The Deaccelerator: A Behavioral Application of a Differentially Imposed Force Schedule to the Accelerator Pedal of a Motor Vehicle to Control Unlawful Highway Vehicle Speed

Richard Schulman
Western Michigan University

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THE DEACCELERATOR: A BEHAVIORAL APPLICATION OF A DIFFERENTIALLY
IMPOSED FORCE SCHEDULE TO THE ACCELERATOR PEDAL OF A MOTOR VEHICLE
TO CONTROL UNLAWFUL HIGHWAY VEHICLE SPEED

by

Richard Schulman

A Dissertation
Submitted to the
Faculty of The Graduate College
in partial fulfillment of the
requirements for the
Degree of Doctor of Philosophy
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The Deaccelerator is a behaviorally designed speed control device that utilizes punishment and reinforcement by way of a differentially imposed force schedule to the accelerator pedal of a motor vehicle when vehicle speed exceeds the preset speed. Specifically, increasing and decreasing accelerator pedal resistance is a negatively accelerated function of behavior producing respective increases and decreases in vehicle speed as speed moves in excess of 1 mph beyond the preset speed. A lesser force schedule generates linear increases and decreases in accelerator pedal resistance as a function of behavior producing respective increases and decreases in accelerator pedal depression once vehicle speed moves in excess of 1 mph beyond the preset speed. Finally, to aid the motorist in maintaining the preset speed, an accelerator pedal position control system is imposed whereby the depressed accelerator pedal and thus the motorist's foot is linearly extended as a function of increasing speed from a potentially fully depressed position at speeds of 1 mph or more below the preset speed to a fully extended position when speed increases to 1 mph over the preset speed. This system provides foot support by utilizing a constant but yieldable force to limit the motorist's degree of accelerator pedal depression to the
position required to maintain the preset speed. The accelerator pedal functions normally at speeds below the operational range of the Deaccelerator.

In the present field study, a Deaccelerator was installed in a state-owned vehicle used by faculty members at Western Michigan University for work-related travel. The Deaccelerator had a preset speed of 55 mph when the vehicle traveled on level and uphill road gradients and, due to speed control error, attained a speed of 56 mph when the vehicle traveled on downhill road gradients. Data on highway speeds generated by the experimental vehicle were collected by digital recorders hidden in the trunk of the vehicle. The data show that highway speeding was practically eliminated when an operative Deaccelerator was part of the experimental condition and that highway speeding, especially at the highest recorded speed category of 60+ mph, was substantial when an inoperative Deaccelerator was part of the experimental condition. The data further show that the vast majority of highway speeds traveled by the experimental vehicle were at the preset speeds, 55 and 56 mph, when an operative Deaccelerator was part of the experimental condition. Thus, the Deaccelerator appears to control highway speeding and reduce the variability in highway traveling speeds.
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CHAPTER I

INTRODUCTION

The Highway Speeding Problem

Highway speeding has been a societal problem of long standing, not only in the United States but in other countries as well. In order to conserve energy, control of highway speeding became an important priority when the United States Government imposed the 55 miles per hour (mph) speed limit in response to the 1974 Arab oil embargo. Data indicated that, besides saving fuel (Department of Transportation [DOT], 1979a, p. 5-6, 1979b, pp. 13-14), the 55 mph speed limit was partially responsible for reducing fatalities associated with highway travel (DOT, 1979a, pp. 4-6, 1979b, p.2). As a result, the 55 mph speed limit has been retained.

Two basic factors are often cited regarding the hazards of highway speeding. These factors are absolute vehicle speed and relative vehicle speed. Absolute vehicle speed is the actual speed being traveled and determines the impact upon collision resulting from an accident. Naturally, the probability and degree of bodily injury resulting from an accident are increasing functions of increases in absolute vehicle speed (DOT, 1979a, pp. 6-7, 1977, p. 13). Contrary to popular opinion, however, absolute speed does not appear to play a role in determining accident probability or accident involvement rates once an accident has occurred. Relative vehicle speed is the speed a given motorist travels
relative to the speeds being traveled by motorists in close physical proximity. As a motorist's vehicle speed increasingly deviates from the mean speed traveled by motorists in close physical proximity, the probability of an accident increases (DOT, 1977, p. 9). This holds true regardless of whether the deviation entails speeds greater than or less than the mean traveling speed. Moreover, the greater the deviation from the mean traveling speed, the greater the number of vehicles involved in an accident (Cerrelli, 1977, p. 5). Thus the function relating variability in vehicle speed in both directions from the mean traveling speed to accident and accident involvement rates is U-shaped (Cerrelli, 1977, pp. 5-6).

Approaches to Solving the Highway Speeding Problem

The Traditional Approach

The traditional approach to highway speed control involves signs posted on the highway stating the legal speed limit, as well as the use of police patrols and radar speed-detection units coupled with punishment in the form of fines, court appearances, and suspension of driving privileges. A central problem is the variable intermittency of these punishing events; for the most part, speeding motorists are caught all too infrequently, relative to the overall time spent speeding, to induce a lasting change in driving behavior. To complicate matters, the increasing popularity of citizens band radios and radar-detection units has further attenuated the effectiveness of police
radar units, resulting in many speeders going unnoticed and consequently unpunished.

It is tempting to suggest that another difficulty is the delay in punishment relative to the behavior it is intended to punish. Punishing events such as fines, court appearances, and suspension of driving privileges are temporally remote from the actual occurrence of speeding upon which their presentation is contingent. Nevertheless, this delay between behavior and consequence probably plays a minor role in reducing the effectiveness of standard punishment procedures. Imagine that conditions were altered so that the delay in punishment were eliminated. (Suppose, for example, that motorists had to pay a fine immediately upon being caught for speeding.) In all likelihood, many motorists would continue to speed. However, if conditions were altered so that motorists were caught with every occurrence of speeding (and following a delay, paid a fine), many motorists would probably soon discontinue speeding. Thus, the effectiveness of standard punishment practices is largely diminished by the unfavorable ratio between the frequency of punishment and the overall time spent speeding rather than the delay between behavior and punishment. (One final note with respect to the delay in punishment concerns the obvious: Simply being stopped by police patrol as a result of speeding is, because of its special relationship to further consequences, a supplementary source of punishment that bridges the elapsed time between behavior and these delayed consequences.)
Visual Stimuli

One approach to the control of highway speeding involves the use of visual stimuli located on the highway. One familiar example, of course, is speed limit posting. Van Houten, Nau, and Marini (1980) cite various sources of evidence (compiled by the Department of Scientific Research, Road Research Laboratory) that posting speed limit signs reduced vehicle speed and resulted in fewer accidents, injuries, and fatalities. Moreover, the evidence suggested that the reduction in vehicle speed produced by posted speed limits affected a greater percentage of motorists traveling well in excess of the mean speed relative to those traveling at or close to the mean speed. Nevertheless, government statistics indicate that despite the numerous postings of maximum speed limit signs across the nation's highways, many motorists continue to travel at vehicle speeds in excess of the speed limit (Johnson, Klein, Levy, & Maxwell, 1980, pp. 23, 26, 36-39).

Dart and Hunter (cited in Van Houten & Nau, 1983) attempted to reduce vehicle speed by locating a visual indicator on the highway that displayed the speed of each motorist traveling across the location of the indicator. If the motorist's speed was in excess of 55 mph, the visual indicator displayed the message "Slow down." Data suggested that the visual display indicator had marginal if any effect in generating speed reduction.

On the other hand, a study by Moncaster and Southgate (cited in Van Houten & Nau, 1983) indicated that speed reduction did occur as a result of a visual indicator that displayed "Police—You are speeding"
when a vehicle exceeding 30 mph approached the indicator. However, as pointed out by Van Houten and Nau (1983), there were several differences between the Dart and Hunter study and the study conducted by Moncaster and Southgate. The message displayed by the visual indicator in the Moncaster and Southgate study may have implied stricter police surveillance and enforcement than the message displayed in the Dart and Hunter study (Van Houten & Nau, 1983). Another difference between the two studies is that Dart and Hunter attempted to control highway speeding whereas Moncaster and Southgate attempted to control urban speeding. It may well be that urban speeding is more readily controlled than highway speeding. Since for a given motorist greater travel time per trip generally occurs on highways as opposed to urban roads, a speeding motorist saves a greater amount of time when traveling the former as opposed to the latter. In addition, unlike highway driving, urban driving often requires frequent reductions in speed as well as actual stops (i.e., stop signs and red lights). Excessive increases in speed may become less valuable if the maintenance of such speeds is frequently disrupted.

In attempting to reduce vehicle speed, Van Houten et al. (1980) investigated the effects of posting a sign that numerically displayed the previous day's percentage of motorists not speeding as well as the highest percentage of nonspeeders recorded in the experiment up to the date of the display. The result of this posted feedback sign was a reduction in vehicle speed, with the greatest reduction occurring for motorists traveling at higher initial velocities. A later study by
Van Houten and Nau (1981) replicated those results using two different highway locations. Moreover, the effectiveness of these signs in reducing speeding was compared with the effectiveness of increased police radar surveillance. The posted feedback signs decreased speeding relative to baseline conditions whereas increased police radar surveillance did not. In fact, the data indicated that speeding rose slightly during the increased police radar surveillance condition.

It should be noted that the studies conducted by Van Houten et al. (1980) and Van Houten and Nau (1981) employed a chosen speed limit rather than the posted speed limit. In both studies the chosen speed limit was higher than the posted speed limit. The higher, chosen speed limit ensured that a greater number of motorists met the nonspeeding criterion and thus ensured higher posted percentages of motorists not speeding.

A later experiment by Van Houten and Nau (1983) compared the efficacy of the feedback sign when a strict as opposed to a lenient criterion was employed. The results of this experiment suggest that a lenient criterion produced greater reductions in speeding than a strict criterion.

Another aspect of the 1983 Van Houten and Nau experiment was to determine the extent to which the initial speed reducing effects of a feedback sign endured as motorists left the vicinity of the feedback sign. It was found that the speed reducing effects of the feedback sign deteriorated as a function of the motorist's distance from the sign.
Still another aspect of the 1983 Van Houten and Nau experiment was to compare the effectiveness of the posted feedback sign with the effectiveness of a marked patrol car parked along the highway and with the effectiveness of a police air patrol program. Initially, both the parked patrol car and the air patrol reduced speeding to a greater extent than the feedback sign, although the magnitude of their effectiveness decreased across time.

A final aspect of the 1983 Van Houten and Nau research was to examine the speed reducing effectiveness of a program entailing the issuance of warning tickets for excessive speeding, plus passing out information fliers to those motorists receiving the warning tickets. This program did produce a reduction in highway speeding. Also tested during this aspect of the study was the traditional police enforcement procedure. The traditional procedure did not reduce highway speeding.

An experiment by Van Houten et al. (1985) demonstrated that posted feedback signs reduced speeding in two cities, one of which employed 10 feedback signs. Moreover, the speeding reductions were correlated with lower accident rates.

Although in general the posted feedback sign procedure used in the studies just reviewed demonstrated some success in controlling vehicle speed, there are three reasons why the results of studies using these signs should be viewed with caution:

1. While there was a reduction in vehicle speed, the posting procedure by no means eliminated the speeding problem.
2. Even though some motorists reduced their speed in the presence of the posted sign, vehicle speed increased once motorists left the vicinity of the sign.

3. As already noted, one Van Houten study involved the posting of 10 feedback signs and found a reduction in speeding. However, these signs were located on city streets or roads rather than on highways. Due to the often extended and continuous nature of highway travel as opposed to city travel where slowing down and stopping are frequent occurrences, it seems unlikely that a nationwide posting of feedback signs located on the highway would be much more effective in controlling vehicle speed than the current practice of posting the maximum highway speed limit. (A theoretical analysis suggests that some motorists may reduce their highway vehicle speed when confronted with a novel feedback sign because the small increase in overall traveling time that would result would be counterbalanced by the altruistic reinforcement the motorist would generate in contributing to a favorable statistic. It is likely, however, that the value of this altruistic reinforcement would be a diminishing function of the amount of increase in the overall traveling time that would result. If confronted with a multitude of highway feedback signs, motorists would probably find the resulting large increase in traveling time too punishing relative to the altruistic reinforcement gained by continually contributing to favorable statistics.)

A study by Galizio, Jackson, and Steele (1979) examined several variables involving visual stimuli and highway vehicle speed. These
variables were a posted speed limit sign, a radar-enforced sign, and a marked patrol vehicle. Their findings showed that only the marked patrol vehicle systematically reduced vehicle speed. In fact, some motorists reduced their speed even though they were not exceeding the speed limit before observing the marked vehicle. Several factors, however, argue against this approach to highway speeding.

One factor involves what the authors termed an "overreaction effect." This term referred to their finding that motorists abruptly reduced vehicle speed in the presence of a marked vehicle even when they were not initially speeding. (The term "overreaction effect" seems an unfortunate word choice because of its implication that the behavior somehow transcends the contingencies responsible for it.) Creating a situation in which motorists in succession abruptly reduce highway vehicle speed produces dangerous driving conditions. As already noted, besides speed per se, variability in speed among traveling motorists presents a hazard to highway safety. If in the presence of a marked vehicle a motorist abruptly reduces speed, this will abruptly generate variability between that motorist's speed and the speed of those motorists traveling in close proximity behind the slowed vehicle. Considering the dangerous condition produced by variability in highway speeds, it should also be noted that since the current use of highway radar patrols often involves marked police vehicles, this practice might actually play a role in undermining highway safety.
Another factor concerns the behavior of the motorist in the absence of a marked car. Vehicle speed would probably decrease only in the marked car's presence, and since placing marked cars close enough to one another along the highways to control vehicle speed continually would be costly, this practice does not appear feasible.

Still another factor is that motorists using radar-detection units could discriminate marked vehicles equipped with radar from those not equipped with radar.

The above review of the effects on vehicle speed of various visual stimuli located on the highway suggests that none of these methods adequately addresses the problem of unlawful speeding. Some of the flaws inherent in the use of these visual stimuli are: (a) their less than complete control of excessive vehicle speed, (b) the inevitable intermittency of their presentation, and (c) the hazardous increase in the variability of vehicle speed among traveling motorists that their use may generate.

In-Vehicle Devices

Another approach to the control of highway speeding entails the installation of a mechanical or electro-mechanical device in a motor vehicle. Three such devices are the governor, the limited speed cruise control, and the trip recorder.

The governor is a device that limits the top road speed of a vehicle by placing a ceiling on either engine revolutions per minute or vehicle speed. Engine and road speed governors have been installed
in a selected population of motor vehicles (notably trucks and buses) in order to reduce fuel consumption. Besides a decrease in fuel consumption (Cross, 1982), a reduction in accident rates has been reported with the use of governors (Weiss, Ligon, Travis, & Seiff, 1981, pp. 19-20).

Rather than being set at the maximum highway speed limit (i.e., 55 mph), engine and road speed governors are often set at a marginally higher velocity (e.g., 58 mph). The rationale for this measure is that the few miles per hour between the legal and the slightly higher governed speed permit the motorist to behave effectively in response to emergency situations. But the effectiveness of this measure is debatable. Since only a few miles per hour above the speed limit are allotted, the maximum velocity may be too low to permit effective behavior when an emergency requiring a larger increase in vehicle speed is encountered.

Another approach to the problem of emergency speeding and the use of a governor is to incorporate a timer that allows the motorist limited temporal access to the vehicle's total performance capacity. For example, the road speed governor may operate so that the motorist can exceed the maximum velocity determined by the governor for a period of 2 minutes, following which the vehicle is automatically slowed to the governed velocity. Unfortunately, there is little to prevent the motorist from intermittently speeding for brief periods of time when not confronted with an emergency situation. In fact, it is possible for the motorist to use the few minutes of speeding time
intermittently for frivolous purposes and then not have the opportunity to speed available when an emergency is suddenly encountered.

Despite its shortcomings, the governor may still improve highway safety in comparison with the operation of motor vehicles not equipped with this speed control device because the governor does limit the top speed of a vehicle, which places a reduced ceiling on the potential severity of impact produced by a collision and reduces the vehicle's potential variability with respect to velocities above the speed limit. Furthermore, because situations that require emergency speeding are infrequently encountered, accidents resulting from an inability to accelerate to a sufficient speed do not have the opportunity to occur very often. In contrast, for motorists operating vehicles not equipped with governors, the opportunity for an accident to occur is relatively high because the opportunity to abuse additional passing power is practically always available.

The limited speed cruise control is a device that allows the motorist to maintain a specific velocity without having to depress the accelerator pedal. Once operative, the device can be disengaged by the motorist either by applying the brake or depressing a button. This device cannot be set beyond or below the maximum speed limit, but rather only at the maximum speed limit (hence the term "limited").

One major problem is readily apparent with this approach to highway speeding. The limited speed cruise control does not sufficiently control for motivational variables. As long as the motorist is not in a hurry to get from one location to another, there is a fairly high
probability that the limited speed cruise control will be used for highway travel. But when reducing highway travel time is important, it is quite likely that the motorist will simply forfeit the comforts of the limited speed cruise control in favor of sustained higher speeds by way of the accelerator pedal since, for all intents and purposes, accelerator pedal depression is practically effortless to execute. When viewed from this perspective, the limited speed cruise control is not really a speed control device at all. In fact, all cruise control devices should be of limited speed in nature, not so much because it would control unlawful highway speeding, but because at least it would not encourage highway speeding.

Another problem worth considering in the use of the limited speed cruise control concerns a potential reduction in highway safety. When vehicle speed is being controlled by cruise control, the motorist's foot is generally not in contact with the accelerator pedal because depressing the accelerator pedal interferes with the speed control action of this device and defeats its intended purpose. When not using cruise control, most motorists are accustomed to the often rehearsed lateral movement of the foot (or leg) when going from the accelerator pedal to the brake. An increase in reaction time regarding the execution of a braking response may occur when the motorist is using cruise control because the typical lateral response is no longer effective. In addition, this potential problem involving increased reaction time may be exacerbated by the relaxed driving conditions resulting from a reduction in the response requirements.
entailed in highway travel when using cruise control. Finally, while
cruise control provides a reduction in response requirements when in
uninterrupted use, both the device's disengagement and re-engagement
require a response. The response requirements involved in disengaging
and re-engaging the cruise control may prove tedious to the motorist
when frequent reductions in vehicle speed are required to avoid rear
end collisions. A dangerous condition may be generated if the motor­
ist delays disengaging the cruise control until absolutely necessary
in the hope of avoiding the inconvenience entailed in temporarily
reducing speed. Questions concerning safety and the use of cruise
control need to be thoroughly addressed by way of experimental research.

The trip recorder is a device installed in a motor vehicle to
store for later retrieval a permanent record of selected highway per­
formance variables generated by a traveling motorist. Some trip
recorders provide an option whereby the traveling motorist can observe
via a visual display a selected highway parameter that is continuously
updated. Trip recorders are most often used in fleets of heavy duty
motor vehicles to promote fuel-efficient driving. (Trip recorders are
also used to provide information concerning a motorist's behavior at
the time of an accident.) Trucking companies that use trip recorders
coupled with management imposed consequences do report savings in
fuel and maintenance costs as well as improved safety records (Weiss
et al., 1981, pp. 13-14, 18, 20, 21). In assessing the trip recorder's
potential, however, some important factors must be considered.
Because the basic function of the trip recorder is simply to store information on highway performance, as opposed to directly altering highway performance, the trip recorder itself is not really a speed control device at all.

Now as already mentioned, along with storing information, some trip recorders provide an optional visual stimulus for the traveling motorist that displays continuously updated information on a specified highway variable. There is experimental evidence, however, that supplying the motorist with ongoing data on driving performance by way of a visual display does not promote fuel-efficient behavior. A study by Lubeck and Rushing (1981) involved installing a trip recorder that, besides storing information, visually displayed to the motorist the current miles per gallon reading, which was updated every second. The purpose of this experiment was to determine if the continuous miles per gallon display would have any effect on the average daily fuel consumption of a state vehicle used by the faculty of a university. To separate the effects of displayed miles per gallon from the display per se, the installed computing device displayed time for a 2-week period before the miles per gallon display was implemented. The results indicated that baseline average daily fuel consumption remained unchanged as a result of the miles per gallon display that was initiated in the experimental condition. (It is probably reasonable to assume that highway speeding was unaffected by the presence of the display.) The authors did point out that the individuals operating the experimental vehicle did not pay for the fuel required to
power it; if the vehicle operators had been responsible for fuel expenses, the installed miles per gallon reading might have exerted some control over behavior determining fuel consumption. Nevertheless, even if an installed visual stimulus like that used in the Lubeck and Rushing experiment would exert some control over vehicle operators paying for their own fuel (which seems unlikely because despite the standard use of speedometers and the well-known inverse relation between fuel savings and increases in speed beyond the maximum limit, highway speeding continues), such a finding would not warrant the sole use of this device for general use since many speeding motorists do not have to pay for their own fuel.

The results of the Lubeck and Rushing study illustrate the ineffectiveness of the trip recorder per se (including the visual stimulus display) in controlling a motorist's driving behavior. Thus in order to control driving behavior effectively, some form of consequence must be used in conjunction with the trip recorder. And of course, some form of management must impose these consequences. Examples of potential managers are company officials, university administrators, and parents of newly licensed drivers. These managers must impose consequences contingent upon a driver's highway performance in accord with the record retrieved from the trip recorder. The consequences may take various forms: They may be financial in nature, or they may entail a change in the availability of certain privileges. The manager imposing these consequences must rigorously adhere to the agreed upon contingency if effective speed control is to be generated and maintained.
Management's task of devising, implementing, and maintaining consequences in accord with records produced by the trip recorder is not always an easy one. The difficulty of this task becomes evident when considering the company with a large fleet of vehicles. First, effective consequences must be devised that are acceptable to both management and the vehicle operators, the latter often being represented by a union. Frequently management devises consequences that would exert sufficient control over driver behavior only to have these consequences rejected by the union. And, even if a potentially effective contingency program is devised that is acceptable to management and union, such a program must be strictly and uniformly enforced. When management imposed consequences are financial in nature, then records must be obtained for each driver, computed, and sent to the payroll office so that appropriate personnel can make the proper adjustments. Such a commitment on the part of managers of large fleets is time consuming and costly. Moreover, any weakness in this commitment is likely to be exploited to the fullest extent by the vehicle operators, rendering the speed control program ineffective.

One final point concerning the use of management imposed consequences in conjunction with the trip recorder is that these consequences are by necessity temporally remote from the driving behavior they are designed to control. These remote consequences may not prove consistently influential in the face of the changing motivational variables that exert ongoing control over a traveling motorist's behavior.
A Behavior Analysis of Highway Speeding

In proposing solutions to the problem of unlawful highway speeding, it seems appropriate to analyze the main behavioral variables that contribute to its production since the effectiveness of a solution rests on the strength of this analysis. This discussion does not include variables such as road and weather conditions—not because these factors do not influence driving behavior, but rather because their influence is already well understood. (For example, people tend to drive more slowly on icy roads.) Nor does it go into detail about the physical stimulation elicited by increasing vehicle speed and subsequent effects on driving behavior; the reason for this lack of detail should become increasingly clear in the analysis that follows. For now, suffice it to say that this factor does not appear to be a major variable with regard to highway speeding.

Behavior is properly analyzed according to its controlling variables. Extending this position to behavior producing unlawful vehicle speed, it seems probable that two operant classes are of major concern. One class comprises behavior producing "necessary" highway speeding, and the other class comprises behavior producing "unnecessary" highway speeding.

There are those infrequent but compelling occasions when highway motorists must exceed the federal maximum speed limit to preserve their safety. Necessary speeding occurs as a consequence of the motorist's response (accelerator pedal depression) to these emergency situations and is reinforcing because of its past differential
correlation with escape from these situations. Moreover, the value (Michael, 1982) of increasing speed as reinforcement increases as a function of the physical proximity and/or approaching speed of the aversive stimulus conditions that characterize an emergency situation. For example, when one motorist passes another on an incline—only to discover a quickly approaching, oncoming vehicle—the threatened motorist will engage in behavior (depression of the accelerator pedal) that is reinforced by increasing vehicle speed. This increase in vehicle speed is reinforcing because it has been differentially associated with successful escape from similar aversive situations in the past. (This contingency seems best described as a random interval, signalled avoidance schedule coupled with escape from the avoidance situation. The avoidance response is also the escape response.)

As reinforcement, the value of increased vehicle speed and thus the current strength of behavior evoked by an emergency situation are determined by the proximity and the speed of the approaching vehicle. Most often, a successful (or unsuccessful) outcome with regard to escape from an emergency situation is determined within a short period of time. Thus, besides the compelling nature of reinforcement (successful escape from a highly aversive situation) and the increased value of vehicle speed, the close temporal relationship between the required behavior and the reinforcing stimulus change produced by escape brings to great strength the response (accelerator pedal depression) producing necessary highway speeding.
A different analysis holds for unnecessary highway speeding and the operant class that generates and sustains it. Increases in vehicle speed reinforce behavior (accelerator pedal depression) producing them because in the past each increment has reduced the time to reinforcement (arrival at one's destination) relative to the time to reinforcement that would have resulted from the maintenance of the vehicle speed that preceded each increase. The relative reduction in the time to arrival is also a function of the rate of acceleration in vehicle speed. The immediate stimulus changes correlated with a given rate of acceleration can function as a supplementary source of conditioned reinforcement and can be discriminative for behavior producing a faster rate of acceleration. There are, however, constraints on behavior that results in continually increasing vehicle speed. As vehicle speed progressively increases, the probability of an automobile accident also increases, as does the likelihood of being ticketed by a highway patrol officer. It seems certain that most motorists have been exposed to a history of punishment that reflects these increased probabilities and that all motorists have acquired contingency-shaped and rule-governed repertoires involving successful movement through densely occupied space. Under most conditions, this history ensures that a motorist will curtail further increases in unlawful vehicle speed at speeds well below the maximum velocity that the vehicle is capable of being driven. Consequently, what generally does occur is that a motorist accelerates to an unlawful vehicle speed and then maintains that established speed for extended periods of time. Not only is unlawful vehicle speed
maintained at a given velocity over time because it cannot increase indefinitely, it is also maintained because decreases in the established speed are punishing in that in the past these decrements have increased the time to reinforcement (arrival). The immediate stimulus changes correlated with a given rate of deceleration can function as a supplementary source of conditioned punishment and can be discriminative for behavior producing an increase in vehicle speed.

This analysis of unnecessary speeding suggests that although the onset of and increases in unlawful vehicle speed are indeed a problem, the maintenance of unlawful vehicle speed presents a greater problem since motorists allocate far more traveling time to the latter than to the former. Even when traveling a great distance, the overall decrease in the time to arrival produced by the onset of unlawful highway speed and its subsequent increase is slight. But by maintaining the increased velocity, in comparison to maintaining a lesser vehicle speed, the time to arrival is greatly reduced. An additional implication of this analysis is that any method that curtails the maintenance of unlawful speed will correspondingly decrease the value of the reinforcement produced by initiating unlawful speed.

Just as the intensity of an aversive stimulus (e.g., the proximity and/or the speed of an oncoming vehicle) determines the current strength of behavior producing necessary speeding, so there are motivational variables determining the current strength of behavior producing unnecessary speeding. The evocative properties of these motivational variables are determined in part by the motorist's history.
with the reinforcements and punishments relevant to these variables. Combined with prevailing conditions of deprivation, aversive stimulation, and/or other establishing operations, the present relationship of these past reinforcements and punishments to arrival at a given destination determines the value of vehicle speed and thus the current strength of behavior producing unnecessary speeding. For example, imagine the motorist who each day travels the freeway when returning home from work. If the stimulus conditions controlling this motorist's driving behavior on the freeway are fairly consistent from one day to the next, then traveling speed will likewise be consistent from one day to the next. Now, suppose that one day a phone call from home informs the motorist that an old friend, not seen for some time, has unexpectedly dropped in but can stay only a short while. Assuming that this long absent friend has provided the motorist with a rich history of reinforcement (and a paucity of punishment) and further assuming that stimulus conditions are otherwise typical, the phone call functions as a motivational variable with regard to current driving behavior because it correlates a powerful source of reinforcement (the friend) with arriving home from work. Since increasing speed is discriminative for a relative decrease in the time to arrival and because the reinforcement currently associated with arrival increases the value of vehicle speed, it is quite likely that in response to the aforementioned phone call the motorist in the present example will travel home at greater vehicle speeds than are customary. Some antecedent variables, however, decrease the value of vehicle speed. To illustrate, let us suppose
that the same motorist is informed that an old but unpleasant acquaintance, rather than a good friend, has unexpectedly arrived for a brief visit. Since decreasing speed is discriminative for a relative increase in the time to arrival and because the punishment currently associated with arrival decreases the value of vehicle speed, it is probable that under these stimulus conditions the motorist will travel home at lower vehicle speeds than are customary. As these examples suggest, a wide range of motivational variables determines the value of vehicle speed and thus the subsequent strength of behavior resulting in unnecessary highway speeding.

From the foregoing analysis it should be clear that the variables controlling behavior that generates unnecessary highway speeding are not nearly as compelling as those controlling behavior that generates necessary highway speeding. Moreover, much of the prolonged behavior (accelerator pedal depression) sustaining unnecessary speeding does not share a close temporal proximity to its final consequence (arrival). These factors generally combine to ensure that behavior producing unnecessary highway speeding is quite weak relative to behavior that produces necessary highway speeding. (The temptation to overestimate the strength of behavior that results in unnecessary highway speeding arises from the frequent occurrences of this behavior. Rather than being indicative of strong behavior, the frequency with which unnecessary speeding occurs may be better analyzed in terms of its ease of execution, infrequent production of punishment, and the nearly continual opportunity it provides to alter the time to arrival.3)
The conclusion of this analysis is that an ideal system for controlling unlawful highway speeding is one in which the capacity for necessary speeding (involving relatively strong but infrequent and briefly executed behavior) is preserved while at the same time unnecessary speeding (involving relatively weak but frequent and prolonged behavior) is drastically reduced despite the wide range of motivational variables that determine its strength.

A Proposed Solution to the Highway Speeding Problem

Experimental research suggests that sufficiently increasing the force required to operate a manipulandum will under similar stimulus conditions decrease the future probability of the reinforced behavior producing that imposed force requirement (Chung, 1965; Miller, 1970). That is, the stimulus change generated by a substantial increase in force requirement functioned as punishment. Miller (1970) addressed the problem of temporal simultaneity of response and consequence in defining an imposed force requirement as punishment. Using a chain schedule, he employed an increase in the force required to operate the manipulandum in the second link of the chain; the result was decreased responding in the first link of the chain. Thus, even with temporal separation of response and consequence, an imposed force requirement functioned as punishment.

Experimental research also shows that behavior that terminates an imposed force requirement produced by reinforced behavior will under similar stimulus conditions increase in its future probability of occurrence (Miller, 1968). That is, the stimulus change produced
by the termination of an imposed force requirement functioned as reinforcement.

A solution to unlawful highway speeding may well consist of the immediate and systematic application of the principles of punishment and reinforcement to the behavior of the speeding motorist. Specifically, punishment and reinforcement may be used to alter the behavior of a motorist by way of a differential force schedule applied to the accelerator pedal of a motor vehicle as a function of respective increases and decreases in unlawful highway vehicle speed. The differential force schedule is also applied to the accelerator pedal as a function of increases and decreases in accelerator pedal depression once highway speeding begins.

An in-vehicle speed control device has been developed that imposes a differential force schedule to the accelerator pedal of a motor vehicle to control behavior producing unlawful highway speed. This study entailed field testing this device, called the Deaccelerator, in a state-owned car used by faculty members at Western Michigan University (WMU) for work-related travel.
CHAPTER II

METHOD

Subjects

The subject in this experiment was a research car provided by the State of Michigan that Western Michigan University faculty used for work-related travel. Data will be presented on this vehicle's performance across the five experimental conditions comprising this field study. Faculty members traveling in this research vehicle were also subjects in that some data produced by individual drivers will be presented. A total of 42 faculty members drove the research vehicle across the five experimental conditions comprising this field study.

Apparatus

Speed Control Equipment: Operational Characteristics of the Deaccelerator

The Deaccelerator encourages the maintenance of a preset speed by limiting the motorist's degree of accelerator pedal depression to the position required to maintain the preset speed. The position control system utilized by the Deaccelerator (which is best described as a foot-operated cruise control) operates across a narrow speed range. Figure 1 shows how the Deaccelerator's position control system operates across a speed range of 54 mph to 56 mph when the preset speed is 55 mph. The typical accelerator pedal travels 2 inches from a fully
Figure 1. Accelerator Pedal Position Control Operation From 54 to 56 MPH With a Preset Speed of 55 MPH

extended position to a fully depressed position. When the Deaccelerator has a preset speed of 55 mph, the motorist can fully depress the accelerator pedal at speeds of 54 mph or less. And, extending in a linear fashion with increasing speed above 54 mph, the accelerator pedal moves the motorist's foot into a fully extended position when vehicle speed reaches 56 mph. As vehicle speed is reduced below 55 mph (such as when moving from a horizontal portion of road surface to an uphill portion of road surface), the position control system allows the motorist to further depress the accelerator pedal to the new position required to increase vehicle speed back to 55 mph. As vehicle speed exceeds 55 mph (such as when moving from a horizontal portion of road surface to a downhill portion of road surface), the position control system moves the accelerator pedal (and thus the motorist's foot) towards an extended position so as to reduce vehicle speed to 55 mph.
The motorist can depress the accelerator pedal beyond the position maintaining the preset speed by overriding the 1/4 pound force (not including the 1/4 pound force generated by the normal return spring of the accelerator pedal) utilized to maintain accelerator pedal position control. Once the force maintaining the position of the accelerator pedal is overridden, increasing accelerator pedal resistance is differentially imposed as a function of increasing vehicle speed above 56 mph.

Once imposed, accelerator pedal resistance differentially decreases as a function of decreasing vehicle speed, with accelerator pedal position control resuming once speed drops below 56 mph but remains above 54 mph. This negatively accelerated distribution of accelerator pedal resistance values occurring as a function of equal changes in vehicle speed in excess of 56 mph ranges from just slightly over 1/4 pounds to 36 pounds. (See Figure 2.)

![Figure 2. Negatively Accelerated Distribution of Imposed Accelerator Pedal Resistance as a Function of Unlawful Highway Vehicle Speed With a Position Control System Operating From 54 to 56 MPH (and With the Horizontal Line at 1/4 Pounds From 54 to 56 MPH Corresponding to the Position Control System Shown in Figure 1)](image-url)
Increases and decreases in accelerator pedal resistance are also a function of respective increases and decreases in accelerator pedal depression once vehicle speed exceeds 56 mph. This depression-based resistance is related to equal changes in accelerator pedal depression, with a linear distribution ranging from 0 to 12 pounds. (See Figure 3.)

![Graph showing increasing and decreasing imposed accelerator pedal resistance as a function of increases and decreases in accelerator pedal depression once the preset speed is exceeded.](image)

**Figure 3.** Increasing and Decreasing Imposed Accelerator Pedal Resistance as a Function of Increases and Decreases in Accelerator Pedal Depression Once the Preset Speed is Exceeded

Once vehicle speed exceeds 56 mph, the total amount of accelerator pedal resistance (not including the return spring) occurring as a function of both speed-based accelerator pedal resistance and accelerator-pedal-depression-based accelerator pedal resistance does not exceed 36 pounds. The accelerator pedal functions normally at speeds of 54 mph or less by providing a 1 pound back force by way of the return spring.
Speed Recording Equipment

Two identical, handmade, digital speed recorders that received input from the same speed sensor provided data for the duration of this study. The dimensions of each recorder were 43.18 cm by 12.7 cm by 4.13 cm. Each recorder stored the amount of time spent for each of the following eight speed categories: 53 mph, 54 mph, 55 mph, 56 mph, 57 mph, 58 mph, 59 mph, and 60 mph and above (60+). The digital display of each speed recorder was comprised of eight vertical rows of light emitting diodes (LEDs), with each row comprised of 18 LEDs in clusters of three and a single LED at the top of each row. Each vertical row of LEDs corresponded to one of the eight speed categories. Timing independently, each recorder sampled vehicle speed at 0.5 second intervals, and if the sampled speed fell into one of the eight speed categories, an LED was lit in the row corresponding to that speed category. The recorders generated data (i.e., illuminated the LEDs) in an octal number base, and a computer program transformed the data into the time accumulated in each of the eight speed categories. Each speed category could store up to 75.1 hours before that particular category began another cycle of counting. A reset switch on each recorder set the counter for all eight speed categories back to zero. A second switch on each recorder turned the activated LEDs either on or off. This feature allowed the experimenter to turn on (illuminate) the activated LEDs only when extracting the stored data and thus helped preserve the battery of the motor vehicle in which the recorders were installed.
Installation of Speed Control and Speed Recording Equipment

A Deaccelerator was installed in a state-provided 1981 American Motors Corporation Concord four-door sedan used by faculty members at Western Michigan University for work-related travel. This research vehicle will be referred to as "Car 3028." The device was located in the engine compartment so as to act on the accelerator pedal by way of the linkage system. The device was not visible from the driving compartment. When operative, the Deaccelerator had an unalterable preset speed of 55 mph. Due to a slight variation in speed control, the vehicle traveled 55 mph on level and uphill road gradients and 56 mph on downhill road gradients when the driver traveled at the preset speed. Because of this variation in speed control, 56 mph as opposed to 55 mph was the maximum "legal" speed in the present study.

Each of the two identical speed recorders was hidden in a molded recess found on each side of the trunk of Car 3028 in such a manner as to be completely invisible even when the trunk was open. Approximately every 2 weeks the speed recorders were removed from Car 3028 and bench tested to ensure that all LEDs were operating and that the timers and frequency counters were calibrated as accurately as possible. Following successful bench testing, the recorders were reinstalled in Car 3028 and road tested. (It should also be noted that frequent calibration checks were conducted to ensure that Car 3028's speedometer continually reflected an accurate reading of vehicle speed.) The faculty drivers were not informed of the recording procedures for the duration of the study.
Procedure

Faculty members could secure a state vehicle for work-related travel by telephoning or stopping at the university's motor pool office and informing the appropriate personnel of the intended day of travel, the destination, and the date of return. Faculty were encouraged to notify the motor pool at least a few days in advance of the actual travel date to ensure that a vehicle would be available. As soon as a faculty member put in a request for a vehicle, the faculty member was sent papers to fill out confirming the upcoming plans. Upon filling out these papers, the faculty member sent them to the motor pool office. On the day of travel, the faculty member went to the motor pool to pick up the car keys from appropriate personnel.

Appropriate personnel at the university motor pool were informed that an experiment was to be conducted with a speed control device installed in Car 3028. They were instructed to keep all information concerning the present experiment confidential. Finally, motor pool personnel were told to assign Car 3028 only to those faculty members whose planned trip involved highway as opposed to urban travel. All informed personnel agreed to cooperate fully. Further instructions given to these personnel will be described as they occurred in various conditions of the experiment.

Baseline 1 Condition: 24 Drivers

The Deaccelerator was inoperative for the duration of this condition. Highway speeds traveled by Car 3028 were recorded for the duration of this condition.
Deaccelerator Plus Sign 1 Condition: 6 Drivers

The Deaccelerator was operative for the duration of this condition. Highway speeds traveled by Car 3028 were recorded for the duration of this condition.

When requesting a vehicle for work-related travel, those faculty members assigned Car 3028 were sent the following notice, along with the papers to be signed confirming the upcoming travel date:

IMPORTANT NOTICE - PLEASE READ
TO ALL USERS OF WMU STATE-OWNED CARS: A device that aids drivers in maintaining the legal highway speed has been installed in some WMU state-owned cars. Since there is a high probability that you will be assigned a car equipped with this device and since this device does discourage highway speeding, it is a good idea for faculty and staff using state cars to leave for their destinations early enough to ensure arrival at the scheduled time assuming a highway traveling speed of 55 mph. Your cooperation is appreciated. Communications and Transportation.

The Deaccelerator was actually installed in only one car. The notice stated that the device was installed in "some" cars in order to convince faculty that the probability of being assigned a Deaccelerator-equipped car was high. This step was taken so that faculty would not arrive late for class on account of the Deaccelerator.

When faculty members assigned Car 3028 picked up the keys, they were asked to read the following sign, posted in the motor pool:

VEHICLE USERS: PLEASE NOTE
The DEACCELERATOR is an energy-saving safety device that is being rotated among WMU vehicles. The DEACCELERATOR operates by producing increases in accelerator pedal resistance with increases in speed above 56 mph and decreases in accelerator pedal resistance as vehicle speed decreases toward 56 mph. At 56 mph the accelerator pedal functions like a foot-operated cruise control by gently positioning your foot so as to maintain 56 mph. You will easily be able to overcome the increases in accelerator pedal resistance that accompany increases in speed above 56 mph.
for emergency or necessary speeding (speeding to avoid an accident). If the DEACCELERATOR is operating in the vehicle you are driving and malfunctions (causes increased accelerator pedal resistance at any vehicle speed), please call collect (616) 345-2853 day or night and identify yourself as a DEACCELERATOR driver. Your cooperation is appreciated.

VEHICLE USERS: PLEASE NOTE
A copy of this notice is affixed to the sun visor on the driver's side of the vehicle.

The Deaccelerator was not actually rotated among WMU vehicles as stated in the notice. This statement was made in case the same driver was assigned Car 3028 during the Deaccelerator Plus Sign 1 condition and the Sign Only condition. A driver who recognized the vehicle might surmise that the Deaccelerator was inoperative during the Sign Only condition due to some malfunction caused by that driver. Although unlikely, this situation might prompt the driver to make an unnecessary telephone call to the experimenter. This potential problem would be eliminated if the same driver simply assumed that the device had been rotated to another vehicle.

Sign Only Condition: 6 Drivers

The Deaccelerator was inoperative for the duration of this condition. Highway speeds traveled by Car 3028 were recorded for the duration of this condition. The sign procedure described in the Deaccelerator Plus Sign 1 condition was in effect for the duration of this condition.

Deaccelerator Plus Sign 2 Condition: 3 Drivers

This condition was identical to the Deaccelerator Plus Sign 1 condition.
Baseline 2 Condition: 3 Drivers

This condition was identical to the Baseline 1 condition.
CHAPTER III

RESULTS

Reliability

Table 1

<table>
<thead>
<tr>
<th>Miles Per Hour</th>
<th>53</th>
<th>54</th>
<th>55</th>
<th>56</th>
<th>57</th>
<th>58</th>
<th>59</th>
<th>60+</th>
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<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
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</tr>
<tr>
<td>Deaccelerator</td>
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<td>0.999</td>
<td>0.997</td>
<td>0.998</td>
<td>0.949</td>
<td>0.991</td>
<td>1.00</td>
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</tr>
<tr>
<td>Plus Sign 1</td>
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<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
</tr>
<tr>
<td>Sign Only</td>
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<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
</tr>
<tr>
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<td>0.933</td>
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<td>0.995</td>
<td>0.933</td>
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</tr>
<tr>
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<td>0.999</td>
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<td>0.999</td>
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</table>

Table 1 shows the reliability coefficients (Pearson product-moment) between the two speed recorders for all eight speed categories between and across all experimental conditions. Not included are data gathered on those days when one of the recorders was inoperative. Out of 24 drivers participating in the Baseline 1 condition, both data recorders were operative across 22 drivers. Out of six
drivers participating in the Deaccelerator Plus Sign 1 condition, both recorders were operative across four drivers. Both recorders were always operative across all other experimental conditions. Also not included in the reliability data shown in Table 1 are data for a given speed category on days when only one recorder provided reliable data for that speed category. Across all experimental conditions, data were not provided for a given speed category on only four occasions; three of those occasions occurred during the Baseline 1 condition, and one occasion occurred during the Sign Only condition.

The reliability data indicate that there was a high degree of correspondence between the two speed recorders between and across all experimental conditions.

Speed Control

All data related to the effectiveness of the Deaccelerator are shown by histograms comprised of the percentage of the total recorded highway traveling time accumulated in each of the eight speed categories. For all histograms, the percentage of total travel time accumulated in each speed category was calculated using the mean of the two travel times accumulated in both digital speed recorders for each speed category. (On those days when only one speed recorder was operative, data provided by that recorder were used. On those days when both recorders were operative but only one recorder provided reliable data for a given speed category, only data from the reliable recorder were used for that speed category.) Also shown is the
percentage of time highway travel in Car 3028 was lawful (53 mph-56 mph) and unlawful (57 mph-60+ mph). Within and across histograms, group data shown for the Baseline 1 condition are ordered according to actual dates of travel. Within and across histograms, group data shown for all of the other experimental conditions are randomly ordered. The actual total travel time is given for all histograms except those related to individual subjects. In meeting university criteria regarding confidentiality, the experimenter agreed to omit data that could be used to identify individual drivers participating in this experimental research. Thus, for individual subjects the total travel time is rounded to the nearest hour of travel time. For example, if a subject traveled a total of 2.7 hours, the time shown would be 3 hours.

Baseline 1 Condition

Figures 4 through 7 show the percentage of the total time that Car 3028 was driven at each of the eight speed categories during the Baseline 1 condition. Also shown are the total recorded highway hours accumulated during this condition as well as the percentage of the total time that Car 3028 was driven lawfully (53 mph-56 mph) and unlawfully (57 mph-60+ mph).

Although 24 drivers participated during this condition, increased resolution results by showing four histograms (Figures 4-7) comprised of data from 6 drivers each, as opposed to one histogram comprised of data from 24 drivers.
Figure 4. Baseline 1 Condition: Percentage of Total Travel Time (10.4 Hours Accumulated by Six Drivers) Car 3028 Spent at Each Speed Category

Figures 4 through 7 show that during the Baseline 1 condition Car 3028 was driven at unlawful speeds for a substantial percentage of the total recorded highway travel time. Moreover, Figures 4 through 7 show that a large majority of highway speeding occurred in the 60+ mph category. Even Figure 7, which shows a distribution containing the least relative amount of time spent in the 60+ mph category and the least relative amount of time spent in the unlawful highway speed category.
Figure 5. Baseline 1 Condition: Percentage of Total Travel Time (11.3 Hours Accumulated by Six Drivers) Car 3028 Spent at Each Speed Category (57 mph-60+ mph), indicates that the relative amount of time allocated to the 60+ mph category exceeded 50%, and in the unlawful highway speed category exceeded 75%. Another interesting aspect of the data is that only the histograms shown in Figures 4 and 5 indicate a relative increase in time spent at unlawful speeds across the sequential order of drivers traveling in Car 3028. Figures 6 and 7 show successive declines in the relative amount of time spent speeding. A final aspect of the
Figure 6. Baseline 1 Condition: Percentage of Total Travel Time (23.2 Hours Accumulated by Six Drivers) Car 3028 Spent at Each Speed Category

data is that for Figures 4 through 7 the 53 mph category contains more time than the 54 mph category.

Figure 8 shows the distribution of data for the driver in the Baseline 1 condition with the greatest percentage of time spent speeding, along with the total recorded highway hours. This driver not only spent a large percentage of time speeding unlawfully but spent a vast majority of speeding time in the 60+ mph category.
Figure 7. Baseline 1 Condition: Percentage of Total Travel Time (15.0 Hours Accumulated by Six Drivers) Car 3028 Spent at Each Speed Category

Figure 9 shows the distribution of data for the driver in the Baseline 1 condition with the smallest percentage of time spent speeding, along with total recorded highway hours. This driver not only spent a small percentage of time traveling at unlawful highway speeds, but accumulated less time in the 60+ mph category than any other speed category. This driver's data were atypical; only one other driver in
the Baseline 1 condition produced similar data with only slightly more relative time allocated to unlawful highway speeds. It should be noted that the driver with the third smallest percentage of time allocated to highway speeding spent 57.1% of recorded travel time at unlawful speeds and 30.2% in the 60+ mph category. Furthermore, appropriate personnel at the motor pool were instructed not to assign
Figure 9. Baseline 1 Condition: Percentage of Total Travel Time (2 Hours) Spent by Individual Least Speeder at Each Speed Category

Car 3028 to the two drivers with the smallest percentage of time spent speeding in the Baseline 1 condition for the duration of the experiment.

A final point worth mentioning is that 20 of the 24 drivers participating in the Baseline 1 condition spent at least 66.6% of their recorded highway traveling time at unlawful vehicle speeds. In addition, 19 of those 24 drivers spent at least 42.7% of their recorded highway traveling time in the 60+ mph category.
Deaccelerator Plus Sign 1 Condition

Figure 10. Deaccelerator Plus Sign 1 Condition: Percentage of Total Travel Time (7.1 Hours Accumulated by Three Drivers) Car 3028 Spent at Each Speed Category

Figures 10 and 11 show the percentage of the total time that Car 3028 was driven at each of the eight speed categories during the Deaccelerator Plus Sign 1 condition. Also shown are the total highway hours accumulated during this condition as well as the percentage of
Figure 11. Deaccelerator Plus Sign 1 Condition: Percentage of Total Travel Time (5.5 Hours Accumulated by Three Drivers) Car 3028 Spent at Each Speed Category

the total time that Car 3028 was driven lawfully (53 mph-56 mph) and unlawfully (57 mph-60+ mph).

Although six drivers participated in the Deaccelerator Plus Sign 1 condition, increased resolution results by showing two histograms comprised of three drivers each, as opposed to one histogram comprised of data from six drivers. The data shown in Figures 10 and 11 indicate
that highway speeding was practically eliminated in the Deaccelerator Plus Sign 1 condition. Moreover, Car 3028 was driven at 55 mph and 56 mph for substantial periods of time, easily eclipsing the amount of time Car 3028 was driven at the other recorded speed categories. In fact, Car 3028 accumulated a greater percentage of time at 56 mph than the percentage of time accumulated for the rest of the speed categories combined, with the exception of the 55 mph speed category.

Although the percentage of time that Car 3028 was driven at unlawful highway speeds was very small, drivers spent the largest percentage of unlawful driving time at 60+ mph. This finding is to be expected since highway passing often involves speeds in excess of 60 mph. Furthermore, as will be seen, unlawful highway speeding across all experimental conditions was by far greatest in the 60+ mph speed category.

Figure 12 shows data for the driver in the Deaccelerator Plus Sign 1 condition with the greatest percentage of time spent speeding, along with the total recorded highway hours. The time allocated to the 60+ mph speed category coupled with the negligible time allocated to the other unlawful speed categories suggests that this driver traveled at speeds in excess of 60 mph. Nevertheless, it should be noted that even this driver spent a substantial percentage of recorded highway time at lawful (especially 55 mph and 56 mph) as opposed to unlawful speeds. Moreover, the driver who produced the second highest percentage of time spent speeding in the Deaccelerator Plus Sign 1 condition allocated only 5.4% of the total recorded time to unlawful highway speeds.
Figure 12. Deaccelerator Plus Sign 1 Condition: Percentage of Total Travel Time (2 Hours) Spent by Individual Greatest Speeder at Each Speed Category

Figure 13 shows data for the driver in the Deaccelerator Plus Sign 1 condition with the smallest percentage of time spent speeding, along with the total recorded highway hours. As can be seen, this driver drove lawfully 100% of the time (in round numbers) with relatively substantial time allocated to 55 mph and 56 mph.
Figure 13. Deaccelerator Plus Sign 1 Condition: Percentage of Total Travel Time (2 Hours) Spent by Individual Least Speeder at Each Speed Category

An interesting difference between the Baseline 1 and the Deaccelerator Plus Sign 1 conditions concerns the percentage of time allocated to 53 mph and 54 mph. In the Baseline 1 condition, for the most part, a greater percentage of travel time was allocated to 53 mph than to 54 mph. During the Deaccelerator Plus Sign 1 condition, with the exception of one driver, a greater percentage of travel time was allocated to 54 mph than to 53 mph.
Sign Only Condition

Figures 14 and 15 show the percentage of total time that Car 3028 was driven at each of the eight speed categories during the Sign Only condition. Also shown is the total highway time accumulated by Car 3028 for each speed category, as well as the percentage of lawful and unlawful speeding. Again, to increase resolution two histograms are

Figure 14. Sign Only Condition: Percentage of Total Travel Time (8.19 Hours Accumulated by Three Drivers) Car 3028 Spent at Each Speed Category
Figure 15. Sign Only Condition: Percentage of Total Travel Time (3.8 Hours Accumulated by Three Drivers) Car 3028 Spent at Each Speed Category

shown, each illustrating data for three of the six drivers participating in the Sign Only condition. The data in Figures 14 and 15 show that highway speeding was prevalent during the Sign Only condition, with the highest percentage of recorded highway travel time allocated to 60+ mph. In fact, both histograms show that a considerably greater percentage of time was spent at 60+ mph than at all of the other speed categories combined.
It should be noted that highway speeding was much more substantial during the Sign Only condition than during the Baseline 1 condition. It should also be noted that as in the Baseline 1 condition, Car 3028 was driven a greater percentage of time at 53 mph than at 54 mph during the Sign Only condition.

Figure 16 shows the distribution of data for the driver in the Sign Only condition with the greatest percentage of time spent speeding.

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**Figure 16.** Sign Only Condition: Percentage of Total Travel Time (3 Hours) Spent By Individual Greatest Speeder at Each Speed Category

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along with the total recorded highway hours. This driver spent a very substantial percentage of recorded travel time in the 60+ mph speed category, while spending relatively small amounts of time in the remaining categories. Only 7.4% of this driver's total highway travel time was spent at recorded speeds below 60+ mph.

Figure 17 shows the distribution of data for the driver in the Sign Only condition with the smallest percentage of time spent speeding

![Graph showing distribution of time spent at recorded highway speeds](image)

Figure 17. Sign Only Condition: Percentage of Total Travel Time (3 Hours) Spent By Individual Least Speeder at Each Speed Category
along with the total recorded highway hours. The percentage of time that this driver spent traveling at 60+ mph was almost half of the total recorded highway traveling time. Thus, although this driver spent the least relative amount of time speeding, a substantial percentage of recorded highway travel time was in the 60+ mph category. An interesting point concerns data for the driver in the Sign Only condition with the second smallest percentage of time spent speeding. This driver allocated 93.4% of the recorded travel time to unlawful highway speeds; moreover, 60.2% of the relative highway travel time was allocated to the 60+ mph speed category.

Deaccelerator Plus Sign 2 Condition

Figure 18 shows the percentage of the total time that Car 3028 was driven by three faculty members at each of the eight speed categories during the Deaccelerator Plus Sign 2 condition. Also shown are the total highway hours accumulated during this condition, as well as the percentage of the total time that Car 3028 was driven lawfully and unlawfully. The data show that (in round numbers) lawful highway driving accounted for 100% of the recorded highway travel occurring during the Deaccelerator Plus Sign 2 condition. As in the Deaccelerator Plus Sign 1 condition, speeds of 55 mph and 56 mph accounted for the vast majority of recorded travel time.

Figure 19 shows the data for the driver in the Deaccelerator Plus Sign 2 condition with the greatest percentage of time spent speeding, along with the total recorded highway hours. Because the relative amount of time spent speeding was extremely small even for the driver
who engaged in the greatest amount of speeding, no data are presented for the driver with the least amount of time spent speeding. As the data indicate, this driver spent a large percentage of recorded travel time at speeds of 55 mph and 56 mph. As was the case for one driver in the Deaccelerator Plus Sign 1 condition, this driver spent slightly more time traveling at 53 mph than 54 mph.
Figure 19. Deaccelerator Plus Sign 2 Condition: Percentage of Total Travel Time (1 Hour) Spent by Individual Greatest Speeder at Each Speed Category

Baseline 2 Condition

Figure 20 shows the total time that three faculty members drove Car 3028 at each of the eight speed categories during the Baseline 2 condition, the total highway hours accumulated during this condition, and the percentage of the total time that Car 3028 was driven lawfully and unlawfully. The distribution of data in the Baseline 2 Condition
is very similar to the distribution of data in the Sign Only condition. Both conditions produced an extremely large percentage of travel time in the 60+ mph category. Moreover, the percentage of lawful and unlawful speeds is almost identical between these two conditions.

Figure 20. Baseline 2 Condition: Percentage of Total Travel Time (10.9 Hours Accumulated by Three Drivers) Car 3028 Spent at Each Speed Category

Figure 21 shows the data for the driver in the Baseline 2 condition with the smallest percentage of time spent speeding, along with
Figure 21. Baseline 2 Condition: Percentage of Total Travel Time (7 Hours) Spent By Individual Least Speeder at Each Speed Category

the total recorded highway hours. Because the relative amount of time spent speeding was extremely high even for the driver who engaged in the smallest amount of speeding, no data are presented for the driver with the greatest amount of time spent speeding. As the data indicate, this driver spent a substantial amount of time traveling at speeds of 60+ mph.
CHAPTER IV

DISCUSSION

The data obtained in the present field test indicate that when an operative Deaccelerator was part of the experimental condition highway speeding was practically eliminated, and when an inoperative Deaccelerator was part of the experimental condition highway speeding was substantial.

During the Baseline 1 condition, highway speeding was prevalent, with the greatest relative period of recorded time being allocated to the 60+ mph speed category. During the Deaccelerator Plus Sign 1 condition, highway speeding was practically eliminated, with speeds of 55 mph and 56 mph comprising the vast majority of recorded highway travel time. The Sign Only condition, which was conducted to assess the sign's role in the speed reduction observed in the Deaccelerator Plus Sign 1 condition, produced a greater relative amount of highway speeding than the Baseline 1 condition. The Deaccelerator Plus Sign 2 condition, which was a replication of the Deaccelerator Plus Sign 1 condition, again showed that the Deaccelerator controlled behavior producing unlawful vehicle speed, with the largest amounts of highway travel time being allocated to 55 mph and 56 mph. The Baseline 2 condition replicated conditions in the Baseline 1 condition and produced data very similar to those produced by the Sign Only condition.

Although the Deaccelerator's control of highway speeding is apparent from the data obtained in this study, there are a number of aspects of this field test that merit discussion.
One aspect concerns the effectiveness of the differential force schedule that the Deaccelerator applies to the accelerator pedal to control unlawful highway vehicle speed. As noted in the "Procedure" section of this research paper, the differential force schedule applied by the Deaccelerator is actually comprised of two concurrently operative force contingencies: a primary force contingency and a secondary force contingency. (Throughout this paper, when referring to the Deaccelerator, the term "differential force schedule" refers to the combined application of these two force contingencies.)

The primary force contingency, as shown in Figure 2, is comprised of a negatively accelerated distribution of accelerator pedal resistance as a function of equal changes in unlawful highway speed. The distribution of this primary force contingency ranges from just slightly over 14 pounds to 36 pounds. The secondary force contingency, as shown in Figure 3, is comprised of a linear distribution of accelerator pedal resistance as a function of equal changes in accelerator pedal depression once highway speeding begins. The distribution of this secondary force contingency ranges from 0 to 12 pounds. (The terms "primary" and "secondary" are used because the primary force contingency utilizes considerably greater force values across a greater range of values than does the secondary force contingency.)

Because of the relatively large difference in force capabilities between the primary force contingency, involving speed-based accelerator pedal resistance, and the secondary force contingency, involving accelerator-pedal-depression-based accelerator pedal resistance, the primary force contingency is considered to be largely responsible for
the Deaccelerator's control over behavior producing highway speeding.

(The major role of the primary force contingency in controlling highway speeding is somewhat confirmed by the fact that Car 3028's accelerator pedal required very little depression to cause the car to accelerate to substantially unlawful highway speeds. The experimenter found that even with a moderate amount of accelerator pedal depression, vehicle speed became uncomfortably high. Thus it is improbable that faculty members came into sustained contact with substantial amounts of accelerator-pedal-depression-based accelerator pedal resistance.) The primary force contingency employs systematically increasing accelerator pedal resistance to differentially punish behavior that produces the onset of and increases in unlawful highway speed. Moreover, the primary force contingency employs systematic decreases in accelerator pedal resistance to differentially reinforce behavior that produces decreases in unlawful highway speed.

For the most part, of course, the behavior that effects changes in unlawful highway vehicle speed (or any vehicle speed, for that matter) is changes in the degree of accelerator pedal depression. However, increases and decreases in accelerator pedal depression do not always produce corresponding changes in vehicle speed. The changes in engine output resulting from changes in accelerator pedal depression can be counterbalanced when the motorist encounters changing road gradients and/or changing wind conditions. Nevertheless, behavior producing changes in accelerator pedal depression is at the very least precursory to behavior that will effect changes in vehicle speed. For this reason the Deaccelerator was programmed to generate a secondary
force contingency whereby once unlawful speeding begins, increasing accelerator pedal resistance is systematically imposed to differentially punish behavior producing increasing accelerator pedal depression. Once resistance has been imposed, the device systematically employs decreasing accelerator pedal resistance to differentially reinforce behavior producing decreasing accelerator pedal depression.

In summary, the Deaccelerator's differential force schedule comprises a primary force contingency in which accelerator pedal resistance is distributed as a function of behavior producing unlawful highway vehicle speed and a secondary force contingency in which accelerator pedal resistance is distributed as a function of accelerator pedal depression once unlawful highway speeding begins.

The data gathered during the course of this field study suggest that the Deaccelerator's use of increasing accelerator pedal resistance functioned to punish the behavior producing it. This finding supports the data generated by previous research indicating the punishing properties of increased force (Chung, 1965; Miller, 1970). Data gathered during the present field study also suggest that the Deaccelerator's use of decreasing accelerator pedal resistance functioned to reinforce the behavior producing it. This finding supports the data generated by previous research indicating the reinforcing properties of decreased force (Miller, 1968).

Data showing the onset of and increases in unlawful highway speed as well as decreases in and termination of unlawful highway speed would have been useful in separating the punishing effects of differentially increasing force from the reinforcing effects of differentially
decreasing force. Unfortunately, the manner in which the data were recorded in the course of the present field study precludes this kind of separation. (Future research on the Deaccelerator could make use of a data collection device known as a tachograph, which by cumulatively plotting increases and decreases in vehicle speed across time allows separation between the behavioral effects of increasing and decreasing force to be easily observed. Use of the tachograph was originally planned in the present research to supplement data generated by the two identical digital speed recorders; however, problems arose when use of the tachograph repeatedly broke the speedometer cable. It is hoped that tachograph technology has improved since this research was conducted.)

Referring once again to the operational characteristics of the Deaccelerator described in the "Procedure" section of this paper, it was noted that besides employing a differential force schedule to control unlawful highway vehicle speed, the Deaccelerator utilizes an accelerator pedal position control system that operates across a narrow speed range so as to aid the driver in maintaining the preset speed. (See Figure 1.) With a preset speed of 55 mph, as in the present experiment, the Deaccelerator uses a constant 14 pound force to position the accelerator pedal and thus the motorist's foot so as to maintain a speed of 55 mph. When vehicle speed falls below 55 mph, the Deaccelerator allows the motorist's foot to further depress the accelerator pedal to the new position now required to increase to and maintain a speed of 55 mph. When vehicle speed exceeds 55 mph, the
Deaccelerator moves the accelerator pedal upward to a position that will reduce vehicle speed to 55 mph. Thus, when changing road gradients and/or changing wind conditions are encountered, the Deaccelerator's accelerator pedal position control system in conjunction with the motorist's foot adjusts the position of the accelerator pedal as necessary to allow the vehicle to maintain the preset speed.

The accelerator pedal position control system utilized by the Deaccelerator was designed to provide comfort to the motorist who travels at the preset speed. If, when contacted, the position control system functioned as a punishing stimulus, it might be expected that motorists would travel at highway speeds below the speed at which the position control system actively manipulates the position of the accelerator pedal. (Highway traveling speeds would probably have to be 2 or 3 mph below the preset speed in order for the motorist to avoid repeated contact with the device's activation due to changing speeds as different road gradients and/or changing wind conditions were encountered.)

The data produced by faculty members who drove Car 3028 during the Deaccelerator Plus Sign 1 and Deaccelerator Plus Sign 2 conditions indicate that the Deaccelerator's position control system did not function as a punishing stimulus. These drivers spent a substantial portion of their traveling time at 55 mph and 56 mph, which were the two speeds that Car 3028 alternated between when the motorist made use of the position control system to maintain the preset speed of 55 mph. Moreover, the speed variation inherent in the Deaccelerator's position control system coupled with the device's calibration to
vehicle speed ensured that when the motorist's accelerator pedal depression was actively controlled by the position control system, more time would accumulate in the 55 mph category than the 56 mph category. The data indicate that this is precisely what occurred.

That motorists utilized the Deaccelerator's position control system to maintain the 55 mph preset speed may have some bearing on another finding that resulted from this field research. As noted in the "Results" section, drivers in the Baseline 1, Sign Only, and Baseline 2 conditions tended to accumulate more travel time at 53 mph than 5^4 mph, whereas in the Deaccelerator Plus Sign 1 and Deaccelerator Plus Sign 2 conditions drivers tended to accumulate more travel time at 5^4 mph than 53 mph. It is possible that across all experimental conditions, some of the time accumulated in the 53 mph category reflects speeding in areas where the posted speed limit was below 55 mph. However, those drivers who participated in the Deaccelerator Plus Sign 1 and Deaccelerator Plus Sign 2 conditions may have accumulated a portion of the time found in the 5^4 mph category as a function of the relatively substantial time they spent traveling at 55 mph during these conditions coupled with the Deaccelerator's operational characteristics. When faculty members traveled at the 55 mph speed limit in Car 3028 when the Deaccelerator was operative, vehicle speed could momentarily drop to 5^4 mph when they encountered an uphill road gradient. Because most highway travel in Car 3028 occurred in Michigan and because Michigan highways for the most part have shallow road gradients, it is unlikely that highway speed would drop below 5^4 mph on an uphill road.
gradient before the Deaccelerator's position control system would allow the motorist to further depress the accelerator pedal to increase vehicle speed back to the preset speed of 55 mph. For those motorists traveling in Car 3028 during the experimental conditions in which the Deaccelerator was not operative, highway speeds were for the most part well above 54 mph. Thus when encountering uphill road gradients, it is unlikely that these motorists would reduce vehicle speed even momentarily to 54 mph. As already mentioned, these motorists in fact allocated a substantial portion of recorded highway travel time to the 60+ mph category. Since it seems likely that their highway speeds were often higher than 60+ mph, a momentary reduction in speed that might occur when encountering uphill road gradients might not reduce speed below 60 mph and thus would not alter the data in any other recorded speed category.

An interesting finding in the present experiment was that speeding was not as prevalent during the Baseline 1 condition as during the Sign Only and Baseline 2 conditions. A factor that plays a likely role in this discrepancy is a general increase in highway speeds over relatively long periods of time. (Besides increasing speed over time, drivers may also spend less time reducing their speed.) Due to various interruptions in this research involving equipment repair and end of semester vacations, an 11 month period of time transpired between the second to the last driver in the Baseline 1 condition and the first driver in the Sign Only condition. It has been reported that highway vehicle speeds are on the increase across the United States (Darlin,
1986). It is possible that increases in highway traveling speeds over time are reflected in the different distributions produced by the Baseline 1 condition as opposed to the Sign Only and Baseline 2 conditions. Only 2 months elapsed between the last driver in the Sign Only condition and the first driver in the Baseline 2 condition, and, as already noted, the distributions of data generated by these two conditions were very similar.

If highway speeds are on the increase, it might be anticipated that this would be reflected across the four ordered histograms composing the Baseline 1 condition. However, data shown across the four histograms composing the Baseline 1 condition indicate relative increases in unlawful speeds from Figure 4 to Figure 5 only. Figures 6 and 7 show successively reduced relative rates of unlawful speeding. Winter was in force during the dates of travel composing Figures 6 and 7. (The last of the six drivers producing the data in Figure 7 drove the research vehicle following equipment repair requiring a fair amount of time and thus this driver did not travel during the winter season.) And although the highways were for the most part kept cleared of snow, there were on some days inclement weather conditions that may have reduced the propensity to speed. (No other experimental condition conducted during the course of this field study occurred during weather conditions that might have reduced highway speeds.) The occasional poor highway traveling conditions generated by winter weather that occurred during travel dates comprising the data shown in Figures 6 and 7 may have counterbalanced what may otherwise have shown up as relative increases in highway speeding across the Baseline 1 condition.
Earlier in this paper, the statement was made that behavior (accelerator pedal depression) generating unnecessary highway speeding (speeding to reduce the time to arrival) was relatively weak. The results of the present research offer support for that statement. The Deaccelerator exerted strong control over behavior producing unlawful speeding by way of a differential force schedule applied to the accelerator pedal. The absolute values of accelerator pedal resistance comprising the differential force schedule were quite small when one considers the force capabilities of the human leg. (As previously noted, the greatest force that the Deaccelerator was capable of producing was 36 pounds.) It might be argued, however, that faculty members do not as a rule constitute a population in which the motivational variables that determine the value of increasing speed are particularly compelling. At first blush, this may appear to be true. But a careful analysis suggests that imposed temporal contingencies can render increasing speed quite valuable to a faculty member engaging in work-related travel. The faculty in the present study generally used state vehicles to travel to educational settings for the purpose of lecturing to a class full of students. From the time the bell rings signalling the beginning of the class or lecture period, a faculty member usually has between 10 to 20 minutes to arrive at class before the students leave. It seems reasonable that faculty members do not wish to travel a fair distance only to confront an empty classroom. Moreover, repeated failure of a faculty member to arrive at class on time could yield punishing consequences. These temporal
factors seem adequately compelling to render increasing speed valuable to the faculty member engaging in work-related travel. The data in the present experiment indicate that the Deaccelerator brought faculty speeding under control, despite these compelling temporal factors.

The minimal amount of time that faculty members engaged in highway speeding during the Deaccelerator Plus Sign 1 and Deaccelerator Plus Sign 2 conditions is especially noteworthy, given the novel situation the Deaccelerator presented to faculty members driving Car 3028. When faculty members read the signs describing the Deaccelerator, it seems probable that these drivers would want to see for themselves exactly how the device performed. And yet despite the novelty of the Deaccelerator, very little speeding actually occurred during those conditions in which the Deaccelerator was operative.

Since the data gathered in the present field test indicate that the Deaccelerator exerts strong control over behavior generating unlawful highway vehicle speed, this device can now be compared to other speed control practices described earlier in this paper. It would appear that the Deaccelerator's behavioral design corrects the many deficiencies found in the other speed control practices.

Unlike visual stimuli located on the highway, the Deaccelerator exerts continuous as opposed to intermittent control over behavior producing highway speeding. Moreover, the Deaccelerator's continuous control of highway speeding does not produce abrupt and/or marked shifts in highway vehicle speed as can occur with the use of intermittently presented visual stimuli. As stated earlier in this paper,
variability in highway traveling speeds plays a major role in deter-
mining accident probability (DOT, 1977, p. 9) and accident involvement
rates (Cerrelli, 1977, pp. 5-6). And, as already noted, intermittently
presented visual stimuli, such as marked patrol vehicles located on
the highway (Galizio et al., 1979) may actually increase accident
probability as well as accident involvement rates by generating abrupt
decreases in vehicle speed once these visual stimuli are observed by
traveling motorists. Data resulting from the present study indicate
that the Deaccelerator maintained highway speeds with less than a 1
mph error range when the driver traveled at the preset speed. The
considerable portion of highway traveling time that occurred at 55
mph and 56 mph kept to a minimum variability in highway speeds trav­
eled by faculty members driving Car 3028 during the Deaccelerator Plus
Sign 1 and Deaccelerator Plus Sign 2 conditions.

While both governors and the Deaccelerator control highway speed­
ing, the latter ensures that optimum engine performance is always
available to the motorist when conditions requiring increasing speed
are encountered. That the governor restricts access to a vehicle's
total performance capacity has rendered use of this device unfavorable
to many motorists.

Unlike the limited speed cruise control, the Deaccelerator ap­
ppears to control highway speeding across a wide range of motivational
variables. Moreover, the Deaccelerator, like the cruise control,
offers the motorist a measure of comfort by way of its systematic
manipulation of the accelerator pedal.
And finally, unlike the trip recorder, the Deaccelerator does not depend on remote, time-consuming, and costly management-imposed consequences for effective speed control. The Deaccelerator imposes immediate consequences (increasing accelerator pedal resistance) for behavior producing the onset of and increases in unlawful highway speed and immediate consequences (decreasing accelerator pedal resistance) for behavior producing decreases in unlawful highway speed. (In fact, as previously discussed, the Deaccelerator's speed-based resistance is supplemented by accelerator-pedal-depression-based resistance to provide immediate consequences for behavior that is precursory to behavior that will effect changes in unlawful highway speed.) A final point is that unlike the trip recorder the Deaccelerator provides a continuously contacted discriminative stimulus when the motorist travels at the highway speed limit. This salient discriminative stimulus is generated by the Deaccelerator's position control system, which, although forcibly yieldable, actively manipulates the position of the accelerator pedal when the motorist travels at the highway speed limit.

Although the data generated during the course of the present field research unequivocally demonstrated the effectiveness of the Deaccelerator and although comparisons with other speed control practices have been made, further applied research should be conducted concerning the effectiveness of this speed control device.

First, research must be conducted with a variety of populations to ensure the Deaccelerator's generality of behavioral effects to those populations. Teenage drivers and drivers of heavy duty motor
vehicles would be interesting populations with which to test the Deaccelerator's effectiveness by way of field research since these two groups are often cited as populations demonstrating poor compliance with posted limits. It would be interesting to see if the differential range of imposed force values employed by the Deaccelerator in the present study would be sufficient to control highway speeding with respect to these two populations of motorists.

Besides testing the Deaccelerator's effectiveness with different populations of motorists, it is essential to assess the device's effectiveness with drivers receiving repeated exposure to the Deaccelerator. In the present study each driver exposed to the Deaccelerator encountered the device on a single occasion only. Follow-up studies should examine the speed reduction properties of the Deaccelerator when the same motorists are repeatedly exposed to this device.

Besides the Deaccelerator's being a practical candidate for further applied research, its behavioral operation has implications and inquiries for the experimental analysis of behavior. Interesting experimental questions may be addressed involving the assessment of the behavioral effects of differential force schedules as opposed to nondifferential force schedules. (Studies addressing such questions should not be restricted to stimuli involving force but should include an evaluation of other stimuli as well.) In the discussion that follows concerning differential and nondifferential force schedules, it is assumed, unless otherwise stated, that the reinforcement that maintains the behavior producing contact with these force schedules is
differentially imposed. (A schedule that changes the magnitude of its reinforcing consequences as a function of changes in response magnitude is referred to as a "conjugate schedule" [Rovee-Collier & Capatides, 1979]. Notwithstanding the less than perfect correlation between accelerator pedal depression and vehicle speed, increasing vehicle speed as a function of the magnitude of accelerator pedal depression is an example of a conjugate schedule.)

The manner in which subjects respond to a differential force schedule as opposed to a nondifferential force schedule could provide answers to questions concerning the effects of frequent and extended exposure to an imposed force requirement. The imposition of a sufficiently high force functions to punish the behavior producing the imposed force. Moreover, once imposed, increased force is, as an aversive stimulus, an establishing operation rendering decreasing force a valuable stimulus change, and that increased force evokes behavior that in the past has produced that stimulus change (Michael, 1982). In response to frequent and prolonged exposure to imposed force, there may be a gradual strengthening of the muscles involved in the execution of behavior producing and sustaining the imposed force. Such muscle strengthening may attenuate the punishing effects of increased force as well as the reinforcing value of decreases in the imposed force. The result may be that over a period of time subjects contact the imposed force more frequently and/or for longer durations. Due to differences in the characteristics of a differential force schedule and a nondifferential force schedule, the differential force schedule may render muscle
strengthening in response to imposed force less probable. (In conducting research involving comparisons of differential force schedules with nondifferential force schedules, decisions would have to be made concerning ways to equate the range of force values that make up the former schedule with the single force value that makes up the latter schedule.)

Differential force schedules systematically increase the imposed force value as a function of the increasing distance across which the subject presses a specified manipulandum. This kind of imposed force schedule functions to differentially punish any class of behavior producing increased travel of the manipulandum. In contrast, nondifferential force schedules impose a single value of force at some point along the travel of a specified manipulandum. Once the nondifferential force schedule is contacted, further travel of the manipulandum does not alter the imposed force value. This kind of imposed force schedule functions to punish a single class of behavior—the behavior producing the onset of the increased force. Once increased force has been imposed, further increases in the distance the subject presses the manipulandum are not differentially punished. Because differential force schedules punish finer portions of behavior than nondifferential force schedules, research might indicate that the former schedule is more effective than the latter in reducing the probability of muscle strengthening as a result of frequent contact with an imposed force requirement.

As already noted, besides possible muscle strengthening as a result of frequent contact with the increased force that is imposed
when the travel of a manipulandum is increased, muscle strengthening could also occur with respect to behavior that sustains or endures a given imposed force value. Once increased force has been imposed, differential force schedules systematically decrease the imposed force as a function of decreases in the distance across which the subject presses a specified manipulandum. When employing a differential force schedule, slight drifts in response topography that produce decreases in the manipulandum's distance of travel bring the subject into contact with reinforcement by way of decreasing values of force. This kind of imposed force schedule ensures that any class of behavior that reduces the distance the manipulandum is depressed is differentially reinforced. Since differential force schedules reinforce small changes in response topography with corresponding decreases in force, this schedule should function to limit the period of time that a subject spends at any increased value of force. (It is presumed that if subjects spend a limited time sustaining any differentially imposed force value, muscles involved in the execution of behavior producing that force value will be less likely to be strengthened by that force value.) In contrast, a nondifferential force schedule ensures that a subject encounters sustained contact with a single imposed force once the force schedule is contacted, regardless of topographical drift to a different point along the force schedule, unless that drift is great enough to terminate the imposed force schedule. This kind of force schedule determines that only one class of behavior is subject to reinforcement by way of decreased force. Because differential force schedules reinforce finer portions of behavior than nondifferential force
schedules, research might indicate that the former schedule is more effective than the latter in reducing the probability of muscle strengthening as a result of the aversive stimulation encountered when the subject sustains contact with a specified value of force. (It should be noted that in studies involving differential force schedules the distance entailed in the response topography that results in complete depression of the manipulandum would seem to be of critical importance. For example, the distance required for a pigeon to depress the response key in the standard key peck chamber is probably too small to be useful in implementing a differentially imposed force schedule. The chamber, however, could be modified so that the pigeon could depress the response key a greater distance. On the other hand, the distance that rats and monkeys can press a lever in their respective standard lever press chambers probably does not require modification in order to be useful in studies employing a differentially imposed force schedule. Moreover, due to obvious constraints regarding the pigeon's physiology coupled with the well established phenomenon of autoshaping, rats and especially monkeys seem far more suitable for studies involving the use of differential force. And a final consideration is the probable interaction between response distance and the corresponding resolution of the imposed gradients of stimulus change that make up schedules involving differentially imposed consequences.)

Another area of inquiry involving differential and nondifferential force schedules concerns possible discriminative, conditioned reinforcing, and conditioned punishing properties that might accrue
to the changing values of force found in a differential force schedule.

(It is assumed that behavior increasing the distance the manipulandum is depressed is differentially reinforced by an increasing gradient of homogeneous consequences. It is also assumed that behavior decreasing the distance the manipulandum is depressed is differentially punished by a decreasing gradient of homogeneous consequences.) These properties could be a byproduct of the correlation between increasing and decreasing force values and corresponding increases and decreases in the differential consequences maintaining the behavior that produces these changing force values. Thus, due to its correlation with differential reinforcement, increasing force could, as a discriminative stimulus, perpetuate behavior generating an increase in force. Again, because of its correlation with differential reinforcement and its acquired discriminative function, increasing force could acquire conditioned reinforcing properties that strengthen behavior producing increasing force. Additionally, because of its correlation with differential punishment, decreasing force could, as a discriminative stimulus, perpetuate behavior generating an increase in force. Again, because of its correlation with differential punishment and its acquired discriminative function, decreasing force could acquire conditioned punishing properties that weaken behavior producing decreasing force. (With respect to a nondifferential force schedule, the properties described above would only be relevant to the onset and offset of the single force imposed by that schedule.)

It should be noted that previous research has shown that punishment can, due to its correlation with reinforcement, become a discriminative
stimulus for behavior producing further punishment (Holz & Azrin, 1961, 1962). Moreover, as a discriminative stimulus, punishment can acquire conditioned reinforcing properties that strengthen behavior producing the punishing stimulus (Azrin & Holz, 1966). (In these studies, Holz and Azrin showed that shock could acquire discriminative and conditioned reinforcing properties due to its correlation with the availability of food reinforcement.) The present analysis suggests that discriminative properties and conditioned punishing properties can accrue to reinforcing stimuli much in the same manner as discriminative properties and conditioned reinforcing properties can accrue to punishing stimuli.

A final area of proposed research is the assessment of differential and nondifferential force schedules when the behavior the force is to alter is maintained by consequences that are differentially graduated as a function of the behavior's response magnitude or by a single, fixed consequence regardless of response magnitude. It might be shown that differential force schedules are more effective than nondifferential force schedules in gaining control of behavior maintained by differential (conjugate) reinforcement or by a single, fixed value of reinforcement.
It should be clear that increasing speed acquires its reinforcing properties because of past correlations with many reinforcing stimulus changes. For example, besides decreasing the time to arrival, increasing speed is reinforcing because of its past differential correlation with overtaking a slower moving object. Increasing speed (and particularly the rate of acceleration in speed) also acquires reinforcing properties because of a past differential correlation with increasing gravity force and the bodily conditions it generates. With respect to an analysis of highway speeding, however, these variables and others play a relatively minor role. (It should be noted that, as forms of reinforcement, overtaking a slower moving object and increasing gravity force probably do play a major role in the kind of speeding often labeled as "drag racing" in which the motorists, often youths, rapidly accelerate in speed rather than maintaining a high speed.)

Although a relative reduction in the time to arrival occurs with necessary speeding and thus produces some overlap with unnecessary speeding, there are, as indicated, significant differences in antecedent and consequent variables that distinguish the former from the latter.

Although the opportunity to alter the traveling time is practically always available, the overall opportunity to alter the time to arrival, assuming a constant maximum speed, is a diminishing function of the time spent traveling.


Lubeck, R. C., & Rushing, M. T. (1981). The effects of instantaneous mpg feedback on driver behavior. Unpublished manuscript, West Virginia University, Department of Psychology, Morgantown, WV.


