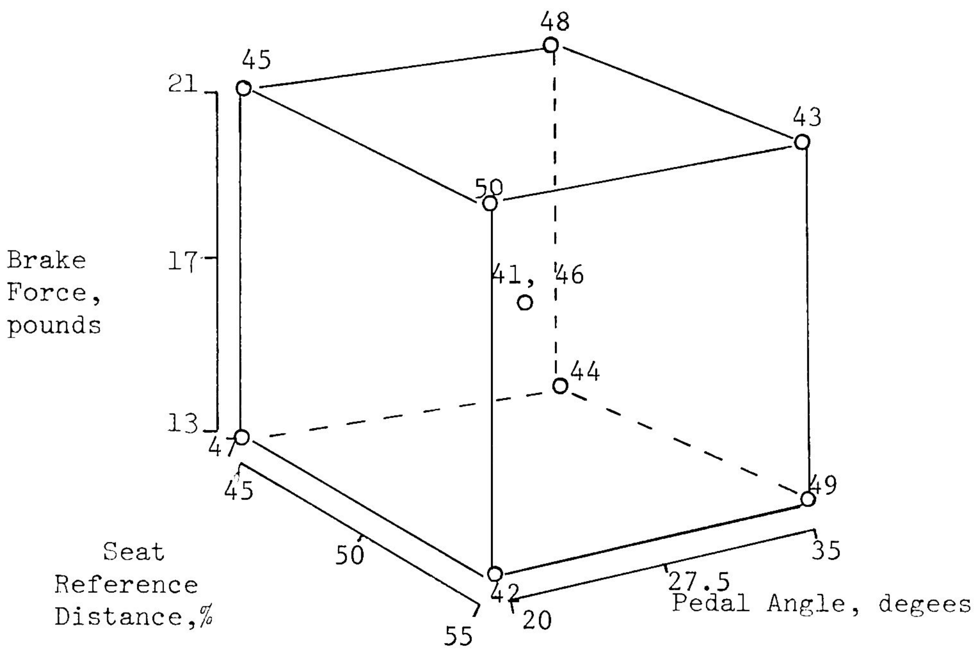
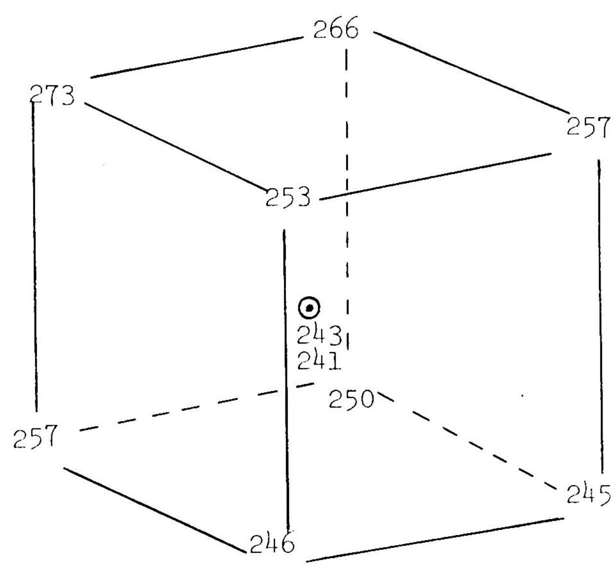


Fig. 10. Reaction times (milliseconds) after eliminating the effect due to brake and accelerator force for phase I to IV.



(a) Cycle of variants



(b) Mean reaction time (milliseconds)after 4 cycles(accelerator force constant @ 6 pounds).

Fig. 11. Pattern of variants and results for three variants for phase V.

Table 10

Mean Reaction Time (milliseconds) of Ten Trials in Phase V

Subject	"Point" 41	42	43	44	45	46	47	48	49	50	Average
G.P.	227	219	251**	215	233	216	242	250	217	209*	228
S.S.	253	232*	239	254	264	247	257	263	255	275**	254
S.W.	235*	268	259	262	278**	249	274	265	236	275	260
S.M.	258	265	279	268	316**	250*	258	287	271	254	271
Average	243	246	257	250	273	241	258	266	245	253	253

* Subject's min. mean time for his ten points (row min.)

** Subject's max. mean time for his ten points (row max.)

Table 11

Consolidated Main Effects and 95% Error Limits (Phase V)

Cycle No.	Cumulative Effects S.R.D.	B	α	S.R.D.xB	S.R.D.xα	B x α	95% Error Limits
2	1.9	11.9	9.9	3.6	-4.9	-0.9	$\pm$ 15.6
3	- 4.8	11.0	10.0	3.7	-1.3	-2.5	$\pm$ 12.1
4	- 2.9	12.9*	11.3*	1.5	-4.1	3.1	$\pm$ 10.2

* Significant effects

are shown in Fig. 11(b). Table 11 shows the cumulative effects and 95% error limits for various effects. The main effects of α and B were found significant; their interaction, however, was not significant. There was again little scope to reduce the brake force since this is the minimum force required to keep the foot on the pedal without actuating the brake. To eliminate the effect of B, points 45 and 47, 50 and 42, 41 and 46, 40 and 44, and 43 and 49 were combined together and overall mean time is shown in Fig. 12. Since the points 32 and 40 are overlapping with points 42 and 50, comparison of the mean time showed that there was a small learning effect.

Phase VI

The next values selected are shown in Fig. 13(a). The value of A was fixed at 6 pounds. Brake force (B) was again varied at 13-17-21. The range of S.R.D. was reduced from that of the last phase (40-45-50) to 47.5-51.25-55%. Alpha was 20-25-30 instead of the 20-27.5-35 of Phase III and IV.

The mean times per subject are tabulated in Table 12. The overall mean time after four cycles is shown in Fig. 13(b). Table 13 shows the cumulative effects and 95% error limits for various effects. None of the main effects or their interaction effects were significant. Again, to study the effect of S.R.D. and α by eliminating the effect due to B, points 55 and 57, 60 and 52, 51 and 56, 58 and 54, and 53 and 59 were combined together and overall mean time is shown in Fig. 14.

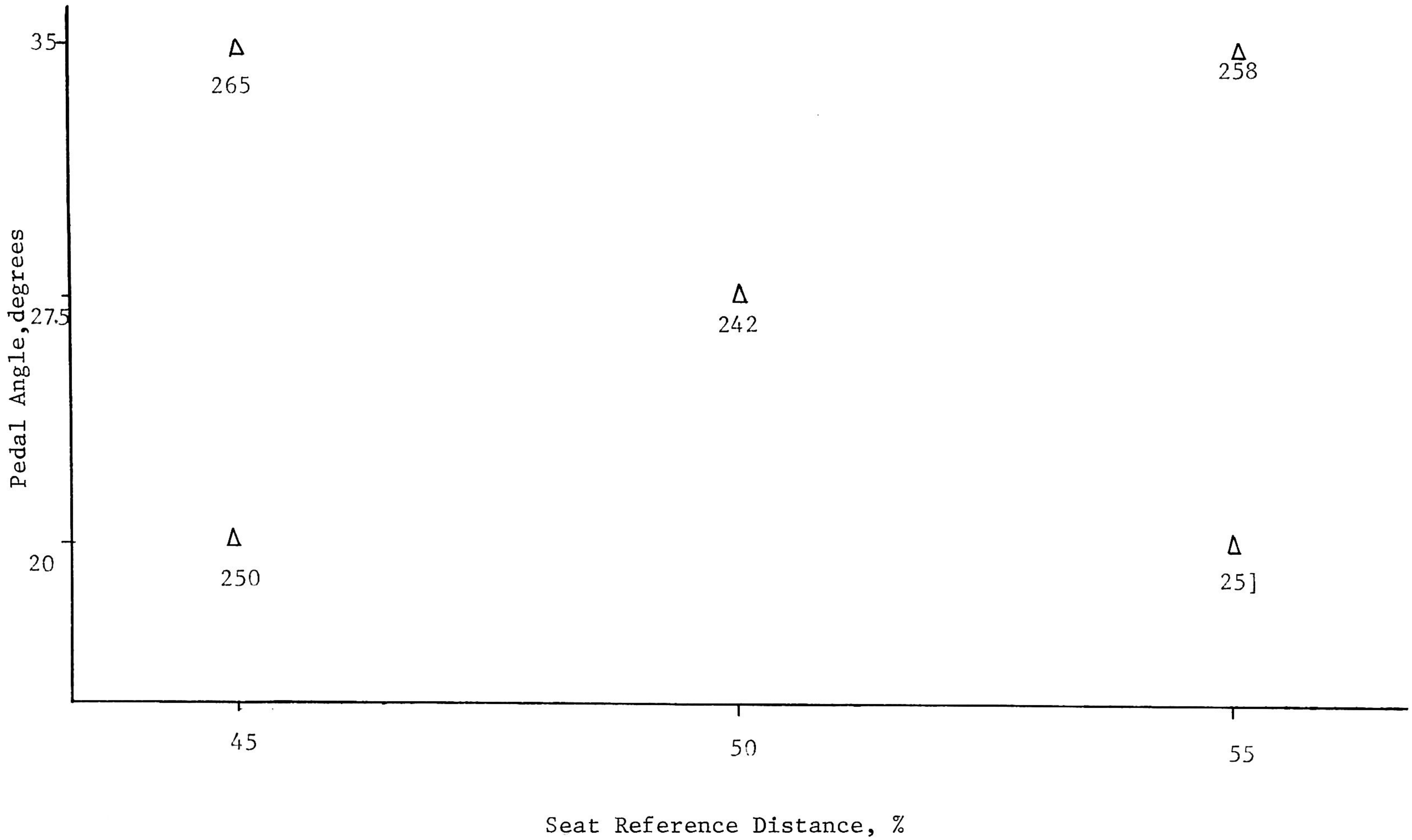
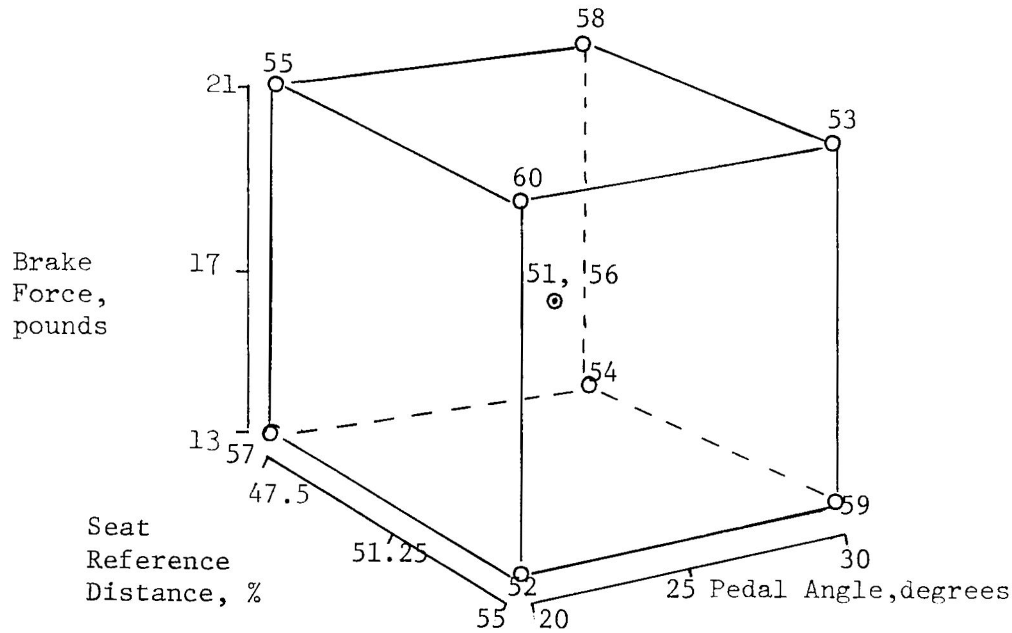
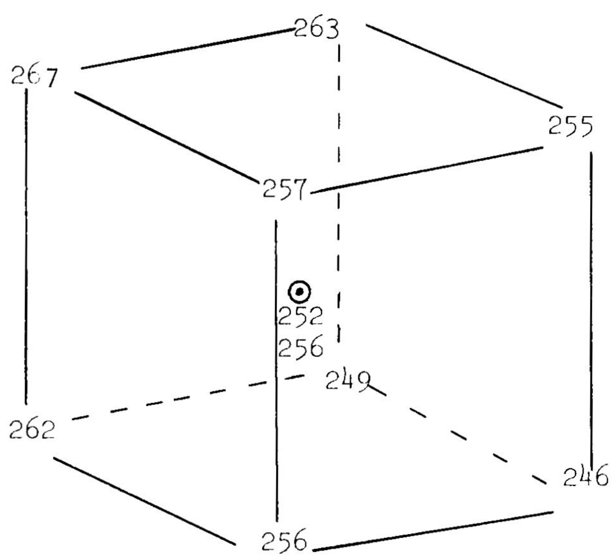


Fig. 12. Reaction times (milliseconds) after eliminating the effect due to brake force for phase V.



(a) Cycle of variants



(b) Mean reaction time (milliseconds) after 4 cycles(accelerator force constant @ 6 pounds).

Fig.13. Pattern of variants and results for three varibles for phase VI.

Table 12

Mean Reaction Time (milliseconds) of Ten Trials in Phase VI

Subject	"Point" 51	52	53	54	55	56	57	58	59	60	Average
S.W.	287	281	277	271	280	294**	286	284	279	263*	280
G.P.	197*	217	217	194	225	206	214	229**	214	219	213
S.M.	267*	275	281	274	296**	272	283	293	263	296**	280
S.S.	258	249	242	238	266	249	266*	246	228*	251	250
Average	252	256	254	244	267	255	262	263	246	257	256

* Subject's min. mean time for his ten points (row min.)

** Subject's max. mean time for his ten points (row max.)

Table 13

Consolidated Main Effects and 95% Error Limits (Phase VI)

Cycle No	Cumulative Effects S.R.D.	B	α	S.R.D.x B	S.R.D.xα	B x α	95% Error Limits
2	-2.5	4.8	2.5	7.0	-4.2	8.5	$\pm$ 12.8
3	-4.9	9.0	4.0	5.3	-3.1	5.1	$\pm$ 9.2
4	-7.2	7.3	7.0	4.0	-1.3	2.0	$\pm$ 7.7

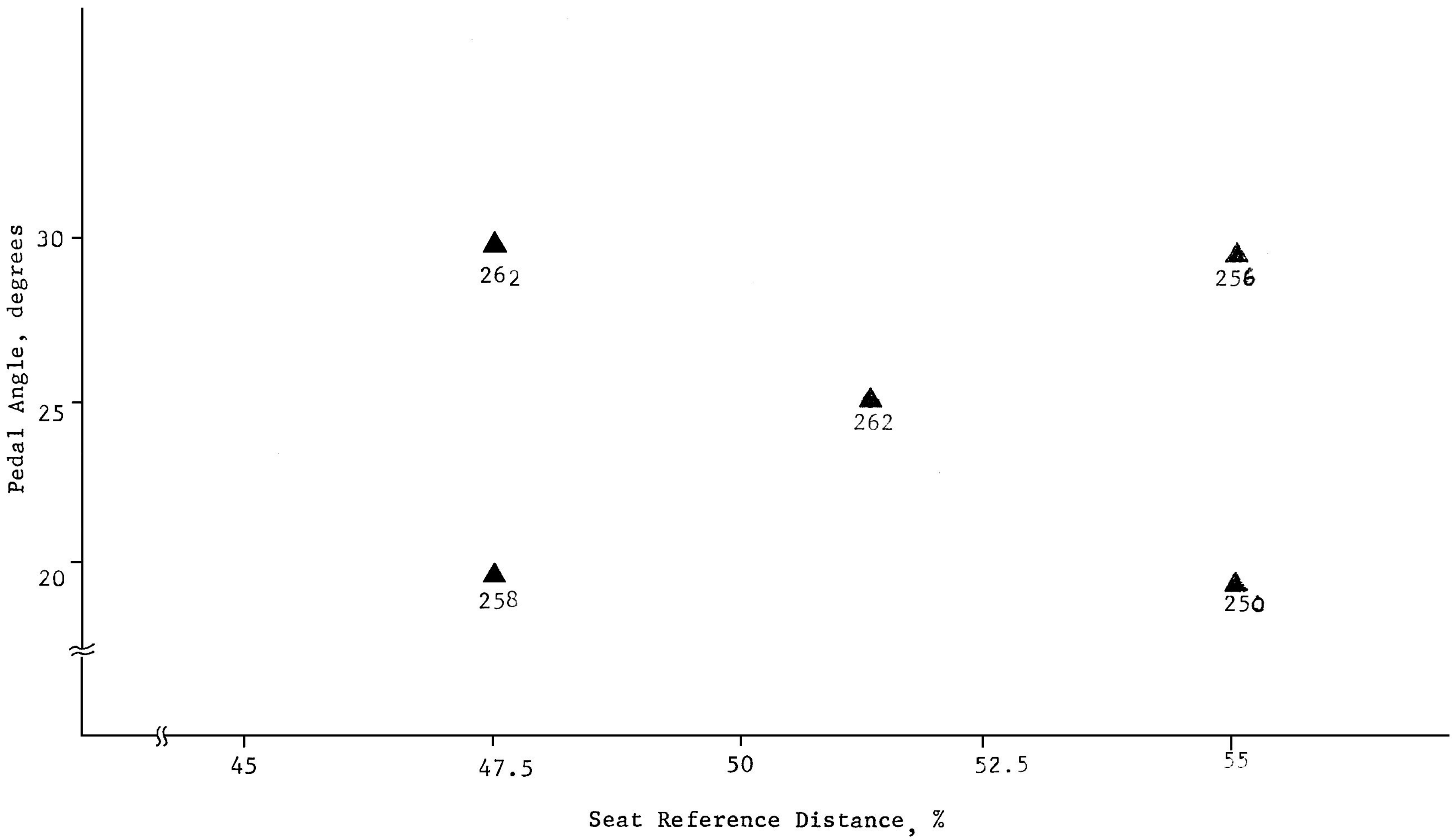


Fig. 14. Reaction times (milliseconds) after eliminating the effect due to brake force for phase VI.

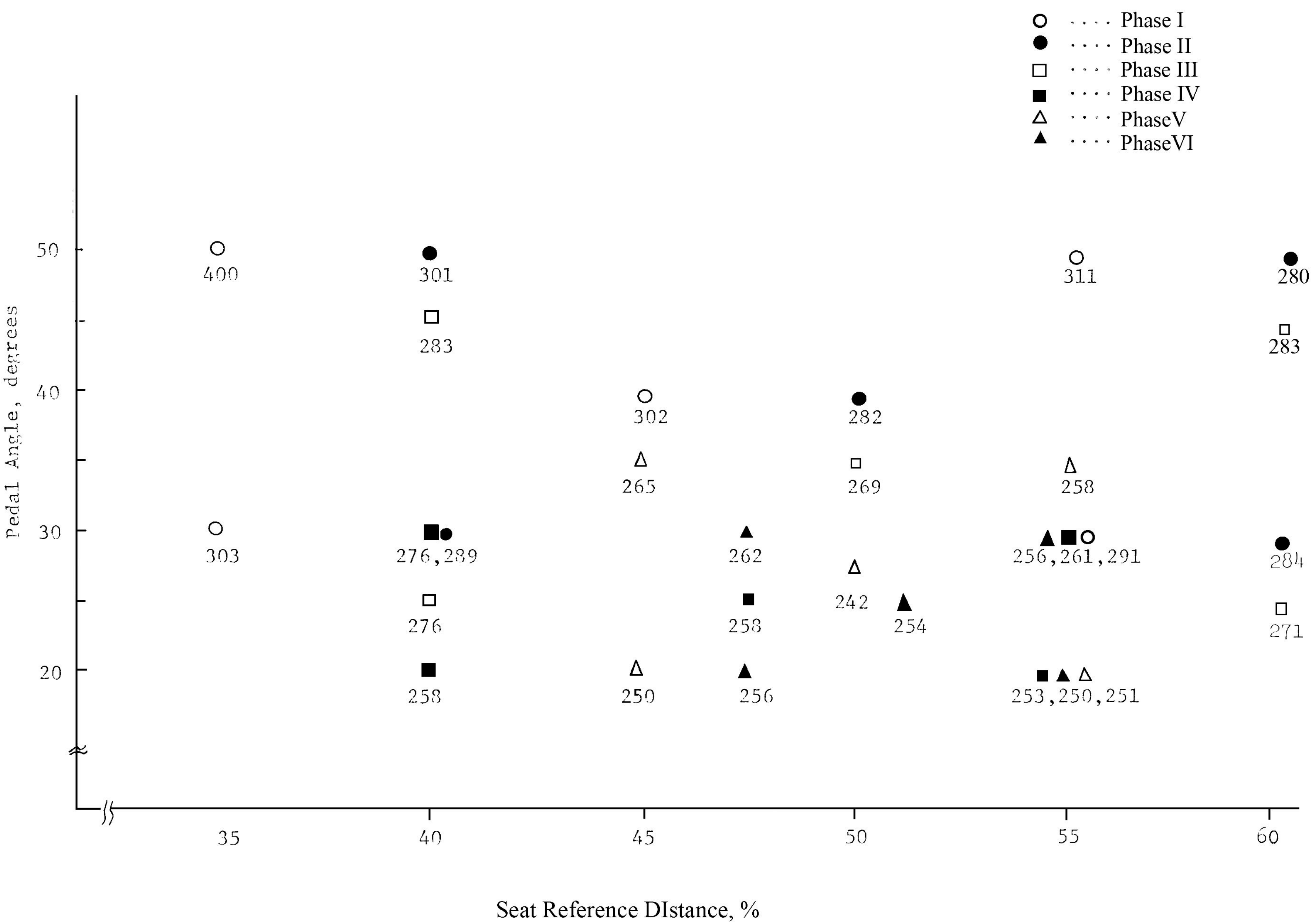


Fig. 15. Reaction times (milliseconds) after eliminating the effect due to brake and accelerator force for phase I toVI

Again, since the points 52 and 60 overlapped the points 42 and 50, and 32 and 40, and similarly the points 53 and 59 overlapped with points 10 and 2, and 33 and 39 of Phase I and IV respectively, the learning effect for the brake pedal could be determined. The overall results for S.R.D. and α (eliminating the effect of A and B) for all the six phases is shown in Fig. 15.

The common points of different phases plotted in the Fig. 15 showed there was some learning as the number of trials increased. The learning curve for the combined brake pedal is shown in the Fig. 16. The mean percentage increase in reaction time over the base (the 600 trials at the end of Phase VI) was calculated for different trials. The calculations are shown in detail in Appendix IV. Then the reaction times of different phases were corrected by dividing by a corresponding factor (shown in Fig. 17) for direct comparison. Corrected points for all the phases are shown in Fig. 18. The relationship between the response (reaction time) and the process variables (S.R.D. and α) is represented by a "response surface." The possible appearance of the response (reaction time) surface showing its contours is also shown in Fig. 18. Note also that the 95% error limits of the surface were ± 25 milliseconds in Phase I but only ± 8 milliseconds in Phase VI.

To compare the savings in reaction time of the integrated brake system with that of the conventional two pedal system, the same four subjects were run at a fixed S.R.D. of 50% of their height and pedal angle of 45° on an American Automobile Association reaction timer. The subjects were given 3 to 5 practice trials. Ten replications were made

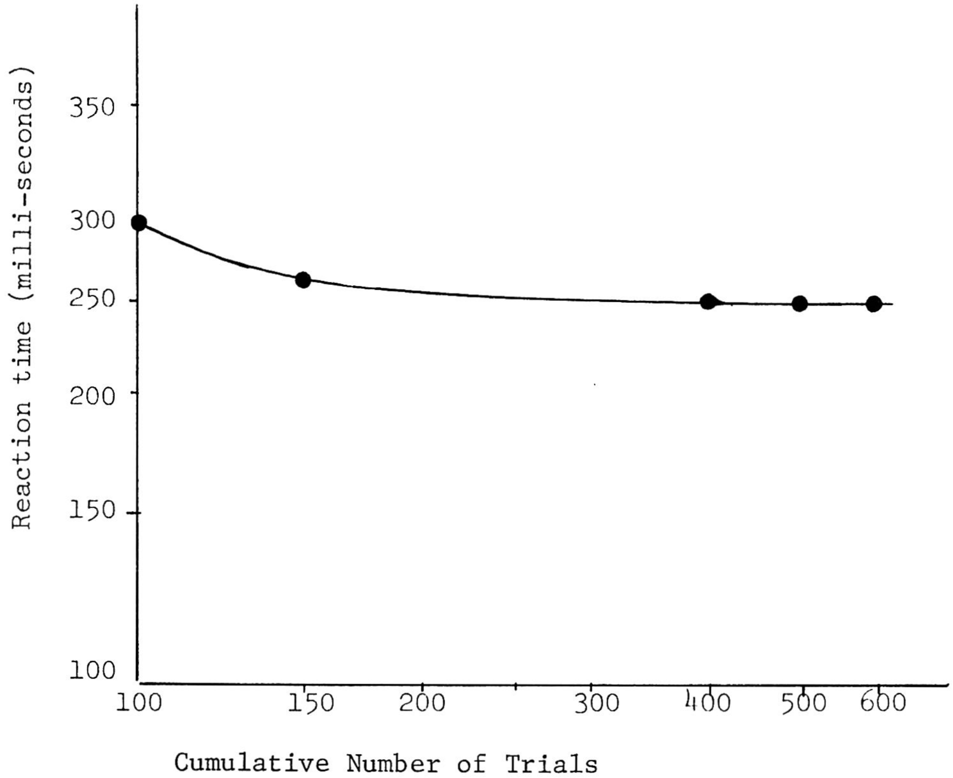


Fig. 16. Learning effect for combined brake pedal in Experiment Seven.

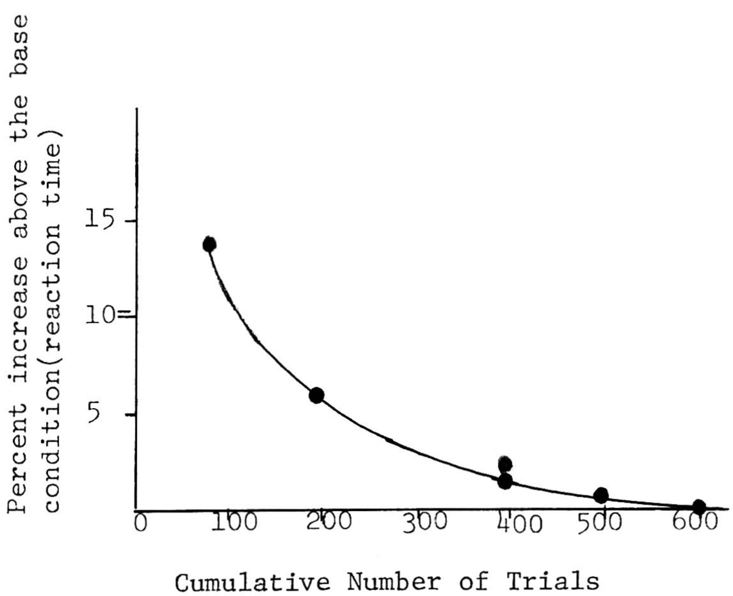


Fig. 17. Relationship of number of trials and percent increase in reaction time above the base condition of 600 trials.

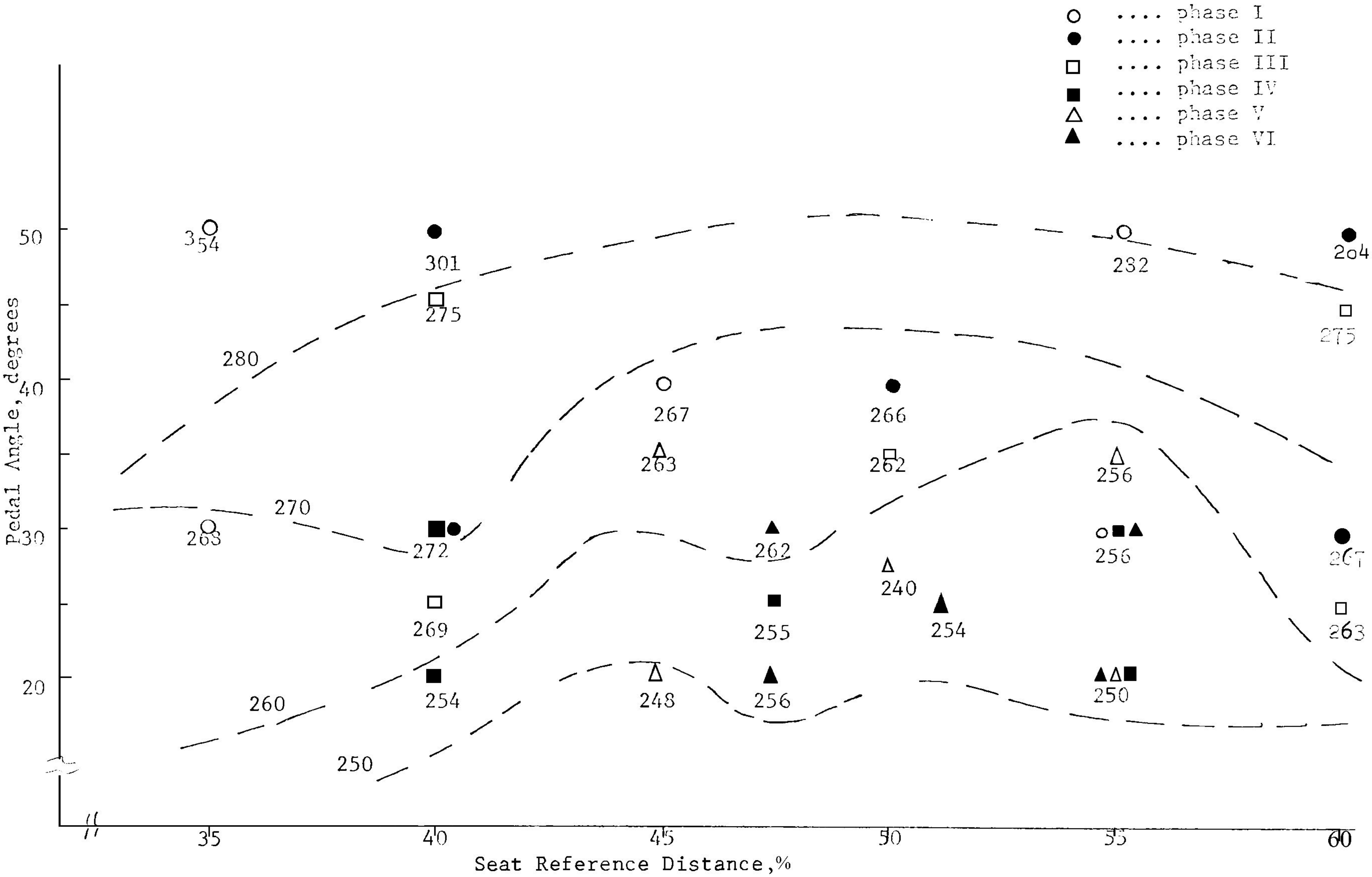


Fig. 18. Reaction times (milliseconds) after eliminating the effect due to brake and accelerator force and learning effect for phase I to VI.

for each subject. The averages of the subjects were 421, 442, 446, and 456 as compared to the averages in phase VI of 213, 250, 280, and 280 milliseconds. The average mean saving in reaction time for the four subjects was 186 milliseconds.

CONCLUSION

No main effects were found to be significant after the completion of Phase VI. Brake and accelerator force had little effect on the reaction time within the range considered. The interaction of the brake and accelerator force with the other variables was also very small. The optimum value of accelerator force can be recommended to be around four pounds; however, the range from 4 to 8 pounds can be used without affecting the reaction time by more than 20 milliseconds. This range is quite in agreement with that of Morgan who had recommended an optimum resistance of 6.5 - 9 pounds for ankle operated pedals. The recommended range of brake force is between 13 to 21 pounds, without losing more than 15 milliseconds. A weight of 13 to 17 pounds is required depending upon the weight of the driver.

Contrary to the expectation of the author, angle of inclination of the brake pedal has a significant effect on the reaction time. Angles greater than 30° had an influence of deteriorating the performance, which is quite astonishing since in most automobiles the range of the accelerator inclination varies from 45° to 65°. The least reaction time was observed at a 20° angle; however, the angles between 20 to 30° had little effect on the performance. Angles smaller than 20° were not included in the study, since the inclination of the pedal will be reduced to around 5 - 10° when the accelerator is full on and ankle movement would not be in the comfortable range of 78° to 96° from the inclination of the thigh. Hence, an optimum range of pedal angle between 20° - 30° can be recommended when both minimum reaction time and comfort are considered without losing more than 5 milliseconds.

There seems to be a wide range of S.R.D. in which performance is within a close range. However, there seems to be an optimum between 45 to 55% of the subject's height with only a change of approximately 11 milliseconds. There was one point which had a low reaction time at the large angle of inclination of 50° and the S.R.D. as 60% of the subject's height. This could be dismissed as being an extremely uncomfortable position to the driver.

It can be said that the criterion of least reaction time does not act as a very serious constraint in the tested range of the four variables studied. This conclusion is significant for designers. It provides a fairly wide working range to select the values of these variables on criteria of more mechanical nature. Mechanical ease of positioning the shafts, linkage design for brake and accelerator actuation, space constraints, etc., may be chosen to determine the exact values of these variables.

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APPENDIX I

Design Considerations for Integrated Control

The shape of the pedal was selected to be rectangular with the dimensions of 3.5" width and 12" length (McFarland et al., 1966). The pedal is spring supported on both shafts to bring it to null position on release of load, and also to prevent it from being in the actuated position due to the weight of the foot and leg. For ankle operated pedals, the optimum resistance is 6.5 - 9 lbs. (Morgan et al., 1963).

Because of the distribution of weight on the foot being concentrated towards the heel side, the spring for the brake shaft had a higher spring constant (66.67 lbs./unit inch) than for the accelerator shaft (10.42 lbs./unit inch).

Pedals operated by ankle action should have a maximum travel of 2 in. (McCormick, 1964). Also, the angle of inflexion about the ankle should not be greater than 30° because this is about half the total range of ankle movement.

The minimum permissable fulcrum distance from the end of the pedal (longitudinal end), x, can be found from

$$\frac{2}{X} = \tan 30°$$

or

$$X = \frac{2}{\tan 30°} = 4''$$

In no condition of testing were the shafts to be placed so that the fulcrum shaft was less than 4" from the end of the pedal which was being depressed.

A heel support was provided at the end of the pedal to prevent the foot from slipping off the inclined pedal.

APPENDIX II

A facsimile of the data recording sheet

Date________________ S.#________

Name___________________________ Yrs. of Drvg. Exp.____

Height______________

Trials Conditions

1										
2										
3										
4										
5										
6										
7										
8										
9										
10										
Total										
Ave.										

Data are brake reaction times in milliseconds.

APPENDIX III

THREE VARIABLE EVOLUTIONARY OPERATION PROGRAM

CALCULATION WORK SHEET

BLOCK I — Project <u>Combined Brake Pedal</u>

CYCLE $n = 3$ — Phase <u>II</u>

Response <u>Reaction time (milliseconds)</u> — Date ____________

Calculation of Averages

	Operating Conditions	(1)	(2)	(3)	(4)	(5)
(i)	Previous Sum for Block I	548	506	599	517	608
(ii)	Previous Average for Block I	274	253	300	259	304
(iii)	New Observations for Block I	274	271	248	282	300
(iv)	Differences (ii) less (iii)	0	-17	52	-23	4
(v)	New Sums for Block I	822	777	847	799	908
(vi)	New Averages for Block I	274	259	282	266	303

Calculations of Standard Deviations

Previous Sum s (all blocks) = 49

Previous Average s (all blocKs) = 25

New s = Range x $f_{k,n}$ = 26

Range = 75

New Sum s (all blocks) = 75

New Average s = $\frac{\text{(New Sum s)}}{(2n-3)}$ = 25

Calculation of Effects

E_1 = (A − BC) effect $\frac{1}{2}(\bar{y}_3 + \bar{y}_4 - \bar{y}_2 - \bar{y}_5$ $= \frac{1}{2}(282 + 266 - 259 - 303) = -20.4$

E_2 = (B − AC) effect $= \frac{1}{2}(\bar{y}_3 + \bar{y}_5 - \bar{y}_2 - \bar{y}_4$ $= \frac{1}{2}(282 + 303 - 259 - 266) = -29.2$

E_3 = (−C + AB) effect $= \frac{1}{2}(\bar{y}_2 + \bar{y}_3 - \bar{y}_4 - \bar{y}_5)$ $= \frac{1}{2}(259 + 282 - 266 - 303) = -13.0$

E_4 = Change in Mean Effect $= \frac{1}{5}(\bar{y}_2 + \bar{y}_3 + \bar{y}_4 + \bar{y}_5 - 4\bar{y}_1$ $= \frac{1}{5}(259 + 282 + 266 + 303 - 4\text{x}274) = 2.6$

APPENDIX III

THREE VARIABLE EVOLUTIONARY OPERATION PROGRAM

CALCULATION WORK SHEET

BLOCK II

CYCLE n = 3

Response Reaction time (milliseconds)

Project Combined Brake Peda

Phase II

Date

Calculation of Averages

	Operating Conditions	(6)	(7)	(8)	(9)	(10)
(i)	Previous Sum for Block II	544	650	541	534	542
(ii)	Previous Average for Block II	272	325	271	267	271
(iii)	New Observations for Block II	264	295	265	278	268
(iv)	Differences (ii) les (iii)	8	30	6	-11	3
(v)	New Sums for Block II	808	945	806	812	810
(vi)	New Averages for Block II	269	315	269	271	270

Calculation of Standard Deviation

Previous Sum s (all blocks) =	75
Previous Averages (all blocks) =	25
New s = Range x $f_{k,n}$ =	15
Range =	44
New Sum s (all blocks) =	90
New Average s = $\frac{\text{(New Sum s)}}{(2n-2)}$ =	23

Calculation of Effects

E_5 = (A + BC) effect = $\frac{1}{2}(\bar{y}_8 + \bar{y}_9 - \bar{y}_7 - \bar{y}_{10})$ = -9

E_6 = (B + AC) effect = $\frac{1}{2}(\bar{y}_8 + \bar{y}_{10} - \bar{y}_7 - \bar{y}_9)$ = -22.8

E_7 = (C + AB) effect = $\frac{1}{2}(\bar{y}_7 + \bar{y}_8 - \bar{y}_9 - \bar{y}_{10})$ = 22.6

E_8 = Change in Mean Effect = $\frac{1}{5}(\bar{y}_7 + \bar{y}_8 + \bar{y}_9 + \bar{y}_{10} - 4\bar{y}_6)$ = 9.8

Calculation of Error Limits

For New Averages = $\frac{2}{\sqrt{n}}$ = $\pm$ 27

For New Effects = 0.71 $\frac{2}{\sqrt{n}}$ = $\pm$ 19

For Change in Mean = 0.63 $\frac{2}{\sqrt{n}}$ = 17

Distance A = $\frac{1}{2}(E_5 + E_1)$ = - 14.7

Force B = $\frac{1}{2}(E_6 + E_2)$ = 3.2

Angle C = $\frac{1}{2}(E_7 - E_3)$ = 17.7

Distance x Force AB = $\frac{1}{2}(E_7 + E_3)$ = 3.8

Distance x Angle AC = $\frac{1}{2}(E_6 - E_2)$ = 26.7

Angle x Force BC = $\frac{1}{2}(E_5 - E_1)$ = 8.1

Change in Mean Effect

$\frac{1}{2}(E_8 + E_4)$ = 6.2

APPENDIX III

THREE VARIABLE EVOLUTIONARY OPERATION PROGRAM

CALCULATION WORK SHEET

BLOCK I

CYCLE n = 4

Response Reaction time (milliseconds)

Project Combined Brake Pedal

Phase II

Date

Calculation of Averages

	Operating Conditions	(1)	(2)	(3)	(4)	(5)
(i)	Previous Sum for Block I	822	777	849	799	908
(ii)	Previous Average for Block I	274	259	282	266	303
(iii)	New Observations for Block I	307	320	293	318	377
(iv)	Differences (ii) less (iii)	-33	-61	-11	-52	-74
(v)	New Sums for Block I	1129	1097	1140	1117	1285
(vi)	New Averages for Block I	282	274	285	279	321

Calculations of Standard Deviations

Previous Sum s (all blocks) = 90

Previous Average s (all blocks) = 23

New s = Range x $f_{k,n}$ = 24

Range = 63

New Sum s (all blocks) = 114

New Average s = $\frac{\text{(New Sum s)}}{(2n-3)}$ = 23

Calculation of Effects

E_1 = (A - BC) effect $\frac{1}{2}(\bar{y}_3 + \bar{y}_4 - \bar{y}_2 - \bar{y}_5)$ = $\frac{1}{2}(285 + 279 - 274 - 321) = -27.9$

E_2 = (B - AC) effect = $\frac{1}{2}(\bar{y}_3 + \bar{y}_5 - \bar{y}_2 - \bar{y}_4)$ = $\frac{1}{2}(285 + 321 - 274 - 279) = +38.7$

E_3 = (-C + AB) effect = $\frac{1}{2}(\bar{y}_2 + \bar{y}_3 - \bar{y}_4 - \bar{y}_5)$ = $\frac{1}{2}(274 + 285 - 279 - 321) = -26.7$

E_4 = Change in Mean Effect = $\frac{1}{5}(\bar{y}_2 + \bar{y}_3 + \bar{y}_4 + \bar{y}_5 - 4\bar{y}_1)$ = $\frac{1}{2}(274 + 285 + 279 + 321 - 4x282) = 6.2$

APPENDIX III

THREE VARIABLE EVOLUTIONARY OPERATION PROGRAM

CALCULATION WORK SHEET

BLOCK II

CYCLE n = 4

Response Reaction time (milliseconds)

Project Combined Brake Pedal

Phase II

Date

Calculation of Averages

	Operating Conditions	(6)	(7)	(8)	(9)	(10)
(i)	Previous Sum for Block II	808	945	806	812	810
(ii)	Previous Average for Block II	269	315	269	271	270
(iii)	New Observations for Block II	316	336	314	319	348
(iv)	Differences (ii) les (iii)	-47	-21	-45	-118	-78
(v)	New Sums for Block II	1124	1281	1120	1131	1158
(vi)	New Averages for Block II	281	320	280	283	290

Calculation of Standard Deviation

Previous Sum s (all blocks) =	114
Previous Averages (all blocks) =	23
New s = Range x $f_{k,n}$ =	36
Range =	97
New Sum s (all blocks) =	150
New Average s = $\frac{\text{(New Sum s)}}{(2n-2)}$ =	25

Calculation of Effects

E_5 = (A + BC) effect = $\frac{1}{2}(\bar{y}_8 + \bar{y}_9 - \bar{y}_7 - \bar{y}_{10})$ = -11.3

E_6 = (B + AC) effect = $\frac{1}{2}(\bar{y}_8 + \bar{y}_{10} - \bar{y}_7 - \bar{y}_9)$ = -29.1

E_7 = (C + AB) effect = $\frac{1}{2}(\bar{y}_7 + \bar{y}_8 - \bar{y}_9 - \bar{y}_{10})$ = 7.9

E_8 = Change in Mean Effect = $\frac{1}{5}(\bar{y}_7 + \bar{y}_8 + \bar{y}_9 + \bar{y}_{10} - 4\bar{y}_6)$ = 9.6

Calculation of Error Limits

For New Averages $\frac{2}{\sqrt{n}}$ = 25

For New Effects = 0.71 $\frac{2}{\sqrt{n}}$ = 18

For Change in Mean = 0.63 $\frac{2}{\sqrt{n}}$ = 16

Distance A = $\frac{1}{2}(E_5 + E_1)$ = -19.6

Force B = $\frac{1}{2}(E_6 + E_2)$ = 4.8

Angle C = $\frac{1}{2}(E_7 - E_3)$ = 17.3

Distance x Force AB = $\frac{1}{2}(E_7 + E_3)$ = 3.3

Distance x Angle AC = $\frac{1}{2}(E_6 - E_2)$ = -21.6

Angle x Force BC = $\frac{1}{2}(E_5 - E_1)$ = - 3.9

Change in Mean Effect

$\frac{1}{2}(E_8 + E_4)$ = 7.9

APPENDIX IV

Calculations for the determination of learning effect

(i) Percent increase in reaction at phase I over phase VI

$$= \frac{\text{Mean time at phase I} - \text{Mean time at phase VI}}{\text{Mean time at phase VI}}$$

$$= \frac{291-256 \times 100}{256}$$

$$= 13.7\%$$

(ii)a Percent increase in reaction time at phase IV over Phase VI

$$= \frac{253-250}{250} \times 100$$

$$= 1.2\%$$

(ii)b Percent increase in reaction time at phase IV over phase VI

$$= \frac{261 - 256}{256} \times 100$$

$$= 1.9\%$$

(iii) Percent increase in reaction time at phase V over phase VI

$$= \frac{251-250}{250}$$

$$= .2\%$$

(iv)a Percent increase in reaction time at phase II over phase IV

$$= \frac{289-276}{276} \times 100$$

$$= 4.7\%$$

(iv)b Percent increase in reaction time at phase II over phase VI

$$= 4.7 \times 1.2$$

$$= 5.6\%$$

Note: These values are plotted in Fig. 17.

DESIGN CONSIDERATIONS OF A COMBINED
BRAKE-ACCELERATOR PEDAL SYSTEM

by

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ABSTRACT

Six previous experiments had demonstrated that a combined brake-accelerator pedal was feasible. This experiment used a searching technique from operations research to determine the effect on reaction time of varying seat reference distance, pedal angle, accelerator force and brake force. The optimum combination results in a reaction time of approximately 242 milliseconds which is approximately .2 seconds less than the time on the conventional separate brake and accelerator controls.

It is recommended that seat reference distance be between 45 and 55% of the driver's height, pedal angle be between 20 and 30 degrees from the floor, accelerator pedal force be between four and eight pounds, and brake pedal force between thirteen and twenty-one pounds.