Abstract

The long-term effects of driving with an active accelerator pedal on driver behaviour were studied by using an in-car observation method over the period beginning 2000 until 2001. The system produced a counterforce in the accelerator pedal when the speed limit was reached, but could be overridden by pressing the accelerator pedal harder. Twenty-eight drivers were studied when driving without the system and then when driving with the system after they had used it in their own cars for at least six months. The results showed that their behaviour towards other road users improved, they had a yielding behaviour correct to a higher degree and were more likely to give pedestrians the right of way at zebra crossings when driving with the active accelerator pedal. It was also found that the time gap to the vehicle in front increased slightly with the system. There were also signs of negative behavioural modifications in the form of drivers forgetting to adapt their speed to the speed limit or the prevailing traffic situation when they were not supported by the system and in low speed areas; these effects, however, were not statistically significant. Together with studies showing improved speed behaviour, the results of this study augur well for great safety effects of the system.

Keywords: Active accelerator pedal; In-car observations; Driver behaviour; Instrumented vehicle

1. Introduction

The strong relationship between the speed level and accidents has been shown in several studies; small speed level changes result in significant changes in the number of accidents (see e.g. Elvik,
Vaa, & Östvik, 1989; Finch, Kompfner, Lockwood, & Maycock, 1994; Nilsson, 1982; Salusjärvi, 1981). An additional finding is that lower speed variance is correlated with fewer accidents (see e.g. Finch et al., 1994; O’Cinnéide & Murphy, 1994; Salusjärvi, 1981). These observations indicate that lower and more even speeds effectively reduce the number of accidents and mitigate the outcome of collisions. However, compliance with speed limits is low, for example, a survey of actual speed levels in Europe (Draskóczy & Mocsári, 1997) showed that speeding is a common phenomenon, especially widespread on urban roads and motorways. So far, speed management has typically been concentrated on the road and its environment (engineering), and on the driver (e.g. enforcement). Engineering measures such as traffic calming have proved to be effective in reducing speed at isolated sites, but the effects are localised in time and space (for an overview see Comte, Várhelyi, & Santos, 1997). Visible enforcement at specified sites, directed towards certain groups of drivers and administered regularly at times when many of the passing drivers are commuters, usually results in an immediate speed reduction. Still, the extent of speed reduction in time and space is very small (see e.g. Hauer, Ahlin, & Bowser, 1982; Östvik & Elvik, 1990; Teed, Lund, & Knoblauch, 1993).

Recent technological advances in information and communications technology offer a much greater flexibility and a broader possibility of influencing speed. Equipment in the road environment or the vehicle itself may provide the driver with information on prevailing speed limits or speed limits in critical conditions or warn him of speed errors or register inappropriate speed or prevent the driver from exceeding the prevailing speed limit.

The concept of speed adaptation via in-car devices has been researched since the eighties. The most promising system, i.e. tactile feedback via the accelerator pedal, has been most researched. Earlier field trials (Almqvist, Hydén, & Risser, 1991; Almqvist & Nygård, 1997; Brookhuis & de Waard, 1999; Carsten & Fowkes, 2000; Persson, Towliat, Almqvist, Risser, & Magdeburg, 1993; Saad & Malaterre, 1982; Schulman, 1985; Várhelyi & Mäkinen, 2001) and simulator experiments (Comte, 1996; Comte, 1998a; Comte, 1998b; Godthelp & Schumann, 1991) have demonstrated the positive effects of such systems. These trials showed that the “intelligent accelerator pedal” had positive effects on speed level, speed variance and car-following behaviour on urban roads. However, one study reported a slight tendency to negative behavioural effects in the form of increased approach speeds and turning speeds at intersections (Persson et al., 1993), while another reported smoother approach speeds and unchanged turning speeds at intersections (Várhelyi & Mäkinen, 2001). Behaviour in interactions with other road users deteriorated according to Persson et al. (1993), improved according to Almqvist and Nygård (1997) and it was unchanged according to Várhelyi and Mäkinen (2001). Várhelyi and Mäkinen (2001) reported shorter time gaps in car-following situations on rural roads. However, in these studies the test drivers did not have a chance to get used to the system in everyday driving, except in one study (Almqvist & Nygård, 1997), where they used the system for two months before being observed. Hence, no long-term adaptation to the system could be observed. It can be assumed that this fact is the reason for some of the conflicting results in these earlier studies, which raised the need for a more comprehensive investigation. From these earlier trials it could be concluded that negative behavioural adaptations and the long-term effects on driver behaviour in real traffic needed more research.

When it comes to the phenomenon of “behavioural adaptation”, an OECD scientific expert group was set up in 1990 (OECD, 1990) to examine the empirical evidence for its “existence”.
Behavioural adaptation was then defined as “those behaviours which may occur following the introduction of changes to the road-vehicle-user system and which were not intended by the initiators of the change”. On the basis of a review of a large number of empirical studies, the expert group concluded that “… behavioural adaptation to road safety programmes does occur although not consistently”. It was stated that the magnitude and direction of its effect could not be precisely stated. The reviewed studies suggested that behavioural adaptation generally did not eliminate safety gains from measures, but tended to reduce the size of the expected effects. Behavioural adaptation can, in practice, appear in many different driving manoeuvres: in change of speed, change of following distance, way and frequency of overtaking, way and frequency of lane changing, late braking, change of level of attention, etc. (Draskóczy, 1994). In hypothesising and testing behavioural adaptation it is important to take into consideration the fact that it is an effect that does not appear immediately when the driving context is changed, but usually appears only after a familiarization period (ibid).

Mechanisms that can lead to behavioural adaptation with regard to a system like an intelligent accelerator pedal are “delegation of responsibility”, “behaviour diffusion”, and “compensatory behaviour”. Carsten (1993) describes “delegation of responsibility” as follows: “Studies had shown that in situations people consider uncontrollable, they want to know who is ‘responsible’ for certain events. If other, generally more powerful, people assume responsibility, it is not unusual to delegate responsibility to them. This delegation of responsibility can lead to behaviour which is potentially more risky, e.g. in emergency situations where those at risk should make their own decisions”. In the case of vehicle-based systems for driver support the driver might delegate the responsibility to the system. A driver supported by an intelligent accelerator pedal is able to devote more attention to the other driving tasks. On the other hand he might become over-reliant on the system. For example, the driver might consider that the system will always know what the speed limit is and will always issue a warning at inappropriate speeds. “Behaviour diffusion” might occur in situations where drivers are not supported by the system, e.g. when driving outside the areas covered by the system, driving non-equipped vehicles or when the system fails (Carsten, 1994). In these cases drivers who become totally reliant on the system might have difficulty in following the changes in the actual speed limits. The notion of “compensatory behaviour” has its origin in the “risk compensation” theory of Wilde (1994) (the notion that road users will use up some of the margin afforded by safety improvements by, for example, driving faster) and the “risk homeostasis” theory of Wilde (1994) (the notion that road users seek to keep their risk constant).

This study aimed at observing how driver behaviour was affected after long-term use of an Active Accelerator Pedal (AAP), and was carried out within the framework of the Swedish National Road Administration’s large-scale trial with Intelligent Speed Adaptation (1999–2002) where 284 vehicles were equipped with the AAP in the city of Lund. The system was activated automatically when the test vehicles were within the test area and could not be turned off. The system was not activated outside the test area.

The AAP consists of a mechanical unit connected to the accelerator pedal, a digital map with all the speed limits within the city boundaries and a GPS-navigator. When the driver tries to exceed the speed limit a counterforce is activated in the accelerator pedal. However, if necessary, the driver can exceed the speed limit by pressing the accelerator with approximately five times more pressure than normally required.
1.1. Hypotheses

The hypotheses to be tested in this study have been derived from earlier studies on the effects of the Active Accelerator Pedal on driver behaviour (Almqvist & Nygård, 1997; Persson et al., 1993; Várhelyi & Mäkinen, 2001) and on theoretical considerations of possible effects of driver assistance systems on driver behaviour. Drivers’ change in speed behaviour is, of course, of great interest when equipment such as the AAP is being studied. The present study, however, is focused on how the AAP affects driver behaviour apart from speed. Nevertheless, in the discussion chapter the AAP’s effect on speed behaviour, presented in more detail in Hjälmdahl, Almqvist, and Várhelyi (2002) and Várhelyi, Hjälmdahl, Hydén, and Draskóczy (in press), will also be discussed.

1.1.1. Hypothesis 1

Drivers do not lower their speed in low speed situations to the same extent when driving with an AAP as when driving without an AAP.

This hypothesis has its origin in the phenomenon of “compensatory behaviour” discussed above. Speed adaptation is a significant safety indicator. Based on in-car observation studies Risser, Teske, Vaughan, and Brandstätter (1982) analysed the correlation between the frequency of errors of different types and the number of observed conflicts for individual drivers. They found significant correlations between, on the one hand, the frequency of error types “speed badly adapted to traffic situation” and “late or absent deceleration at intersections or on approaches” and, on the other, the number of observed conflicts. Carlqvist and Persson (1988), in an in-depth study of accidents in the city of Växjö, identified the critical behaviour that led to these accidents. They found that too high speed in relation to the environmental and interactional demands accounted for 21% of the accidents.

1.1.2. Hypothesis 2

Behaviour towards other road users will improve (the drivers will be more willing to give priority to other vehicles and pedestrians).

This hypothesis originates from the empirical findings that drivers entering an interactive situation at lower speeds are more willing to give priority. Hydén and Várhelyi (2002), in an evaluation study of the effects of small roundabouts as speed reducing measures, concluded that car drivers showed more consideration to vulnerable road users and pedestrians got priority twice as often after the introduction of the roundabouts. They also showed that the number of expected injury accidents for pedestrians decreased by 80%. Towliat (2001) showed that the introduction of speed cushions as speed reducing measures improved drivers’ give-way behaviour towards pedestrians, and at the same time decreased the number of serious conflicts between these groups. Yielding behaviour was shown to be an important safety indicator. Carlqvist and Persson (1988), in their in-depth study of accidents, found that erroneous yielding behaviour accounted for 26% of the accidents. Carsten, Tight, Southwell, and Plows (1989) found that failure to yield was one of the main driver failures leading to urban traffic accidents. Drivers’ behaviour towards vulnerable road users is naturally an important safety indicator, but it is also an indicator of the formers’ situation awareness, communication skills and, in many countries, their law abidance.
1.1.3. Hypothesis 3
The law abidance of drivers in AAP-cars can change in a positive or negative direction (fewer/more stops at stop signs, larger/smaller proportion of driving against red).
This hypothesis has its origin in the notion of “behavioural adaptation” discussed above. Behaviour at traffic lights was shown to be an important safety indicator as well. Risser et al. (1982) found significant correlations between the error type “unlawful behaviour at traffic lights” and the number of observed conflicts for individual drivers.

1.1.4. Hypothesis 4
The time gap to the vehicle in front will increase.
This hypothesis also has its origin in the notion of “behavioural adaptation” discussed above. Car-following behaviour is another important safety indicator. Risser et al. (1982) found significant correlation between the error type “short distance to the preceding car” and the number of observed conflicts for individual drivers. In a similar study, Chaloupka, Risser, Zuzan, and Lukascheck (1985) concluded that “keeping too short a distance” was among the most serious of errors. Mäkinen and Kulmala (1987) studied accidents and headway on urban roads and found that rear-end collisions were the second most frequent accident type on the road type with a mean headway of four seconds. Moreover; Risser (1997) reported a relationship between police reported accidents and too short headway to the vehicle in front. On the other hand Nilson (1993), who reviewed the literature regarding this issue, concluded that a direct connection between traffic safety and short headways could not be established.

1.1.5. Hypothesis 5
The drivers get used to the system “taking control” and thereby delegate responsibility for certain driving tasks.
This hypothesis has its origin in the phenomenon of “delegation of responsibility” and “behaviour diffusion” discussed above.

2. Method
2.1. Selection of test drivers
From the total population of the 284 test drivers participating in the large-scale trial in Lund 28 were selected for the study. These selected individuals were assigned to groups with regard to gender, age and initial attitude to the AAP (all drivers in the large-scale trial answered a short questionnaire with questions about, among others, their attitude towards the AAP-system). The drivers in the large-scale trial were randomly selected from the national motor vehicle registry, the objective being to have an even mix of gender, age and positive/negative attitude to the AAP. However, since the test drivers had to agree to the installation of the system voluntarily, there was a slight bias towards drivers with a positive attitude to the AAP. There was also a bias in vehicle ownership towards middle-aged men, which was reflected in the test driver sample in this study as well. Table 1 shows the test driver distribution.
2.2. Observation method

The selected test drivers were observed by means of an in-car observation method, originally developed by Risser (1985) and designed to observe learning drivers. The method, however, also proved to be useful for studying driver behaviour in real traffic. The observations are carried out by two observers, riding along in the car with the driver, where one of the observers (called the coding observer) studies standardised variables such as speed behaviour, yielding behaviour, lane changes and interaction with other road users. The other observer carries out “free observations” such as conflicts, communication and special events that are hard to predict, let alone to standardise. The method was validated by Risser (1985) when he showed that there was a correlation between observed risky behaviour and accidents. Other validation work was done by Hjälm Dahl and Várhegyi (2004) who showed that drivers’ speed levels with observers in the car did not differ from their speed levels when driving their own cars. They also demonstrated that it was possible to train observers to perform the observations objectively and reliably. The method has been used with good results in several observational studies before this (see for instance Almqvist & Nygård, 1997; Comte, 2001 and Risser & Lehner, 1997). In the present study, an instrumented vehicle was used in addition to the observers to increase the quality of standardised variables, e.g. speed, and to make it possible to measure and register time gaps to the vehicle in front.

2.3. Study design

The test drivers were observed twice. The first test drive was carried out without the AAP being activated and before they had had any experience of the AAP. The second test drive was carried out when the test drivers had had at least six months of experience of driving with the AAP in their own cars. During this second test drive the AAP was activated within the test area but not outside, see Table 2.

Whether to use a control group or not was discussed in the start-up phase of the study. The advantage of using a control group is that effects caused by the studied system can be separated from possible effects due to the drivers’ “learning” the test route or becoming accustomed to the observers and the test situation. The disadvantage is of course that it takes extra resources. It was argued that, for a control group to be useful, it would have to be about the same size as the test group, but that was not feasible with the resources allocated to this study. It was further argued that the chance of learning effects was rather small since there was a period of at least six months between the two studies.
2.4. Test route

A specific route of 33 km, which took approximately 45 min to drive, was designated for the drives. In addition, each driver drove 15 min before the observations started to get used to the instrumented vehicle and the test situation. The test route consisted of varying driving conditions including all the legal speed limits in Sweden, both inside and outside Lund. It was divided into smaller parts with the same characteristics. In total there were 26 different observed sections, categorized into 7 different street types, see Table 2.

2.5. Apparatus

The instrumented vehicle used in this study was a 1999 Toyota Corolla with instrumentation designed and developed by VTT, Technical Research Centre, Finland. The car was equipped with three cameras, one facing forward, one facing backward and one directed at the driver’s face. The cameras were mainly used by the observers to discuss and clarify uncertain situations after the test drives, for instance whether a pedestrian actually intended to cross the road when the vehicle was approaching or not. The vehicle was also equipped with logging facilities and the variables measured and used in this study were: time, distance to vehicle in front and speed. Data was stored with a 5 Hz frequency.

2.6. Observed variables

2.6.1. Speed adaptation in low speed situations

Speed adaptation in this study was analysed based on speed with regard to the situation. Speeds with regard to speed limits and average speeds were analysed elsewhere (Hjälmåhl et al., 2002 and Várhelyi et al., in press). The variables that describe speed adaptation are the coded variables “speed adaptation at obstacles” and “speed with regard to the situation”. Examples of obstacles

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**Table 2**
The different street types included in the study

<table>
<thead>
<tr>
<th>Street type</th>
<th>Speed limit (kph)</th>
<th>Driving speed (kph)</th>
<th>AAP activated automatically</th>
<th>Number of observed sections</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Arterial road</td>
<td>50</td>
<td>≈50</td>
<td>Yes</td>
<td>6</td>
<td>Mainly car traffic, signal-controlled junctions and crossings</td>
</tr>
<tr>
<td>Main street</td>
<td>50</td>
<td>≈50</td>
<td>Yes</td>
<td>5</td>
<td>Cyclists and roadside parking to some extent</td>
</tr>
<tr>
<td>Main street with mixed traffic</td>
<td>30–50</td>
<td>≈30</td>
<td>Yes</td>
<td>2</td>
<td>A large proportion of pedestrians and cyclists, interactions mid section</td>
</tr>
<tr>
<td>Central street</td>
<td>30</td>
<td>≈30</td>
<td>Yes</td>
<td>1</td>
<td>Cars and vulnerable road users on equal terms</td>
</tr>
<tr>
<td>Rural through road</td>
<td>30–50</td>
<td>30–60</td>
<td>No</td>
<td>5</td>
<td>Rural road through small towns, few interactions</td>
</tr>
<tr>
<td>Rural road</td>
<td>70–90</td>
<td>60–100</td>
<td>No</td>
<td>6</td>
<td>Rural road</td>
</tr>
<tr>
<td>Motorway</td>
<td>110</td>
<td>≈110</td>
<td>No</td>
<td>1</td>
<td>Motorway</td>
</tr>
</tbody>
</table>

are road works, parked cars etc., i.e., obstacles that require some kind of evasive action from the
driver, like braking or swerving. Speed with regard to the situation implies that there is no direct
obstacle that has to be passed, but that the speed should be adapted anyway, for instance if there
are children in the vicinity of the road or if a bus is stopping to let passengers off.

2.6.2. Behaviour towards other road users

The variables describing behaviour towards other road users were yielding behaviour and
interaction with unprotected road users, (in priority situations and in interactions). The yielding
behaviour to other vehicles was classified as “OK”, “hesitant” or “dangerous/short gap”. For a
situation to be registered as a yielding situation there had to be another vehicle present.
Approaching an intersection or a roundabout without any other vehicle present was not classified
as a yielding situation. Behaviour towards pedestrians was observed in interactions at pedestrian
crossings. Swedish law gives the pedestrian the right of way at pedestrian crossings.

2.6.3. The drivers’ law abidance

Law abidance of the drivers was studied by the free observer since traffic violations are hard to
standardise.

2.6.4. Time gap

The distance to the vehicle in front, presented as time gap (i.e., the distance in meters from the
front of the test vehicle to the rear of the vehicle in front divided by the speed measured in m/s)
was measured by a lidar (laser-radar) mounted in the front of the instrumented vehicle. It was
registered five times per second. The distance was measured in meters with 0.1 m accuracy and the
maximum measurable distance was 127 m. Apart from registering distance to the vehicle in front,
the lidar could pick up reflections from parked cars, road signs etc. Video-recordings were used to
separate this data from the relevant data. Car-following situations were analysed according to the
definition below.

For a situation to be classified as a car-following one, several criteria have to be established: (1)
The time gap between the vehicles should be 4.5 s or less. A commonly used figure for mea-
surements with pneumatic tubes is 5 s between the vehicles’ front axels (see e.g. Nilsson, 2001).
With the assumption that a normal vehicle is approximately 4.5 m long, the two measures will be
the same at 32.4 kph. (2) The difference in speeds between the vehicles should be less than ±4 kph.
This is a commonly used figure to filter out overtaking situations when measuring with pneumatic
tubes (see e.g. Nilsson, 2001), but it can also be considered a reasonable limit for the vehicles to
interact with each other. The difference in speed was calculated using the speed of the test vehicle
and the change in distance. There was some instability in the measured distance that occurred due
to road and vehicle geometry, hence an average over 7 measurements, i.e. 1.4 s was used to in-
crease stability in the data. (3) The car-following situation should last for at least five seconds.
This was to filter out situations where the vehicles were together at a traffic light and then chose
different routes at the next junction without really interacting with each other. (4) The speed
should be at least 10 kph to filter out traffic queues. (5) The final condition is that the difference in
speed should not be one-sided; that is, if the test driver drives away from a traffic light following
a vehicle, which chooses a driving speed up to 4 kph faster and then after a while exceeds the 4.5 s
boundary; alternatively, the test driver catches up with another vehicle and then overtakes it.
If these five criteria are met the registered time gaps are not affected by the fact that the drivers might be restricted in speed when driving with the AAP, and it can thereby be excluded that any differences between the two test-situations are due to system effects.

2.6.5. Delegation of responsibility

The phenomenon “delegation of responsibility” is represented by events that can be interpreted as the driver, relying on the fact that the system takes care of tasks other than giving support to keep the speed limit, delegates to the system some of the tasks other than the system was designed for. With the AAP, tasks that the drivers might delegate to the system are those of keeping the speed limit and keeping track of the current speed limit. The events that could be an indication of delegation of responsibility were noted by the free observer.

2.7. Analyses

The analyses of the observations aimed at finding patterns and correlations that would suggest behavioural changes. The standardised variables were analysed quantitatively and tested for statistical significance by Chi2-test for those on the nominal scale and by t-test for those on the quota scale. The free observations were organised into groups to match a certain phenomenon or hypothesis and were analysed qualitatively. The number of free observations in each group was often too small to test for statistical significance; instead the analysis of free observations aimed at explaining findings from the standardised variables. In some cases they also contributed to generating new hypotheses for further research.

In the analysis of time gaps each driver’s car following was compared individually with and without the AAP for the different road sections described in Table 2. Consequently, only those drivers who had a car-following situation on the same street types with and without the AAP were included in the analysis. The time gaps were tested for statistical significance for each driver and street type by independent samples t-test and the overall difference was tested by sign test.

3. Results

The analysis of the observed data was made for each of the different stretches described in Table 2. The number of observations differed between the different stretches. For instance, the number of interactions with unprotected road users was significantly higher on central streets than on arterial roads where most of the pedestrian crossings are signal controlled. To make the results more transparent and to get sufficient data for statistical analysis the stretches were grouped into; “within test area” and “outside test area”. Within the test area the drivers were supported by the AAP-function in the after situation, whilst this was not the case outside the test area. The results are presented according to the hypotheses they correspond to.

3.1. Speed adaptation in low speed situations

The events belonging to the category “speed adaptation at obstacles” were registered as “OK”, “late/hard braking” and “badly adapted speed” and there were 58 registered events without AAP
and 46 with AAP within the test area. The registrations are presented in Table 3. The percentage of cases where speed adaptation was “OK” decreased from 93.1% to 91.3% when driving with the AAP, but the difference is statistically not significant ($p = 0.244$). The number of registered events of speed adaptation with regard to the traffic situation was too low to draw any conclusions from; there were only 10 registered events evenly distributed with and without the AAP.

3.2. Behaviour towards other road users

In total, there were 94 yielding situations without and 94 situations with the AAP within the test area. The percentage of correct yielding behaviour increased from 88% to 96% when driving with the AAP. The difference is statistically significant when the “OK” registrations are compared with the registrations of erroneous yielding behaviour: “hesitant” and “dangerous/short gap”, however, only on the $p < 0.10$ level. Outside the test area there were 47 yielding situations without and 46 with the AAP. The percentage of correct yielding behaviour increased from 94% without the AAP, to 96% with the AAP, but that increase is not statistically significant ($p = 0.851$).

When analysing the recorded data it turned out that the number of recorded events for pedestrians outside the test area was too low to draw any conclusions, so a comparison could only be carried out for pedestrians within the test area. The number of observations of interactions with pedestrians within the test area was 118 without the AAP and 115 with the AAP and the classification and distribution can be seen in Table 4.

Table 3
The test drivers’ speed adaptation at obstacles without and with the AAP inside the test area

<table>
<thead>
<tr>
<th></th>
<th>Without AAP</th>
<th></th>
<th>With AAP</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$n$</td>
<td>%</td>
<td>$n$</td>
<td>%</td>
</tr>
<tr>
<td>OK</td>
<td>54</td>
<td>93.1</td>
<td>42</td>
<td>91.3</td>
</tr>
<tr>
<td>Late/hard braking</td>
<td>4</td>
<td>6.9</td>
<td>2</td>
<td>4.3</td>
</tr>
<tr>
<td>Badly adapted speed</td>
<td>0</td>
<td>0.0</td>
<td>2</td>
<td>4.3</td>
</tr>
<tr>
<td>Sum</td>
<td>58</td>
<td>100</td>
<td>46</td>
<td>100</td>
</tr>
</tbody>
</table>

Table 4
The distribution of registrations regarding the test drivers’ yielding behaviour when interacting with pedestrians at pedestrian crossings

<table>
<thead>
<tr>
<th>Interaction with pedestrians at pedestrian crossings</th>
<th>Without AAP</th>
<th></th>
<th>With AAP</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$n$</td>
<td>%</td>
<td>$n$</td>
<td>%</td>
</tr>
<tr>
<td>The driver yields early</td>
<td>64</td>
<td>54</td>
<td>78</td>
<td>68</td>
</tr>
<tr>
<td>The driver yields late</td>
<td>7</td>
<td>6</td>
<td>5</td>
<td>4</td>
</tr>
<tr>
<td>The pedestrian forces the driver to stop</td>
<td>5</td>
<td>4</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>The pedestrian waits at roadside</td>
<td>29</td>
<td>25</td>
<td>25</td>
<td>22</td>
</tr>
<tr>
<td>The driver forces the pedestrian to stop</td>
<td>13</td>
<td>11</td>
<td>5</td>
<td>4</td>
</tr>
<tr>
<td>The driver puts the pedestrian in danger</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Total</td>
<td>118</td>
<td>100</td>
<td>115</td>
<td>100</td>
</tr>
</tbody>
</table>
3.3. The drivers’ law abidance

The majority of the traffic violations occurred within the test area. There were 14 events registered without the AAP and 5 with the AAP (note that speeding was not included in traffic violations in this study). The occurrence of traffic violations can be considered to be Poisson distributed and under this assumption the difference is statistically significant \( p < 0.05 \). It should be mentioned, however, that two types of traffic violations dominated; consciously driving against yellow lights and stopping in an area designated for cyclists before signalised intersections. The severity of the traffic violations can be considered as low and there might even have been a learning effect when driving along the route the second time, even though there was a period of at least six months between the test drives. A conservative interpretation is therefore that the number of traffic violations did not increase.

3.4. Time gap

In total there were 2.5 h of driving in a car-following situation, evenly distributed between with and without AAP and approximately 70% registered within the test area. The number of drivers that had car-following situations with and without the AAP varied from 16 for the arterial roads, 10 for the main streets and 8 for the main streets with mixed traffic down to less than 5 for the rest of the street types. Due to the low number it was only on the arterial roads that any statistically significant difference could be found \( p < 0.05 \), see Table 5.

The average, unweighted, time gap for the drivers presented in Table 5 is 1.72 s without the AAP and 1.89 s with the AAP. The mean speed for the drivers in Table 5 during the car-following situation on the arterial roads was 37.5 kph without the AAP and 38.7 kph with the AAP. The distribution of time gaps for these drivers is shown in Fig. 1.

An analysis was also carried out to compare time gaps in different speed intervals. This was to see whether the differences were dependent on street types or on speed level, and to make a comparison between the results of this trial in Lund and the results of an earlier trial conducted within the framework of the EU-project MASTER (Várhelyi & Mäkinen, 2001), see Table 6.

As can be seen in Table 6 the results of the two trials are in line with each other even though the relative lengths of time gaps are different. This is most likely due to different measurement methods and a slightly different definition of a car-following situation. For none of the trials could any difference be found in the lower speed interval, while there was a difference in the interval \( 30 < V < 50 \) kph. A comparison, where speeds above 50 kph were included (above 50 kph means that the driver is speeding, which occurred to a higher degree without the AAP), gave an even larger difference indicating that the AAP’s effect on time gaps increases when the speed increases. The same effect could be found on mean speeds where the AAP had a high effect on arterial roads.
but a very small effect in central streets in which the speeds were already low without the AAP (Hjälmdahl et al., 2002).
3.5. Delegation of responsibility

The observed events having to do with “delegation of responsibility” are listed in Table 7. As seen in Table 7 most of the events that can be attributed to “delegation of responsibility” occurred outside the test area where the AAP was not active. The numbers are small but the difference is apparent (\( p < 0.01 \)) assuming that the events are Poisson distributed. Thus, it can be stated that a certain degree of delegation of responsibility occurred.

Table 7

Events indicating delegation of responsibility

<table>
<thead>
<tr>
<th>Description</th>
<th>Without AAP</th>
<th>With AAP</th>
</tr>
</thead>
<tbody>
<tr>
<td>Positive</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Negative</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

\( n' \): In the Lund trial \( n \) denotes the number of registrations with the lidar which means that \( n/5 \) is the number of measured seconds. In MASTER \( n \) denotes the number of observed situations.
4. Discussion

The observations in this study aimed at establishing whether the AAP leads to any changes in driving behaviour and driving style, and especially to see if there are any negative behavioural changes which can reduce the safety effect that the AAP should have had due to lower and more even speeds (Almqvist et al., 1997; Brookhuis & de Waard, 1999; Carsten & Fowkes, 2000; Hjålmdahl et al., 2002; Vårhelyi & Mäkinen, 2001).

The numbers of events recorded with and without the AAP are similar in size, which indicates stability in the measurement method and the test conditions. Together with the large number of observations for some of the variables, this provides for good possibilities for analyses. However, for some variables there were not enough observations to state with certainty that there is an effect. Still, it does raise the need for further research.

Hypothesis 1, “Drivers do not lower their speed in low speed situations to the same extent when driving with AAP as when driving without AAP” can neither be verified nor rejected due to too few observations. There were no clear signs of compensatory behaviour when the drivers drove with the AAP. The number of “badly adapted speed at obstacles” and “late/hard braking” increased within the test area but the difference is small and not statistically significant. Outside the test area there were too few situations to trace any effects. Studies of approach speeds and turning speeds based on the logged data in the large-scale trial in Lund (Vårhelyi et al., in press) could reject the hypothesis that drivers do not lower their speed to the same extent as they do without the system. The findings from this study, however, cannot rule out that such an effect exists.

Hypothesis 2, “Behaviour towards other road users will improve (the drivers will be more willing to give priority to other vehicles and pedestrians)” can be verified. The percentage of correct yielding behaviour increased from 88% to 96% within the test area when driving with the AAP. Thus, there was a strong tendency towards improved yielding behaviour. Interactions with pedestrians improved statistically significantly, and correct yielding behaviour increased from 54% to 68% when driving with the AAP ($p < 0.05$). These results are in line with the results from Almqvist and Nygård (1997) who found that the behaviour towards other road users improved after the test subjects had used an in-car speed limiter for two months. Vårhelyi and Mäkinen (2001) did not find any difference in behaviour towards other road users and Persson et al. (1993) found that behaviour actually deteriorated when driving with a speed limiter. Those studies, however, did not look at long-term behavioural modifications. Instead, these trials were carried out as a comparison between two consecutive test drives. The present results reinforce earlier empirical findings of Hydén and Vårhelyi (2002) and Towliat (2001) who showed that drivers entering in an interactive situation with lower speeds are more willing to give priority to pedestrians at pedestrian crossings. Vårhelyi (1998), observing the behaviour of drivers approaching a pedestrian crossing, found that in encounters, three out of four drivers maintained the same speed or accelerated (even over the speed limit of 50 kph) to signal that they do not intend to give way to the pedestrian at the crossing. The AAP, reminding the driver of the speed limit, obviously prevents the driver from such signalling. Subjective measures through questionnaires have also shown that the drivers believe they are more aware of pedestrian presence and they yield to a higher degree (Falk, Hjålmdahl, Risser, & Vårhelyi, 2002).

Hypothesis 3, “The law abidance of drivers in AAP-cars can change in a positive or negative direction (fewer/more stops at stop signs, larger/smaller proportion of driving against red)” can
neither be verified nor rejected. Due to the small amount of observations and to the low severity of the traffic violations it is too daring to say that the law abidance has improved. A conservative interpretation of the results is that the law abidance has not worsened due to the AAP.

Hypothesis 4, “The time gap to the vehicle in front will increase” can partly be verified. The time gap to the preceding vehicle increased on arterial roads. The analysis shows that the effect of the AAP increases when speed increases. This result can be compared with the results of other studies in the field with and without a speed limiter; Persson et al. (1993) concluded that distance to the vehicle in front increased and Vårhelyi and Mäkinen (2001) found that distance to the vehicle in front increased within urban areas but decreased on rural roads.

Hypothesis 5, “The drivers get used to the system ‘taking control’ and thereby delegate responsibility for certain driving tasks” can be verified. There were some signs of delegation of responsibility in the form of the drivers not changing their speed when entering a new speed limit zone where the system was not active (i.e. outside the test area). Without the AAP this was only registered once while it was observed nine times when the test drivers had been driving with the AAP in their own cars for at least six months. There is only one variable in this study that indicates delegation of responsibility and the number of observations is relatively small. However, the difference between the two test drives is so apparent that it is highly probable that “delegation of responsibility” exists to a certain degree.

In-vehicle speed adaptation systems, such as the AAP, have proved to have a large safety potential due to reduced speeds, but earlier studies had also shown that there were some behavioural modifications when driving with such systems. Examples of this from earlier studies are: deteriorated interaction with other road users, changed headway and law abidance. The current study differs from the earlier studies in that in this study it was possible to observe behavioural modifications after using the system for a longer period of time. The drivers in this study had been driving with the AAP in their own cars for at least six months and in some cases for up to one year before their behaviour in the “after” situation was observed.

Analysis of speed data logged in the drivers’ own vehicles during everyday driving showed that the test drivers’ compliance with the speed limits improved considerably when driving with the AAP (see Table 8) and the safety effect due to reduced mean speeds was estimated to range from a

<table>
<thead>
<tr>
<th>Street type/speed limit (kph)</th>
<th>No of measured stretches</th>
<th>Mean speed at mid-block (unweighted) for all stretches (kph)</th>
<th>Change (kph)</th>
<th>Expected decrease in fatal accidents (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Arterial road/70</td>
<td>8</td>
<td>76.0 (without AAP) 71.1 (With AAP)</td>
<td>-4.9*</td>
<td>23</td>
</tr>
<tr>
<td>Arterial road/50</td>
<td>10</td>
<td>55.3 (without AAP) 50.3 (With AAP)</td>
<td>-5.0*</td>
<td>32</td>
</tr>
<tr>
<td>Arterial road/50</td>
<td>19</td>
<td>52.8 (without AAP) 49.1 (With AAP)</td>
<td>-3.7*</td>
<td>25</td>
</tr>
<tr>
<td>Main street/50</td>
<td>12</td>
<td>45.2 (without AAP) 43.2 (With AAP)</td>
<td>-2.0*</td>
<td>17</td>
</tr>
<tr>
<td>Main street, mixed traffic/50</td>
<td>12</td>
<td>38.1 (without AAP) 37.1 (With AAP)</td>
<td>-1.0</td>
<td>10</td>
</tr>
<tr>
<td>Central street/30</td>
<td>8</td>
<td>28.7 (without AAP) 27.0 (With AAP)</td>
<td>-1.7</td>
<td>22</td>
</tr>
</tbody>
</table>

*Statistically significant difference according to t-test and sign test (p < 0.05).
10% reduction in the number of fatal accidents on main streets with mixed traffic up to a 32% reduction on arterial roads with a 50 kph speed limit (Hjälmdahl et al., 2002). These estimations were made by using the “power model” (Nilsson, 2000) which only considers the change in mean speed and presupposes that no other changes have taken place. Hjälmdahl et al. (2002) also showed that the variance in speed decreased and these changes in speed behaviour indicate a great traffic safety potential.

The present study has shown that the AAP brings other effects too, apart from changes in the speed level and speed variance, such as improved behaviour towards other road users. The drivers showed a more correct yielding behaviour at intersections and yielded early for pedestrians to a higher extent when driving with the AAP. This indicates that the system does not change behaviour immediately but driving with it for a longer period of time does. This finding reinforces earlier empirical findings on the mechanisms of behavioural adaptation, articulated by Draskóczy (1994), saying that behavioural adaptation does not appear immediately when the driving context is changed, but usually appears only after a time.

Another positive effect is that the time gaps increased on arterial roads when driving with the AAP. On other street types no effect could be found due to the low number of car-following events. The increase in time gap is quite small but it means that the drivers on average will have an extra 0.17 s disposable for reaction time or 1.79 m extra to stop when driving at 38 kph, which was the mean speed during the car-following situations.

There were also signs of behavioural modifications that could have a negative effect on safety. The most apparent phenomenon was the fact that, after having driven with the AAP for a longer period, some of the test drivers forgot to change their driving speed when entering a new speed limit zone in areas where the AAP was not active. Such a result is to be expected when the AAP is only active in certain areas. The number of observations of this phenomenon was quite low but there were clear differences between driving without the AAP and driving with it. This is a very important aspect, since during an introductory phase there will be areas not covered by the system and there will be cars not equipped with the system. Further research is needed on how drivers react, after getting used to the system, when driving in areas or cars where the AAP is not in operation.

In addition to these observed behavioural effects, subjective measurements of the test drivers’ workload and experience with the system via interviews (see Falk et al., 2002) revealed that they felt a slightly higher time pressure and that they were holding up others in traffic when driving with the AAP. In-depth interviews revealed that these negative effects were most apparent on roads with a mean speed above the speed limit. Such effects can be expected when the number of equipped vehicles in traffic is low. On the other hand, some positive indications of decreased driver workload were found too, such as the test drivers stating that they looked less frequently at the speedometer and that they needed to use the accelerator and the brakes less frequently.

An overall conclusion regarding the safety effect of the AAP must be that; even though there are signs of behavioural modifications that could diminish the positive effects on traffic safety, these diminishing effects are by far exceeded by the additional safety potential due to lowered speed, in combination with the positive change in car-following behaviour and improved interaction with other road users.
References


O’Cinnéide, D., & Murphy, E. (1994). *The relationship between geometric road design standards and driver/vehicle behaviour, level of service and safety*. Traffic Research Unit, University of Cork, UK.


