Fuel efficient driving training - state of the art and quantification of effects
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Abstract

A new area of traffic education, training in fuel efficient driving, is reviewed. This training is often said to reduce fuel consumption, accidents, emissions, and wear and tear on vehicles. These claims, made mainly by educators and bureaucrats, and said to have scientific backing, are found to be wanting; most of the possible effects are totally unsubstantiated, while the most central, reduction in fuel consumption, is well below the highest figures mentioned. Research problems and general methodology regarding the variable of fuel consumption reduction are discussed. Although it is fairly easy to show the large potential of training under experimental conditions, it is rather complicated in a field setting. However, it is necessary to study the effects in the drivers' natural environment, because of the many possible sources of error in controlled settings which tend to inflate the effect. What is possible during training should therefore rather be seen as a maximum of what can be achieved, while the effect in real life driving is usually far below. Being a new area of research, it is uncertain exactly how effects should be measured, apart from fuel consumption. This problem is discussed and the results from a quantification of effects of training in fuel efficient driving are presented. The changes in driving style are described in terms of acceleration patterns; mean accelerations (over time) increased and mean decelerations decreased, while the time spent on a stable velocity decreased. Also, the mean acceleration and deceleration over distance was fairly well correlated with fuel consumption, and very clear differences could be seen on several acceleration-related variables as a result of training. These results show that acceleration patterns are a workable way of quantifying this type of training.

Keywords: fuel, driving, traffic, training, acceleration

1. INTRODUCTION

In the last two decades of the 20th century, an interest in the effects of driving style upon fuel consumption arose. Technical studies of this problem showed that there was a very strong impact indeed; even without going to any extremes in behavior, differences between different styles ran to tens of percent [1, 2, 3, 4]. This type of research showed that there was a potential for reducing fuel consumption per distance by influencing the behavior of drivers.

While many agents would have an interest in reduced fuel consumption for economical reasons, this is also tied to the question of pollutants, thus attracting the eyes of organizations with an environmental agenda. However, it should be pointed out that the equation fuel/pollutants is far from easy. As there are many different pollutants, which differ in their amount of emission with different uses of the engine, the reduction of fuel consumption does not necessarily reduce all types of emissions [5].

Training in fuel efficient driving in Sweden and Finland is today almost totally dominated by the brand name EcoDriving, which originated in Finland in the nineties (see www.ecodriving.com),while there are similar variants in Holland and Switzerland [6]. The proponents of this kind of training do not only claim that it reduces fuel consumption (by 5 to 15 percent, depending on who you talk to, see for example [7]) and emissions, but also prevents accidents [5, 8] reduces wear and tear on vehicles as well as drivers, even that it increases driver status ('theory' lesson on EcoDriving in Uppsala, Sweden, 2002-03-27).

The picture painted is thus extremely cheerful; with a few hours of training, people may make substantial differences in very problematic areas. These claims are often said to have scientific backing. However, it is very uncommon for any specific source to be named. A literature search was therefore undertaken. Various databases covering psychology, transport and energy were searched (PsycInfo, Sciencedirect, Transguide, ETDEWEB (www.etde.org/etdeweb)), revealing about nothing at all. A few reports were located through various personal contacts, almost all of them recent Swedish work of low quality. Most of the vague references concerning Finnish research proved to be dead ends.

It must therefore be concluded that all claims about effects of EcoDriving and similar techniques, apart from fuel consumption and some types of emissions, are unsubstantiated. Also, the work on fuel consumption is scarce and of low quality, about half of it concerning itself only with the training situation or experiments, not how people drive in actual traffic. Furthermore, no studies have covered a time period longer than one year after training [9]. The question of changes in emissions is also troublesome, as it is very complicated.

The instructions used in EcoDriving are mainly about planning in advance to avoid braking, using the engine brake, accelerating strongly and shifting into higher gear before 2500 rpm (for petrol engines), see further the Appendix. This verbal description is the base for specific instructions with the aim of facilitating these behaviors; for example keeping an eye on traffic lights up ahead to prepare for early (engine-) braking if they would turn red. Such instructions may be readily understandable to about anyone, but it is not certain how they should be translated into measurable variables, apart from fuel consumption. Although this may be enough in many situations, it is not that very informative in terms of behavior. The reason for being interested in behavior is mainly to be able to measure variables that might explain why training is not working in some cases, but also, if couched in positive terms, exactly what behaviors are having an effect. This might have an impact on how training is commenced, as the principles used may not be optimal, especially over a longer time frame, i.e. some advice may be hard to use or remember, as shown by van de Burgwal and Gense [6]. Also, it is important to find a measure of training effects which may be implemented as a longitudinal outcome variable along with fuel consumption.

In principle, a variety of methods for measuring driver behavior could be used. For example, vehicle data (rpm, fuel consumption, speed etc) is available from about any engine with electronic fuel injection (with the right kind of measuring equipment). Such data may be interpreted in terms of behavior of the driver with the accompanying features of reliability over time and individual differences.

A different type of data gathering would involve an observer scoring observable behavior, like brake appliance or engine braking. This is pretty much what the instructors do during training, taking notes of what parts of the pupil's driving style need to be changed. However, such a method is not only very work intensive, but also not very reliable, as people are not very good observers.

There is quite a different way of measuring driver behavior; by acceleration patterns. These have been studied as predictors of traffic accidents [10, 11, 12], but also of fuel consumption [4]. The advantages of acceleration patterns as individual differences variables are that they have been shown to be stable over time [13, 14], are rather easily measured, and make sense in the present circumstances as measures of the behaviors training are supposed to change. From the instructions given in EcoDriving training, it might be expected that mean deceleration should decrease, while mean acceleration should increase.

The rest of this paper will present data from training sessions in fuel efficient driving, thus testing the described method of quantifying the effects of such education. The main questions are whether some sort of acceleration measure can predict fuel consumption, but also whether there are clear differences between runs on such variables. The data are from a project evaluating the effects of Heavy EcoDriving for bus drivers concerning fuel consumption, acceleration patterns and passenger reactions in a two-year time-frame (see **www.psyk.uu.se/hemsidor/busdriver)**.

2. METHOD

During the spring of 2002, about 300 drivers at the bus company Gamla Uppsalabuss in Uppsala, Sweden were trained in Heavy EcoDriving. Some of the practical driving sessions were monitored with a logging equipment used for data gathering en route in another part of the project. The logging equipment calculated accelerations and decelerations with 4Hz, using the signals from the speedometer. The bus used was a Volvo with an automatic gearbox.

Training was undertaken in a city environment, on one of two pre-determined stretches of streets (the shorter one was used during rush-hour as to get

Table 1: Means and standard deviations of some driving style variables for the first and second run of training. Acceleration variables in m/s2, time for driving and standstill in seconds, fuel consumption in liters/100 km. * demark that the difference between runs is significant at p<.05, *** <.0001 (one-tailed). N=35. Note that the stretch driven was not always the same between drivers. (E) denotes Econen data, all other data from logging equipment by Drivec.

	Mean deceleration		Mean acceleration		Time for driving		Fuel consumption (E)		Time for standstill	
	Mean	Std	Mean	Std	Mean	Std	Mean	Std	Mean	Std
First run	-.500	.074	.538	.088	1393	143	39.35	2.37	120	64.8
Second run	-.424	.042	.659	.067	1337	146	33.56	2.10	97	55.9
Difference	.076, 15.2% ***		.121, 22.5% ***		-56, 4.0%, ns		-5.79, 14.7% ***		-23, 19.2%, ns	

approximately the same time for driving for each pupil). The bus driver (this part of the training was individual) was first asked to drive the stretch 'as usual', and was then given advice on how he could save fuel. Sometimes the instructor would show how it could be done, and/or the bus driver tried the recommendations. Thereupon the measuring stretch was driven again, sometimes with continuos instruction from the instructor (see Appendix). Afterwards, the fuel consumption and time for driving were compared between runs. Measuring of these parameters were done with an Econen[1] device, which is the equipment normally used by EcoDriving instructors. This apparatus uses the signals from the electronic fuel injection system to calculate, among other things, total fuel consumption for a specified run. Fuel consumption data for the present study was supplied by the driver training company.

Due to errors in the data gathering procedures, the sample of bus drivers became rather small, and it was therefore supplemented with a number of other personnel, mainly employees working in the garages. This work involves moving buses for cleaning and re-fuelling. Although these people were not bus drivers and their normal driving style would probably not be like that of those employed as such, the data may nevertheless be used in the present study, as it concerns itself with the study of how changes in driving behavior may be measured in a meaningful way in conjunction with fuel consumption reduction.

The calculation of acceleration values may be done in a number of ways, each describing an aspect of driver behavior. There is no consensus about exactly how this should be done, and so, the values chosen here are somewhat ad hoc. Their value lies mainly in how well they can predict aspects of fuel consumption, but also in what they may tell us about driving style in a more general sense.

In the present work, a three-way basic partitioning of data was chosen; deceleration, acceleration and even speed. This partitioning means that any part may change in amount of time it is in action, but also in mean strength when it applied. Thus, for example, it is expected that the mean strength of deceleration will decrease, but on the other hand also that the time used for braking will increase between runs. However, the total amount of deceleration (mean deceleration times the time used) will decrease, and this is what makes the difference in terms of fuel consumption.

[1] Developed by the Finnish company Paetronics, now in partnership with Siemens.

3. RESULTS

35 bus drivers and other personnel from the bus company were monitored during training. The descriptive data for the acceleration variables of the first and second drives are displayed in Table 1, along with time for driving and fuel consumption. It may be seen that mean deceleration decreased and mean acceleration increased on the second drive, while time for driving and fuel consumption decreased. The time for standstills did decrease strongly, but this difference was not significant, due to the large standard deviations.

As the time spent in each mode of acceleration changes as well as the mean strength, the best predictor of fuel consumption should be deceleration per kilometer of each run, i.e. mean deceleration multiplied by the time spent in the mode divided by the distance. Thus, deceleration per kilometer correlated -.38 (p<.05) with fuel consumption per kilometer in the first run, and -.41 (p<.05) on the second. As deceleration has a negative sign, this means that as there was a lesser amount of deceleration, there was also less fuel consumption.

Most variables tested correlated between runs, some of them very strongly. However, as the distance used for driving was not the same for all drivers, variables were time or distance is not held constant will be spuriously inflated in their correlations. However, variables that are independent of distance and time also correlate fairly well between runs. Thus, the Pearson correlations between first and second run (N=34 for all) was .51 (p<.01) for mean acceleration, .38 (p<.05) for mean deceleration, .54 (p<.01) for fuel consumption per kilometer, and .43 (p<.01) for speed.

Table 2: Means and standard deviations of the time spent in different acceleration modes in seconds during the first and second run of training. * demark that the difference between runs is significant at p<.01, *** p<.0001 (one-tailed). N=35.

	Time for deceleration		Time for acceleration		Time for even speed	
	Mean	Std	Mean	Std	Mean	Std
First run	606	73.8	573	67.8	94	15.8
Second run	719	82.2	469	51.6	53	15.6
Difference	113, 18.6%, ***		-104, 18.2%, ***		-41, 43.6%, ***	

However, there may be an influence of congestion, as this should be similar between runs but different between drivers, so these associations should be interpreted with some caution.

The first run of the first training session for available days were compared to the first run of each session later in the day. It was found that the morning runs had a mean fuel consumption per 100 km that was 2.5 percent higher than later first runs, a difference that was not significant at p<.10, given the small sample sizes (12 and 29 subjects, respectively). On the second run, on the contrary, it was the group with initial higher consumption that had a 2.1 percent lower consumption.

4. CONCLUSION

The most basic problem with a study such as this is what to measure. The choice of (some specific types of values of) accelerations may be questioned, but it is noteworthy that the effects and correlations found were rather strong, and in agreement with predictions. It may therefore be concluded that accelerations are indeed a rather good measure of driving behavior and training effects, even when using such simple variables as mean deceleration. The variables tested here do not only show clear differences between runs, but are also associated with fuel consumption.

Some methodological limits to the present study must be kept in mind. The most difficult problem concerned the mapping over time and distance of the two sources of data; Econen and the logging equipment. On variables which could be found in some form in both sets of data, i.e. distance and speed, there were clear discrepancies. These could be traced to one single instructor, who clearly deviated in the data supplied. However, as this concerns 16 out of 35 cases, and most differences were very strong and clear, the basic conclusions drawn here should still be valid. Also, the discrepancies noted should make any correlations found between Econen and logging data weaker than otherwise. It is only the differences between runs in Econen data that should be interpreted with some caution.

Furthermore, the use of different distances and time of day for different drivers by the instructors has the possible result of inflated correlations in some cases. This, however, only involves the interpretation of the consistency of driving style between runs, as discussed below.

On the other hand, some outliers (>2 std) were present, which had the effect of decreasing some correlations. As they could not be shown to be erroneous, they were retained. This had an influence mainly on the associations between mean deceleration, acceleration and fuel consumption, which were not reported, but a small effect could still be found when the acceleration variables were held constant for distance. These correlations could therefore be somewhat higher.

In the present work, very simple calculations were used concerning the acceleration variables. For example, the different amounts of energy involved when accelerating a vehicle at different speeds were disregarded. Such a method is defensible given the low speeds involved, but should probably not be used in a rural setting, or other roads, with higher speed limits.

The results presented above may tell us several things about how the driving style of the pupils changed after instruction. As expected, accelerations were 'compressed' into shorter bursts of stronger change in speed, while decelerations changed the other way. This means that drivers learned to use the engine in a more effective way when accelerating, and to brake softer. The reduction of time spent in zero acceleration (Table 2) may seem unexpected, as an even speed under many circumstances would be a desirable thing. However, there are explanations for this effect. First, it should be remembered that the driving environment was urban, with very short stretches of road without crossings. As the instructions are to use the engine brake for a slower braking, the time spent braking must increase, and if this time is not made up for by reduced time for accelerations, there will be less time left for zero acceleration. It should also be noted that on modern

Yet another aspect is the mean reduction in time for driving; this also makes a cut in the available time for different acceleration modes.

The change in total time for standstills tell a different thing about the effects on driving style; pupils must have learned to look ahead and start their deceleration earlier, thus preserving more of their kinetic energyand avoiding unnecessary idling.

It is of importance to note that fuel consumption on the two runs correlated, as did several acceleration variables (however, as discussed above, this might in part be a result of congestion). This means that a sizeable part of the initial driving style (in terms of fuel consumption and acceleration patterns) was still present after training, and the conclusion must be that, although gains were impressive (but see also the next paragraph), there is still more potential for reduction. This may also be seen in the standard deviation of fuel consumption; it changes very little between runs, although, in a perfect world, all drivers should have achieved the lowest possible level, i.e. their driving style would be optimal and thus very similar between drivers.

On the matter of standard deviation, it may be noted that the correlations between fuel consumption and various acceleration variables tended to be lower for the second run. This is what could be expected; as driving style is becoming more similar and the standard deviations become smaller for all variables, correlations will shrink, despite the actual association probably being the same.

Concerning reduction in fuel consumption, an artifact seems to be at hand, which probably tends to inflate the figures somewhat. The first run in the first training session of each day tended to have a higher consumption than later first runs, despite these drivers having a lower consumption on the second run. This probably means that there is an effect of a cold starts, which increases the difference between runs in the first session. Another explanation would be that drivers who are under average (have a higher initial fuel consumption) achieve a larger reduction than others, which does not sound very plausible, especially given the correlations between runs on different variables discussed above. This artifact makes the reduction stated above (referring to the figures in Table 1) somewhat too high. Exactly how much is not possible to ascertain, but as there were four sessions each day, the mean should probably be 0.5 to 0.6 percent units lower. It should be pointed out that if cold starts have influenced results, such behavior by the instructors were against the rules for the company doing the training[2].

It might be noted that the correlations reported do not necessarily imply that decelerations are decisive for fuel consumption, but it does show that it is fair marker under the present circumstances, i.e. it might be used as a proxy for fuel consumption in situations were such data are not available, or were the aims are more along the lines of describing driving style.

Some final points may be made; the possibilities of saving fuel are obviously rather large. However, today it does not seem possible to achieve these large differences outside of training sessions and experiments [9]. With the advance of vehicle computers, the problem also moves into a new dimension. Comparative research is needed to edge out the various effects and interactions, and improving both training and technology, which are probably far from optimal today. Also, there is a need for the development of useful measuring principles concerning driver behavior in relation to fuel consumption, training and technical aids. The present work has tried to achieve the latter goal, and has as its main conclusion that simple acceleration parameters are useful in this respect.

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Appendix

EcoDriving training is marketed by EcoDriving International (see www.ecodriving.com). In Sweden it is under the control of the driver trainers' organization, i.e. they handle certification, work with the Swedish Road Administration for the promotion of EcoDriving etc.

Although in theory the set of rules and procedures used in EcoDriving should ascertain that the training is rather uniform between pupils, this is not the case. Partly, this is because instructions are tailored to the specific needs of the pupils, both on a group and an individual level. For example, the type of driving undertaken should be similar to their normal traffic environment, and individual instructions depending upon what errors each person are making. However, word of mouth tells that different instructors have different achievement levels, i.e. their pupils on the mean have different reduction rates, something which could only be explained by instructors' individual interpretation of the training curricula.

It is for these reasons not possible to give a generally valid description of how the training is commenced. Instead, the general principles applied will be described (some of these are about gear-shifting, and were thus not applicable in the present study), along with some of the more common instructions used during the training at Gamla Uppsalabuss.

General principles:

Do not use more than half-throttle

Change gear before 3000 rpms

Plan ahead, as to avoid braking, i.e. adjust your speed in an early phase by the use of friction.

Use a uniform throttle when a desirable speed has been achieved, i.e. do not compensate when loosing speed at an inclination

Drive at the highest possible gear

Use the engine brake instead of the brake pedal

Do not overtake unnecessarily

Specific instructions used:

'Accelerate more strongly'

'Start the acceleration earlier'

'Release throttle in descents'

'Plan continuously ahead'

There is also a 'theory' group session were a trainer talks mainly about environmental problems, pollution by vehicles, and different ways of reducing fuel consumption. This includes air resistance, service, tires etc.