OPTIMIZING THE DESIGN OF A DUAL BRAKE-ACCELERATOR PEDAL

by 683

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Pilani, India, 1967

A MASTER'S THESIS

submitted in partial fulfillment of the

requirements for the degree

MASTER OF SCIENCE

Department of Industrial Engineering

KANSAS STATE UNIVERSITY

Manhattan, Kansas

1969

Approved by:

Major Professor

ACKNOWLEDGEMENTS

The author is deeply indebted to Dr. Stephan A. Konz, major professor, for his unselfish contribution of time and constructive guidance during the preparation of this thesis. Sincere thanks are due to Dr. F. A. Tillman, Head, Department of Industrial Engineering, Dr. L. E. Grosh and Dr. B. L. Smith, members of the committee, for their constant encouragement.

The help and cooperation of the faculty, specially, Professor Byers, and staff of the Department of Industrial Engineering is appreciated.

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INTRODUCTION

Safe automobile driving requires the fullest attention of mind, body and spirit, yet almost everybody thinks that he is able to drive. The automobile takes a heavy toll of life every year in the United States. A traffic death occurs every ten minutes and an injury every 19 seconds. Expressing this another way, in 1966, 27.1 deaths per 100,000 population (The World Almanac, 1968) occurred from auto accidents or more than 53,000 deaths and 1.9 million injuries. The total cost of traffic accidents including insurance coverage exceeded $12 billion.

Continuous attention has been given by the automotive industry and by government to the problem of safety. As a result, the annual highway death rate per 100,000,000 miles of travel has dropped steadily since 1930 - 16.0 persons in 1930 compared to 5.6 in 1965. Safer driving, safer cars and safer highways can share most of the credit for the improving situation. To combat this tremendous toll of lives, many groups are increasing their efforts toward making automobile travel safer. Just as the accidents occur from Los Angeles to New York, in all the seasons, on expressways and waysides, in all types of cars, with teenagers and senior citizens, the solution must be many sided. Most of these efforts may be classified under three general headings: man, machine and environment.

The man - machine - environment components of automobile driving are represented by the operator, the car and the road. Which one of the three should be modified to obtain optimum results?

It is difficult to have 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). A billion dollars divided by 100 million operators is $10 per operator. Considering the cost of both instructor and equipment, it is doubtful that ten dollars would give more than one hour of instruction. Moreover the results of the instruction may not be fruitful.

On an average, one mile of road costs one million dollars, depending upon natural conditions. One billion dollars would pave one thousand miles and keep 99.06 percent of existing roads untouched. Especially serious is the problem of city streets. Thus, it is expensive to modify either the man or the environment.

In the U.S.A., automobiles are produced at an average rate of eight million per year. The estimated half life of cars is five years; that is, five years from now more than half of the cars on American roads will be manufactured after today. Roughly 7.4 million American cars were sold in 1967, so one billion dollars would allow $135 per automobile. Therefore, the modification of the automobile seems the most cost-effective approach.

The measure of safety is directly related to the margin of permissible error. The greater this margin the smaller the chance of an accident or, if an accident occurs, the smaller the extent of it. One parameter of design is the time between the decision of the controller and the reaction of the machine. The quickness with which the driver can make the vehicle react to any situation is a very important factor in driving - especially at high speeds. It is believed that shorter the operator's reaction time, the greater the margin of error. In other words, the automobile can be driven at a higher speed with equal safety or maintain the same speed with increased safety; which option the driver will select is unknown.

If the time to apply the brakes on the presentation of a stimulus is reduced the overall reaction time of braking will be decreased. A study on a brake-reaction time testing machine shows the following trend for 50,000 average motorists (Olmstead, 1936):

1. A fast reacting motorist has a tendency to drive at higher speeds than a slow reacting motorist. This tends to nullify the advantage that fast reacting motorists should have over slow reacting motorists in case they are required to stop.
2. The accidents are in direct proportion to driving mileage, and that all motorists, regardless of their reaction time, are equally subject to accidents. Those who react quickly are involved more frequently than those who react slowly.
3. An average motorist will decrease his reaction time during the first four years of driving, but after four years of driving there is no improvement.

The brief interval between sensing a stimulus and reacting in response to the stimulus is called "reaction time". The reaction time can be further subdivided into:

1. Sensing time: the time required to sense a signal. It is a function of the properties of the signal (size, intensity, duration).
2. 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 and amount of practice.

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

If any of these factors can be controlled so that their time of execution is reduced, the reaction time will be reduced.

Sensing time is of the order of a few hundredths of a second. Although sensing time varies with the different senses, differences in the lag in hearing, touch and sight are small and probably insignificant. Sensing time depends upon the signal characteristics such as the size of the source, intensity, etc.. The larger the size of the visual signal, the faster to some extent the sensing time. Sensing time is faster to visual signals that strike the center rather than 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).

Decision time depends upon the central transmission of the sensory impulses to the motor fibers. It is comprised of the time taken by the perceptual, translation and central effectory mechanisms, and is proportional to the logarithm of the number of alternative choices (Hicks, 1952). A memory drum theory of neuromotor reaction (Henry and Rodgers, 1960) proposed a nonconscious mechanism using stored information to channel the existing nervous impulses and presented stimuli into appropriate neuromotor coordination centers causing the desired movement. As the complexity of the response movement increases, the response latency period also increases. Yet the process is not clearly understood.

For simple tasks it takes about 20% longer to respond with the feet than with the hands. Response with preferred limb (for example, the left hand for left handed people) is about 3% faster than with the non-preferred limb (Teichner, 1954). So, if the speed of activation of a control is the prime factor, the order of selection for left handed operators should be left hand, right hand, left foot and right foot.

The extent of variation in the reaction time also depends on the environmental conditions as well as the persons involved (Woodworth & Schlosberg, 1954).

Since the automotive designer cannot economically modify the input danger signals (sensing time), the emphasis was on designing a brake control which reduced decision and response time. Since the hands, while driving, already have many tasks it was decided to assign the control of braking to the feet. The question then is why not use the left foot for braking?

The saving in the reaction time occurs only when the left foot is on the brake pedal. The cars with automatic transmission could use the left foot for braking, but this way the operator would be denied of the freedom of movement of any of his limbs. The above position is certainly not a comfortable one while driving. The left foot braking is not feasible in the automobiles with stick shift, in which the left foot operates the clutch pedal. One other task, which the left foot has to occasionally perform, is to depress the dimmer switch when needed.

Thus it was decided to assign control of both acceleration and deceleration to the right foot. To minimize reaction time it was decided to use one control with two functions rather than two individual controls, each with its own function. The problem was to optimize the design of the dual-function pedal.

LITERATURE SURVEY

Single Action Pedals

The earliest efforts to determine optimal foot pedal design were made by Barnes, Hardaway and Podolsky (1942). The five pedals differed mainly in the location of the fulcrum. The criterion of selection of a particular type was least time for a stroke. They concluded that the pedal with the fulcrum at its heel required least time for a stroke. Ayoub and Trombley (1967) also concluded that the optimal position for the fulcrum, with load attached at the ball of the foot, is at the heel. Their criteria were minimum reaction time to a visual stimulus and travel time against a fixed stop. Minimum travel time was with the foot-tibia angle of 78 degrees, but due to certain reasons, 84 degrees is their recommended angle. Trumbo and Schneider (1963) came to the same conclusion that the pedal pivoted at the heel and requiring downward movement of toe resulted in minimum response time.

McFarland (1966) recommended that for pedal forces over 20 pounds, the long axes of the foot and lower leg should form a 90 degree angle, the angle requires least muscular effort, to hold the foot in position. For small pedal forces (under 20 pounds), the knee angle should be at least 90 degrees -- preferably 135 degrees or more.

Every operator has a range of seat locations, requiring the least energy expenditure and providing the most comfort. This location is specified with reference to the seat reference point (S.R.P.), where the back of the seat surface intersects the back rest, in the midline. Where less than 20 pounds of pedal force is needed, the S.R.P. - pedal distance should be increased from 47.5 percent of stature to 55 percent, for comfort.

McFarland recommends 55 percent of the person's height.

Dual Function Pedals

A type of dual function control for cars has been developed by Humphrey, Inc., (1968). In this design, three distinct zones are: an upper braking zone, a middle neutral zone and a lower acceleration zone. The only limitation in this is that, while driving, the operator has to keep his foot constantly on the pedal or the automobile will come to a sudden stop.

Versace (1966) at the Human Factors Department of 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.

To the author's knowledge no experimental work regarding the reaction times on dual function systems has been done except at Kansas State University. To date seven experiments have been conducted on dual function pedals at Kansas State University. The first three of these experiments have been described in detail by Konz and Daccarett (1967). Experiment number four, five and six have been described in detail by Kalra (1968).

In the first experiment the relative quickness of activating a control by hand and by foot were compared for twelve subjects. The conditions were:

1. Honk horn. Starting position - hand on horn rim.
2. Honk horn. Starting position - hand on steering wheel.
3. Depress brake. Starting position - left foot on brake.
4. Depress brake. Starting position - right foot on depressed accelerator.

The times in condition 1 (.38 seconds) and 3 (.39 seconds) were not statistically significant from each other but were significantly ($p < .05$) faster than condition 2 (.55 seconds) and 4 (.59 seconds). The advantage was due to the elimination of the movement of the limb from one location to another location.

Experiment two, on 121 subjects, used a combined brake and accelerator pedal design by Winkleman (U.S. patent 2,878,908). Pressing of the toe caused acceleration while depressing the heel caused the braking. There was an interlock to prevent simultaneous actuation of both the controls. The average time (.41 seconds) for the dual pedal system was significantly lower than that for condition four in experiment one (.59 seconds).

A more direct comparison of the conventional system versus the combined control was made in experiment three. The three conditions were:

1. Depress conventional brake. Starting position - left foot on brake.
2. Depress conventional brake. Starting position - right foot on depressed accelerator.
3. Depress combined pedal. Starting position - right foot on depressed accelerator.

Twenty five university faculty and students were used as subjects. Times of the twenty five subjects were significantly ($p < .05$) less in condition 1 (.29 seconds) than 3 (.36 seconds) than 2 (.45 seconds).

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 combined control was tested on a highway against the conventional accelerator and brake pedal. Sixteen subjects drove two miles on a two lane highway without intersections with one control and then drove back with the other control in place. The average time for the combined control (.47 seconds) was significantly ($p < .01$) lower than for the conventional system (.57 seconds).

Experiment five was performed without the interlock system, the device which prevented simultaneous actuation of the brake and the accelerator on the combined control. The three conditions were:

1. American Automobile Association (AAA) reaction timer. Starting position - right foot on depressed accelerator.
2. 1960 Rambler parked in the laboratory. Starting position - right foot on depressed accelerator.
3. Combined control. Starting position - depressed accelerator.

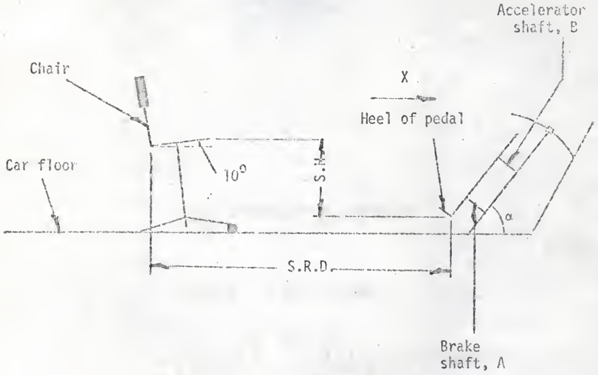
The combined pedal with a reaction time of .323 seconds was found to be significantly ($p < .01$) faster than both the AAA reaction timer (.482 seconds) and Rambler (.432 seconds).

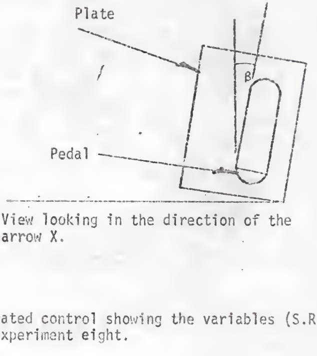
Experiment six was run to determine the effect of varying some of the parameters in the design of the integrated pedal. More specifically, the distances between the heel of the pedal to the brake and accelerator shaft were altered. The criterion was the minimum reaction time. No specific values of these variables or any combination were better than others. The above result is of great significance to designers, since it provides a fairly wide working range to select the values of these variables to suit the mechanical design of the product.

Experiment seven (Wadehra, 1968) was conducted to determine the best combination of pedal angle with the floor, brake force, accelerator force and seat reference distance (S.R.D.) for minimum reaction time. Wadehra concluded that the brake and accelerator force had little effect on the reaction time. The value of the brake force was varied between 13 to 21 pounds, without losing more than 15 milliseconds. A range of 4 to 8 pounds was found to be the optimum accelerator force. The recommended optimum range of pedal angles was between 20 to 30 degrees. Seat reference distance seemed to be optimum between 45 to 55 percent of the subject's height.

PROBLEM

Experiment eight was conducted to determine the effect of varying some of the parameters in the design of the dual function pedal. The parameters under study were (1) α, inclination of the foot pedal with the automobile floor, (2) S.R.D., the seat reference distance, the distance between heel of the pedal and intersection of seat surface with the back rest of the seat, (3) S.H., seat height (front edge of the seat) above the heel of the pedal and (4) β, the angle by which the pedal assembly is rotated in the clockwise direction around the vertical axis (Fig. 1). The aim was to determine the combination of the variables which gave the minimum reaction time.





View looking in the direction of the arrow X.

Fig. 1. Sketch of integrated control showing the variables (S.R.D., S.H., α, β) in experiment eight.

METHOD

Experimental Apparatus

The experimental set up shown in Plate 1, 2 and 3, was similar to that of Kalra (1968), except certain elements were incorporated to partially simulate driving conditions. The original set up consisted of the following:

1. Biomechanic chair
2. Integrated brake/accelerator pedal box
3. Actuation indicator bulb
4. 100 watt lamp covered with red cellophane
5. Control switch
6. 1/100 second reaction timer
7. D.C. power (12 V/200 mA).

Experiment six and seven were conducted in the Human Engineering Laboratory, without the driving environment. On the contrary, experiment eight was conducted in an automobile (1956 Chevrolet) with its engine running. The subject felt the engine vibrations, heard the engine noise and had to look through the windshield for the red light to appear during the test. The 100 watt lamp, covered with red cellophane, was kept at eye level about 15 feet away from the subject. It simulated the tail light of a car. This resulted in a more realistic driving environment. In experiment seven the lamp was placed 5 feet away at eye level.

The front seat was removed from the automobile to make room for the chair, which was installed behind the steering wheel. The chair had an adjustable back rest and a nonpadded seat. The seat height could be

PLATE I

A Left View of the Combined Brake-Accelerator Pedal

PLATE II

Experimental Apparatus

varied from 8 to 14 inches. It was rectangular in shape (17.5 inches wide and 15 inches long) with corners rounded off. The lower half of the steering wheel was cut in order to make room for the subject's legs. The pedal was kept in line with the center of the right leg. The accelerator portion of the pedal was attached to the engine by a link arrangement, so that the engine speed would be varied.

The two shafts of the pedal 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 (12 V/200 mA) was used in the circuit. The bulbs were off when no control was in operation. When the accelerator was depressed, the green bulb went on, and when it was released and the brake depressed, the green bulb went off. If, by mistake, both the shafts were depressed, the red bulb went on and a buzzer sounded, indicating the faulty operation to the subject.

The reaction timer was connected through an operating switch to both the rear shaft relay switch and the 100 watt lamp. The control switch had a dual role to play; one was to turn on momentarily the 100 watt lamp and the second was to reset the reaction timer to zero position after the reaction time for one trial had been recorded. The throw over control switch was used also to turn on the bulb and start the reaction timer. The lamp went off as soon as the rear shaft was depressed by 1/16th of an inch. Then the time was recorded from the reaction timer by the experimenter.

The distances of the two shafts from the heel of the pedal were kept fixed at 4.5 and 7.5 inches from the heel although their distances seem to have no significant effect on the reaction time (Kalra, 1968). The rear shaft (Fig. 1), A, acted as a fulcrum when the pedal was pressed in the forward direction and the foreshaft, B, acted as a fulcrum when the pedal was pressed in the rearward direction. The forward and backward pressing motions correspond to the accelerating and braking the car respectively. The brake (15 pounds) and accelerator (6 pounds) spring forces were kept constant. From experiment seven, Wadehra (1968) had concluded that accelerating spring force, if varied between 4 to 8 pounds, affects the reaction time no more than 20 milliseconds. The recommended range of brake force is between 13 to 21 pounds, without losing more than 15 milliseconds.

Design of the Experiment

A searching technique called EVOP (EVolutionary Operation of Processes) (Box and Hunter, 1959) was used for calculating the effect of the variables in the experiment. Two main features of EVOP are:

1. Variation
2. Selection of favorable variables.

The parameters are changed in small intervals such that, due to the changes incorporated, the path of steepest descent (ascent) can be approximated to lead towards the minimum (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 new levels of the same variables or different variables.

Before any alterations are 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 minimum (maximum). Thus, it is an example of a step-by-step process, with

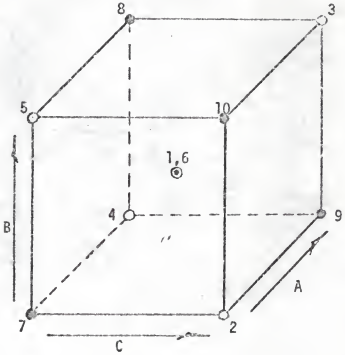


Fig. 2. Sketch showing a 2^3 factorial design with a center point.

○ indicates five trials of Block I of the cycle.

● indicates five trials of Block II of the cycle.

the direction of the step so as to lead to the minimum (maximum). The prime advantage of EVOP is from an experimental strategy viewpoint and the ease of understanding by people not sophisticated in statistics rather than any statistical gain.

A 2^3 factorial design (Fig. 2) with a center point was used in the experiment. Three variables were studied at a time as calculation forms for four variables were not available to the experimentor and, more important, the interactions become quite complex for the four variable design. A three variable EVOP was used to evaluate the significance of the main effects (A, B, C) (Fig. 2) and the interaction effects (A x B, A x C, B x C). Running averages, Yi's (i identifying the conditions 1 through 10), were calculated from the mean times for each subject. A single cycle was broken into two blocks of five runs each as indicated by the open and filled circles shown in Fig. 2. The values of $E_1, E_2, \ldots E_7$, are given by the following set of equations:

E_1 = (A - BC) effect = $1/2\ (Y_3 + Y_4 - Y_2 - Y_5)$

E_2 = (B - AC) effect = $1/2\ (Y_3 + Y_5 - Y_2 - Y_4)$

E_3 = (-C + AB) effect = $1/2\ (Y_2 + Y_3 - Y_4 - Y_5)$

E_5 = (A + BC) effect = $1/2\ (Y_8 + Y_9 - Y_7 - Y_{10})$

E_6 = (B + AC) effect = $1/2\ (Y_8 + Y_{10} - Y_7 - Y_9)$

E_7 = (C + AB) effect = $1/2\ (Y_7 + Y_8 - Y_9 - Y_{10})$

From the combined information of Block I and Block II, the main effects and the interaction effects were calculated as follows:

A effect = $1/2\ (E_5 + E_1)$

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

C effect = $1/2\ (E_7 - E_3)$

A x B interaction effect = $1/2\ (E_7 + E_3)$

A x C interaction effect = $1/2\ (E_6 - E_2)$

B x C interaction effect = $1/2\ (E_5 - E_1)$

A data recording sheet was designed to record the data (Appendix I). Sample calculations for four successive cycles illustrating the use of EVOP in calculating Yi's, the main effects, their interaction effects and the 95% error limits for these effects are given in Appendix II. The calculation form is that given by George Box and Stuart Hunter (1959).

The first three variables selected were α, S.R.D., and S.H.. Alpha, the pedal surface angle with the floor, was varied from 50 to 60 degrees (Wadehra, 1968), in steps of five degrees. S.R.D., the seat reference distance, the distance between heel of the pedal and intersection of seat surface with the back rest surface of the seat, was varied from 40 to 60 percent (Wadehra, 1968) of the subject's height, in steps of 10 percent. S.H., the seat height from the heel of the pedal, was varied from 10 to 14 inches (McFarland et al., 1966), in steps of 2 inches. β, the angle of twist of the pedal (Fig. 1) in the clockwise direction, was kept constant and equal to zero degrees. The specific values of the parameters have been shown in Fig. 3 for Phase I, giving ten points for the experiment. Twelve readings were taken at each operating condition for each subject. The lowest and the highest reading were then discarded, leaving ten readings at each point of the cube for each of the four subjects.

Subjects

Four paid male students, each having at least four years of driving experience were used as subjects. The average age was twenty three years and all were between 67 to 72 inches in height. The same four subjects were run in all the phases in order to minimize the subject effect.

Experimental Procedure

Before starting the experiment the 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. The rear wheels of the car were jacked up and it was put in drive gear during the experiment. The engine was started and the subject was asked to hold the pedal depressed in the forward direction (accelerating position) and look at the red lamp in front. The speedometer needle was to be maintained between 15 to 20 m.p.h., controlled by the pressure on the pedal. The hands were on the steering wheel. As soon as the red light came on, he was to release the accelerator and apply the brake. The moment the brake was applied the red light went off and the timer gave the time in milliseconds. If, after presentation of the stimulus, both the controls were pressed simultaneously, the buzzer sounded, and the data was disregarded. It may be desirable in the commercial design to automatically disengage one mode if a certain percent of the other mode is actuated. No extra rest period was given other than that available during the changing conditions.

A time gap of five seconds or more is sufficient to prevent treating the two consecutive stimuli as one stimulus (Telford, 1931). This time between two successive stimuli was also sufficient to prevent an anticipative response to a signal about to occur (Morgan et al., 1963).

In experiment seven, an appreciable learning effect (7.5 percent) was noticed. In order to reduce this effect a subject was given five practice trials at each condition. Also the operation of the pedal was thoroughly

PLATE III

A Subject Performing the Task

explained to him. The sequence of the first subject was so arranged as to reduce the effort of changing the experimental set up. The sequence of the subject two was the mirror image of subject one's. Subject three followed a different sequence and subject four's sequence was the mirror image of subject three's. The sequence was varied in each phase.

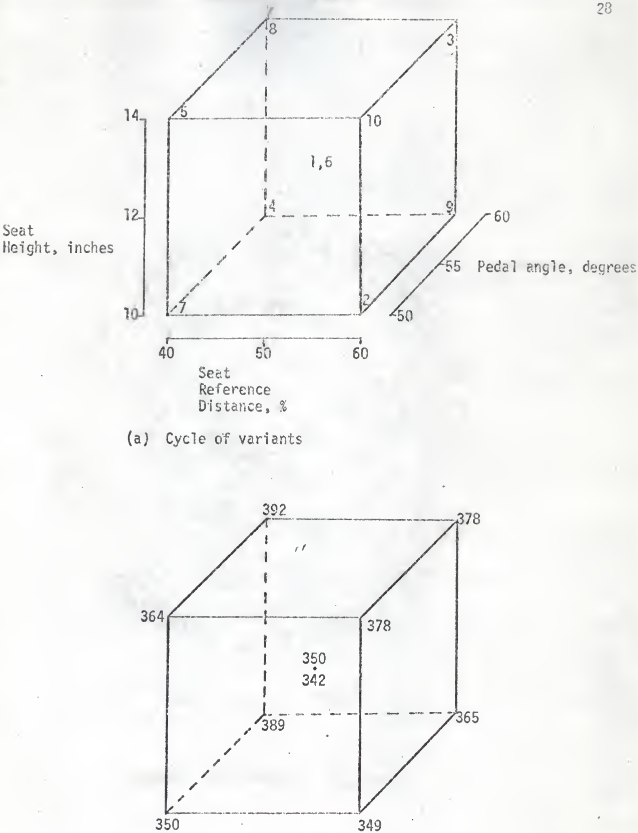
The experiment was run in five phases. The values of the parameters for each phase were selected from the previous phase in the direction of the steepest descent until the minimum was located.

RESULTS

Phase I

The parameters under study were seat reference distance (S.R.D.), pedal angle (α) and seat height (S.H.). The points 1 through 10 are given in Fig. 3(a). The angle of twist, β, was kept constant at zero degrees. Reaction times for the four subjects are summarized in Table 1. The times, given in thousandths of a second (milliseconds), are the mean times taken at each point for each subject, based on ten readings. Three variable EVOP was used to calculate the significance of the main effects (α, S.H., S.R.D.) and the interaction effects (α x S.H., S.R.D. x α, S.H. x S.R.D.). The results of the calculations after each cycle of Phase I are summarized in Table 2. The 95% error limits are also tabulated.

As seen from Table 2, the main effects of α had a significant effect on the reaction time at completion of Phase I (after four cycles). A change of 10 degrees changed the response 20.5 milliseconds or, assuming linearity, 2 milliseconds per degree. There was no significant effect of S.R.D. or S.H. at the completion of Phase I. None of the interactions were significant at the completion of Phase I. The response surface ascended with an increase in α, the pedal angle. In other words, reaction times were higher with increasing values of α. At the end of Phase I, the variation of the response surface at 95% error limits was $\pm$17.8 milliseconds. EVOP directly presents the useful information that the response surface varies $\pm$17.8 milliseconds by chance; therefore the effects above 17.8 milliseconds are significant. The error term is based on 40 observations.



(a) Cycle of variants

(b) Mean reaction time (milliseconds) after 4 cycles (angle of twist constant at 0 degrees).

Fig. 3. Pattern of variants and results for three variables for Phase I.

Table 1

Mean reaction time (milliseconds) of ten trials in Phase I.

Subject	Points 1	2	3	4	5	6	7	8	9	10	Average
C. P	358*	389	414	486**	380	369	376	419	408	416	401
C. N.	375	389	413	392	405	365	340*	417**	402	405	390
S. W.	324	291*	336	379**	343	305	333	370	320	314	331
S. C.	345	326	350	301*	331	329	350	359	331	375**	340
Average	350	349	378	389	364	342	350	392	365	378	366

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

**Subjects maximum mean time for his ten points (row maximum).

Table 2

Consolidated main effects and 95% error limits (Phase I).

Cycle No.	Cumulative Effects α	SH	SRD	α x SH	SRD x α	SH x SRD	95% Error Limits
2	31.5*	10.5	- 2.5	-17.0	22.0	-4.0	$\pm$23.0
3	31.5*	10.5	12.0	-13.5	16.0	-6.0	$\pm$18.5
4	20.5*	14.5	6.5	- 7.0	12.0	-6.0	$\pm$17.8

*Significant effect

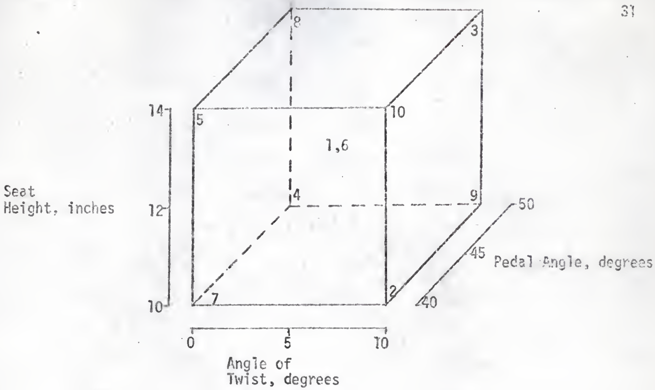
Phase II

It was decided to study the effect of β, the angle of twist, on the reaction time in this phase. The seat height was kept at the same three levels as in Phase I. It was found that subjects were uncomfortable at 60% S.R.D.. However, S.R.D. was kept constant at 40% of the subject's height in all ten conditions of this phase. As pedal angle was significant in the last phase, with the lower angles being more favorable, it was decided to vary α between 40 to 50 degrees in steps of 5 degrees.

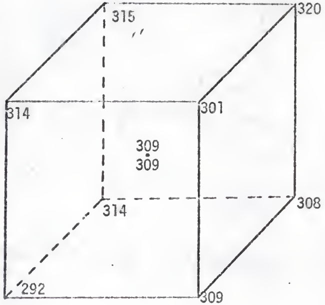
The new values of the variables selected are shown in Fig. 4(a). The mean reaction time for the ten points after four cycles are shown in Fig. 4(b). The mean times for each cycle are given in Table 3. Table 4 shows the cumulative effects and 95% error limits for various effects. The main effect of α was the only one found significant. This time a change of 10 degrees changed the response 10.5 milliseconds or 1 millisecond per degree. Because of the lower error limits, this was still significant. Even though the S.H. effect was not significant at 95% level, the seat height did influence the reaction time. The β effect was very small, which was contradictory to what the author had earlier expected. So, it was decided to drop β as a variable and keep it constant at 10 degrees in Phase III.

Phase III

The new set of variables selected were α, S.R.D., and S.H. See Fig. 5(a). S.R.D. was varied at 40 - 45 - 50 percent of the subject's height. The values of S.H. were reduced to 9 - 9.5 - 10 inches. α was kept the same as that of Phase II (40 - 45 - 50). The results are shown



(a) Cycle of variants



(b) Mean reaction time (milliseconds) after 4 cycles (seat reference distance constant at 40 percent).

Fig. 4. Pattern of variants and results for three variables for Phase II.

Table 3

Mean reaction time (milliseconds) of ten trials in Phase II.

Subject	Points										
	1	2	3	4	5	6	7	8	9	10	Average
S. C.	300*	307	320	302	313	322**	308	322	314	307	312
C. P.	292	300	310	312	326**	298	291	318	280*	318	305
C. N.	334**	327	308	329	320	309	293	311	330	286*	315
S. W.	309	302	342**	313	298	307	276*	308	307	292	306
Average	309	309	320	314	314	309	292	315	308	301	309

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

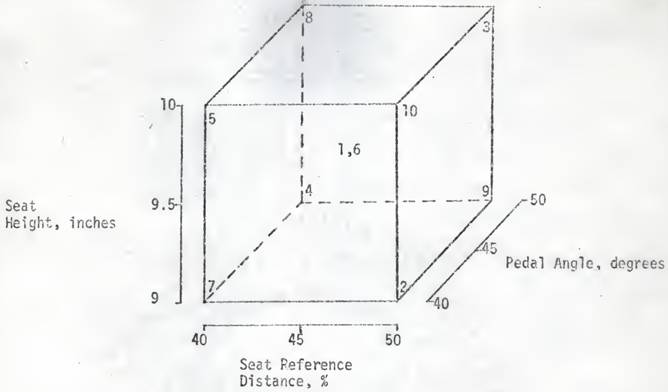
**Subject's maximum mean time for his ten points (row maximum)

Table 4

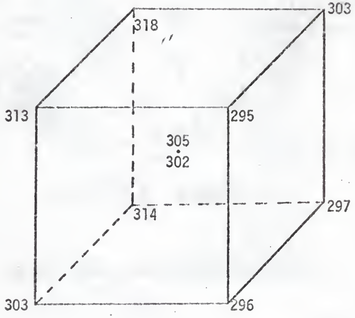
Consolidated main effects and 95% error limits (Phase II).

Cycle No.	Cumulative Effects						95% Error Limits
	α	SH	β	α x SH	α x β	SH x β	
2	1.5	12.5*	4.5	.5	5.5	1.5	$\pm$ 9.4
3	5.0	6.0	3.0	-2.0	2.0	7.0	$\pm$11.1
4	10.5*	7.0	-1.0	0	1.0	4.5	$\pm$ 9.5

*Significant effect



(a) Cycle of variants



(b) Mean reaction time (milliseconds) after 4 cycles (angle of twist constant at 10 degrees).

Fig. 5. Pattern of variants and results for three variables for Phase III.

Table 5

Mean reaction time (milliseconds) of ten trials in Phase III.

Subject	Points 1	2	3	4	5	6	7	8	9	10	Average
C. P.	310	293	300	317	323	306	297	325	299	297	307
C. N.	307	307	314	323	315	318	321	328	309	306	315
S. C.	303	289	301	311	325	290	294	313	303	289	302
S. W.	299	294	296	306	289	294	301	306	278	289	295
Average	305	296	303	314	313	302	303	318	297	295	305

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

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

Table 6

Consolidated main effects and 95% error limits (Phase III).

Cycle No.	α	SH	SRD	Cumulative Effects α x SH	α x SRD	SH x SRD	95% Error Limits
2	7.0*	5.0	15.5*	- .5	2.0	3.0	±6.5
3	7.5*	6.0*	15.5*	-3.0	- .5	5.0	±5.4
4	6.25*	4.75	14.25*	.25	1.75	2.25	±5.4

*Significant effect

in Fig. 5(b). The main effect of α and S.R.D. were found to be significant (Table 6). The estimate of the slope due to α was 6.25/10 or 0.6 milliseconds per degree; the estimate of the slope due to S.R.D. was 14.25/10 or 1.4 milliseconds per percent. The reaction time (298 milliseconds at 50% S.R.D.) was comparatively low with the increase in S.R.D., and seemed to rise as the pedal angle increased. The seat height did not significantly affect performance of the system. The same three variables were selected for Phase IV as in Phase III.

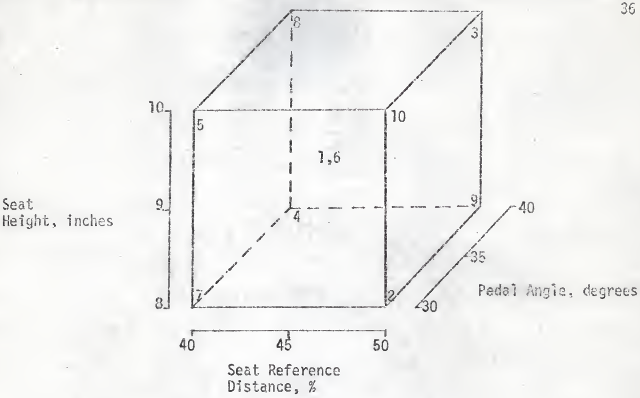
Phase IV

The values of the variables are shown in Fig. 6(a). S.H. was investigated over a broader range at 8 - 9 - 10 inches. The pedal angle was varied in steps of 5 degrees between 30 to 40 degrees instead of 40 to 50. However, the range of the variable S.R.D. was kept at the same three levels of Phase III. The angle of twist, β, was constant at 0 degrees for all ten conditions. The mean times per subject are tabulated in Table 7. Table 8 shows the cumulative effects and 95% error limits for various effects.

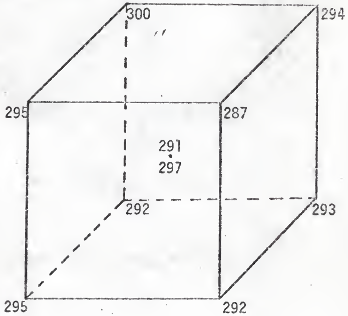
The effect of α was not significant at this lower range of alpha. Seat height was not a significant variable even with a two inch range of search. S.R.D. was significant at the lower level of α. The estimated slope is 4.25/10 or 0.4 milliseconds per percent. Note the reduction in error limits which permitted declaration of the slight slope as significant. Since seat height again was not a significant variable, it was decided to drop it as a variable and reintroduce β.

Phase V

It was decided to keep the seat height at a constant value of 10



(a) Cycle of variants



(b) Mean reaction time (milliseconds) after 4 cycles (angle of twist constant at 0 degrees).

Fig. 6. Pattern of variants and results for three variables for Phase IV.

Table 7

Mean reaction time (milliseconds) of ten trials in Phase IV.

Subject	Points										
	1	2	3	4	5	6	7	8	9	10	Average
C. N.	305	295	304	297	301	308	313	305	297	302	303
S. W.	296	290	295	302	296	288	295	300	293	283	294
S. C.	285	280	284	290	293	292	283	289	286	271	285
C. P.	280	303	295	281	290	299	289	305	295	292	293
Average	291	292	294	292	295	297	295	300	293	287	294

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

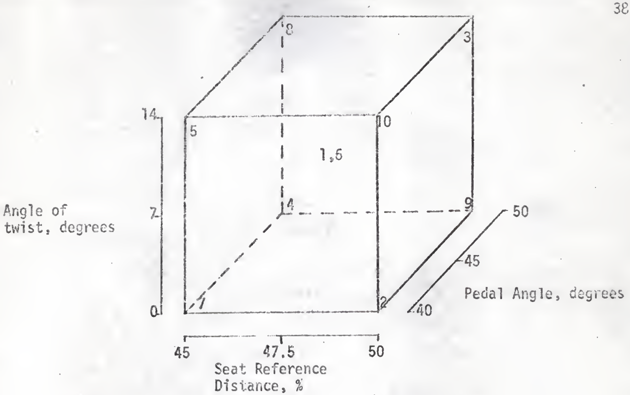
**Subject's maximum mean time for his ten points (row maximum).

Table 8

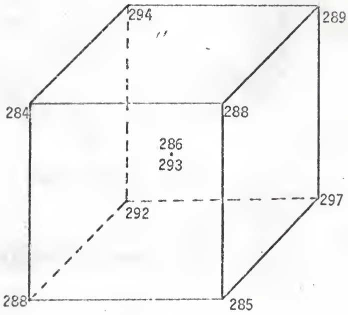
Consolidated main effects and 95% error limits (Phase IV).

Cycle No.	α	SH	SRD	Cumulative Effects α x SH	α x SRD	SH x SRD	95% Error Limits
2	2.25	.25	6.25*	3.25	-2.75	-1.75	$\pm$4.5
3	3.25	.25	7.25*	1.75	-3.25	.75	$\pm$3.6
4	2.75	.75	4.25*	3.25	-1.25	2.75	$\pm$4.1

*Significant effect



(a) Cycle of variants



(b) Mean reaction time (milliseconds) after 4 cycles (seat height constant at 10 inches).

Fig. 7. Pattern of variants and results for three variables for Phase V.

inches in all 10 conditions of this phase. The variables selected were β, S.R.D. and α. The angle of twist, β, was varied from 0 to 14 degrees. The angle of twist of 14 degrees was the maximum angle possible in this experimental apparatus. Seat reference distance was varied at 45 - 47.5 - 50 percent of the subject's height instead of the 40 - 50 range of previous phases. The pedal angle was varied at 40 - 45 - 50 degrees as in Phase II and III (Fig. 7(a)). Table 10 shows the cumulative effects and 95% error limits for various effects. The main effect of pedal angle was the only one significant. The estimate of the slope was 6.0/10 or 0.6 milliseconds per degree; this is compatible with the 1.0 slope from Phase II and 0.6 slope in Phase III.

The search was terminated after Phase V, as the feasible surface had been scanned. It is interesting to note that the 95% error limits of the surface were ±17.8 milliseconds in Phase I and only +4.6 milliseconds in phase V. The minimum reaction time was 284 milliseconds for point 5 in Phase V.

Since seat height and β were never significant their effect was ignored and the overall results for S.R.D. and α for all the five phases are shown in Fig. 8. The common points of the five phases (Fig. 8) showed some learning as the number of trials increased. The learning curve for the combined brake pedal is shown in Fig. 9. Then the reaction times of each phase were reduced to Phase V as their reference base, by multiplying by a certain factor (obtained from Fig. 9) for direct comparison. The multiplying factor was determined by considering each point of different phase (Fig. 9) as 100 percent and finding what percent the fifth phase

Table 9

Mean reaction time (milliseconds) of ten trials in Phase V.

Subject	Points										
	1	2	3	4	5	6	7	8	9	10	Average
S. C.	276	271	283	290	277	288	276	285	278	284	281
C. P.	285	289	289	293	288	292	286	297	305	279	290
S. W.	293	291	288	295	275	292	295	303	308	293	293
C. N.	292	289	298	291	297	299	297	293	297	296	295
Average	286	285	289	292	284	293	288	294	297	288	290

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

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

Table 10

Consolidated main effects and 95% error limits (Phase V).

Cycle No.	Cumulative Effects						95% Error Limits
	α	β	SRD	α x β	α x SRD	β x SRD	
2	8.75*	- .75	1.75	-1.75	.75	1.25	$\pm$6.9
3	9.25*	-3.25	.25	- .75	1.75	1.25	$\pm$5.4
4	6.25*	-1.75	- .25	- .75	- .25	.75	$\pm$4.6

point was of the 100 percent. Thus, by the above procedure, the multiplying factor for each phase was calculated (Appendix III). Adjusted points for all the phases are shown in Fig. 10. The possible appearance of the response surface showing its contours is shown in Fig. 11. The times given are the adjusted average reaction times (Fig. 11) at various conditions.

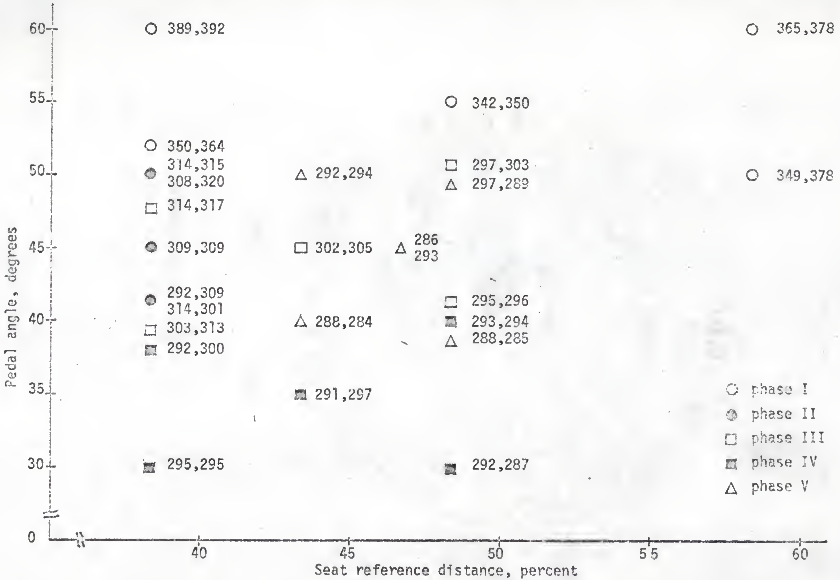


Fig. 8. Reaction times (milliseconds) after ignoring the effect of seat height and angle of twist for phase I to V.

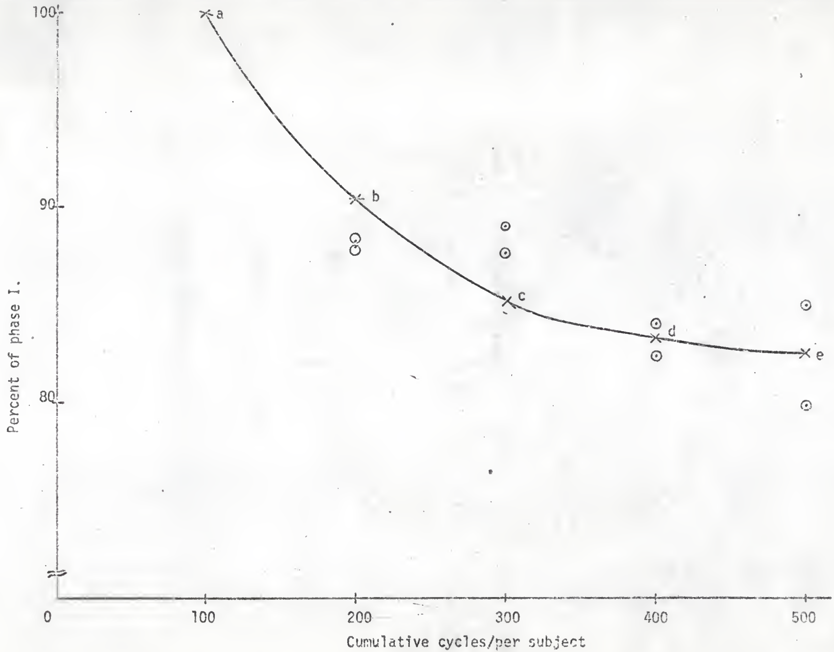


Fig. 9. Learning effect for combined brake pedal in experiment eight.

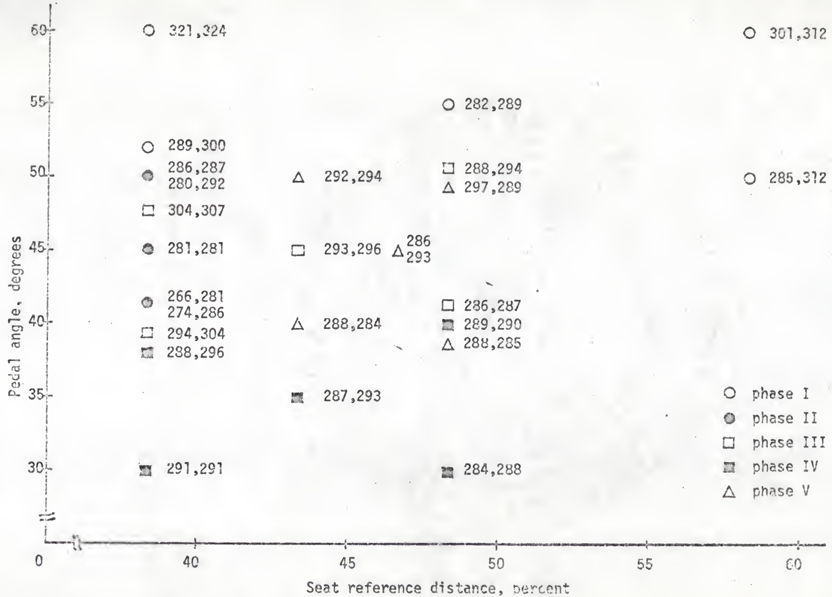


Fig. 10. Reaction times (milliseconds) after ignoring the effect of seat height and angle of twist, with respect to phase V as base, for phase I to V.

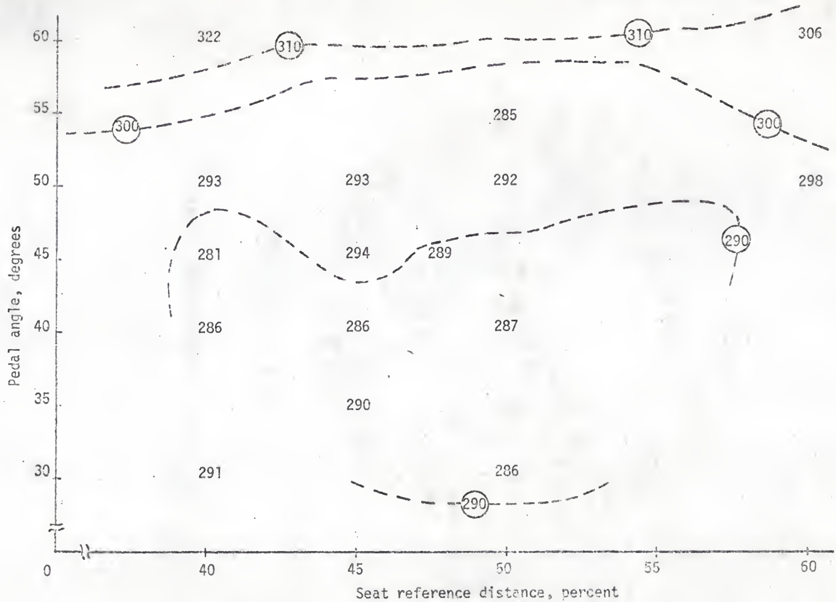


Fig. 11. Average reaction times (milliseconds) after ignoring the effect of seat height and angle of twist, with respect to phase V as base.

CONCLUSIONS

In Phase V, the only main effect found significant was that of α. It indicated that, for optimum results, pedal angle should be lower than 45 degrees. No interaction effects were significant during the whole experiment. This is important information for designers. It says that the variables could be studied on an independent basis, and their optimum ranges determined by only considering their own effects.

There is no definite optimum design since reaction time is more or less the same over a certain range of the values of the variables. The optimum value of seat height can be recommended to be around nine inches; however, a range from 8 to 10 inches can be used without affecting the reaction time by more than 10 milliseconds. This range is most frequently used on American cars. There seems to be a wide range of S.R.D., in which the performance is within a close range. However, the optimum seems to lie between 40 to 50% of the subject's height, without losing more than 8 milliseconds. This range is suggested as the subjects did not feel comfortable beyond this range. By using the above range for S.R.D., and the seat adjustment arrangement common on most cars, most of the American population can be comfortably seated. For an American male 72.8 inches (95th percentile) tall, 40% S.R.D. is 29 inches, and for an American female 59 inches (5th percentile) tall, 50% S.R.D. is 29.5 inches. The S.R.D. for in between heights is within a close range of the optimum zone, and could be adjusted by moving the seat.

There seems to be a wide range of pedal angles in which the performance is within a close range. The suggested optimum value is between 30 to 45 degrees, without losing more than 5 milliseconds. This range of pedal angles does differ from what presently is being used in most automobiles (55 to 70 degrees). Pedal angles less than 30 degrees were not studied, as smaller angles tend to shift the pedal assembly towards the steering wheel, which in turn shifts the seat backward, and the subject would be unable to hold the steering wheel comfortably. Thus, for this pedal assembly, pedal angles smaller than 30 degrees would require redesigning of the entire space available in the car. The suggested optimum range of pedal angle in experiment seven (Wadehra, 1968) is between 20 to 30 degrees. However, in experiment seven the seat height was 15.7 inches instead of the 8 to 10 inches of experiment eight.

Contrary to the expectation of the author, angle of twist (within the range considered) did not have a significant effect on the reaction time. This is significant information for designers; it says that the angle of twist could be varied between 0 to 14 degrees without a significant effect on the reaction time.

The reaction time was found to be about 30 to 40 milliseconds higher than that from experiment seven (Wadehra, 1968). This might be due to the fact that experiment eight was performed on an automobile with its engine running and the rear wheels moving. The subject felt the engine vibrations, heard the engine noise and was looking through the windshield for the red light to appear. The stimulus was placed 15 feet away from the subject at eye level. On the other hand, experiment seven was performed on a chair in a laboratory without the driving environment, and the stimulus was placed 5 feet away at eye level.

Again, the testing of these variables can use different criteria. Reaction time is only one criterion. Another could be fatigue associated with the relative frequency of application of brake and accelerator under various driving situations.

In conclusion, an analysis of the man-machine-environment system indicates modification of the automobile is the cost - effective approach, a combined brake - accelerator pedal system is both feasible and effective (saving about 200 milliseconds) and the designer of a dual function pedal has considerable freedom in its design.

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APPENDIX I

Data Recording Sheet

Name:______________ Phase:______________

Height:______________ Cycle:______________

Yrs. of Driving Exp. ______ Date:______________

Sequence											
Conditions											
Trials	1	2	3	4	5	6	7	8	9	10	Average
1											
2											
3											
4											
5											
6											
7											
8											
9											
10											
Total											
Average											

APPENDIX II

THREE VARIABLE EVOLUTIONARY OPERATION PROGRAM

CALCULATION WORK SHEET

BLOCK I

CYCLE $n = 1$

Response Reaction time (milliseconds)

Project Combined Brake Pedal

Phase 5

Date

		Calculation of Averages (1)	(2)	(3)	(4)	(5)	Calculation of Standard Deviation	
(i)	Previous Sum for Block I						Previous Sum s (all blocks)	=
(ii)	Previous Average for Block I						Previous Average s (all blocks)	=
(iii)	New Observations for Block I	276	271	283	290	277	New s = Range x $f_{k,n}$	=
(iv)	Differences (ii) less (iii)						Range	=
(v)	New Sums for Block I	276	271	283	290	277	New Sum s (all blocks)	=
(vi)	New Averages for Block I	276	271	283	290	277	New Average s $\frac{(\text{New Sum s})}{(2n - 3)}$	=

Calculations of Effects

E_1 = (A - BC) effect = $\frac{1}{2}(\bar{y}_3 + \bar{y}_4 - \bar{y}_2 - \bar{y}_5) = 12.5$

E_2 = (B - AC) effect = $\frac{1}{2}(\bar{y}_3 + \bar{y}_5 - \bar{y}_2 - \bar{y}_4) = -0.5$

E_3 = (-C + AB) effect = $\frac{1}{2}(\bar{y}_2 + \bar{y}_3 - \bar{y}_4 - \bar{y}_5) = 6.5$

E_4 = Change in Mean Effect = $\frac{1}{5}(\bar{y}_2 + \bar{y}_3 + \bar{y}_4 + \bar{y}_5 - 4\bar{y}_1) = 3.4$

APPENDIX II

THREE VARIABLE EVOLUTIONARY OPERATION PROGRAM

CALCULATION WORK SHEET

BLOCK II

CYCLE $n = 1$

Response Reaction time (milliseconds)

Project Combined Brake Pedal

Phase 5

	Calculation of Averages	(6)	(7)	(8)	(9)	(10)	Calculation of standard Deviatio	
(i)	Previous Sum for Block II						Previous Sum s (all blocks)	=
(ii)	Previous Average for Block II						Previous Averages (all blocks)	=
(iii)	New Observations for Block II	288	276	285	278	284	New s Range x $f_{k,n}$	=
(iv)	Differences (ii) less (iii)						Range	=
(v)	New Sums for Block II	288	276	285	278	284	New Sum s (all blocks)	=
(vi)	New Averages for Block II	288	278	285	278	284	New Average s $\frac{\text{(New Sum s)}}{(2n - 2)}$	=

Calculation of Effects

E_5 = (A + BC) effect = $\frac{1}{2}(\bar{y}_8 + \bar{y}_9 - \bar{y}_7 - \bar{y}_{10}) = 1.5$

E_6 - (B + AC) effect = $\frac{1}{2}(\bar{y}_8 + \bar{y}_{10} - \bar{y}_7 - \bar{y}_9) = 7.5$

E_7 = (C + AB) effect = $\frac{1}{2}(\bar{y}_7 + \bar{y}_8 - \bar{y}_9 - \bar{y}_{10}) = -0.5$

E_8 = Change in Mean Effect = $\frac{1}{5}(\bar{y}_7 + \bar{y}_8 + \bar{y}_9 + \bar{y}_{10} - 4\bar{y}_6) = 5.8$

$\alpha = \frac{1}{2}(E_5 + E_1) = 7.0$ $\qquad \alpha \times \beta = \frac{1}{2}(E_7 + E_3) = -3.5$

$\beta = \frac{1}{2}(E_6 + E_2) = 3.5$ $\qquad \alpha \times SRD = \frac{1}{2}(E_6 - E_2) = 4.0$

$SRD = \frac{1}{2}(E_u - E_3) = 3.0$ $\qquad \beta \times SRD = \frac{1}{2}(E_5 - E_1) = 5.5$

Calculations of Error Limits

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

For New Effects $.71 \frac{2}{\sqrt{n}}$ =

For Change in Mean $.63 \frac{2}{\sqrt{n}}$ =

Change in Mean Effect

$\frac{1}{2}(E_8 + E_4) = 1.2$

APPENDIX II

THREE VARIABLE EVOLUTIONARY OPERATION PROGRAM

CALCULATION WORK SHEET

BLOCK I

CYCLE $n = 2$

Response Reaction time (milliseconds)

Project Combined Brake Pedal

Phase 5

Date

Calculation of Averages

		(1)	(2)	(3)	(4)	(5)
(i)	Previous Sum for Block I	276	271	283	290	277
(ii)	Previous Average for Block I	276	271	283	290	277
(iii)	New Observations for Block I	285	289	289	293	288
(iv)	Differences (ii) less (iii)	-9	-18	-6	-3	-11
(v)	New Sums for Block I	561	560	572	583	565
(vi)	New Averages for Block I	280	280	286	291	282

Calculation of Standard Deviation

Previous Sum s (all blocks) =	
Previous Average s (all blocks) =	
New s = Range x $f_{k,n}$ =	4.5
Range =	15
New Sum s (all blocks) =	4.5
New Average s $\frac{(\text{New Sum s})}{(2n - 3)}$ =	4.5

Calculations of Effects

$E_1 \doteq (A - BC)$ effect $= \frac{1}{2}(\bar{y}_3 + \bar{y}_4 - \bar{y}_2 - \bar{y}_5) = 7.5$

$E_2 = (B - AC)$ effect $= \frac{1}{2}(\bar{y}_3 + \bar{y}_5 - \bar{y}_2 - \bar{y}_4) = -1.5$

$E_3 = (-C + AB)$ effect $= \frac{1}{2}(\bar{y}_2 + \bar{y}_3 - \bar{y}_4 - \bar{y}_5) = -3.5$

E_4 = Change in Mean Effect $= \frac{1}{5}(\bar{y}_2 + \bar{y}_3 + \bar{y}_4 + \bar{y}_5 - 4\bar{y}_1) = 3.8$

APPENDIX II

THREE VARIABLE EVOLUTIONARY OPERATION PROGRAM

CALCULATION WORK SHEET

BLOCK II

CYCLE $n = 2$

Response Reaction time (milliseconds)

Project Combined Brake Pedal

Phase 5

Calculation of Averages

		(6)	(7)	(8)	(9)	(10)
(i)	Previous Sum for Block II	288	276	285	278	284
(ii)	Previous Average for Block II	288	276	285	278	284
(iii)	New Observations for Block II	292	286	297	305	279
(iv)	Differences (ii) less (iii)	-4	-10	-12	-27	5
(v)	New Sums for Block II	580	562	582	583	563
(vi)	New Averages for Block II	290	281	291	291	281

Calculation of standard Deviatio

Previous Sum s (all blocks)	= 4.5
Previous Averages (all blocks)	= 4.5
New s Range x $f_{k,n}$	= 9.6
Range	= 32
New Sum s (all blocks)	= 14.1
New Average s $\frac{(\text{New Sum } s)}{(2n - 2)}$	= 7.05

Calculation of Effects

$E_5 = (A + BC)$ effect $= \frac{1}{2}(\bar{y}_8 + \bar{y}_9 - \bar{y}_7 - \bar{y}_{10}) = 10.0$

$E_6 - (B + AC)$ effect $= \frac{1}{2}(\bar{y}_8 + \bar{y}_{10} - \bar{y}_7 - \bar{y}_9) = 0$

$E_7 = (C + AB)$ effect $= \frac{1}{2}(\bar{y}_7 + \bar{y}_8 - \bar{y}_9 - \bar{y}_{10}) = 0$

$E_8 =$ Change in Mean Effect $= \frac{1}{5}(\bar{y}_7 + \bar{y}_8 + \bar{y}_9 + \bar{y}_{10} - 4\bar{y}_6) = -3.2$

$\alpha = \frac{1}{2}(E_5 + E_1) = 8.75$ $\qquad \alpha \times \beta = \frac{1}{2}(E_7 + E_3) = -1.75$

$\beta = \frac{1}{2}(E_6 + E_2) = -.75$ $\qquad \alpha \times SRD = \frac{1}{2}(E_6 - E_2) = .75$

$SRD = \frac{1}{2}(E_u - E_3) = 1.75$ $\qquad \beta \times SRD = \frac{1}{2}(E_5 - E_1) = 1.25$

Calculations of Error Limits

For New Averages $\frac{2}{\sqrt{n}}$ $= 9.7$

For New Effects $.71 \frac{2}{\sqrt{n}}$ $= 6.9$

For Change in Mean $.63 \frac{2}{\sqrt{n}}$ $= 6.1$

Change in Mean Effect

$\frac{1}{2}(E_8 + E_4) = .3$

APPENDIX II

THREE VARIABLE EVOLUTIONARY OPERATION PROGRAM

CALCULATION WORK SHEET

BLOCK I

CYCLE $n = 3$

Response Reaction time (milliseconds)

Project Combined Brake Pedal

Phase 5

Date

Calculation of Averages

		(1)	(2)	(3)	(4)	(5)
(i)	Previous Sum for Block I	561	560	572	583	565
(ii)	Previous Average for Block I	280	280	286	291	282
(iii)	New Observations for Block I	293	291	288	295	275
(iv)	Differences (ii) less (iii)	-13	-11	-2	-4	7
(v)	New Sums for Block I	854	851	860	878	840
(vi)	New Averages for Block I	285	284	287	293	280

Calculation of Standard Deviation

Previous Sum s (all blocks)	= 14.1
Previous Average s (all blocks)	= 7.05
New s = Range x $f_{k,n}$	= 7.0
Range	= 20
New Sum s (all blocks)	= 21.1
New Average s $\frac{(\text{New Sum s})}{(2n - 3)}$	= 7.03

Calculations of Effects

E_1 = (A - BC) effect = $\frac{1}{2}(\bar{y}_3 + \bar{y}_4 - \bar{y}_2 - \bar{y}_5) = 8.0$

E_2 = (B - AC) effect = $\frac{1}{2}(\bar{y}_3 + \bar{y}_5 - \bar{y}_2 - \bar{y}_4) = -5.0$

E_3 = (-C + AB) effect = $\frac{1}{2}(\bar{y}_2 + \bar{y}_3 - \bar{y}_4 - \bar{y}_5) = -1.0$

E_4 = Change in Mean Effect = $\frac{1}{5}(\bar{y}_2 + \bar{y}_3 + \bar{y}_4 + \bar{y}_5 - 4\bar{y}_1) = .8$

APPENDIX II

THREE VARIABLE EVOLUTIONARY OPERATION PROGRAM

CALCULATION WORK SHEET

BLOCK II

CYCLE $n = 3$

Project Combined Brake Pedal

Phase 5

Response Reaction time (milliseconds)

Calculation of Averages

		(6)	(7)	(8)	(9)	(10)
(i)	Previous Sum for Block II	580	562	582	583	563
(ii)	Previous Average for Block II	290	281	291	291	281
(iii)	New Observations for Block II	292	295	303	308	293
(iv)	Differences (ii) less (iii)	-2	-14	-12	-17	-12
(v)	New Sums for Block II	872	857	885	891	856
(vi)	New Averages for Block II	291	286	295	297	285

Calculation of standard Deviatio

Previous Sum s (all blocks)	= 21.1
Previous Averages (all blocks)	= 7.03
New s Range x $f_{k,n}$	= 5.25
Range	= 15.0
New Sum s (all blocks)	= 26.35
New Average s $\frac{(\text{New Sum s})}{(2n - 2)}$	= 6.59

Calculation of Effects

$E_5 = (A + BC)$ effect $= \frac{1}{2}(\bar{y}_8 + \bar{y}_9 - \bar{y}_7 - \bar{y}_{10}) = 10.5$

$E_6 - (B + AC)$ effect $= \frac{1}{2}(\bar{y}_8 + \bar{y}_{10} - \bar{y}_7 - \bar{y}_9) = - 1.5$

$E_7 = (C + AB)$ effect $= \frac{1}{2}(\bar{y}_7 + \bar{y}_8 - \bar{y}_9 - \bar{y}_{10}) = - 0.5$

$E_8 =$ Change in Mean Effect $= \frac{1}{5}(\bar{y}_7 + \bar{y}_8 + \bar{y}_9 + \bar{y}_{10} - 4\bar{y}_6) = - 0.2$

$\alpha = \frac{1}{2}(E_5 + E_1) = 9.25$ $\qquad \alpha \times \beta = \frac{1}{2}(E_7 + E_3) = - .75$

$\beta = \frac{1}{2}(E_6 + E_2) = -3.25$ $\qquad \alpha \times SRD = \frac{1}{2}(E_6 - E_2) = 1.75$

$SRD = \frac{1}{2}(E_u - E_3) = 0.25$ $\qquad \beta \times SRD = \frac{1}{2}(E_5 - E_1) = 1.25$

Calculations of Error Limits

For New Averages $\frac{2}{\sqrt{n}}$ $= 7.6$

For New Effects $.71 \frac{2}{\sqrt{n}}$ $= 5.4$

For Change in Mean $.63 \frac{2}{\sqrt{n}}$ $= 4.8$

Change in Mean Effect

$\frac{1}{2}(E_8 + E_4) = .3$

APPENDIX II

THREE VARIABLE EVOLUTIONARY OPERATION PROGRAM

CALCULATION WORK SHEET

BLOCK I

CYCLE $n = 4$

Response Reaction time (milliseconds)

Project Combined Brake Pedal

Phase 5

Date

		Calculation of Averages				
		(1)	(2)	(3)	(4)	(5)
(i)	Previous Sum for Block I	854	851	860	878	840
(ii)	Previous Average for Block I	285	284	287	293	280
(iii)	New Observations for Block I	292	289	298	291	297
(iv)	Differences (ii) less (iii)	-7	-5	-11	2	-17
(v)	New Sums for Block I	1146	1140	1158	1169	1137
(vi)	New Averages for Block I	286	285	289	291	284

Calculation of Standard Deviation

Previous Sum s (all blocks)	= 26.35
Previous Average s (all blocks)	= 6.59
New s = Range x $f_{k,n}$	= 7.1
Range	= 19
New Sum s (all blocks)	= 33.45
New Average s $\frac{\text{(New Sum s)}}{(2n - 3)}$	= 6.69

Calculations of Effects

E_1 = (A - BC) effect = $\frac{1}{2}(\bar{y}_3 + \bar{y}_4 - \bar{y}_2 - \bar{y}_5) = 5.5$

E_2 = (B - AC) effect = $\frac{1}{2}(\bar{y}_3 + \bar{y}_5 - \bar{y}_2 - \bar{y}_4) = -1.5$

E_3 = (-C + AB) effect = $\frac{1}{2}(\bar{y}_2 + \bar{y}_3 - \bar{y}_4 - \bar{y}_5) = -0.5$

E_4 = Change in Mean Effect = $\frac{1}{5}(\bar{y}_2 + \bar{y}_3 + \bar{y}_4 + \bar{y}_5 - 4\bar{y}_1) = 1.0$

APPENDIX II

THREE VARIABLE EVOLUTIONARY OPERATION PROGRAM

CALCULATION WORK SHEET

BLOCK II

CYCLE $n = 4$

Project Combined Brake Pedal

Phase 5

Response Reaction time (milliseconds)

	Calculation of Averages	(6)	(7)	(8)	(9)	(10)
(i)	Previous Sum for Block II	872	857	885	891	856
(ii)	Previous Average for Block II	291	286	295	297	285
(iii)	New Observations for Block II	299	297	293	297	296
(iv)	Differences (ii) less (iii)	-8	-11	2	0	-11
(v)	New Sums for Block II	1171	1154	1178	1188	1152
(vi)	New Averages for Block II	293	289	294	297	288

Calculation of standard Deviatio

Previous Sum s (all blocks)	= 33.45
Previous Averages (all blocks)	= 6.69
New s Range x $f_{k,n}$	= 4.8
Range	= 13
New Sum s (all blocks)	= 38.25
New Average s $\frac{(\text{New Sum s})}{(2n - 2)}$	= 6.4

Calculation of Effects

$E_5 = (A + BC)$ effect $= \frac{1}{2}(\bar{y}_8 + \bar{y}_9 - \bar{y}_7 - \bar{y}_{10}) = 7.0$

$E_6 - (B + AC)$ effect $= \frac{1}{2}(\bar{y}_8 + \bar{y}_{10} - \bar{y}_7 - \bar{y}_9) = -2.0$

$E_7 = (C + AB)$ effect $= \frac{1}{2}(\bar{y}_7 + \bar{y}_8 - \bar{y}_9 - \bar{y}_{10}) = -1.0$

$E_8 =$ Change in Mean Effect $= \frac{1}{5}(\bar{y}_7 + \bar{y}_8 + \bar{y}_9 + \bar{y}_{10} - 4\bar{y}_6) = -0.8$

$\alpha = \frac{1}{2}(E_5 + E_1) = 6.25$

$\beta = \frac{1}{2}(E_6 + E_2) = -1.75$

$SRD = \frac{1}{2}(E_u - E_3) = .25$

$\alpha \times \beta = \frac{1}{2}(E_7 + E_3) = -.75$

$\alpha \times SRD = \frac{1}{2}(E_6 - E_2) = -.25$

$\beta \times SRD = \frac{1}{2}(E_5 - E_1) = .75$

Calculations of Error Limits

For New Averages $\frac{2}{\sqrt{n}} = 6.4$

For New Effects $.71 \frac{2}{\sqrt{n}} = 4.60$

For Change in Mean $.63 \frac{2}{\sqrt{n}} = 4.05$

Change in Mean Effect

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

APPENDIX III

Calculations for the determination of learning factor

The learning factor was determined by considering each point of different phase (Fig. 9) as 100 percent and finding what percent the fifth phase point was of the 100 percent.

Phase I

Considering the points 'a' and 'e' (Fig. 9), it was found that 'e' is 82.5% of 'a'.

$$\text{Correction factor} = \frac{0.825}{100} \times 100$$

$$= 0.825$$

Thus, the mean reaction times of phase I were multiplied by 0.825 for direct comparison.

Phase II

Considering the points 'b' and 'e' (Fig. 9).

$$\text{Correction factor} = \frac{0.825}{0.905}$$

$$= 0.911$$

Hence, the mean reaction times of Phase II were multiplied by 0.911 for direct comparison.

Phase III

Considering the points 'c' and 'e' (Fig. 9).

$$\text{Correction factor} = \frac{0.825}{0.8525}$$

$$= 0.970$$

Hence, the mean reaction times of Phase III were multiplied by 0.970 for direct comparison.

Phase IV

Considering the points 'd' and 'e' (Fig. 9).

$$\text{Correction factor} = \frac{0.825}{0.835}$$

$$= 0.988$$

Hence, the mean reaction times of Phase IV were multiplied by 0.988 for direct comparison.

Phase V

Fifth phase mean reaction times remained unchanged since this phase was the base.

OPTIMIZING THE DESIGN OF A DUAL
BRAKE-ACCELERATOR PEDAL

by

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AN ABSTRACT OF A MASTER'S THESIS

submitted in partial fulfillment of the

requirements for the degree

MASTER OF SCIENCE

Department of Industrial Engineering

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1969

ABSTRACT

The effect of varying four parameters in the design of a dual function pedal was determined. The experiment was performed under partially simulated driving conditions. No interaction effects were significant. This means that the variables can be evaluated on an independent basis, and their optimum ranges determined considering their own effects.

A reaction time of 284 milliseconds was recorded for the optimum design; the conventional two pedal system requires 450 to 500 milliseconds.

The optimum pedal angle is between 30 to 45 degrees, without losing more than 5 milliseconds. The optimum seat reference distance can lie between 40 to 50% of the subject's height, without losing more than 8 milliseconds. The optimum value of seat height is recommended to be nine inches; however, a range from 8 to 10 inches can be used without affecting the reaction time by more than 10 milliseconds. The angle of twist, when varied from 0 to 14 degrees did not have a significant effect on the reaction time.