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Interpretation of driving style tips

Application of the major driving style tips of 'New Style Driving' by passenger car drivers and the effects on fuel consumption and tail pipe emissions

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Summary

Because of the reduced reserves of fossil fuels and the worldwide concern about the greenhouse effect of CO2 emissions, much attention has been focussed lately on the reduction of fuel consumption of road transport. Since the oil crisis in the early seventies, great effort has been put into improving the fuel economy of passenger cars. Because the weight, however, of the average vehicle has increased gradually over the years due to safety precautions, the efforts put into improving engine and car technology have not yet led to a substantial decrease in fuel consumption.

Besides the applied engine and vehicle technology, the fuel economy of a car is also influenced by the behaviour of its driver. In order to address the influence of a driver on the fuel consumption of road vehicles, the Dutch government and Novem have developed a national programme called 'The New Driving Force' ('Het Nieuwe Rijden').

The main factor influencing fuel consumption is driving style, which can be influenced in different ways. The New Driving Force programme aims at encouraging an economical driving style a.o. by means of handing driving style tips to the Dutch public. These tips are:

1. Shift as soon as possible at a maximum of 2500 rpm (for diesel a maximum of 2000 rpm) to a gear as high as possible. (In Dutch: *Schakel zo vlot mogelijk bij maximaal 2500 toeren (voor diesel maximaal 2000 toeren) naar een zo hoog mogelijke versnelling*.)
2. Press the throttle quickly and vigorously just as much that you can keep up with the traffic. (In Dutch: *Trap daarbij het gaspedaal snel en doortastend zover in dat u vlot met het verkeer kunt meerijden.*)
3. Do not shift down to a lower gear too early, and keep the car rolling without disengaging the clutch and in a gear as high as possible. (In Dutch: *Schakel niet te snel terug en laat de auto zo lang mogelijk zonder de koppeling in te drukken in een zo hoog mogelijke versnelling uitrollen.*)

The way an individual car driver will interpret these driving style tips will be decisive for the success of the programme. Therefore, in order to find out how the tips that are communicated on a corporate level (mass media, brochures, leaflets etceteras) are interpreted by the 'average Dutch car driver', Novem has asked TNO Automotive to find answers to the following research questions:

- Do car drivers correctly bring the three major "new style driving" tips into practice?
- What are the differences in driving behaviour between instructed drivers bringing into practice the three major "new style driving" tips and non-instructed drivers?
- What are the quantitative consequences on fuel consumption and tail pipe emissions of different interpretations of the instructions compared to the 'average driving style' of non-instructed drivers?
- If the research shows a need for this, how can the major driving style tips be adjusted?

In order to answer these questions TNO Automotive developed and executed a research programme that consists of the following parts:

Part I:	the recruitment of 24 testdrivers to participate in the research
Part II:	an on-the-road measurement campaign with the 24 testdrivers putting into practice the new driving style tips while the actual trip data were recorded.
Part III:	measurements on a chassis dynamometer in the TNO laboratory, in order to quantify the emissions and fuel consumption consequences of the testdrivers' interpretation of 'new style driving'.

From part II of this study has been concluded that when car drivers are positively motivated it is indeed possible to change (elements of) their driving style by means of corporate communication in writing. Shifting earlier seems to appeal to most of the drivers, while driving more fluently and anticipating on traffic situations is a natural reaction in order to drive fuel economic.

However, the actual message of New Style Driving as expressed in the three driving style tips is too complex and tip 1 and tip 2 are too contradictory to most drivers to be applied in practice. Many testdrivers experienced tip 2 as contradictory to economic driving. Some testdrivers remarked that it even encouraged speeding. Therefore probably most often this tip was being ignored completely. The study also shows that in a worst case situation, the formulation of the tips can even lead to misinterpretation and thus unwanted driving behaviour.

Regarding the fuel consumption and emission effects, the chassis dynamometer programme showed that considerable reductions in fuel consumption from 5% to 25% can be obtained by a change of driving style. However, the programme did not point to a direct relation between application of tip 2 (a higher throttle position) and a reduction of fuel consumption. The parameter that related most strongly to fuel consumption was the dynamics of a certain trip. A misinterpretation of the tips showed an increase of the fuel consumption though.

The exhaust emissions of modern passenger cars seem to vary more from car to car than was ever the case before, as is expressed by variation the measurement data of the effects of especially CO, HC and NO_x emissions. This variation is most probably a matter of the way modern engines are calibrated.
The effects on exhaust emissions of the various interpretations of New Style Driving were in many cases found to be not significant or not of the same magnitude as shown in previous study, because of the latest generation of technology tested and because of the different reference driving styles that have been used.

Taking into account the difficulties with the interpretation of tip 2 which can even lead to a misinterpretation and the fact that a relation between the application of this tip and a reduction in fuel consumption can't be proven, the general conclusion can be drawn that tip 2 in its current form should not be part of communication in writing of New Style Driving. How to exploit the potential of driving style changes in real life, seems to be more a question of how to motivate car drivers to drive more defensive than a matter of how to communicate the exact principles of New

Style Driving. Most car drivers instinctively do seem to know how to drive economically by reducing driving dynamics and speed.

Therefore, an adjusted formulation of New Style Driving on a corporate level should be aimed at motivating drivers to adapt their driving style in such a way that it becomes more fluent. It must also challenge car drivers not to think that New Style Driving means a slow or boring driving style. What should be kept in mind when reformulating tips is that driving with low engine speeds has theoretically and practically proven to be very efficient in order to reduce fuel consumption.

Because of the displayed significant positive influence of reducing driving dynamics, it is therefore also important to impose a fluent driving style on car drivers by means of an appropriate design of roads and traffic management next to trying to change their behaviour.

Samenvatting

Vanwege de afname van de voorraden fossiele brandstoffen en de wereldwijde zorg om het broeikaseffect van CO_2 uitstoot, wordt er de laatste jaren veel aandacht besteed aan het verminderen van het brandstofverbruik van het wegverkeer. Sinds de oliecrisis begin jaren zeventig is de efficiency van personenwagenmotoren sterk verbeterd. Door een geleidelijke toename van het gewicht door de jaren heen onder invloed van veiligheidsvoorschriften hebben de verbeteringen op het gebied van motor- en voertuigtechnologie echter niet geleid tot een substantiële afname van het brandstofverbruik.

Naast de toegepaste technologie, wordt het brandstofverbruik van een auto ook beïnvloed door het gedrag van de bestuurder. Om dit aspect onder de aandacht te brengen, hebben de Nederlandse overheid en Novem een programma ontwikkeld onder de naam 'Het Nieuwe Rijden'.
De belangrijkste factor die het brandstofverbruik beïnvloedt is de rijstijl. Deze kan op verschillende manieren worden beïnvloed. Het programma 'Het Nieuwe Rijden' probeert een zuinige rijstijl aan te moedigen door onder andere het communiceren van rijstijltips naar het Nederlandse publiek. De belangrijkste tips zijn:

1. Schakel zo vlot mogelijk bij maximaal 2500 toeren (voor diesel maximaal 2000 toeren) naar een zo hoog mogelijke versnelling.
2. Trap daarbij het gaspedaal snel en doortastend zover in dat u vlot met het verkeer kunt meerijden.
3. Schakel niet te snel terug en laat de auto zo lang mogelijk zonder de koppeling in te drukken in een zo hoog mogelijke versnelling uitrollen.

De manier waarop een individuele automobilist deze tips zal interpreteren zal beslissend zijn voor het succes van het programma. Om er achter te komen hoe deze tips in de praktijk worden geïnterpreteerd door de gemiddelde Nederlandse automobilist wanneer ze worden gecommuniceerd op 'corporate' niveau (massa media) heeft Novem aan TNO Wegtransportmiddelen gevraagd antwoord te vinden op de volgende onderzoeksvragen:

- Brengen automobilisten de drie belangrijkste tips van Het Nieuwe Rijden correct in de praktijk?
- Wat zijn de verschillen in het rijgedrag van automobilisten die zijn geïnstrueerd met Het Nieuwe Rijden en automobilisten die niet zijn geïnstrueerd?
- Wat zijn de kwantitatieve consequenties op het brandstofverbruik en uitlaatgasemissies van diverse interpretaties van Het Nieuwe Rijden door automobilisten, in vergelijking met de rijstijl van niet-geïnstrueerde automobilisten?
- Indien het onderzoek daartoe aanleiding geeft, hoe kunnen de belangrijkste rijstijltips worden aangepast?

Om deze vragen te kunnen beantwoorden heeft TNO een onderzoek uitgevoerd, dat uit de volgende drie delen bestond:

Deel I:	werven van 24 representatieve testrijders voor deelname aan het onderzoek
Deel II:	metingen op de weg met de 24 testrijders waarbij de rijstijltips in de praktijk moesten worden gebracht, terwijl de ritdata opgenomen werd
Deel III:	metingen op de rollenbank in het TNO laboratorium teneinde de effecten op brandstofverbruik en uitlaatgasemissies te kunnen kwantificeren.

Uit deel II van het onderzoek is geconcludeerd dat het mogelijk is om door middel van 'corporate' communicatie (elementen van) de rijstijl van een automobilist te veranderen indien deze daartoe positief gemotiveerd is. Vroeger opschakelen spreekt de meeste testrijders aan, en vloeiend rijden en het anticiperen op het overige verkeer is een natuurlijke reactie teneinde zuiniger te gaan rijden.

De precieze boodschap van Het Nieuwe Rijden zoals deze in de drie rijstijl tips verwoord is, is echter te complex en tip 1 en tip 2 zijn op het eerste gezicht te tegenstrijdig om voor de meeste rijders begrepen en in de praktijk gebracht te worden. Dit wordt met name veroorzaakt door tip 2. Veel testrijders ervoeren deze tip als tegenstrijdig met zuinig autorijden, terwijl sommigen zelfs vonden dat deze tip aanzet tot hard rijden. Dit resulteerde er vaak in dat deze tip volledig werd genegeerd. In het slechtste geval kan de huidige formulering zelfs leiden tot misinterpretatie, waarbij er juist sprake was van onzuinig en ongewenst rijgedrag.

Ten aanzien van de effecten op brandstofverbruik en uitlaatgasemissies, toonde het meetprogramma op de rollenbank aan dat een verandering van rijstijl kan leiden tot verbruiksreducties van 5% tot 25%. Uit het meetprogramma kon echter geen directe relatie tussen het juist toepassen van tip 2 (een hogere gaspedaalstand) en een lager verbruik worden aangetoond. De parameter die het best overeenkwam met het verbruik bleek de dynamiek van een rit te zijn. Bij misinterpretatie van de tips steeg het verbruik.

De uitlaatgasemissies lijken bij moderne personenwagens sterker te variëren dan ooit tevoren, zoals bleek uit de variatie van de gemeten effecten op met name CO, HC en NO_x emissies. Deze variatie wordt waarschijnlijk veroorzaakt door de manier waarop moderne personenauto's worden gekalibreerd.
De effecten die zijn gevonden bleken vaak niet significant en in ieder geval niet van dezelfde orde als geconstateerd in eerder onderzoek, vanwege de laatste generatie technologie die getest is en vanwege de verschillen in referentierijstijlen.

Gezien de moeilijkheden met de interpretatie van tip 2, die zelfs tot misinterpretatie kan leiden, en de niet aangetoonde relatie tussen juist toepassen van tip 2 en een lager brandstofverbruik, luidt de algemene conclusie dat tip 2 het beste kan worden weggelaten uit de rijstijltips van Het Nieuwe Rijden. Hoe automobilisten aan te sporen tot een zuiniger rijgedrag is meer een kwestie van ze te motiveren tot het in de praktijk brengen van een vloeiende en anticiperende rijstijl. De meeste automobilisten schijnen instinctief te weten dat een lagere ritdynamiek leidt tot een lager verbruik.

Een aangepaste formulering van de rijstijltips van Het Nieuwe Rijden moet daarom gericht zijn op het motiveren van automobilisten tot een vloeiendere rijstijl. Daarbij moet benadrukt blijven worden dat Het Nieuwe Rijden zeker geen langzame en saaie rijstijl is, waarbij in acht moet worden genomen dat het rijden bij lage toerentallen zich als zeer effectief heeft bewezen bij het verminderen van het brandstofverbruik.

Vanwege het aangetoonde positieve effect van een lagere dynamiek op het brandstofverbruik, is het ook belangrijk hier bij de aanleg van wegen rekening mee te houden om zodoende automobilisten een vloeiende rijstijl op te kunnen leggen.

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Appendices

1 Introduction

Because of the reduced reserves of fossil fuels and the worldwide concern about the greenhouse effect of CO2 emissions, lately much attention has been focussed on the reduction of fuel consumption of road transport. Since the oil crisis in the early seventies, great effort has been put into improving the fuel economy of passenger cars. Because the weight of the average vehicle has increased gradually over the years due to safety precautions, the efforts put into improving engine and car technology, have not yet led to a substantial decrease in fuel consumption.

Besides the applied engine and vehicle technology, the fuel economy of a car is also influenced by the behaviour of its driver. In order to address the influence of a driver on the fuel consumption of road vehicles, the Dutch government and Novem have developed a national programme called 'The New Driving Force' (Het Nieuwe Rijden). The programme consists of addressing driver/buyer related fuel economy topics and purchase behaviour. Four major areas of interest are addressed:

1) Driving style,
2) Checking tyre pressure regularly,
3) Fuel economy labelling for passenger cars (buyer information),
4) In car equipment, like on board economy metering and cruise control (user information).

The main factor influencing fuel consumption is driving style, which can be influenced in different ways. The New Driving Force programme aims at encouraging an economical driving style a.o. by means of handing driving style tips to the Dutch public. The way an individual car driver will interpret these driving style tips will be decisive for the success of the programme. Therefore, in order to find out how the tips that are communicated on a corporate level (mass media, brochures, leaflets etceteras) are interpreted by the 'average Dutch car driver', Novem has asked TNO Automotive to find answers to the following research questions:

- Do car drivers correctly bring the three major "new style driving" tips into practice?
- What are the differences in driving behaviour between instructed drivers bringing into practice the three major "new style driving" tips and non-instructed drivers, and why do these differences occur?
- What are the quantitative consequences on fuel consumption and tail pipe emissions of different interpretations of the instructions compared to the 'average driving style' of non-instructed drivers?
- If the research shows a need for this, how can the major driving style tips be adjusted?

In order to answer these questions TNO Automotive developed and executed a research programme of which the results are described in this report. It was not the final objective of the programme to obtain exact numerical emission factors, but to evaluate the driving style tips and to formulate recommendations for adjusting the driving style tips if considered necessary.

This research is related to a greater research programme sponsored by the Flemish government, which also focuses on the influence of traffic calming measures on fuel consumption and tail pipe emissions. Driving styles were a relatively small part of the Flemish programme, but not as extensively in order to investigate the previously described research questions of Novem. By co-financing the Flemish project, Novem gave the Flemish project a broader scope by giving the opportunity to sort out these research questions.

2 "New Style Driving"

2.1 Technical background

The New Driving Style is based on a Swiss protocol (ECO-DRIVE) that essentially implicates an optimised use of the engine map in combination with improved anticipation of situations occurring in traffic. The optimised use of the engine map is realised by shifting to high gears at low engine revolutions (rev's), combined with an increased throttle depressing. This gives rise to overall lowered average engine speeds (low friction in engine) and decreased throttling losses, because of the average wide opened throttle. In fact when propulsion energy is needed, it is generated in an optimal point in the engine map (see explanation in appendix A 'theoretical background'). In combination with extended anticipation in traffic and thus using the car's kinetic energy for rolling out, fuel economy should be improved. This driving style does not result in faster accelerations of the car, because the amount of power available at low engine speeds is relatively low, even if the throttle is opened relatively wide

2.2 History

Several years ago the new driving style briefly described above addressing optimised fuel consumption was introduced in Switzerland. This style, called 'ECO-DRIVE', has been introduced in the Netherlands by the VVCR (Verkeers Veiligheids Centrum Rozendom) under the name 'Ecolomic driving'. This style was adopted and slightly adjusted by Novem in the "New Driving Force' programme. The initial protocol of Ecolomic driving has been used in a 1999 TNO study into the effectiveness of 'ecolomic' driving. This study will be described shortly in the next section.

2.3 The 1999 TNO study

In 1999 TNO Automotive executed an investigation in order to determine the effects on fuel consumption and tail pipe emissions of applying different driving styles in modern passenger cars [Gense, 2000]. Within the programme four different driving styles were used. The reference style in the investigation was the style as educated during the driving course for obtaining a driving-license, being a '*defensive style*'. Two supposedly fuel economical styles were used as well, being the very slow accelerating '*egg style*' together with the at that time newest Dutch version of the Swiss 'ECO-DRIVE' called '*new style driving*'. (This 'new style' combined defensive driving with a special way of accelerating and shifting: throttling at 75% while keeping rev's low by early upward gear shifting) 'Sporty driving' represents the environmental opposite of these styles, involving the use of high engine rev's and power. Four experienced TNO drivers drove five different cars on a mixed track in the neighbourhood of Delft, the Netherlands. They each used one of the four driving styles described before, while the driving patterns were recorded. For each of the driving styles the recorded driving patterns were compressed to short testcycles using statistical tools developed by TNO. These testcycles could be driven on a chassis dynamometer for the purpose of measuring fuel consumption and tail pipe emissions. In total 15 cars were subjected to the testing procedure.

The results of these 15 cars were averaged. The measured relative changes in emissions and fuel consumption, compared to defensive driving, are listed in the table below:

Table 1 *Results of the 1999 TNO study*

Driving style	sporty	new style	egg
	(%)	(%)	(%)
Average speed	+3	+2	-10
Driving dynamics	+80	-8	-15
avg. engine rev's	+20	-7	+1
Fuel consumption	+34	-5	<1
CO_2	+30	-6	+1
CO	+750	+78	+4
HC	+280	+31	+22
NOx	+91	+7	-18
Particles	+69	-32	-25

When looking at the driving characteristics of all four styles used (while obeying speed limits), no major differences in average speed could be observed. Only the 'egg style' was rather slow. Obviously the cars had been forced to drive in a certain way caused by traffic surrounding the car ('traffic forced' driving in combination with speed limits). These small differences allow the conclusion that the measured differences between the driving styles, were mainly caused by the way the cars were operated. The differences between driving styles are clearly visible when driving dynamics and average engine rev's of the driving styles used are compared. For instance driving 'sporty', involved 80% more driving dynamics and an average 20% higher engine rev's.

The effects of the differences in driving styles appeared clearly in the fuel consumption and the tail pipe emissions of the cars tested. The 'egg style' appeared to save no fuel but can lead to slightly higher emissions of CO and HC, but lower NO_x and particles. While applying 'sporty driving' fuel consumption and tail pipe emissions rose dramatically. 'New style' proved to save about 5% of fuel compared to the 'defensive' reference driving style but mostly at the cost of higher emissions. These higher emissions were assumed to be caused by the use of 75% throttle at low rev's during acceleration, causing engine operation in a badly calibrated part of the engines performance map. This resulted in the recommendation to reduce the throttle position during acceleration to a maximum of 50%. It was assumed that this would most probably reduce the negative effects of new style driving, without threatening the fuel consumption benefit. The achievable reduction in fuel consumption of an average Dutch driver using the 'new style' was expected to be bigger than the measured 5%, because the average Dutch driving style most probably is less defensive than the reference used during the investigation. Practical tests (not executed by TNO) show possible fuel savings from 5% up to 25%.

2.4 Driving style tips

During the 1999 study it became clear that some changes in the Ecolomic driving protocol would enhance the overall environmental advantages of this new way of driving. Next to actual changes in the technical protocol (less than 75% throttle), the way the technical driving style recommendations should be communicated to the general public where the major issues of enhancement. The enhancement resulted in the following "new style driving" tips that are the subject of this investigation:

1. Shift as soon as possible at a maximum of 2500 rpm (for diesel a maximum of 2000 rpm) to a gear as high as possible. (In Dutch: *Schakel zo vlot mogelijk bij maximaal 2500 toeren (voor diesel maximaal 2000 toeren) naar een zo hoog mogelijke versnelling*.)
2. Press the throttle quickly and vigorously just as much that you can keep up with the traffic. (In Dutch: *Trap daarbij het gaspedaal snel en doortastend zover in dat u vlot met het verkeer kunt meerijden.*)
3. Do not shift down to a lower gear too early, and keep the car rolling without disengaging the clutch and in a gear as high as possible. (In Dutch: *Schakel niet te snel terug en laat de auto zo lang mogelijk zonder de koppeling in te drukken in een zo hoog mogelijke versnelling uitrollen.*)

3 Design of the programme

In order to answer the research questions a research programme was designed that consists of three parts:

Part I:	the recruitment of 24 testdrivers to participate in the research
Part II:	an on-the-road measurement campaign with the 24 testdrivers putting into practice the new driving style tips while the actual trip data were recorded.
Part III:	measurements on a chassis dynamometer in the TNO laboratory, in order to quantify the emissions and fuel consumption consequences of the testdrivers' interpretation of 'new style driving'.

Each part will be described separately in the next sections.

3.1 Part I: Recruitment of testdrivers

In the 1999 study, the on-the-road measurements were executed with TNO personnel. However, TNO personnel has too much knowledge on the technical background of new style driving to be regarded as representative for the average Dutch driver. It was not the aim of this study to collect data on average Dutch drivers, but comparing several driving styles.
In order to obtain more representative trip data for average driving, in this study the researchers chose to recruit a group of test drivers that would represent the 'average' Dutch driver. The size of this group had to be large enough to determine the effect of the tips given on individual driving behaviour itself and on fuel consumption and emission relevant vehicle parameters. The number of participants needed for statistical relevance of investigating driving behaviour has been determined in an earlier study executed for Novem [Van der Voort, 2001[1]], and was found to be 12. Since the effects of the tips on drivers of petrol and diesel fuelled passenger cars were expected to be different (because of the differences in engine characteristics), the interpretation of the tips has been investigated separately for petrol and diesel. Therefore a group of 24 drivers has been selected for this investigation (12 petrol drivers and 12 diesel drivers).

This group has been selected in a similar manner as in the earlier study, i.e. by using a local newspaper advertisement. In order not to influence the test persons on beforehand, the advertisement did not mention that the test concerned 'new style driving'. It must be noted that selecting participants like described above, will most likely attract people with more than average interest in vehicles and their technology, slightly influencing the "average driver" selection.

From the response of the advertisement 24 drivers were selected, in age between 25 and 67 years old, with at least 5 years of driving experience, driving at least 10.000 km per year. The distribution between male/female and petrol/diesel drivers should be equal. During August and September 2002 the test drivers were scheduled to participate in the test. The programme each test driver underwent is described in the next section.

[1] design and evaluation of a "Fuel Efficiency Support Tool"

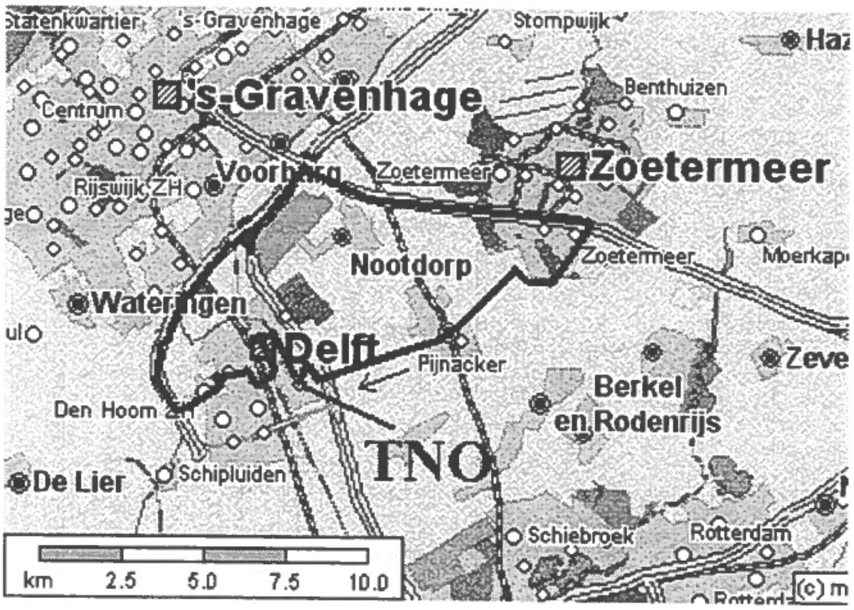
3.2 Part II: recording and analysis of real world 'new style driving'

The basic idea for this part of the research programme consisted of recording and analysis of real world trips of the test drivers who where instructed the 'new style driving' tips.

3.2.1 *Recording of real world trips*

The selected persons drove a route in and around Delft, in a vehicle provided by TNO that was equipped with a data logger. This route is the same route as used in the 1999 study to enable comparisons. The route consists of an urban part, an extra-urban part and a highway part and has a duration of 50 minutes.

Figure 1: *Test route*



For sampling the driving data two cars (petrol and diesel) were used. These cars were of the same type as used in the 1999 study: an Opel Vectra 1.6 16V petrol Euro 3 and an Opel Vectra 2.0 DTI diesel Euro 3. The Opel Vectra's were chosen because of their easy and average driving and handling characteristics and because they are very common in the Netherlands. The engine type choice is based on being highly representative for the Dutch car park for the near future. For the petrol car this means: small engine capacity, high power output, low torque at low engine rpm, electronic throttle actuation and advanced emission control technology (Euro IV). For the diesel car this means: high power output, turbo charging, 16 Valve technology, electrically controlled direct fuel injection, and oxidation catalyst emission control (Euro III).

Table 2 *Actual cars used for registration of real world trips*

Model	Engine type	Fuel	Transmission	Vehicle mass	kW/ton ratio
Opel Vectra	1.6 16V 74 kW	Petrol	Manual	1347	55
Opel Vectra	2.0 Dti 16V 74 kW	Diesel	Manual	1396	53

In the test each person drove the route three times:

1. The *first* time, the drivers were given the opportunity to get acquainted with the test vehicle and to explore the route, while driving their own style.
2. The *second* time, the driving pattern of the drivers was recorded, while the test drivers again drove their 'every day' driving style, without any further instructions. This trip will be further referred to as the **'pre-instruction trip'**.

After the second run was finished, the testdrivers were presented with the 'new style driving' instructions. The tips were presented in writing, because most people are likely to hear from 'new style driving' through advertisements in magazines and papers or by reading the internetsite. Therefore, the researchers were not allowed to answer any questions of the test drivers regarding 'new style driving' at this point. Before starting the third run, the testdrivers were given the opportunity to get accustomed to 'new style driving'.

3. The *third* time the route was driven the testdrivers were implementing their own interpretation of the tips. This trip will be further referred to as the **'post-instruction trip'**.

TNO personnel accompanied the test drivers on each occasion, taking notes on the actual driving behaviour of the testdrivers and on comments and remarks that they made while driving.

All trips were driven in the morning just after rush hour in order to assure driving under reproducible (non-congested) traffic situations. During the morning the test drivers were also asked to fill in two questionnaires.

Measuring driving patterns during the trips was done by means of a data log system that was installed in the test vehicle. This system recorded a.o.: vehicle speed, engine rpm time and throttle position. All signals were recorded at a frequency of 1 Herz. The gear positions were calculated afterwards.

3.2.2 Data analysis

For the analyses of the 'pre-instruction' and 'post-instruction' trips, first several parameters had to be calculated. These parameters are listed in the next table, which also indicates each parameter's importance for one of the three driving style tips. This will be further explained after the table.

Table 3 *Trip parameters*

Name	**Unit**	**Comment**	**Relevant for tip no.**
Average speed	[km/h]	When speed > 0 km/h	
Average RPM	[rpm]	When speed > 0 km/h	1
Average throttle position	[%]	When speed > 0 km/h	2
Average acceleration	[m/s2]		
Average deceleration	[m/s2]		
Relative Positive Acceleration (RPA)	[m/s2]	Measure for the dynamics of a certain trip pattern: $\int_0^T (v_i * a_i^+)\, dt / x$	
Positive Kinetic Energy (PKE)	[m/s2]	Acceleration energy needed in a certain trip pattern: $\sum(v_f^2 - v_s^2)$, dv/dt>0 / x	
Cycletime	[sec]		
Cycledistance	[m]		
Percentage stop time	[%]		
Average duration of a stop	[sec]		
Average duration of a sequence	[sec]		
Maximum acceleration	[m/s2]		
Maximum deceleration	[m/s2]		
Percentage accelerating (time)	[%]		
Percentage decelerating (time)	[%]		
Propulsion energy	[kJ/km]		
Number of gearshifts	-		
Number of shifts up	-		1
Average RPM before shift up	[rpm]		1
Number of shifts down	-		3
Average RPM before shift down	[rpm]		3
Average throttle position under acceleration	[%]	Acceleration > 0	2
Average throttle before shift up	[%]	Average calculated over 4 seconds prior to shift up	2
Engine braking in 5th gear	[sec]	Throttle = 0% and acceleration < 0	3
Engine braking in 4th gear	[sec]	"	3
Engine braking in 3rd gear	[sec]	"	3
Engine braking in 2nd gear	[sec]	"	3
Engine braking in 1st gear	[sec]	"	3

Conclusions can be drawn from the differences between the 'pre- and post-instruction' trips. These differences can be regarded as significant when they amount to more than 10%, because experience has taught that driving the same trip twice already can result in differences up to 10%.

In general, the most important parameters that characterise a trip are average speed, acceleration and the dynamics (RPA). But besides these parameters, there are also parameters calculated that can give an indication of whether a certain driving style tip has been put into practice by a certain driver. For each tip, this is discussed in more detail below.

Tip 1: When a driver changes his behaviour in such way the he or she shifts to a higher gear as soon as possible, the average rpm before shifting will drop. This will also increase the number of shifts up, because the driver will not be sticking in a low gear. At constant speed, driving in a higher gear means also that the rpm's are lower, and therefore the overall average rpm of a trip will be lower too, if a driver uses the tip in a correct manner.

Tip 2: Pressing the throttle of a vehicle results in acceleration, when a gear is engaged. Therefore, an increase in the average throttle under acceleration will be an indication that a driver is pressing the throttle fastly and vigorously, just as tip 2 prescribes.
This process especially will occur when accelerating from standstill and shifting up to higher gears (in combination with tip 1). Therefore the average throttle position has been calculated just before a shift up.

Tip 3: The total time the vehicle is decelerating by means of engine braking is calculated for each gear. When the distribution of this engine braking time shifts to the higher gears, this is an indication that a driver is using tip 3 in a correct way. Engine braking in a high gear also means that a shift down will be at a lower rpm, therefore this parameter is also calculated.

There are also a lot of parameters calculated that are not specifically needed for the above-mentioned analysis, but they may be useful for checking the pre- and post-instruction trips on their consistency.

Besides a numerical analysis of the trip data, also the observations of the researchers accompanying the drivers on their trips are taken into account. Also the questionnaires that have been filled in are a valuable source of information.

In chapter 5 the results of this part of the study are described.

3.3 Part III: measuring the effects on fuel consumption and tail pipe emissions

In addition to determining the interpretation and application of the driving style tips, the actual effects of certain ways of interpretation of the tips on the tail pipe emissions and fuel consumption of modern passenger cars have been measured. For this purpose, a measurement campaign has been developed using cars driving a representative selection of the driving patterns recorded on the road. In order to measure the emission parameters, several cars drove a trip (driving cycle) on a chassis dynamometer, while measuring the tail pipe emissions. Based on the results of part II (significant differences), dedicated 'short cycles' were developed. This section describes the general approach that was followed.

3.3.1 Development of 'short cycles'

For efficiency reasons, not every recorded trip could be driven on the chassis dynamometer. Therefore only a small representative part of the real world trip was programmed and projected to the driver. In fact at least 6 minutes of driving for one measurement is necessary in order to obtain reliable measurement data.

This 'compression' of data to a trip of 6 minutes is executed by using a method initially developed at TNO Automotive by C.J.T. van de Weijer [van de Weijer, 1997]. This method consists of the determination of several representative parameters, describing the total practical trip, followed by comparing these parameters with the same parameters of smaller parts of the total trip. The best fitting partial trip is then determined statistically using the Chi2 method. The difference between the characteristic values of the real trip and those of the compressed trip should not be bigger than 5%.
The parameters used for the trip characterisation are the same as listed in table 3. In order to obtain the best possible characterisation of a driving cycle within the project, the most important parameters are the ones related to speed and acceleration (deceleration) of the car in combination with the use of the engine map. Especially RPA has proven to be a parameter that characterises a trip very well. In fact RPA represents a combination of average speed and positive accelerations.

The eventual selection of the short cycles to be driven on the chassis dynamometer will depend on the results of part II. The selection will therefore be discussed in chapter 6.

3.3.2 Chassis dynamometer measurements

Once the short cycles have been developed and an appropriate selection has been made, they are driven in the laboratory on a chassis dynamometer, while measuring the tail pipe emissions. This approach involves measuring tail pipe emissions and fuel economy separately from the actual driving on the road. In fact the time/speed and gearshift diagram of the actual trip on the road is presented to a professional driver in a car on the chassis dynamometer, while the tail pipe emissions and fuel economy are measured with equipment outside the car. The chassis dynamometer is adjusted to simulate the driving resistances (inertia, drag and rolling resistance) of the actual car being measured. The reason for this approach is the fact that legislation on the point of measuring tail pipe emissions and fuel economy, is based on measurements with fixed measurement equipment in a roller bench laboratory under controlled climatological conditions. Although measuring emissions on the road in technically feasible, TNO has chosen for the high stability, high repeatability and the possibility to test a large number of vehicles under the same conditions of measurements under laboratory conditions.

The tail pipe emissions and fuel consumption can vary widely in relation to the type of car and the type of driving pattern used. Therefore it is extremely important to test a considerable number of cars in order to achieve an as high as possible significance of the measured results. For this reason, testing only the two Opel Vectra's as used in part II was regarded as insufficient. Within this part of the project, 12 cars were subjected to the measurements: 7 petrol cars and 5 diesel cars. Because New Style Driving is especially suited for cars with the latest technology and also to obtain a data set that is both valid for the current as well as for the future vehicle fleet, only modern emission class cars were tested (Euro 2 and Euro 3). The cars actually tested are listed below.

Table 4 *Cars test on chassis dynamometer*

Fuel	Vehicle make	Model	Leg.cat.	Eng.displ.	Veh.Mass	Pmax	P/W
				[cm^3]	[kg]	[kW]	[kW/tonne]
petrol	BMW	316I	Euro 3	1895	1334	77	58
	Daewoo	Tacuma	Euro 3	1761	1428	72	50
	Ford	Mondeo	Euro 2	1988	1358	96	71
	Opel	Vectra	Euro 3 (D4)[1]	1598	1347	74	55
	Renault	Laguna	Euro 3	1783	1468	88	60
	Toyota	Corolla	Euro 3	1398	1097	71	65
	Volvo	S80	Euro 3 (D4)[1]	2435	1501	125	83
diesel	Opel	Vectra Dti 16V	Euro 3	1995	1396	74	53
	Peugeot	406 Hdi	Euro 3	1997	1441	80	56
	Renault	Clio Dci	Euro 3	1461	1054	48	46
	Toyota	Corolla	Euro 3	1867	1154	51	44
	Volkswagen	Passat TDI 66 kW	Euro 2	1896	1427	66	46

[1] Vehicle meets Euro 4 emission levels under the current Euro 3 type approval procedure

All cars were equipped with a manual transmission. The car selection described above, gives a good representation of the most modern part of the Dutch vehicle fleet regarding the technologies used and the amount of kilometres driven with certain types of fuel.

All tests were executed with hot engines only, because cold start effects are not interesting when investigating the interpretation of driving style tips.

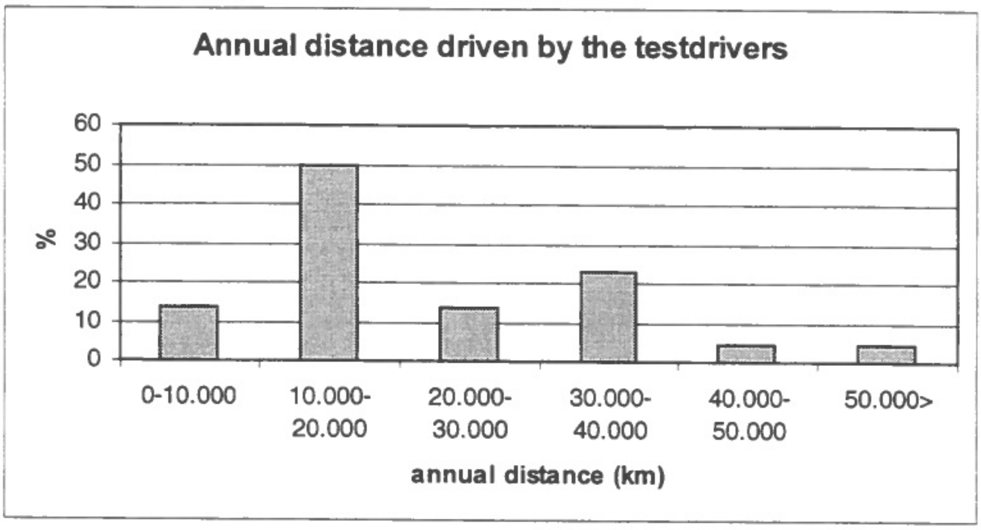
4 Result of part I: Recruitment of test drivers

In this chapter the results of the recruitment of the test drivers is discussed in more detail. After the advertisement had been placed in the local newspaper, more than 50 people responded. Many respondents were male petrol drivers, and it appeared rather difficult to find sufficient female diesel drivers. Therefore, a 50%/50% distribution between male/female and petrol/diesel was not achieved. The actual composition of the group test drivers that participated was as following:

	Petrol	Diesel
Male	6	7
Female	7	4

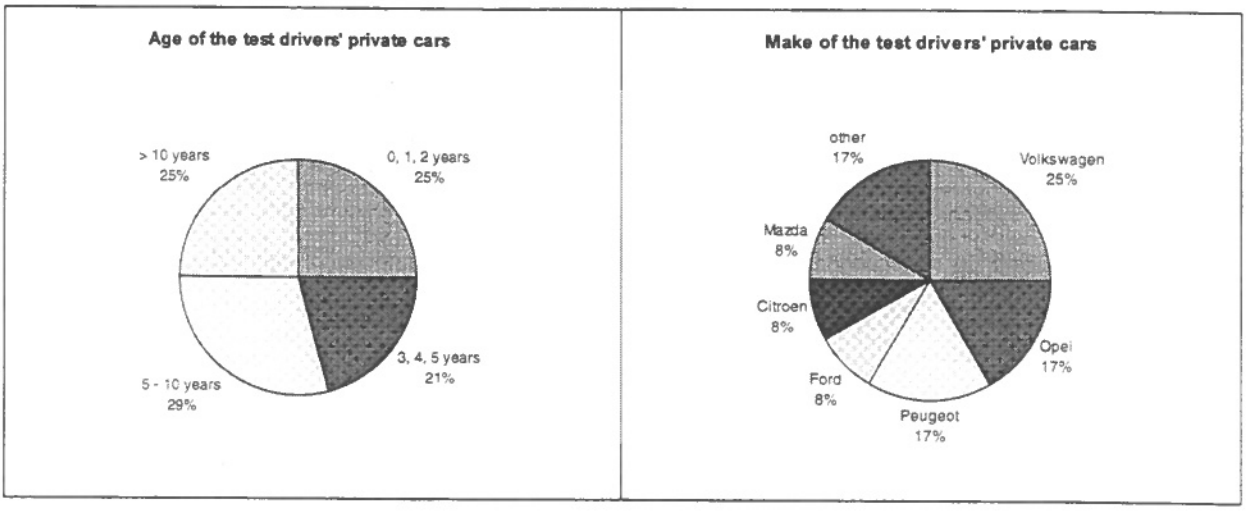
This group of test drivers was very balanced in terms of age and division of private/professional drivers. Also the annual distance driven by the test drivers varied from approximately 10,000 kilometres to 100,000 kilometres. The distribution is given in the next figure.

Figure 2 *Annual distance driven by the test drivers*



Also the ages and the makes of the test drivers' private cars show a large diversity, as can be seen in the next figures.

Figure 3 *Ages and makes of the test drivers' private cars*



Before starting the third trip of the test programme, the drivers were asked whether they had already heard from 'New Style Driving'. Nine persons could confirm this, of which two claimed that they also put it into practice. When asked to describe 'New Style Driving' most of them associated this with an economical driving style by keeping the engine rpm low and shifting up to a gear as high as possible. Driving more 'fluent' was also mentioned. A majority of 15 (out of 24) persons however had never heard of 'New Style Driving'.

5 Results of part II: recording and analysis of real world 'new style driving'

After the on the road test-drives had been completed, the collected data was analysed on driving behaviour parameters, by calculating the parameters as described in section 3.2.2. As mentioned earlier, this pure parametric analysis is needed in combination with the more qualitative observations of driving behaviour by the test witnesses and drivers.
In general, it appeared that the pre- and post-instruction trips showed very little differences for the highway part of the route. These highway parts consisted of only one acceleration in combination with shifting up, after which a period of a relatively constant speed followed. As the tips have a strong focus on the way a driver operates throttle and gearbox, it is not surprising that the pre- and post-instruction highway-trips very often did not show any significant differences. Therefore, the analysis of the data will focus only on the urban and extra-urban parts of the route.

The data analysis is presented here in two parts; in the first part the data is evaluated in order to discover certain trends without looking too much into the details of the trip data. In the second part the trends discovered in the first part are further assessed by a numerical analysis.

5.1 Data analysis part I

For each test driver it is determined (based on a combination of qualitative and quantitative results) to which extent the 'New Style Driving' tips had been put into practice. Based upon this it appeared that specific groups of test drivers could be identified. These specific groups will be further discussed in the next sections for both the petrol and the diesel drivers.

5.1.1 Petrol

After all parameters of each trip had been calculated, it appeared that the performance of the petrol drivers could be divided into 4 categories:

1. Drivers who use all three tips correctly. (3 persons)
2. Drivers who use tip 1 and tip 3 correctly but who consequently do not put into practice tip 2 (3 persons)
3. Drivers who show no significant difference in their driving style after the instruction (6 persons)
4. Drivers who use all three tips incorrectly (1 person)

Each category will be discussed briefly.

1. All tips correct
This category consists of three persons. They showed 'new style driving' in almost every aspect after the instruction. Applying tip 2 in an urban environment was found to be difficult according to these persons, or even impossible, because it implies faster accelerating and that is very often not possible in urban traffic. This is also reflected in the data, because the differences between the pre- and post instructions trips appeared to be the greatest in the extra urban part. In two cases

the driving dynamics were slightly lower, but the one person increased the dynamics a lot in the extra-urban part because she applied tip 2, as she explained later.
These persons also clearly managed to apply tip 3 without difficulties.

2. *Tips 1 and 3 correct, but not tip 2*

Another group that could be clearly distinguished, were three persons who only applied tip 1 and tip 3, but not in combination with tip 2. The main reasons given were that they didn't understand this tip or because their "common sense" told them that a high throttle position in combination with a high gear means a high fuel consumption and also a high speed in areas were this is not allowed, especially urban areas. Three persons have much lower dynamics in their driving style after the instruction. Also the correct application of tip 3 was clearly visible (data and observations).

3. *No significant difference*

The largest group of persons, 6, didn't show a significant difference in their driving style before and after the instruction. Three of these drivers already had some 'new' elements in their initial driving style, whereas the driving style of the others can be characterised as average (before and after instruction).

4. *Incorrect*

One person focused so much on tip 2, that he forgot to keep an eye on the rev-counter. Higher rpm, speed and dynamics were the result.

5.1.2 Diesel

The performance of the diesel drivers can be divided into 3 categories:
1. Drivers who use all three tips correctly. (2 persons)
2. Drivers who use tip 1 and tip 3 correctly but who do not put into practice tip 2 (3 persons)
3. Drivers who show no significant difference in their driving style after the instruction (6 persons)

No diesel driver interpreted the tips incorrectly. Generally, the same remarks as made for the petrol drivers also apply for diesel drivers. One general comment on the diesel car that was often heard, was that the engine characteristics of the Opel Vectra 2.0 DTi are very well suited for high rpm's, because of the turbo-lag at low revs, which is common for modern turbocharged diesel engines. Just when the tips advise the driver to shift up (before 2000 rpm) the engine starts to deliver its power, so he or she can't use it. This is often experienced as frustrating.
The driving style of the testdrivers who showed no difference after the instruction did not already include elements of New Style Driving in their initial driving style.

5.2 Data analysis part II

With test drivers divided into the above-mentioned groups, the data can be analysed in more detail by looking at some typical trip parameters of each group. The figures on the next pages show the standard deviation of the differences that occurred between the pre- and post-instruction trips. Not only the magnitude of the differences becomes clear, but also insight is given in the spread of the changes per group. The figures have been made for the urban part and the extra urban part of the trip. In the case of the petrol driver that interpreted the tips incorrectly, a standard deviation could not be calculated (only 1 measurement). For reasons of visibility in the graphs however, in this case the standard deviation has been given the value of 1%.

First a general characterisation of the trips is presented, followed by a more detailed analyses based on certain typical behaviour, addressing the effects on driving behaviour related to each tips separately.

5.2.1 *General trip characterisation*

In general a trip can be characterised by its average speed and its driving dynamics. Therefore the next figures show the differences that occurred after the instruction for both of these parameters.

Figure 4 *Average speed (v-gem); standard-deviation of difference between pre- and post instruction trips of each group identified*

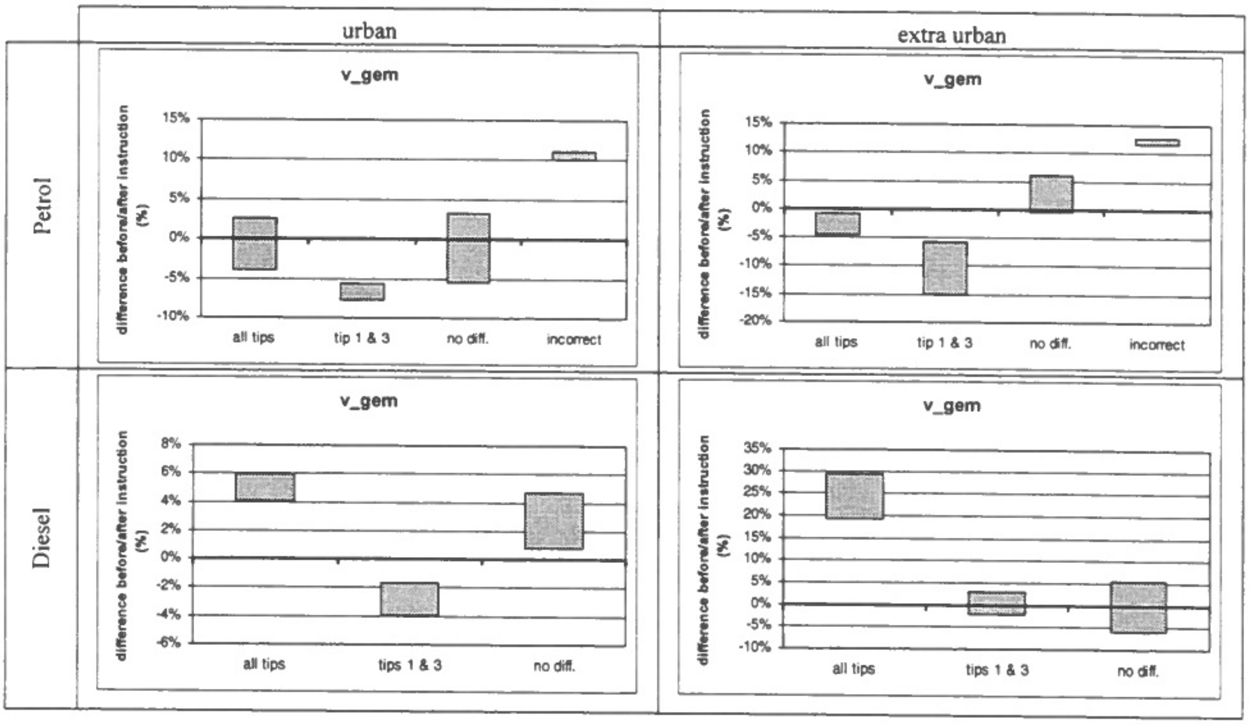
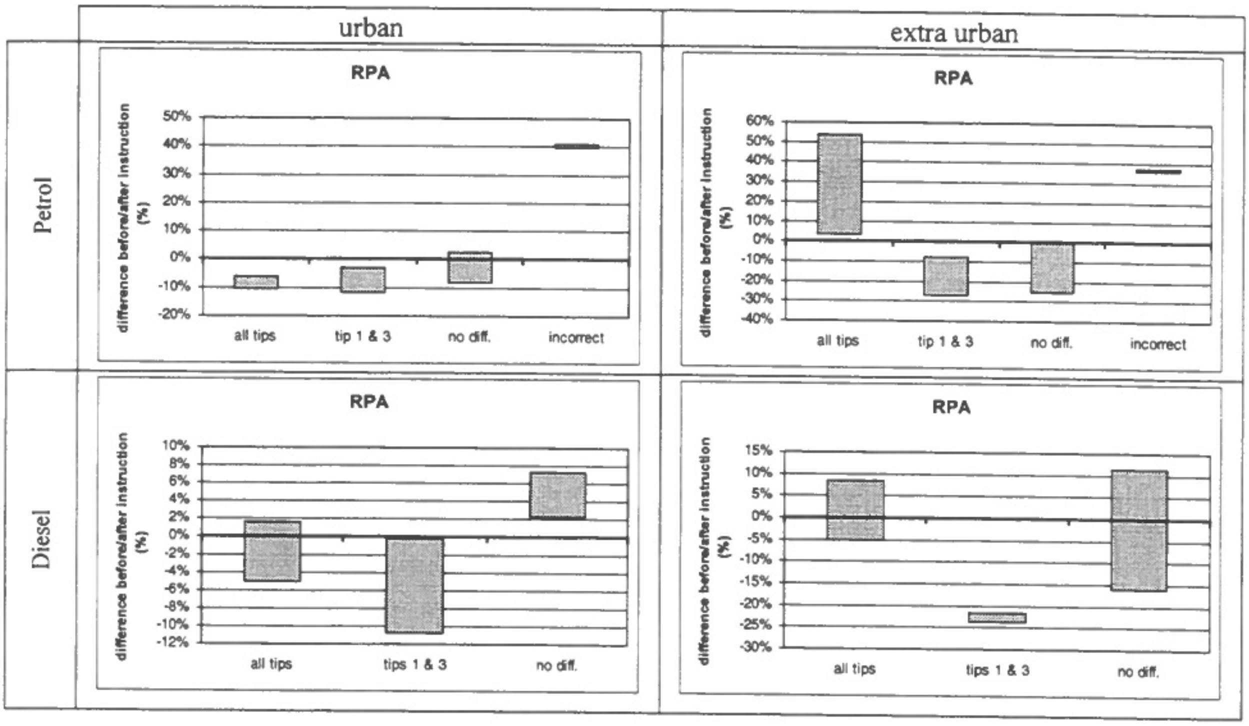


Figure 4 shows that the test drivers who applied all tips didn't significantly lower their average speed, which shows that 'New Style Driving' does not result in slower driving. The drivers who only applied tip 1 and 3 had a strong tendency to slow down their speed. The fact that the diesel drivers even managed to increase their speed in the extra urban part was due to some congestion that occurred in the pre-instruction trip.

Figure 5 *Trip dynamics (RPA); standard-deviation of difference between pre- and post instruction trips of each group identified*



In general a tendency to drive more fluently after the instruction (lower RPA) is visible, this is however most strong for the persons who applied tip 1 and 3. Remarkable is the increase of dynamics in the extra urban part for the drivers who applied all tips. This can be explained by the fact that application of tip 2 can result in a higher acceleration of the vehicle, which may occur in areas where the behaviour is not limited by surrounding traffic, such as extra urban roads. The tendency to accelerate to higher speeds was also observed by the drivers themselves.

It is clearly visible that the driver who interpreted the tips incorrect increased speed and dynamics significantly.

5.2.2 *Tip 1*

In this section several parameters typical for tip 1 will be analysed for each group identified.
When a driver shifts up at lower engine rpm, the average rpm of a trip will be lower, which is illustrated in the next figure.

Figure 6 *Average engine rpm (n_gem); standard-deviation of difference between pre- and post instruction trips of each group identified*

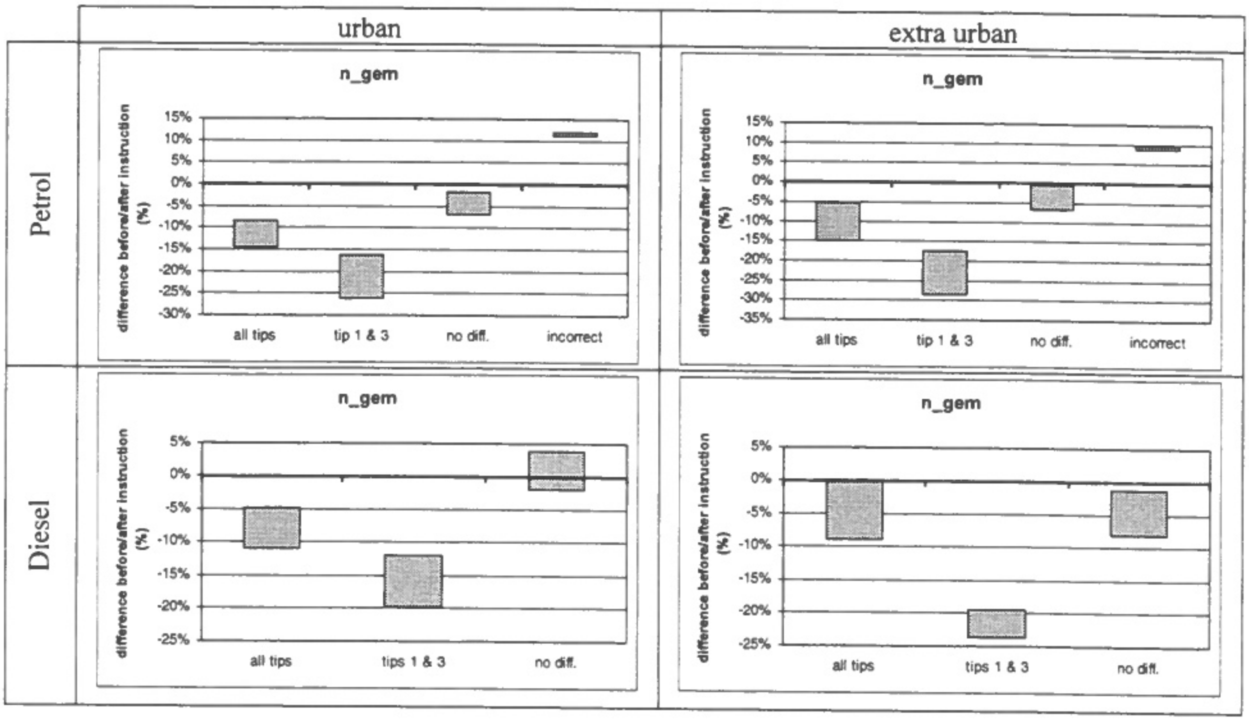
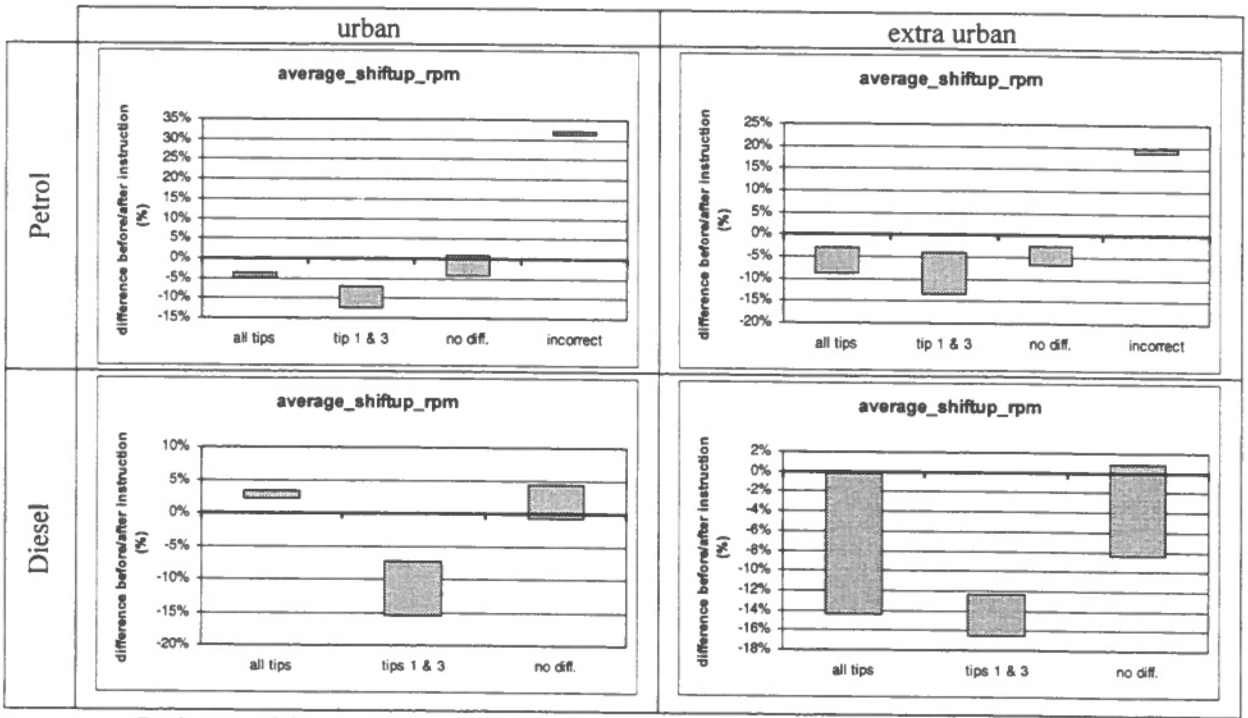


Figure 7 *Average engine rpm before shifting up (average_shiftup_rpm); standard-deviation of difference between pre- and post instruction trips of each group identified*



Both sets of figures illustrate clearly that drivers have lowered the engine rpm, except for the person who interpreted the tips incorrectly. The largest reduction is visible for the drivers who applied tip 1 and 3.

5.2.3 *Tip 2*

In this section several parameters are presented that relate to tip 2 (throttle position) during the trips, of each group identified.

Figure 8 *Average throttle position; standard-deviation of difference between pre- and post instruction trips of each group identified*

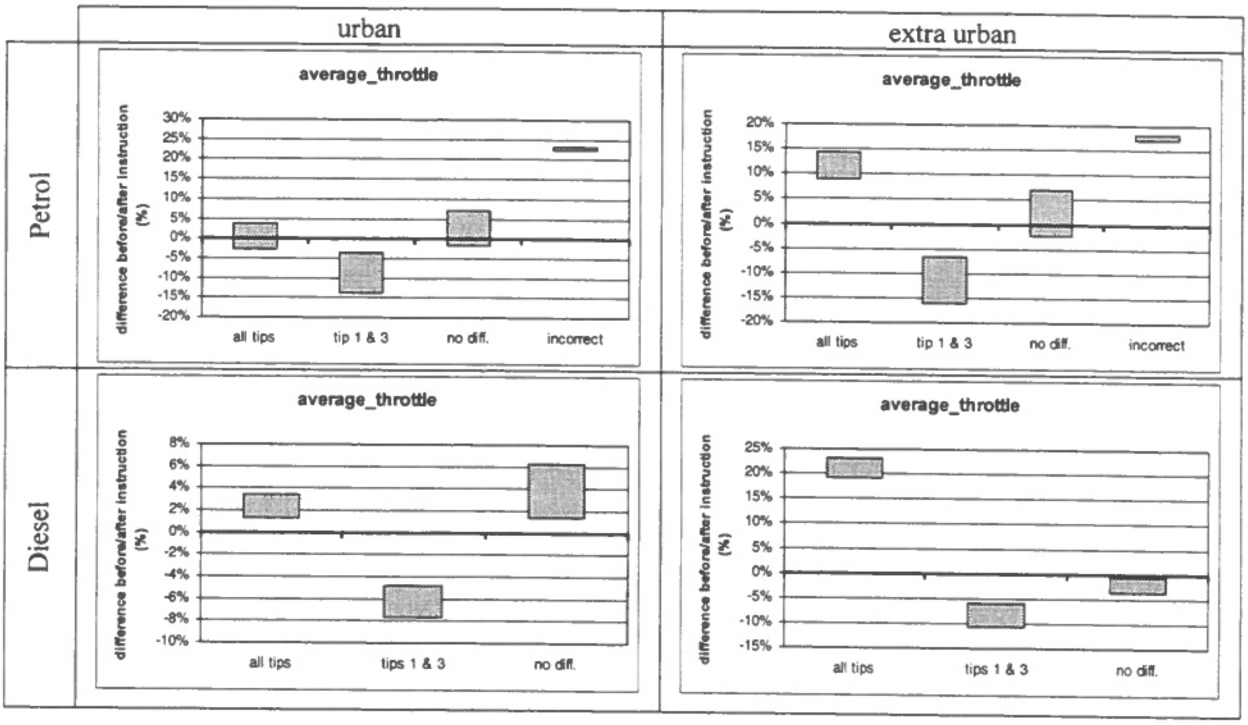


Figure 9 *Average throttle position before shifting up; standard-deviation of difference between pre- and post instruction trips of each group identified*

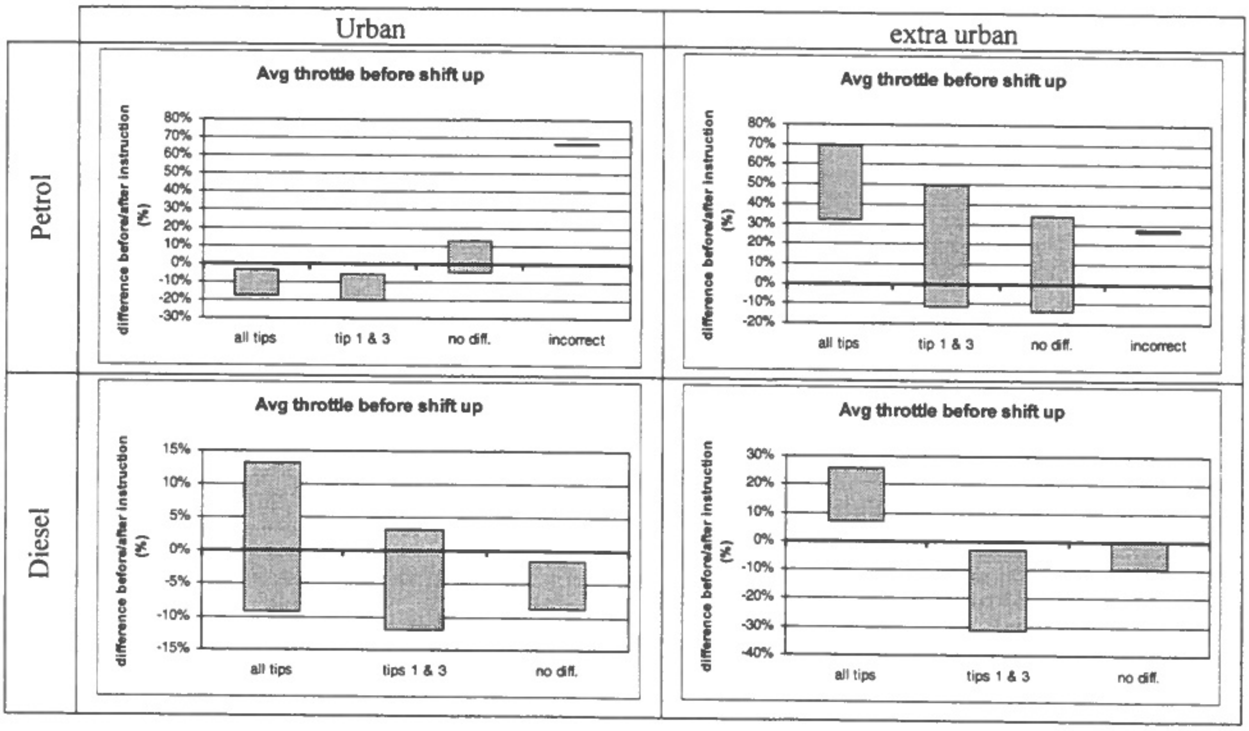
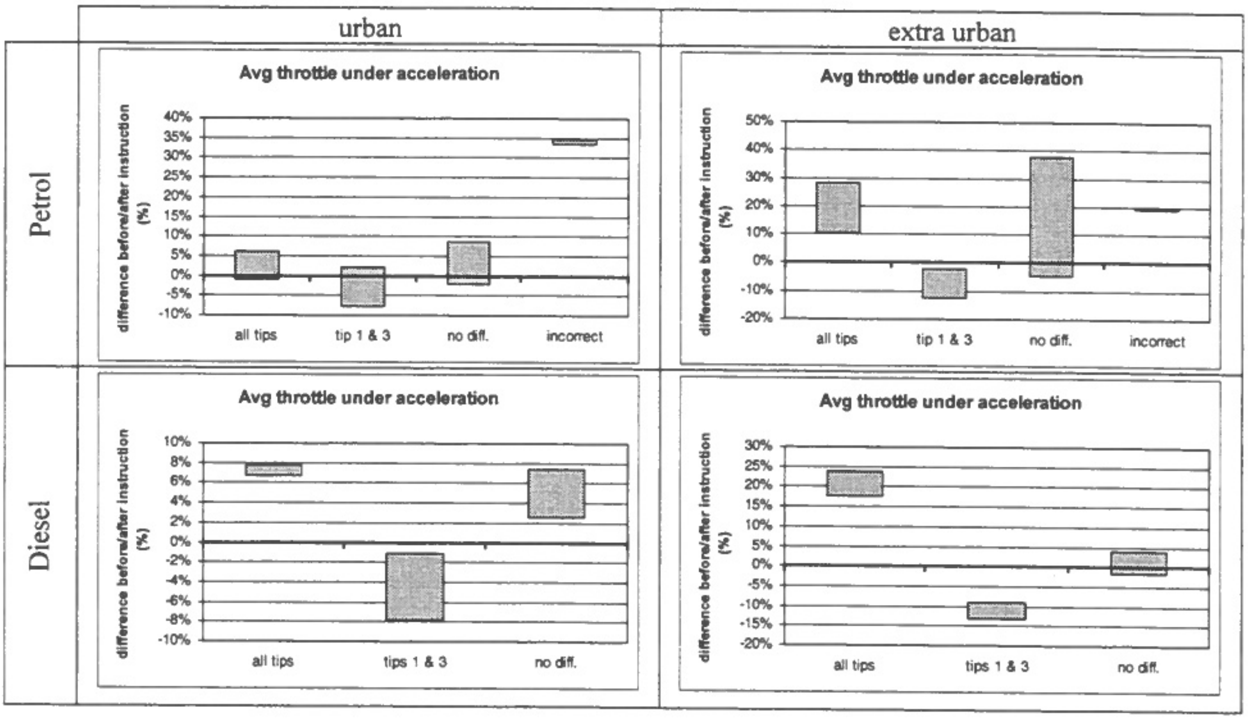


Figure 10 *Average throttle position under acceleration; standard-deviation of difference between pre- and post instruction trips of each group identified*

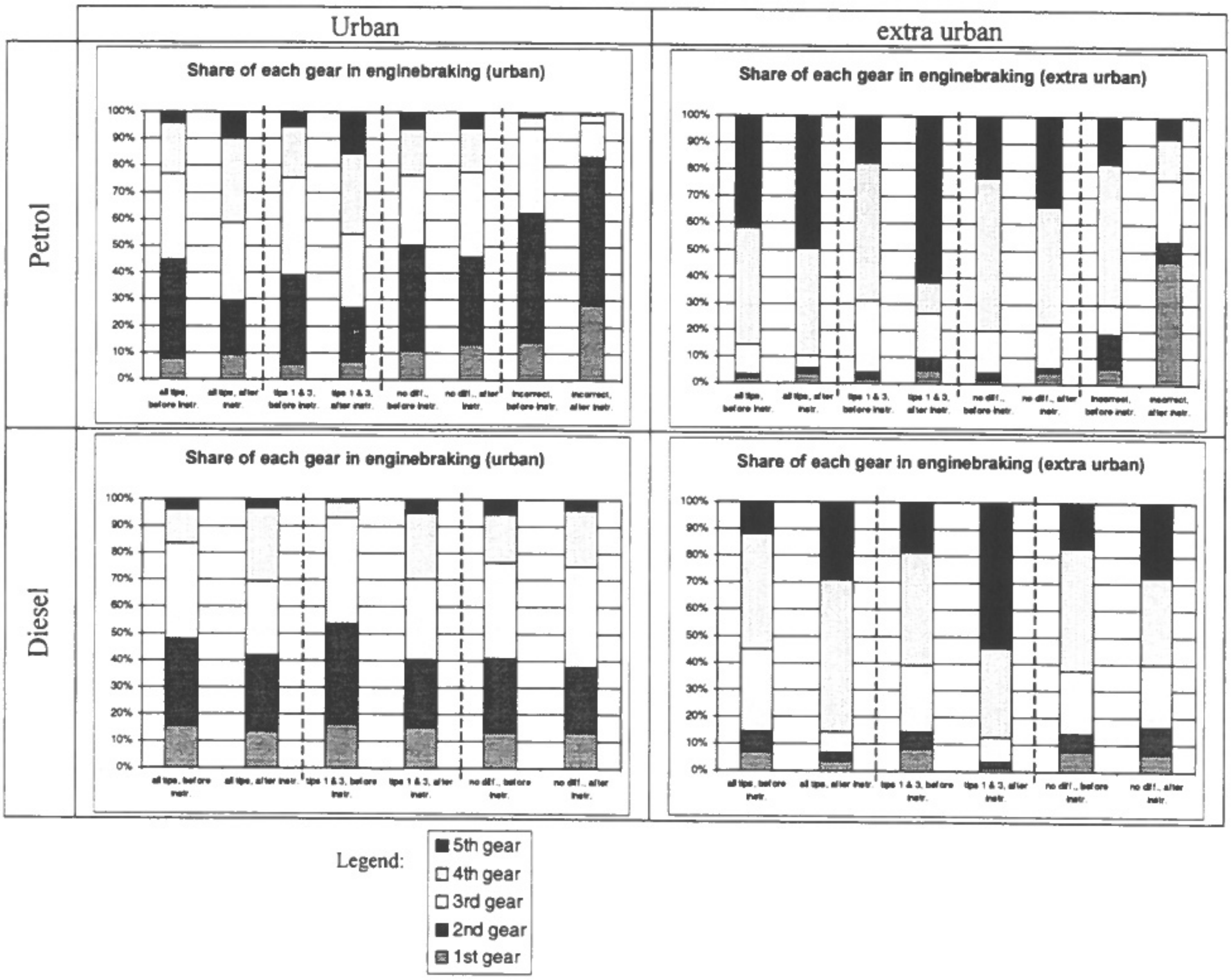


The distinction that has been made between the groups is also visible here. Remarkable is the fact that the increase in throttle position for the group that applied all tips is the largest in the extra urban part. Apparently the test drivers could apply this tip better in situations with less traffic, where there is more room for higher accelerations without limitation of surrounding traffic.

5.2.4 *Tip 3*

The share of each gear while engine braking (a deceleration with a gear engaged and a throttle position of 0%) before vs. after the instructions reflects the amount to which tip 3 has been applied by the testdrivers. A larger share of the higher gears (especially 4th and 5th gear) indicates that the drivers engine braked according to tip 3. The share of each gear is presented graphically by the columns in the next figure.

Figure 11 *Share of each gear in engine braking, pre- and post instruction trips of each group identified*

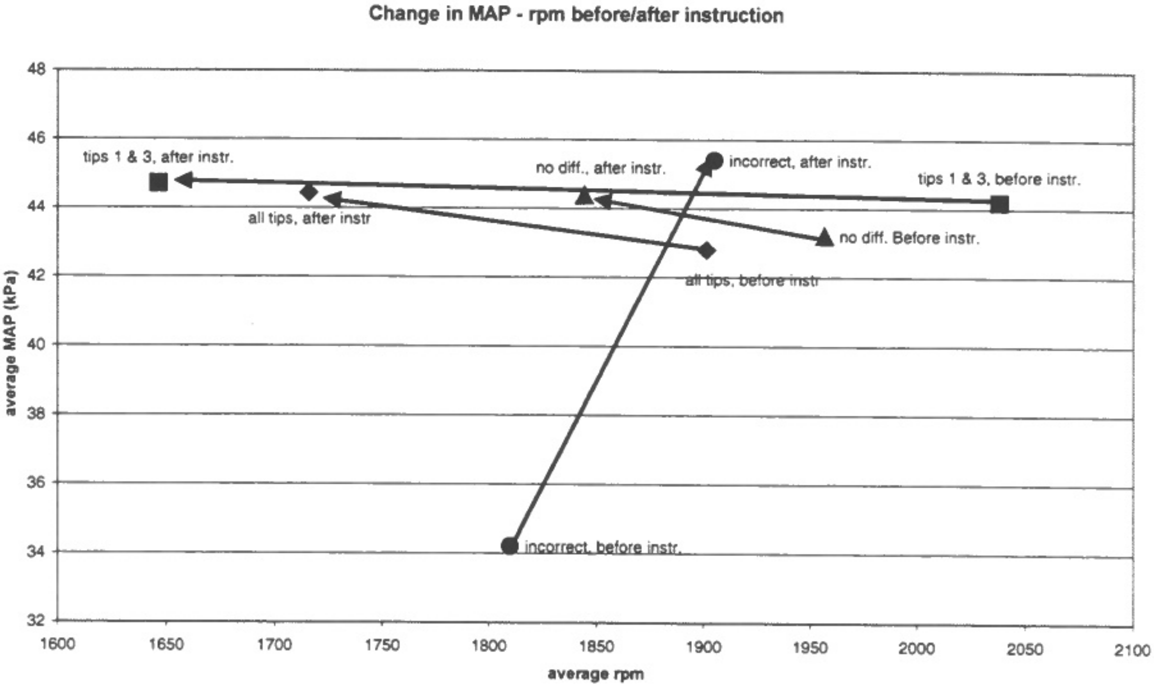


It is visible that the 4th and the 5th gear have a higher share after the instruction for those groups of drivers who applied tip 3.

5.2.5 *Engine map*

An Opel Vectra petrol is equipped with a MAP-sensor (Manifold Absolute Pressure). The signal of this sensor is a measure of average engine torque. Therefore, it was decided also to log this signal during the test programme. An analysis of the average MAP values gives insight in the way that the tips have been applied. In the next figure, the average MAP values are displayed against the average engine rpm of the four groups of test drivers that have been identified in this chapter, before and after instruction. A movement along the horizontal axis indicates (to lower rpm) that tip 1 has been applied. A movement along the vertical axis, towards higher average pressures, means that the engine load/torque has increased which indicates that tip 2 (a higher throttle position) has been applied.

Figure 12 *Change in average Manifold Air Pressure/average engine rpm before/after instruction of the 'New Style Driving' tips*



Except for the person who interpreted all tips incorrectly, all test drivers lowered the engine rpm after the instruction. However, the increase of the engine load appears to be very modest, which is rather surprising for the group of persons who applied all tips according to the analysis conducted earlier in this chapter. A reason for this phenomenon could be that the increase of the throttle, and therefore the increase of the engine load, only occurs during a short period of time, compared to the total trip length. The effect of this increase of engine load becomes relatively small when averaged over the total trip. The person who interpreted the tips incorrect increased the engine load a lot, caused by the higher speed and dynamics of his trip after the instruction.

5.3 Remarks of the test drivers

The previous sections showed a numerical analyses of the trip data, from which certain conclusions can be drawn. It is important, however, to confront this analysis with the personal experience of the test drivers in order to make recommendations for adjusted tips. Therefore, after the third trip was completed the test drivers were asked to fill in a second questionnaire. The major findings are summarised in this section, grouped according to the categorisation as used in the previous sections.

Remarks of test drivers who applied all tips correctly

Each driver in this group found that tip 1 is very easy to understand. There was no consensus on tip 2. One person indicated that tip 2 appears to be in contradiction with tip 1: "How can one press the throttle quickly and vigorously and at the same time keeping the engine rpm low?" Tip 2 encourages speeding remarked another test driver. Several test drivers indicated that they only focused on the application of tip 1. But in practice, as the analysis in the previous section showed, this already automatically implicated a higher throttle position. One person confirmed this by saying afterwards that when looking back to the third trip "I think I subconsciously also applied tip 2".

Tip 3 appeared to be no problem for these test drivers.

Remarks of test drivers who applied tip 1 and tip 3 correctly

Also this group of test drivers found tip 1 very easy to understand. There were various opinions on tip 2, however. Although the analysis of the data showed otherwise, some drivers indicated they did (try to) apply tip 2. Apparently they interpreted this tip by a quicker throttle actuation instead of a higher throttle position. However, the frequency at which the data has been collected (1 Hz) does not allow to do a further analysis on this hypothesis. A clearer formulation of tip 2 is desirable, according to some persons. Especially when applying a "quick" throttle actuation it is rather difficult to adapt one's speed to the surrounding traffic.

Tip 3 appeared to be no problem for these test drivers.

Remarks of test drivers who had no significant difference after the instruction

This group of test drivers showed no significant differences in the trip parameters after instruction, but their perception of it was not always in correspondence with the data logged. The opinions on the tips varied from 'very clear' to 'very unclear'.

Most test drivers had no difficulties comprehending tip 1. Some suggested that this tip should also provide information on minimum rpm, and not only the maximum rpm at which to shift to a higher gear.

Tip 2 gave several drivers the impression that it meant that they had to drive faster, which is obviously not the case. It is important to give an actual demonstration of what is meant, one person remarked, because it is rather difficult to comprehend that 'New Style Driving' does not mean driving very slowly. While being given this requested demonstration (after trip III), the very low fuel consumption figures that could be seen on the board computer made this way of driving even more enjoyable, the test driver remarked.

As was mentioned also by the other groups, several persons remarked again that tip 1 and tip 2 seem to be contradictory at first glance. When trying to put this into practice the test drivers experienced that they were driving faster.

Some drivers who didn't understand the tips asked for a demonstration afterwards of 'New Style Driving' by the accompanying TNO employee. This then appeared to be a revelation for these persons.

One test driver found that more explanation to the tips is needed, the tips are very minimal.

Remarks of test drivers who interpreted the tips incorrectly

This test driver was fully convinced he applied the tips correctly. However, he associated 'New Style Driving' with gaining speed as fast as possible and then keeping the speed constant.

5.4 Discussion

One thing that became clear after the test program was that it is very important to have a group of testdrivers that is big enough to have a good impression on how the driving style tips are put into practice. An aspect that should be taken into account when discussing the results is that the testdrivers were already positively motivated in the first place to participate in the test. Secondly, they were more encouraged to put into practice the tips under influence of the presence of TNO staff, than may have been the case in real life. This means that in practice the effects that have been observed here will probably be smaller.

None of the testdrivers met the profile of 'New Style Driving' as a whole, but most of them interpreted some elements of it when they thought the situation allowed for it. In other words, none of the testdrivers fully exploited the potential of New Style Driving.

Although both the pre-instruction trip and the post-instruction trip were driven outside peak hours, it appeared that the traffic could differ significantly due to random occurrences such as slow (agricultural) vehicles. These occurrences have been removed from the data as much as possible, but it is impossible to fully eliminate these effects from the data analysis.

Regarding the interpretation of the tips the following remarks can be made:

The message of tip 1 was clear for almost every testdriver, though the eventual application varied among the testdrivers. This seems logical from the point of view that lower engine rpm's are easily to be associated with an economical driving style. This does not count for tip 2 however. Though it is explainable from a technical point of view that pressing the throttle fastly and vigorously will result in an increased engine efficiency if applied in a correct way, many testdrivers experienced this tip as contradictory to economic driving. Some testdrivers remarked that it even encouraged speeding. Therefore most often this tip was ignored at all. The data also shows that tip 2 was mainly applied in the extra urban part of the route, Apparently, the testdrivers that somehow comprehended how to apply tip 2 only managed to do this extra urban, where the distances between traffic participants are greater and where higher speeds are reached.
The application of tip 1 results in a drop of the engine rpm for the whole part of an urban and an extra urban trip, whereas correct application of tip 2 will only result in higher throttle positions in relatively short time intervals, for instance when accelerating from standstill at traffic lights. Therefore the overall increase in engine load (efficiency) will remain very small when a trip as whole is considered. This is illustrated by the MAP values in figure 12 where the increase in engine load of the testdrivers who applied tip 2 is of the same magnitude as the increase in engine load of the other groups of testdrivers (the person who interpreted the tips incorrectly excluded). Most striking is the decrease in engine rpm of the testdrivers who only focused on tip 1.

Tip 3 contains a message that is easy to comprehend, and therefore was applied by almost every testdriver in a correct manner. The only remark that can be made here is that when engine braking, the full shut-off usually stops below 1500 rpm in modern passenger cars. Engine braking in fifth gear below 60 km/h therefore brings no further reduction in fuel consumption.

It is obvious that tip 1 and tip 3 should be part of the communication to the general public. Regarding tip 2 however, a trade off must be made between the complexity of the message to be communicated to the general public versus the fuel consumption and emission gains that may be achieved. Also the effects of a misinterpretation must be taken into account.

Both the gains that may be achieved as well as the effects of a misinterpretation will be determined in the next part of this study.

6 Results of part III: measuring the effects on fuel consumption and tail pipe emissions

6.1 Design of the measurement program

For reasons of time and financial resources it was impossible to subject the trips of each test driver to a measurement programme on the chassis dynamometer. Therefore the measurement programme on the chassis dynamometer had to be designed in such a way that the questions as determined in part II of this study are answered; the fuel consumption and emission gains that may be achieved by applying tip 2 in combination with tip 1 and tip 3, compared to the application of only tip 1 and tip 3. Also the effects of a misinterpretation of the tips should be taken into account.

The benefits of tip 2 can be determined by comparing the results of the trips driven by the testdrivers who applied all tips correctly with those of the testdrivers who only applied tip 1 and tip 3 correctly. The tips did not influence highway driving, therefore no emission tests were executed for the highway parts.
Each group identified in the previous chapter consisted of several test drivers however. In order to fit the trips of the remaining groups to the available time and budget, further choices had to be made. The researchers, together with Novem, chose to select from each group the testdriver that displayed the kind of behaviour of the group as a whole most strikingly, to maximise the (expected) effects on the chassis dynamometer.

The purpose of this measurement program is to gain insight into the parameters that are critical factors for emissions and fuel consumption. Therefore it was permitted to choose typical trips from typical drivers to be driven on the chassis dynamometer, instead of averaging several trips belonging to a certain category. Since only the trips of one single testdriver per group have been driven on the chassis dynamometer, the values presented in this chapter are indicative of typical effects that may occur by using a certain way of driving.

The on the road measurements were executed with a petrol and a diesel car. Accordingly eight test cycles were developed for both petrol and diesel, as displayed in the next table. These cycles were used to test 7 petrol cars and 5 diesel cars (see table 4).

Table 5 *Test cycles*

	Before instruction		after instruction	
	urban	Extra urban	urban	Extra urban
All tips	x	x	x	x
Tips 1 and 3	x	x	x	x

In order to oversee the effects of a misinterpretation of all tips, the trips of this specific test driver were added to the above-mentioned test programme. For time and budget reasons however, these trips were driven with one car only, the Opel Vectra (petrol), because this vehicle was also used to record the trip on the road.

The next figures show the average speed and RPA of the actual trips driven on the chassis dynamometer.

Figure 13 *Average speed and dynamics (RPA) of the actual trips driven on the chassis dynamometer*

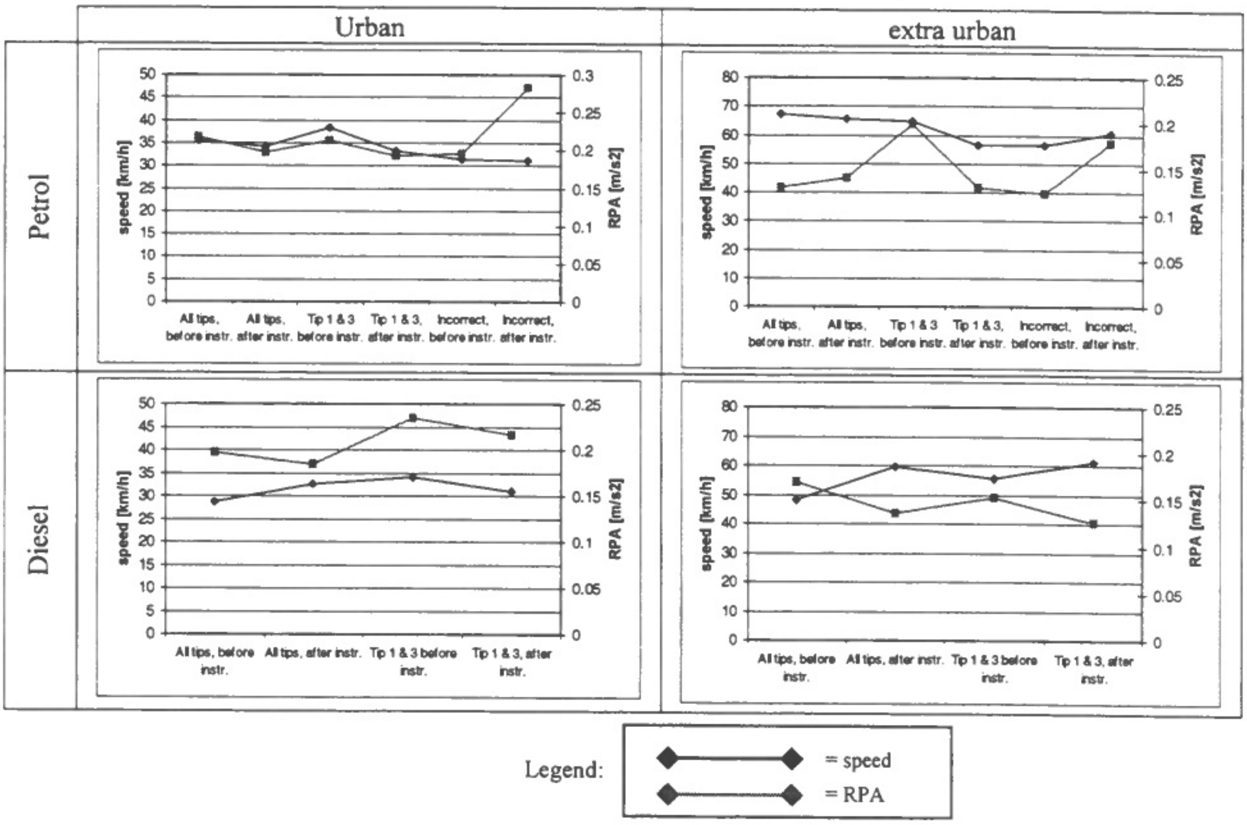


Table 6 *Differences in trip parameters of chassis dynamometer test cycles*

		difference (%) before/after instruction			
		speed	RPA	engine RPM	throttle pos.
petrol	All tips, urban	-4%	-9%	-3%	-4%
	All tips, extra urban	-3%	9%	-3%	10%
	Tips 1 & 3, urban	-13%	-10%	-33%	-21%
	Tips 1 & 3, extra urban	-12%	-35%	-37%	-21%
	Incorrect, urban	-1%	45%	7%	18%
	Incorrect, extra urban	8%	44%	8%	16%
diesel	All tips, urban	13%	-6%	-11%	4%
	All tips, extra urban	24%	-20%	3%	29%
	Tips 1 & 3, urban	-9%	-7%	-23%	-12%
	Tips 1 & 3, extra urban	10%	-18%	-24%	-2%

The RPA values usually drop after the instruction, which indicates that the testdrivers drove more fluently. The average speed after instruction either increased or decreased, which indicates that the testdrivers were not necessarily driving slower after the instruction, and that the speed also depends on the actual traffic situation on the road, as explained in the previous chapter. The engine rpm's of the trips of the selected person who applied tip 1 and tip 3 show a larger reduction after instruction compared to the trips of the selected person who applied all tips. The person who applied the tips incorrectly showed a large increase of the dynamics. The increase of the throttle position when all tips are applied is only visible in the extra urban part, which is in line with the findings of the previous chapter.

6.2 Fuel consumption and tail pipe emissions

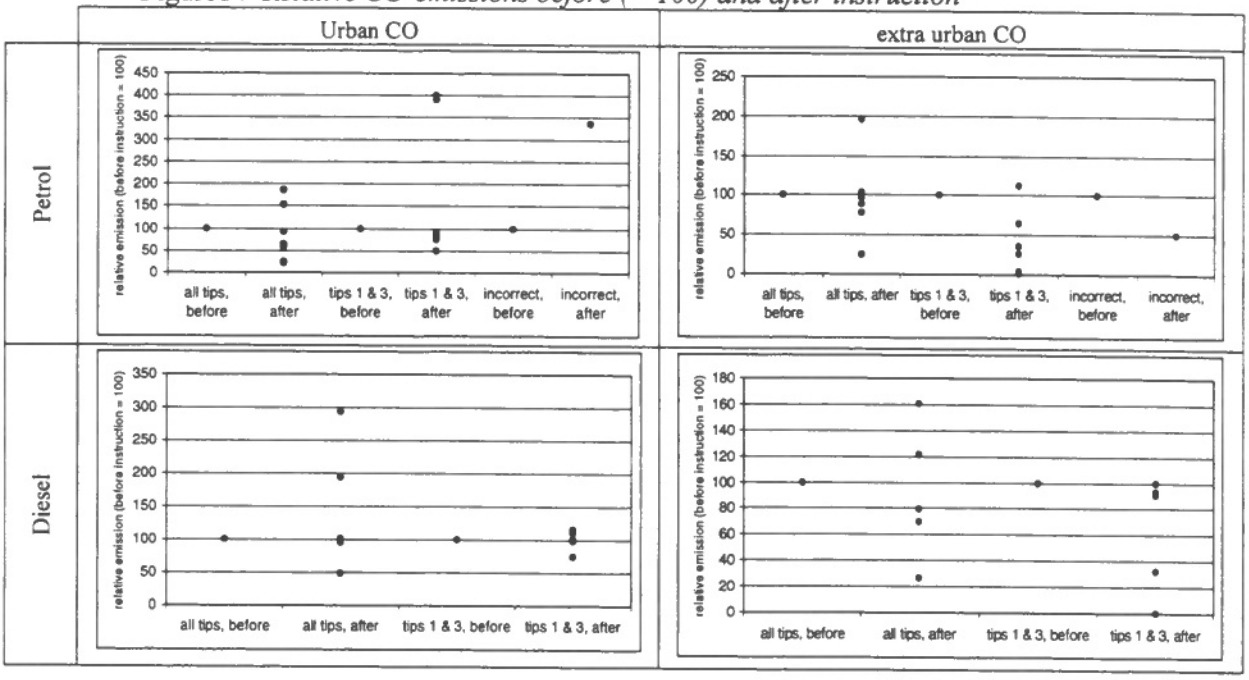
In Annex B the absolute values of the chassis dynamometer measurements are presented graphically. Because the purpose of this part of the investigation is to gain insight into the (relative) effects, the figures on the next pages show the relative emissions of the trips before (= value 100) and after the instruction of each car tested. To determine the statistical relevance of the relative differences, the outliers have been determined using the Grubb's test, and excluded from the dataset.

The average difference between the pre- and post-instruction trips has also been calculated. To assess the significance of the average differences, a paired t-test has been executed at probability levels of 95% and 80%. Because only one car has been tested on the 'incorrect' cycles, it is not possible to determine the significance of these measurements.

6.2.1 CO emissions

The next figures show the differences of the CO-emissions between the trip before instruction (=100) and the trip after instruction from the measurement programme.

Figure14 *Relative CO-emissions before (= 100) and after instruction*



These figures show that generally the differences of the CO emissions can vary a lot. As a result, the differences when averaged have a low significance, (with some exceptions) as is displayed in the next tables.

Table 7 *Average relative differences of CO-emissions and their statistical significance, petrol cars*

CO petrol	Difference after /before instruction	significant	
		at 95%	at 80%
All tips urban	-15%	no	no
All tips extra urban	2%	no	no
Tips 1 and 3 urban	81%	no	no
Tips 1 and 3 extra urban	-59%	yes	yes
Incorrect urban	237%	-	-
Incorrect extra urban	-50%	-	-

Table 8 *Average relative differences of CO-emissions and their statistical significance, diesel cars*

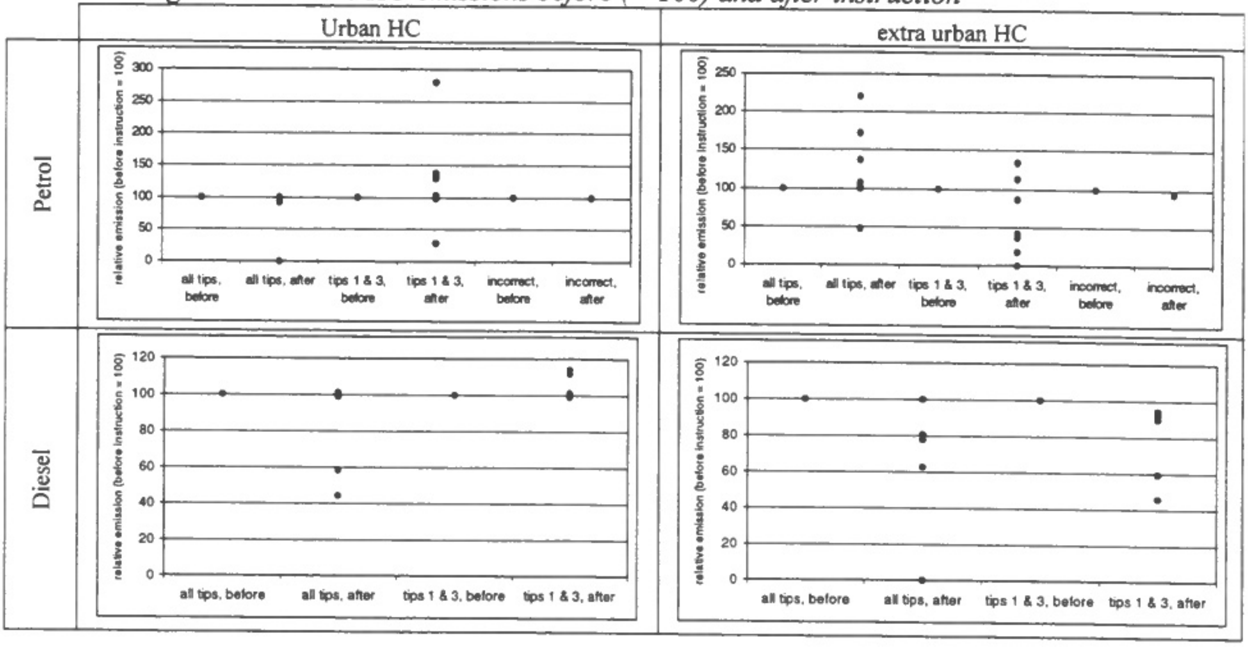
CO diesel	Difference after /before instruction	significant	
		at 95%	at 80%
All tips urban	46%	no	no
All tips extra urban	-8%	no	no
Tips 1 and 3 urban	1%	no	no
Tips 1 and 3 extra urban	-37%	no	yes

The average relative differences before/after instruction show large values. However, only in the case of the extra urban trip in which tips 1 and 3 were applied, the differences are significant (at 95% and 80% for petrol and 80% for diesel). Because of this lack of significance no further conclusions can be drawn regarding the effects on CO-emissions of a certain (mis-) interpretation of the driving style tips.

6.2.2 *HC emissions*

The next figures show the differences of the HC-emissions between the trip before instruction (=100) and the trip after instruction from the measurement programme.

Figure 15 *Relative HC-emissions before (= 100) and after instruction*



These figures show that generally the differences of the HC emissions can vary a lot, just like the CO-emissions. As a result, the differences when averaged have a low significance, (with some exceptions) as is displayed in the next tables.

Table 9 *Average relative differences of HC-emissions and their statistical significance, petrol cars*

HC petrol	Difference after /before instruction	significant	
		at 95%	at 80%
All tips urban	-36%	no	yes
All tips extra urban	27%	no	no
Tips 1 and 3 urban	30%	no	no
Tips 1 and 3 extra urban	-39%	no	yes
Incorrect urban	0%	-	-
Incorrect extra urban	-6%	-	-

Table 10 *Average relative differences of HC-emissions and their statistical significance, diesel cars*

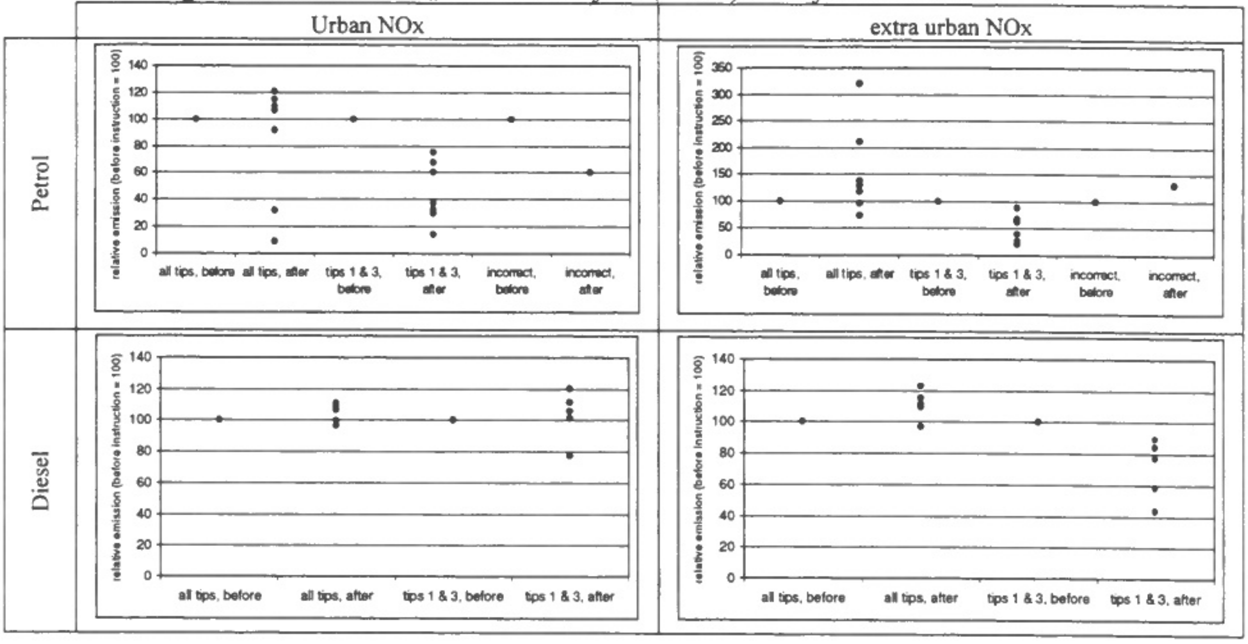
HC diesel	Difference after /before instruction	significant	
		at 95%	at 80%
All tips urban	-19%	no	yes
All tips extra urban	-35%	no	yes
Tips 1 and 3 urban	7%	no	yes
Tips 1 and 3 extra urban	-24%	no	yes

The differences are 6 out of 8 times significant at a probability of 80%.

6.2.3 NO_x emissions

The next figures show the differences of the NO_x-emissions between the trip before instruction (=100) and the trip after instruction from the measurement programme.

Figure 16 *Relative NO_x-emissions before (= 100) and after instruction*



The differences of the NO_x-emissions show less variation than the differences of the CO- and HC-emissions, especially for the diesel cars tested. As a result, the average differences are significant more often (see next tables).

Table 11 *Average relative differences of NO_x-emissions and their statistical significance, petrol cars*

NO_x petrol	Difference after /before instruction	significant	
		at 95%	at 80%
All tips urban	-16%	no	no
All tips extra urban	55%	no	yes
Tips 1 and 3 urban	-55%	yes	yes
Tips 1 and 3 extra urban	-47%	yes	yes
Incorrect urban	-40%	-	-
Incorrect extra urban	32%	-	-

Table 12 *Average relative differences of NO_x-emissions and their statistical significance, diesel cars*

NO_x diesel	Difference after /before instruction	significant	
		at 95%	at 80%
All tips urban	4%	no	yes
All tips extra urban	11%	no	yes
Tips 1 and 3 urban	3%	no	no
Tips 1 and 3 extra urban	-29%	yes	yes

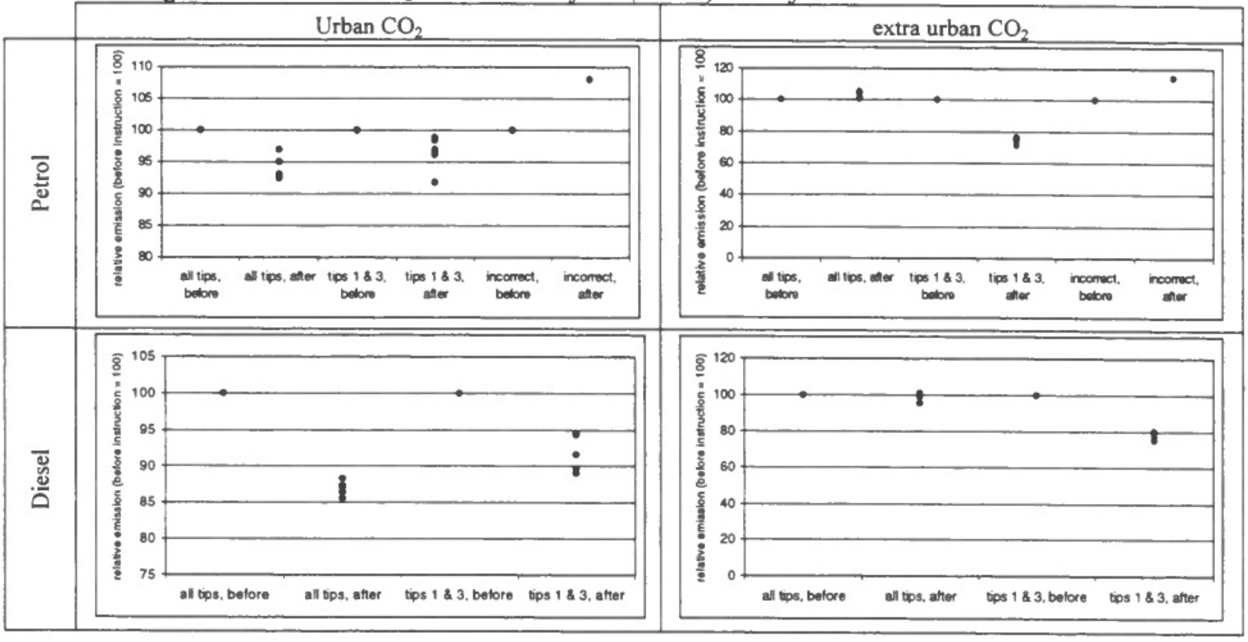
The NO_x reductions of around 50% for petrol cars under application of tip 1 and 3 have a high significance. The increase of the NO_x emission of 55% for petrol cars under application of all tips extra urban has a significance of 80%, which can be attributed to the application of tip 2.

The differences that the diesel cars show are small, with the exception of the significant reduction of 29% for tip 1 and 3 extra urban. Apparently, diesel cars are less sensitive to different driving styles than petrol cars are.

6.2.4 *CO_2 emissions*

The next figures show the differences of the CO_2-emissions between the trip before instruction (=100) and the trip after instruction from the measurement programme.

Figure 17 *Relative CO_2-emissions before (= 100) and after instruction*



As can be concluded from these figures, the variation of the CO_2-emissions is not as large as the variations that could be seen in the differences of the CO-, HC and NO_x-emissions. Consequently, the average differences also have a high significance.

Table 13 *Average relative differences of CO_2 emissions and their statistical significance, petrol cars*

CO_2 petrol	Difference after /before instruction	significant	
		at 95%	at 80%
All tips urban	-6%	yes	yes
All tips extra urban	4%	yes	yes
Tips 1 and 3 urban	-4%	yes	yes
Tips 1 and 3 extra urban	-25%	yes	yes
Incorrect urban	8%	yes*	yes*
Incorrect extra urban	14%	yes*	yes*

* assumption

Table 14 *Average relative differences of CO_2 emissions and their statistical significance, diesel cars*

CO_2 diesel	Difference after /before instruction	significant	
		at 95%	at 80%
All tips urban	-13%	yes	yes
All tips extra urban	-2%	no	yes
Tips 1 and 3 urban	-8%	yes	yes
Tips 1 and 3 extra urban	-22%	yes	yes

The differences that are measured have a high significance almost without exception. Therefore it can be assumed that the measured differences for the 'incorrect' trips can also be regarded as significant (although this can not be calculated). With the exception of the extra urban trip (petrol), in which all tips were applied or when the interpretation was incorrect, every trip showed a modest to large reduction in CO_2-emission, even up to 25 %.
Because of this high significance, the change of the trip parameters (table 6) could be set out against the change in CO_2-emissions (tables 13 and 14) in the next table. For reasons of clarity, no absolute values are mentioned, the differences are indicated by 'plusses', 'minuses' or neutral (o).

Table 15 *Change in CO_2 emissions / fuel consumption (FC) versus change in trip parameters*

		difference before/after instruction				
		speed	RPA	engine RPM	throttle pos.	CO_2 / FC
petrol	All tips, urban	o	-	o	o	-
	All tips, extra urban	o	+	o	+	+
	Tips 1 & 3, urban	-	-	--	--	-
	Tips 1 & 3, extra urban	-	--	--	--	--
	Incorrect, urban	o	++	+	++	+
	Incorrect, extra urban	+	++	+	++	++
diesel	All tips, urban	+	-	-	o	--
	All tips, extra urban	++	--	o	++	-
	Tips 1 & 3, urban	-	-	--	-	-
	Tips 1 & 3, extra urban	+	--	--	o	--

The trips that show a lower CO_2-emission/fuel consumption consequently show a decrease in RPA after the instruction, but not necessarily a decrease of average speed and average engine RPM or an increase of the average throttle position. Vice versa, the higher dynamics of the 'incorrect' trips results in higher fuel consumption. Apparently, the dynamics are the most determining parameter that influences the fuel consumption and CO_2-emissions.

6.2.5 Fuel consumption

Because fuel consumption and CO_2 emissions are directly related to each other, the remarks that have been made in the previous section about CO_2 apply also for fuel consumption. The differences measured therefore also have the same values, so the same remarks and conclusions also apply here. In Annex B.5 the absolute values are included.

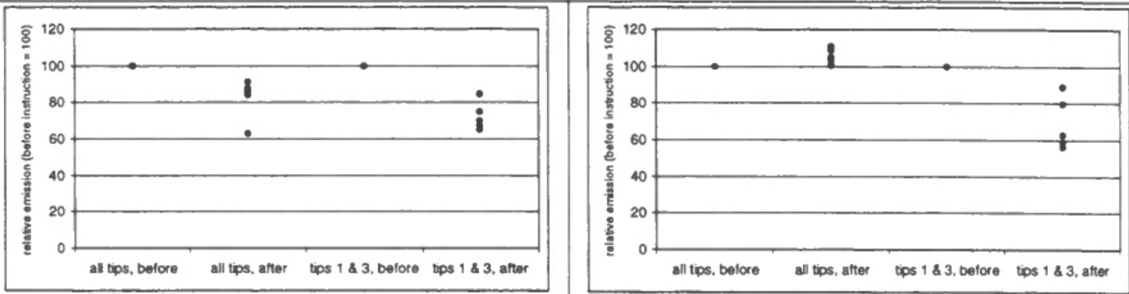
6.2.6 *Particulate matter (PM_{10})*

The next figures show the differences of the particulate emissions (PM_{10}) between the trip before instruction (=100) and the trip after instruction from the measurement programme. The PM_{10}-emissions were of course only measured from the diesel cars.

Figure 18 *Relative PM_{10}-emissions before (= 100) and after instruction*

	Urban PM_{10}	extra urban PM_{10}

Diesel



As can be concluded from these figures, the variation of the PM_{10}-emissions is, just like the CO_2-emissions, not as large as the variations that could be seen in the differences of the CO-, HC and NO_x-emissions. Consequently, the average differences also have a high significance.

Table 16 *Average relative differences of PM_{10} emissions and their statistical significance, diesel cars*

PM_{10} diesel	**Difference after /before instruction**	**significant**	
		at 95%	**at 80%**
All tips urban	-18%	yes	yes
All tips extra urban	6%	yes	yes
Tips 1 and 3 urban	-27%	yes	yes
Tips 1 and 3 extra urban	-31%	yes	yes

Without exception, the differences in PM_{10} emissions that have been measured before/after instruction are significant.
Because of this high significance, the change of the trip parameters (table 6) could be set out against the change in PM_{10}-emissions (table 16) in the next table.

Table 17 *Change in PM_{10} emissions versus change in trip parameters*

		difference before/after instruction				
		speed	RPA	engine RPM	throttle pos.	PM_{10}
diesel	All tips, urban	+	-	-	o	-
	All tips, extra urban	++	--	o	++	+
	Tips 1 & 3, urban	-	-	--	-	-
	Tips 1 & 3, extra urban	+	--	--	o	-

Generally, the reductions of RPA and PM_{10}-emissions do seem to correspond, with the exception of the 'All tips, extra urban'-trip. The slight emission increase therefore might be caused by the increased average throttle position of this trip.

6.3 Discussion

Reliability of data obtained.
The values shown in section 6.2 can by no means be regarded as representative for the full potential of New Style Driving, because too many random effects are involved in the determination of these factors. The trip data obtained in part II shows that none of the testdrivers fully exploited the driving style tips. Also the influence of the actual traffic situation on the road can not be neglected, which is illustrated by the variation of the average speed values of the pre- and post-instruction test cycles.

In addition to what has been stated in the previous sections it can be concluded that even when a large number of vehicles is subjected to a chassis dynamometer measurement programme, the measured differences between the pre- and post-instruction trips in many cases spread too much to be regarded as significant. This is especially the case for CO and HC emissions, where many times, when averaged; the effects are not significant. On one hand this is caused by the very low values that have been measured, which approaches the detection thresholds of the equipment at the TNO laboratory. On the other hand this also indicates that engine calibration can vary a lot between different car manufacturers. Probably, some car manufacturers design the lambda control strategy for optimal driveability under every real life circumstance, while only optimizing for low emissions during the official type approval cycles. This has also been concluded in the 1999 study.

Actual data obtained

In comparison with the 1999 investigation the effects on tail pipe emissions of applying "New style driving" were now found to be much smaller or even not significant. The positive effects measured on fuel consumption, however, are of the same order as in the 1999 study. It must be kept in mind though, that the goals and setup of the 1999 study and the underlying study are quite different. Whereas in 1999 various driving styles were compared, in this study, the way driving styles tips are interpreted by individuals is subject of study. There are however some reasons to be identified for the differences in the effects found:

Firstly, in 1999 TNO staff who fully understood the technical background behind New Style Driving, and therefore managed to apply this driving style exactly as prescribed, executed the on-the-road measurements. In the underlying investigation, people without any knowledge on the technical background of New Style Driving were asked to apply the tips. As the analysis in part II showed, none of the testdrivers fully exploited the second tip. This may have taken away some of the extremities measured in the 1999 study. The fact that this tip was found difficult to understand (and thus often neglected), has caused smaller throttle positions during accelerations than in the previous investigation, not triggering full load enrichment so often (most probable cause of the excessive emission increase in the 1999 study). The fact that no actual throttle position is prescribed anymore (as was done in the 1999 study), may also have had some positive effect on the emissions. The 1999 included the 75% throttle advice, which has been changed to the formulation that is subject of the underlying investigation. Therefore, not mentioning the 75% advice may also have reduced the throttle position during acceleration, and further reducing the effects on the emissions.

Secondly, the reference driving style against which the comparison is made also differed in 1999 from the current results. Whereas in 1999 the reference driving style was defined as an average 'defensive' driving style, the current investigation uses pairs of real world trips from one person at a time that are compared: the pre-instruction (=reference) trip and the post-instruction trip. Both trips therefore approach real world driving more closely than the reference driving style practiced in 1999. The probable underestimation of the possible fuel consumption benefit of 'New Style Driving' mentioned in the 1999 study, due to the rather defensiveness of the reference trip, can therefore not be confirmed by the current study because the references are not comparable.

And finally, the cars that have been tested here are equipped with technology that has progressed from the 1999 vehicle selection. This means that under influence of the tighter emission limit values (especially Euro III and D4, but also the Euro 2 vehicles), the petrol cars tested here are often equipped with the latest generation of emission control technology, such as electronic throttle actuation and high-speed lambda control. The diesel engines for the same reason are equipped with electronic engine management, enabling better emission performance over a wider range of engine loads. Depending on the engine calibration, this technology can to some extent take away the emission peaks that would occur under sudden engine load changes, while maintaining good driveability.

Bearing in mind that tip 2 has been applied mainly in the extra urban trips, as explained in part II and which is also visible in table 16, the benefits of this tip on fuel consumption are not very clear. The changes in fuel consumption were found to correspond with the changes in driving dynamics (RPA), which can be regarded as the predominant parameter that impacts fuel consumption.

7 Conclusions

The conclusions from this study can roughly be divided in two parts:
-conclusions regarding the communication of the tips drawn from the on-the-road measurements
-conclusions regarding fuel consumption and tail pipe emissions drawn from the chassis dynamometer measurements.

Both parts will first be treated separately.

Communication of the tips
In general, it can be concluded that when car drivers are positively motivated it is indeed possible to change (elements of) their driving style by means of corporate communication in writing. Shifting earlier seems to appeal to most of the drivers, while driving more fluently and anticipating on traffic situations is a natural reaction in order to drive fuel economic.

However, the actual message of New Style Driving as expressed in the three driving style tips is too complex and tip 1 and tip 2 are too contradictory to most drivers to be applied in practice. This is especially the case for tip 2. Many testdrivers experienced this tip as contradictory to economic driving. Some testdrivers remarked that it even encouraged speeding. Therefore probably most often this tip was being ignored completely.

The study also shows that the persons who somehow comprehended how to apply tip 2, mainly managed to do this extra urban, where there is less traffic and higher speeds are reached.

The study also shows that in a worst case situation, the formulation of the tips can even lead to misinterpretation and thus unwanted driving behaviour. In this context it should be taken into account that people participating in this test program, were positively motivated towards driving cars and technical issues, than will be the case for the average Dutch person. The fact that during the investigation only one participant showed erratic driving behavior after instruction, will therefore be an underestimation for the average Dutch person.

When drivers are educated in New Style Driving by means of a personal training, the message could be better communicated. Though not part of this study, the reactions of test drivers to the occasional demonstrations after the actual test of New Style Driving by TNO personnel are an indication for this.

Fuel consumption and tail pipe emissions
Regarding the fuel consumption and emission effects, the chassis dynamometer programme showed that considerable reductions in fuel consumption from 5% to 25% can be obtained by a change of driving style. However, the programme did not point to a direct relation between application of tip 2 (a higher throttle position) and a reduction of fuel consumption. The parameter that related most strongly to fuel consumption was driving dynamics.

A misinterpretation of the tips showed an increase of the fuel consumption though.

The exhaust emissions of modern passenger cars seem to vary more from car to car than was ever the case before, as is expressed by variation the measurement data of the measured effects of especially CO, HC and NO_x emissions. This variation is most probably a matter of the way modern engines are calibrated.
The effects on exhaust emissions of the various interpretations of New Style Driving were in many cases found to be not significant or not of the same magnitude as shown in previous study, because of the latest generation of technology tested and because of the different reference driving styles that have been used.

Therefore the call for a type approval test cycle that is more representative for real world driving still remains valid. Because this is not to be expected before 2008 it is important to keep collecting data on real world emissions of modern passenger cars.

General
Taking into account the difficulties with the interpretation of tip 2 which can even lead to a misinterpretation and the fact that a relation between the application of this tip and a reduction in fuel consumption can't be proven, the general conclusion can be drawn that tip 2 in its current form should not be part of communication in writing of New Style Driving. How to exploit the potential of driving style changes in real life, seems to be more a question of how to motivate car drivers to drive more defensive than a matter of how to communicate the exact principles of New Style Driving. Most car drivers instinctively do seem to know how to drive economically by reducing driving dynamics and speed (limit exceedings).

Because of the displayed significant positive influence of reducing driving dynamics, it is therefore also important to impose a fluent driving style on car drivers by means of an appropriate design of roads and traffic management next to trying to change their behavior.

Regarding the approach followed in part II of this investigation it can be concluded that it has clearly shown the importance of data collection on a group of persons of a significant size. Even using a considerable test size as used in this investigation, it appeared difficult to fully eliminate the random occurrences in real world traffic. However, it is believed that with the current dataset the conclusions on the interpretation of New Style Driving are robust. Also the approach followed in part III showed its value: development of real world cycles in combination with measurements on many different vehicles seems to be the only way to collect real world emission and fuel consumption data with sufficient reliability.

8 Recommendations

In this study it has been concluded that tip 2 is too complex and that its theoretical benefit on fuel consumption does not show in practice. Whereas shifting up earlier and engine braking can very well be a part of New Style Driving, the throttle advice of tip 2 could best be deleted completely, in case no thorough explanation of the technical background or a real life demonstration (training) can be given. For the formulation of adjusted tips, therefore a trade off must be made between the complexity of the message to be communicated to the general public versus the fuel consumption and emission gains that may be achieved. Also the effects of a misinterpretation must be taken into account.

Reducing fuel consumption seems to be more a matter of reducing driving dynamics, i.e. keeping the speed of a vehicle as constant as possible, as of changing throttle operation. Therefore, an adjusted formulation of New Style Driving on a corporate level should be aimed at motivating drivers to adapt their driving style in such a way that it becomes more fluent. It must also challenge car drivers not to think that New Style Driving means a slow or boring driving style. What should be kept in mind when reformulating tips is that driving with low engine speeds is theoretically and practically proven to be very efficient in order to reduce fuel consumption. By keeping engine speed low the driving dynamics will reduce implicitly because of the decreased responsiveness of the car at low engine speeds. In addition the engine efficiency will increase because driving at low rpm will force drivers to open the throttle wider. The problem however with deleting tip 2 will be that the main message of the tips will be: drive fluently! This message most probably will appeal less to people, whereas tip 2 had more of a "drive dynamically" appeal and added a 'new' element to this driving style.

However, taking into account the possible negative effects of misinterpretation of tip 2, it is recommended that tip 2 should be deleted. This recommendation is underlined by the fact that "1 out of 24" showing negative effects, will most probably be an underestimation of the practical situation in which less technical and motivated persons will read the tips.
The challenge for the communications experts working on "the New Driving Force" program will be to substitute tip 2 by something else addressing peoples feelings regarding car driving.

Some input to what should be addressed instead of tip 2, probably can be found in the researchers observation when showing some test drivers what was really the intention of all tips. People mostly had a "aha Erlebnis" mentioning that this way of driving "really felt good". The feeling of a car accelerating quickly at a low engine speed and low noise level seemed to appeal to these test drivers. In line with the researchers findings on this point, a comparable study on the interpretation of the tips as a part of an individual training can be recommended. The current study suggests that under such circumstances driving style tips might be comprehended better, once people "get the feeling".

The effect of traffic calming measures in order to encourage this effect also should not be underestimated. This seems to be obvious, but this investigation showed that considerable gains in fuel economy can indeed be achieved.

9 References

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A Theoretical background

In order to understand the effects of driving behaviour on the fuel consumption and tail pipe emissions of passenger cars, some background information concerning the physics and mechanics of fuel consumption and emissions has to be taken into account. Basically the propulsion energy is influenced by three parameters: *car type, road type and driver behaviour*. An explanation on all three parameters is given below:

A.1 Car type

The amount of fuel a car consumes in order to drive a certain trip, is directly related to the amount of propulsion energy needed to perform this trip. The propulsion energy has to be generated by the vehicle's engine. The engines environmental performance (and fuel economy) is not constant, but depending on the part of the engines operating area (engine map) being used to generate the propulsion energy. The combination of propulsion energy demand and engine performance, results in certain fuel consumption properties and certain tail pipe emissions The propulsion energy (expressed in kJ/km) has to be generated by the car's engine and is needed to overcome 4 kinds of resistances:

- rolling resistance (tyres, bearings)
- wind resistance (drag)
- slope of the road (overcoming differences in altitude)
- mass inertia (acceleration and deceleration)

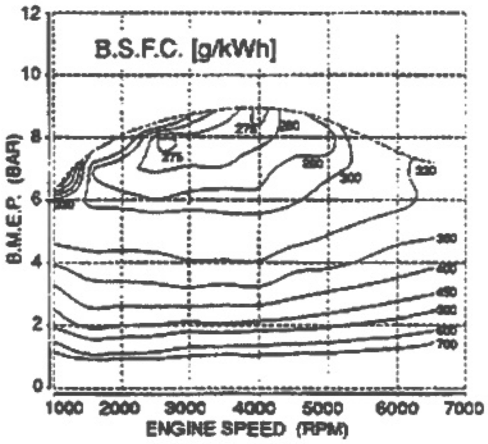
These resistances each have specific car related characteristics, like described below.

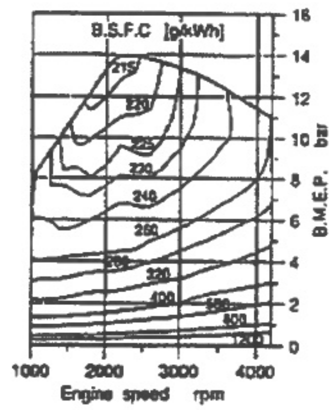
- The rolling resistance of a car is mainly caused by the deformation of the tyres during driving. This deformation energy is mainly influenced by the vehicle weight in combination with the tyre pressure. It increases linear with the vehicle speed, except for very low and very high speeds, at which the rolling resistance increases more significantly. For a small part the resistance of the bearings of the wheels are contributing to the rolling resistance. The rolling resistance of 4 tyres at 50 km/h is about 5 kW, depending on type of tire (ECO, normal, winter and sport) and its width (next to rolling resistance, the width of a tire also influences the wind resistance of a car).
- Wind resistance is caused by turbulences generated by a car moving with a difference in speed to the air surrounding it. The main parameters influencing the wind resistance are the aerodynamic layout of the cars bodywork (expressed in Cw) and the projected frontal area of the bodywork (A). The wind resistance increases to the 2^{nd} power with the vehicle speed, resulting in an increase of propulsion energy (per km) up to a 2^{nd} power related to the vehicle's speed. (theoretically this effect would lead to an increase of a cars fuel consumption when driving at 130 km/h instead of 100 km/h of about 70 %. But because the engine's efficiency increased with higher engine loads, the actual negative effect is reduced to about 35%).

- The slope of the road is directly proportional to the propulsion energy needed to overcome the difference in altitude. A positive slope will increase the necessary propulsion energy. A negative slope will decrease the necessary propulsion energy, possibly reducing the energy to negative values, which will result in the necessity for braking (heating away energy).
- Acceleration and deceleration of a car (driving dynamics) will cause a demand for propulsion energy (respectively braking energy) in direct relation to the vehicles inertia. The vehicle inertia arises partly from the vehicles weight (static inertia) and partly from the vehicle rotating parts (wheels, engine parts). The vehicle weight by far, is the most important parameter. The amount of propulsion energy needed is linear with the vehicle weight and is to a 2^{nd} power related to the actual acceleration or deceleration (in m/s^2).

Based on the parameters described above it is clear that the main factor responsible for fuel consumption and tail pipe emissions, is the type of car used. The combination of vehicle weight, drag factor, projected frontal area and rolling resistance, lead to a certain amount of propulsion energy being necessary to drive a certain trip. In order to generate this propulsion energy the engine build into a car will consume fuel and produce exhaust gasses. But the fuel consumption and exhaust gas production do not depend only on the amount of propulsion energy needed. This is caused by the fact that:

- The combustion properties of an engine are different for each speed- and load point of the engine. Therefore the parts of the engine map which is used during a certain trip, dictates the fuel consumption and tail pipe emissions. Thus the driver is influencing the fuel consumption and tail pipe emissions, because he dictates the parts of the engine map used. Two typical engine maps regarding specific fuel consumption are shown below (right for diesel, left for petrol). In the diagrams the 'brake specific fuel consumption' is presented, dependant of 'brake mean effective pressure' (value for engine load) and 'engine speed'. It can be clearly seen that the optimal (minimal) fuel consumption area in the engine map is situated at about 50% of the maximum engine speed and at high engine loads.





- Modern cars are fitted with some kind of emission reduction system (catalyst converter, exhaust gas recirculation) which reacts specifically to the changes in exhaust gas amount and composition. Because of the basic differences between petrol engines and diesel engines, both types react very different to certain ways of driving behaviour. In general the fuel consumption and tail pipe emissions of a petrol engine are much more sensitive to the way it is used, than a diesel engine.

In order to obtain the best possible performance (drive ability and environmentally) the cars combustion properties are calibrated by the manufacturer. The combustion properties of a modern engine are programmed in an ECU (electronic control unit) depending on some main engine parameters like, engine speed, manifold absolute pressure (MAP), intake air amount and temperature, throttle position, lambda etc. The maps stored inside the ECU are determined during calibration of the car. These calibrations are conducted in order to obtain tail pipe emissions according to international limits (ECE). As far as possible within the limits, fuel economy and drive ability of the car are also addressed during calibration.

But calibration according to ECE limits involves testing according to a standard test procedure, which is not quite representative for actual driving. In fact the average speed and dynamics of the test cycle are relatively low compared to actual situations. The gearshift points are also fixed, and the same for all cars. As a result of this test procedure, a well-calibrated car (on the ECE test) does not guarantee a good environmental performance of the car during actual driving. In fact the more a car differs from the average, the bigger the differences between the test procedure and the actual driving will be.

All together a large amount of parameters influence the actual fuel consumption and tailpipe emission of a car in an almost unpredictable way. Based on this statement, practical tests have to be executed, taking into account the most important parameters mentioned above.

A.2 Road type (traffic flow type)

The type of road which a car is driven on, is of great influence on the amount of propulsion energy needed and therefore on the cars fuel economy and tail pipe emissions. Next to the maximum speed allowed (directly influencing the average speed also), the driving dynamics of the car on a road, dictated by the traffic and the driver, are of great influence on the car's fuel economy and tail pipe emissions. In general, roads can be divided into urban, rural and highway. In respective order the average speed will increase while the driving dynamics will decrease. In urban situations the effective amount of propulsion energy needed is mainly influenced by the rolling resistance and the driving dynamics, while the necessary propulsion energy for highway driving is dominated by the wind resistance of a car. Rolling resistance, wind resistance and dynamics to an almost equal extent influence rural driving. For the Dutch situation the effect of slopes is minimal.

In practical situations the amount and type of traffic on the road also influence the average speed and driving dynamics of a car. The effects of this type of influence (congestion) are not taken into account within this programme. (A separate programme is being executed).

A.3 Driver type

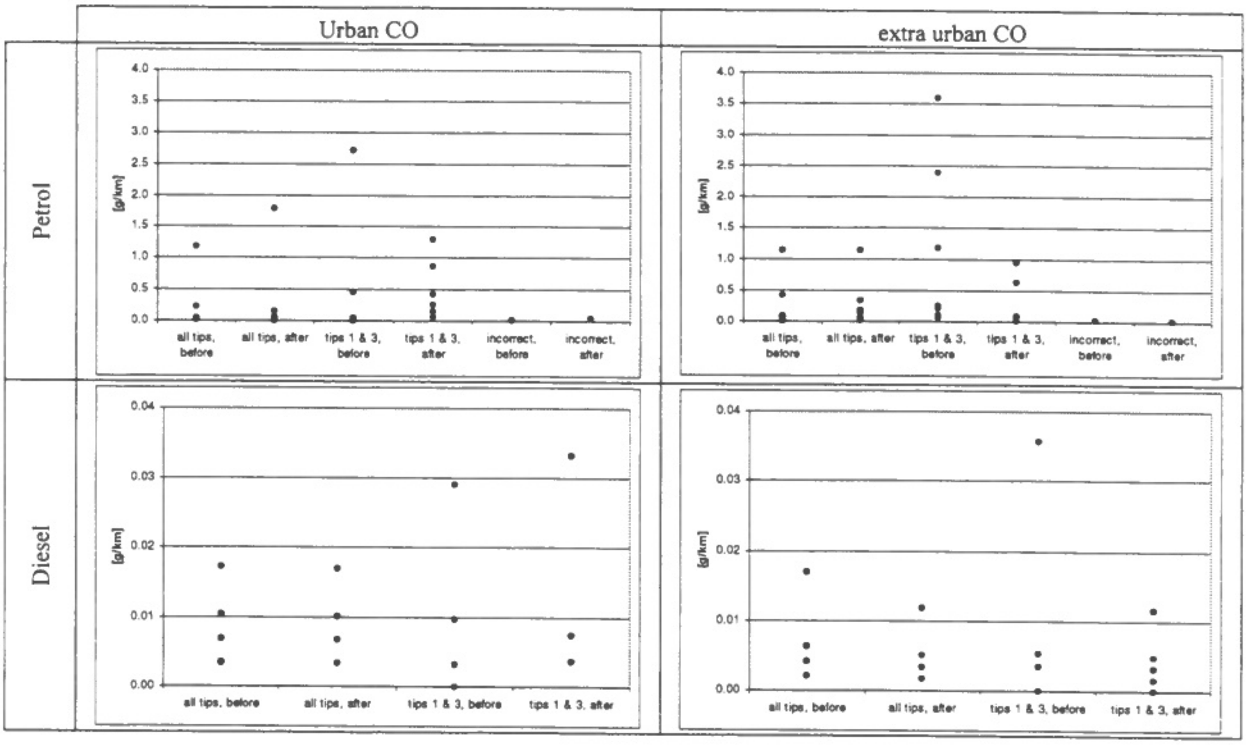
Next to the road type and car type, the type of driver is a very important factor regarding a cars environmental performance. The driver is responsible for the way the car is used in traffic. Which average speed and which variations in speeds occur, largely depend on the driver. Furthermore the driver, also influences the way the necessary propulsion energy is generated, because he dictates the throttle and gear positions of the car, and therefore the part of the engine map used in order to obtain the necessary propulsion energy. Not only the way in which energy is generated is dictated by the driver, but also the way energy is 'wasted by braking' is dictated by the driver. An anticipating driving behaviour in this respect will result in a smaller amount of kinetic energy being wasted.

B Chassis dynamometer measurement results

The next figures show the absolute values of the results of the chassis dynamometer measurements.

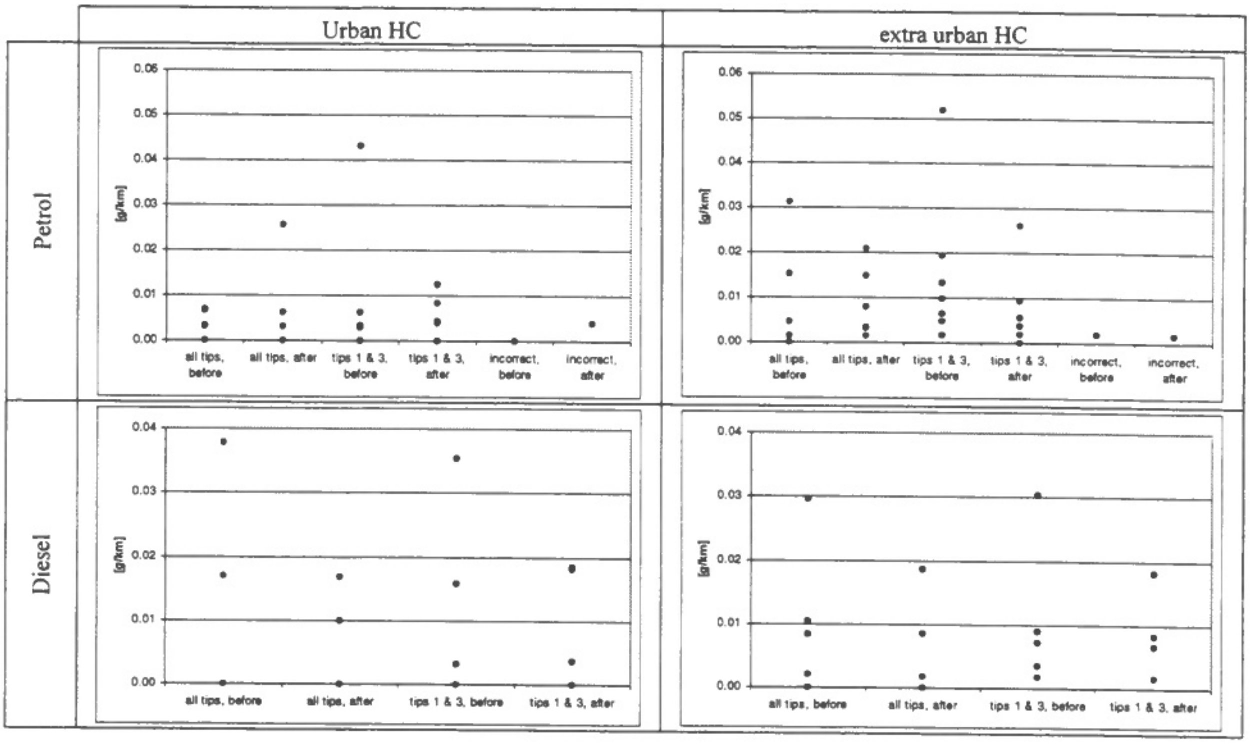
B.1 CO-emissions

Figure B1 *CO emissions*



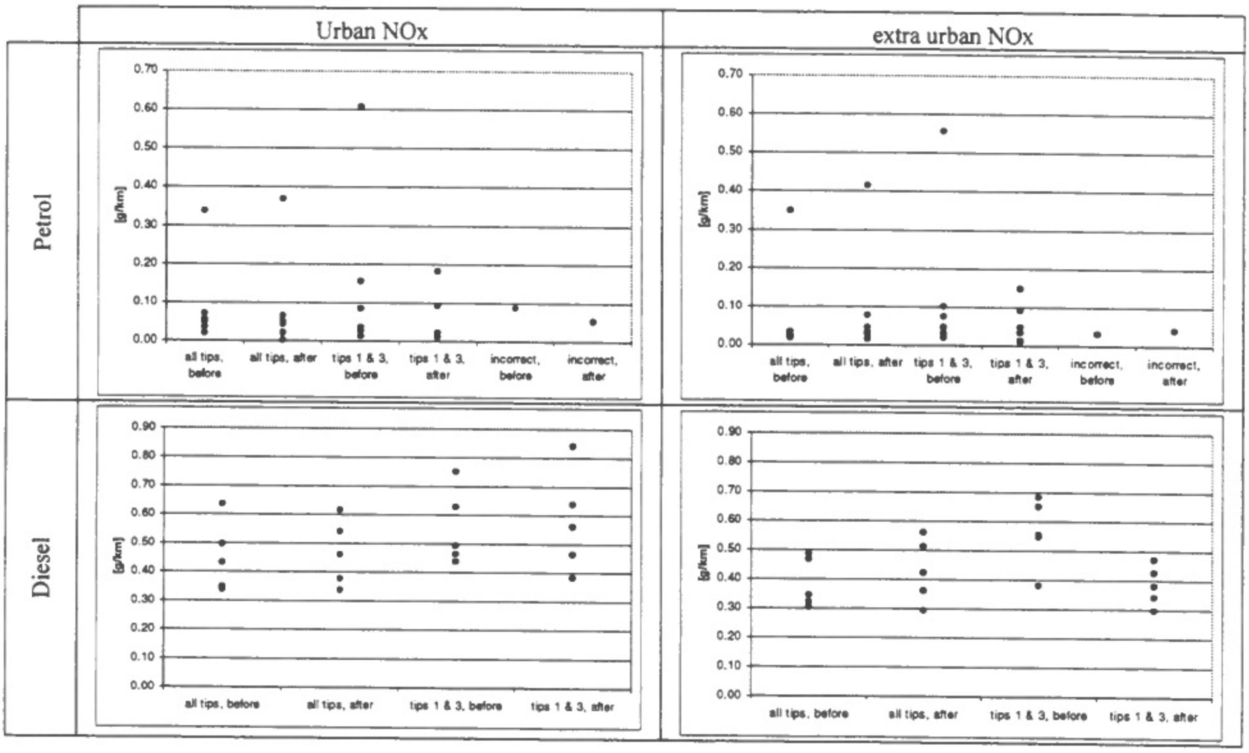
B.2 HC-emissions

Figure B2 *HC emissions*



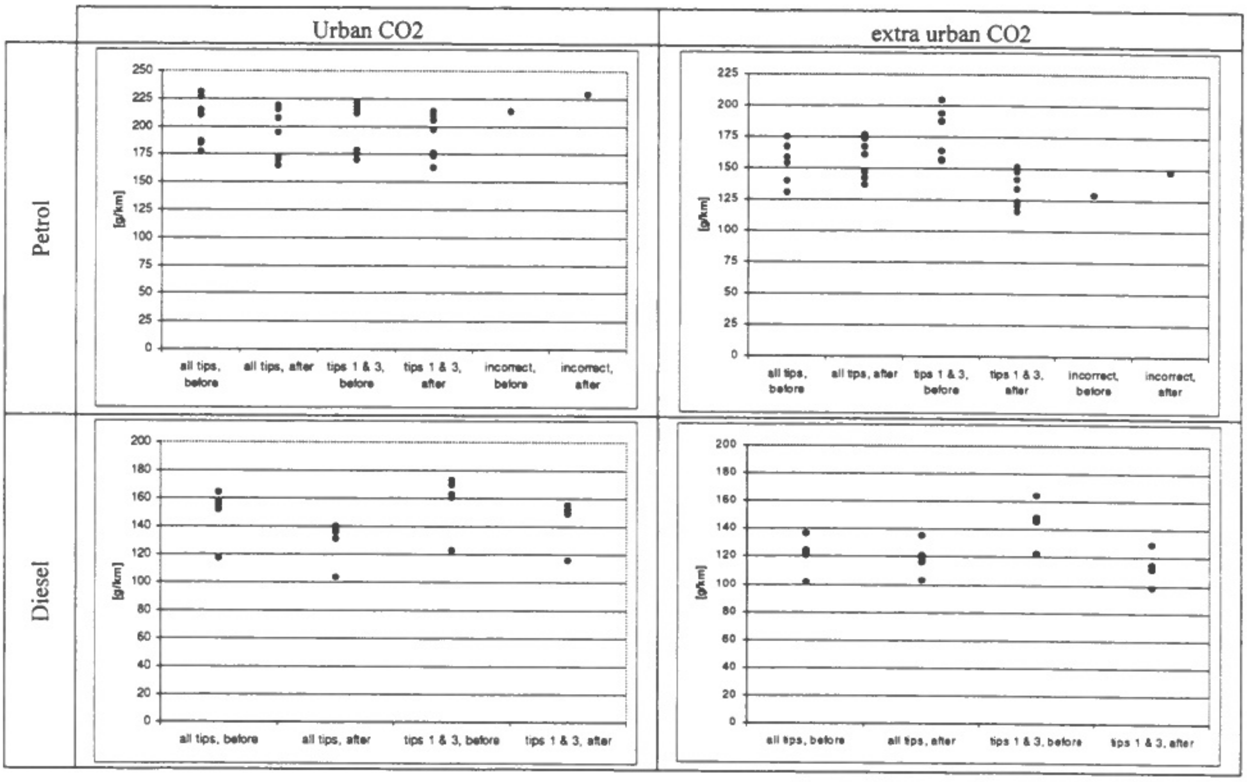
B.3 NO_x-emissions

Figure B3 *NO_x-emissions*



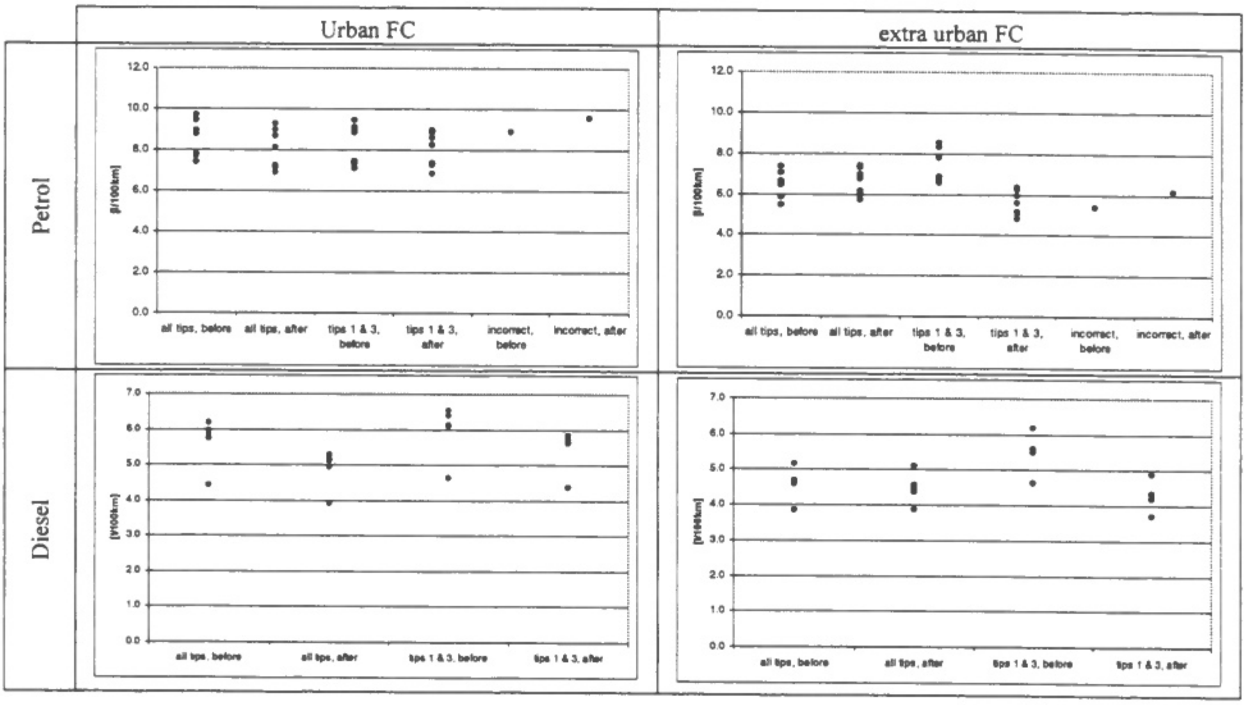
B.4 CO_2-emissions

Figure B4 *CO_2-emissions*



B.5 Fuel consumption

Figure B5 *Fuel consumption (FC)*



B.6 Particulate matter (PM_{10})

Figure B6 Fuel consumption (FC)

	Urban PM10	extra urban PM10
Diesel