Controls for Automotive Brakes

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•IT is well known that the automotive death rate per year is over 40,000; this can be dramatized as "In 1965, 35 times more deaths than Viet Nam" or 500,000 deaths since 1953. For every death, there are many injuries; in 1965 there were 49,000 deaths and 1,850,000 injuries. In addition to the suffering and sorrow from death or injury, there is the dollar; $8.9 billion of them in 1965 (1). The problem is serious.

The problem also is complex. Just as the accidents occur from Key West to Seattle, during summer and winter, on expressways and dirt roads, in compact and competition cars, with sober teenagers and tight senior citizens, the solutions must be many-faceted. This paper describes some exploratory research on the controls for automotive brakes. The hope is to increase the operator's permissible margin of error (avoid accidents) or, alternatively, to decrease the consequences of an error (less serious accidents).

THE EXISTING SYSTEM

The presently used control system for automotive brakes is foot-actuated. Although it is possible to actuate the control with the left foot, existing designs make this awkward and fatiguing so, in effect, the control usually is actuated by the right foot. According to Morgan et al (2), "It requires about 20 percent longer to respond with the foot than the hands; response with the preferred limb is about 3 percent faster than the nonpreferred limb. Thus, for right-handed operators, when the controls must be selected entirely on the basis of speed of activation, the order of selection should be right hand, left hand, right foot and left foot."

However, in the typical driving task, the left foot is idle while the other three limbs are occupied. The right foot is assigned the task of activating both the acceleration control and the deceleration control. The left foot is utilized only in the 20 percent of automobiles that have standard transmissions and then only when the gears must be shifted.

EXPERIMENT ONE

Task

Sixty-watt light bulbs were positioned 15 ft ahead of the front bumper and in line with the headlights of a stationary 1964 model American auto. Upon the onset of either light, the subject honked the horn or depressed the brake pedal. The conditions were:

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

The time from the light onset until the horn or brake light received an electrical pulse was timed electronically.

Subjects

Twelve university faculty and students, with an average age of 38, volunteered. Each subject had four times recorded for each of the four conditions. The sequence of conditions was randomized.

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Results

The average time for Condition 1 was 0.38 sec, for 2 was 0.56 sec, for 3 was 0.39 sec and for 4 was 0.59 sec. The times seem consistent with the results of other investigations of reaction times. Warrick, Kibler and Topmiller (3) reported a median time of 0.60 sec for alerted secretaries to reach 11 in. to a button from a typewriter keyboard; this is roughly analogous to Condition 2 which had an average time of 0.56 sec. A Wilcoxon Matched-Pairs Signed-Ranks test (4) established that Conditions 1 and 3 were not significantly different, 2 and 4 were not significantly different but 1 and 3 were significantly shorter than 2 and 4.

Discussion

Perhaps the most interesting fact is 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 sec is equivalent to 9 ft at 30 mph and 18 ft at 60 mph.

The advantage seems to reside in the elimination of the movement of the body member to the control rather than foot vs hand differences. When Condition 1 is compared with 3 and 2 with 4, the hand is faster than the foot by 0.01 and 0.03 sec. These differences are an order of magnitude less than the differences between the body member moving to the control vs the body member starting at the control. Since the elimination of the body limb movement not only had the largest saving but also eliminated the possibility of moving and missing, it was decided to concentrate on elimination of movement between controls.

One possible concept is to design the brake control so that the left foot (the only body limb not normally occupied during driving) rests on the control. Another concept is to give one of the three remaining limbs the brake control task in addition to its primary task but to combine the controls of the primary task and the braking task. If the control is to be combined, probably it is simpler mechanically to combine the brake control with the accelerator than with steering since the position of the foot is relatively constant while the position of the hands varies not only from driver to driver but also while turning. Of course, a brake control which simply required moving the entire wheel rather than a portion of the wheel might be quite satisfactory.

Because a combined brake and accelerator pedal was available (5), it was the focus of the next experiment.

EXPERIMENT TWO

Winkleman's combined control (5) activates the accelerator when the toe is pressed down and activates the brake when the heel is depressed. An interlock prevents simultaneous operation.

Task

A single 60-watt light was placed approximately 5 ft straight ahead of the subject who was seated in an ordinary wooden chair in a laboratory. He depressed the "accelerator" until the needle on a dial before him pointed to 40; at the light onset, he lifted his toe and depressed his heel 1 in. to actuate the "brake." Each subject was given four trials after 10 to 20 sec instruction and practice.

TABLE 1

REACTION TIMES FOR BRAKING WITH COMBINED CONTROL, EXPERIMENT TWO

Subject Characteristics	No. of Subjects	Avg Reaction Time (sec)
Subjects also in Exp. One	11	0.41
Other subjects	110	0.42
Total subjects in Exp. Two	121	0.42
Female with heels	11	0.44
Female without heels	29	0.44
Total female	40	0.44
Total male	81	0.41
Age of subject:		
14-25	55	0.40
26-35	15	0.40
36-45	9	0.42
46-65	39	0.45
Unknown	3	0.44

Subjects

One hundred twenty-one visitors to an Engineering Open House volunteered their services; of the 121, 11 had also participated in Experiment One. The subject characteristics and the results are given in Table 1.

Results

The subjects from Experiment One had times representative of the 121. 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 combined control was significantly ($p < .01$) lower when it was tested with a Wilcoxon Matched-Pairs test (4).

Therefore, although a direct comparison between controls could not be made for all 121 subjects, it seems likely that the average savings of 0.21 sec enjoyed by the 11 would also be enjoyed by the other 110.

Some other characteristics also are interesting. There seemed to be no difference in reaction times between women with high heels and those without high heels. The lower time for men than women is not statistically significant, but men normally have faster times than women (6). The correlation between age and reaction time was significant ($p < .001$) when the Spearman Rank Correlation Coefficient was calculated.

Since these data, as are most performance data, were positively skewed, it is of interest that the minimum reaction time was 0.27 sec, the maximum time was 0.94 and 95 percent of the average times were less than 0.60.

The data, although suggestive, are not conclusive since the experimental conditions were not exactly identical. In addition, it was noticed that the subject's times decreased with practice. Therefore, the third experiment was tried.

EXPERIMENT THREE

Task

Two brake control devices were used:

1. An American Automobile Association reaction timer; this "black box" of the conventional system had a "clutch" pedal, a "brake" pedal, an "accelerator," signal lights and a timing mechanism.
2. The Winkleman combined control.

Microswitches on the combined control were connected with the AAA timer and with two 60-watt light bulbs mounted at eye level in front of the subject's chair. Light 1 was activated by the accelerator of either control; light 2 could be activated by the experimenter provided light 1 was on. When light 2 was activated, a relay produced a "snap of the fingers" sound; thus the subject had both a visual and an auditory cue. The timer automatically recorded the time between the onset of light 2 and the 1-in. depression of the brake.

Subjects

Twenty-five university faculty and students, with an average age of 28, volunteered.

Procedure

Three conditions were tested:

1. Depress conventional brake. Starting position of left foot on brake.
2. Depress conventional brake. Starting position of right foot on depressed accelerator.
3. Depress experimental brake. Starting position of right foot on depressed accelerator portion of the combined control.

Each subject had ten times recorded for each of the three conditions. The sequence of conditions was randomized. Each subject took from three to six practice trials.

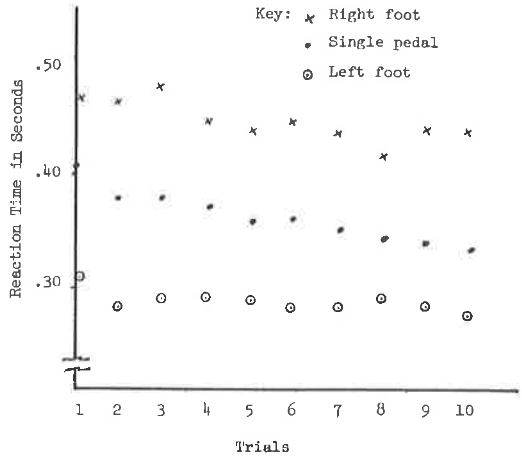

Figure 1. Effect of learning on reaction time for the three controls.

TABLE 2

ANALYSIS OF VARIANCE, EXPERIMENT THREE

Source	df	SS	F
Subjects	24	2, 546	—
Controls	2	86, 993	129. 45*
Trials	1	4, 793	38. 04*
Sub × Controls	48	672	7. 72*
Sub × Trials	24	126	1. 45
Controls × Trials	2	486	5. 59*
Residual	48	87	
Total	149		

*$p < .01$.

Results

A subjects × treatments (trials) × treatments (conditions) analysis of variance was calculated (Table 2 and Fig. 1). For computational simplicity the total of the first five trials was considered as trial one and the second five as trial two in the analysis of variance.

Both trials and conditions were significant ($p < .01$). The significant effect of trials means that the subjects improved with practice and the significant effect of conditions means that the reaction time was affected by the type of control. A Wilcoxon Matched-Pair Signed-Rank test established that the times for all three controls are different from each other; that is, the 0.29 sec when using the left foot was significantly ($p < .05$) less than the 0.36 sec of the combined control and the 0.36 sec was significantly less than the 0.45 sec when using the right foot.

The significant subject × control interaction indicates that certain subjects did better on certain controls; the significant trials × controls interaction indicates that the rate of learning was not the same for all three controls.

Discussion

The experiments to date have been more interesting than informative. A laboratory is certainly not the same as the highway. The controls which minimize movement may be even better when operated in an actual automobile, or far worse. The relatively small decrement with age for the combined control indicates it might be especially advantageous for older drivers.

Training may or may not be a problem. None of the users to date have had any problem even with as little as 10 sec instruction. Of course, none were in danger of losing their life either. A system in which the existing brake pedal remained in place and a combined accelerator-brake pedal was connected in parallel might be advantageous. It would eliminate any possible regression problem in emergencies, would permit simultaneous use of the brake and accelerator and, perhaps most important, would minimize automotive industry opposition to something new since it could be sold as an extra-cost option.

In any case it seems that additional research is desirable to give drivers that "most important quarter-second."

REFERENCES

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5. Winkleman, C. U.S. Patent, Number on request.
6. Versace, J. Ford Motor Co., Human Factors Head, personal communication, March 1966.

Discussion

E. S. KRENDEL, Professor of Statistics and Operations Research, University of Pennsylvania—It is always commendable when new techniques or devices are suggested to improve the performance of motor vehicles. Tradition and the harsh demands of economic competition have dominated design and innovation decisions for far too long. In the present climate of interest in improving the safety with which man-automobile systems operate, long overdue suggestions may finally get a fair hearing.

Konz and Daccarett have examined human acceleration and braking behavior in an effort to use the output actuators—hands and feet—of the human operator more effectively. A measure of the importance of this problem is indicated by the present confusion which exists among driver training schools as well as among licensing jurisdictions on the advisability of braking with the left foot; in fact, about 25 percent of these jurisdictions fail candidates for braking with the left foot.

Belzer and Huffman (7) examined brake response with left and right feet in various starting positions and thus clearly demonstrated that "right foot braking in the usual manner is superior to left foot braking unless the left foot is already poised on the brake pedal when a demand for quick braking occurs." The question of what dangers exist because of the possibility that the left-foot braker has allowed his right foot to linger on the accelerator has not been explored. Belzer and Huffman obtained time delays somewhat lower than did Konz and Daccarett. For example, the quivalent condition to Experiment One, Condition 4, for which the paper under discussion determined the delay to be 0.59 sec, resulted in 0.46 sec in the referenced study. The reason may be that the subjects were younger—all of them being 15 years old in the earlier study.

A general agreement exists, however, between the findings, where comparable, of the paper under discussion and the paper by Belzer and Huffman, and this serves to reinforce the general findings.

That a parallel braking system—i.e., a conventional and a combined accelerator and brake system—will be a feasible interim device to overcome habit prejudices is rather doubtful at present because of the additional costs. As the authors rightly point out, more data, particularly on highway and stress-producing circumstances, will be needed for a more complete evaluation. Certainly, the combined brake and accelerator pedal is an attractive and promising concept.

However, I have personal reservations of a more general sort. Drivers may fall into a car-following behavior which is consistent with the delays which they know exist in the system. As an example of introspective data, I know that I behave differently when I drive a car with power brakes than when I am using a conventional hydraulic braking system. I adapt in such a way as to, in effect, maintain more or less equal margins of error. I suspect that this is a common characteristic of drivers. It is certainly the characteristic form of behavior exhibited by humans in coupling with a control system characterized by lags. If this view be true, then the major problems in traffic safety may be more successfully attacked in the perceptional and judgmental aspects of driving than by effecting possible improvements in braking times. Despite this caveat, however, I do feel that the possible improvements suggested by Konz and Daccarett are desirable and that their suggested method of implementation merits further test and study.

Reference

7. Belzer, E. G., Jr., and Huffman, W. J. The Quickness of Selected Right Foot and Left Foot Braking Techniques. Traffic Safety, Vol. 10, No. 3, pp. 72-78, Sept. 1966.

J. E. UHLANER, U.S. Army Personnel Research Office—The extremely interesting study on automotive braking devices interests me not only because it is a carefully planned and executed research project, but also because it is representative of the caliber of human engineering required as input to the overall systems approach to automotive safety. This approach studies the characteristics of the total organized system, rather than the separate parts. In the area of automotive safety this involves the interaction of the driver, his machine and the total surrounding environment, and encompasses the design of equipment, both machines and roads, and the selection and training of drivers.

This systems approach is relatively new, but the need for it has been recognized for several years. In 1964, Drucker and I reported the results of a study of driver selection tests (8). At that time we stated that while licensing in terms of the personal limitations of the driver is a legitimate basic approach to reducing accidents, it was, and still is, our belief that a broader approach is obviously needed. This need arises from the fact that the traffic accident usually occurs not as a result of a single variable—such as inattentiveness because of fatigue or preoccupation, slippery roads, or insufficient light—but as a result of a complex of variables. Indeed, one of the most encouraging signs of progress in recent years is the success of driving safety researcher personnel in reducing the total problem to manageable proportions. Just as the military man and the weapon or machine with which he interacts and the environment in which he performs his assigned duties are viewed as a man-machine or man-weapon system, so the driving process gradually has begun to be considered as a system. From this point of view, malfunction of the driver system can occur because of (a) poorly designed and mantained vehicles, (b) poor roads and poorly controlled traffic patterns, and (c) poor driving.

In line with this, I believe that ultimate reduction of accidents is likely to come about through more effective human engineering of the automobile, the road, and the traffic system, as well as through greater effort in understanding the driver process. Particularly needed is a better understanding of the relationships involved in various situational behaviors—that is, the psychological functioning in driving both at night and in daylight on turnpikes, in rural areas, and in the city.

This research approach dictates highly sophisticated simulation facilities and should be directed toward the alternate outcomes of educating the potential driver (and retraining the old driver) to difficulties inherent in a variety of conditions, or limiting the situations in which he may be permitted to drive.

Since public officials are inclined to shrink away from any action which would eliminate millions of drivers from the road in order to reduce the national accident rate, it seems necessary to embark on this systems approach to driving research. This is essentially a reexamination of the total problem to consider the interaction involved in the man-vehicle-road-traffic complex and to derive principles of engineering traffic, vehicles, roads, and identifiable driver limitations.

In line with this, it would seem that the next step in the program initiated by Konz and Daccarett would be to validate their findings on a large population sample. This sample would have to include not only the range of average drivers, but also those at either end of the spectrum—the very good and the very bad, in terms of whatever criterion is adopted. Then, the results could be fed into a simulation study which would examine the task within the overall driving setting rather than in isolation in the laboratory. These results could be fed, in turn, into vehicle design studies and into driver training research. In this manner, the findings reported here could be developed into an operational improvement of the modern automobile—an improvement based on a combination of carefully controlled laboratory research, simulation research and the latest advances in equipment design and training techniques. It is only through such an integrated approach to the entire problem of the man-vehicle-environment complex that progress in automotive safety research will be accomplished.

Reference

8. Uhlaner, J. E., and Drucker, A. J. Selection Tests—Dubious Aid in Driver Licensing. Highway Research Record 84, pp. 41-53, 1965.

ROBERT C. O'CONNELL, U.S. Bureau of Public Roads—I first want to compliment the authors for undertaking research which I believe does have a direct application to operating a motor vehicle more safely. Nearly everyone has heard of the existing differences between the several state driving examinations. In some states, driver examiners are refusing licenses to applicants who use the left foot for braking during the driving test. In other states, examiners criticize drivers for not using left-foot braking for more sensitive control of the vehicle in heavy traffic. Each method of braking has several good and bad points. For example, critics believe that drivers having the left foot poised on the brake tend to "ride" the pedal, with the result that the brake lights are excessively illuminated thus lowering their value in intervehicular communication. There probably is more control of the vehicle with the left foot poised on the brake, but what then happens to this driver when he must drive a car equipped with a clutch and change his braking habits entirely? This is the main reason that some driver examiners feel the left foot should be on the floorboard when the vehicle has an automatic transmission and that all accelerating and braking should be done with the right foot.

Early automobile design required a driver to use both feet in controlling a car. Both feet were in regular use between the clutch, brake, accelerator pedal, and light switch, thus requiring heavy use of the slowest acting parts of the body, the limbs. I agree with the authors that our current method of vehicular control has historically grown "like Topsy."

This particular study and others that have measured brake reaction time point out that generally three-tenths of a second can be saved in braking time by using the left or right foot poised over the brake. Three-tenths of a second difference in response time amounts to 4.4 ft at 10 mph, 13.2 ft at 30 mph, and 30.8 ft at 70 mph. Therefore, we are talking in terms of improving stopping distances by approximately 4 ft to about 10 yd in emergency braking situations. At first glance, this might seem insignificant; however, in an emergency situation such distances can make a difference between a near miss and a collision. In my opinion, the advantages offered by making a small adjustment in the design in the vehicle braking system are well worthwhile.

Although the position of the operating controls on vehicles has frequently been changed, I believe we must agree that we are generally bound by the criteria of steering through the use of hands and arms with the control of acceleration and deceleration to be provided by the feet and legs. It would seem almost incongruous to require the hands, fingers, or arms to provide the braking function while at the same time attempting to steer the vehicle. Therefore, what limitations in vehicle design must we consider in the application of criteria designed to improve braking time?

Before attempting to answer this question, I believe a review of past and present practices would be helpful. The problem of left-foot braking became prevalent with the advent of the automatic transmission, and about a decade ago it appeared that the standard-shift vehicle would be a relic of the past. However, a current fascination for the "jet set" is to discuss "four on the floor"; whether we like it or not some younger drivers are prone to "dig out" at the turn of the traffic signal light and these drivers do prefer a manual clutch. Similarly, some drivers in mountainous regions prefer to have the clutch operation for use in downhill deceleration. Therefore, it appears that there will always be some need in vehicle design for manual clutch operation. By the same token, the acceleration function probably must be limited to the right foot even though many of us probably remember the throttle and spark control on the steering post of the old "Model T."

This problem involves driver limitations as well as vehicle design limitations. Our modern driver must be an ambidextrous individual because of the many different types of vehicles that he may be required to drive. A personal car generally differs from the fleet car or the commercial truck that an average driver must regularly use in his day-to-day business and pleasure. It therefore seems to me that, with the physical handicaps of the human and the mechanical limitations of the vehicle, we can adopt the results of this paper to effect an improvement in the design of the vehicle.

Possibly the only difference I might express with the authors' recommendations would be to suggest that the acceleration pedal be designed separately from the braking pedal. I would argue against the proposed system of utilizing a combined brake and accelerator with an over-the-center action. In my opinion, there is an advantage gained in some lateral transfer of the foot or at least the toe part of the foot from the accelerator to the brake pedal with no movement of the leg. I am also of the opinion that there is more sensitivity in the toe of the foot than in the heel. The advantage gained would be in requiring similar toe actions for both accelerating and decelerating. In other words, we are asking for a similar response to accelerate the vehicle and to brake it which depends upon a similar pressure by the toe. Thus, the harder you push the accelerator the faster the vehicle will go and similarly for braking the harder you push the brake the more quickly you will decelerate. However, no research exists to support this opinion. Many commercial buses do utilize two separate pedals for toe action, leaving the heel in approximately the same position on the floorboard.

I believe the results of this study can be utilized for design improvements that would provide an accelerator pedal and a brake pedal on a continuous plane, approximately level with each other so that the heel of the right foot can remain in one position, with no need to raise the entire leg for the proper braking action. Perhaps the brake will have to be a power brake, which would minimize the downward movement of the toe. I further believe that the length required to depress the brake, that is, the downward motion, should not be greater than the totally depressed position of the accelerator.

This research paper does advance our knowledge of human factors as they affect driving capabilities, and I would like to see the laboratory results applied to a real situation to further evaluate the effectiveness of improved vehicle design. In particular, I think the design changes that would keep the heel of the right foot in a permanant position on the floor, utilizing the toe of this foot to effect the process of acceleration and deceleration through the use of two separate pedals, offers excellent possibilities for safer motor vehicle operation.

STEPHAN KONZ and JOSE DACCARETT, Closure—We thank the reviewers for their constructive comments. We feel it is unfortunate that the impetus for a systems study of automotive brakes must come from a university and that none of the reviewers is from the automotive industry, but perhaps it is unrealistic to expect the industry to be more concerned with safety than sex.