DRIVERS' EVALUATIONS OF THE ACTIVE ACCELERATOR PEDAL IN A REAL-LIFE TRIAL

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In a large-scale field trial, conducted between 2000 and 2001, the test drivers used the Active Accelerator Pedal for between 6 and 12 months in their regular cars. The drivers' evaluations, elicited by questionnaires after one month of usage and at the end of the trial, were analysed with ANOVA (repeated-measure) and compared to the objectively measured effects in the same trial. The drivers found the system to be effective in decreasing their speed and believed their risk of being fined for speeding decreased drastically. On the other hand, their workload increased and their emotional state deteriorated. They reported an increased feeling of obstructing other drivers and reduced driving enjoyment. Between-subject effects showed a different way of using the system depending on age; younger drivers used the supporting function of the system more, while older drivers found the counter force more of a command to lower their speed. Time effects showed the importance of long-term evaluations and the interaction effects demonstrated how development of driver responses over time depend on driver type and initial attitude. Comparing driver subjective experiences and objectively measured effects, discrepancies were found in the magnitude of speed changes and car-following distances. The delegation of responsibility coincided well with the objectively measured effects.

Key Words: Active Accelerator Pedal, Field trial, Driver experiences, Workload, Emotional state, Long term effects

1. INTRODUCTION

The Active Accelerator Pedal (AAP), an overrideable, tactile in-car speed management system designed to prevent speeding, has overall demonstrated a large traffic safety potential. The system has shown, among other things, reductions in mean speeds and speed variance[1,2]. In addition, Hjälmdahl and Várhelyi[3] found improved behaviour towards other road users and slightly larger following distances, which imply an additional traffic safety potential. However, some negative behavioural modifications were also reported, such as drivers forgetting to adjust their driving to the speed limit when not supported by the system. Based on the reduction in mean speeds Hjälmdahl et al. estimated a reduction of injury accidents of between 8% and 25% and a reduction in fatal accidents of between 10% and 32%, under the assumption that all cars were equipped with an AAP[1]. Nevertheless, the effects on traffic safety of any driver assistance system are also influenced by driver workload and driver emotional state. An increased workload may result in overloading the driver, with distraction, errors and increased risk of accidents as a consequence. On the other hand, under certain circumstances in-car technology may have the opposite effect on workload and lead to monotonous driving (see for example, references[4-6]). Changes in emotional state such as anger and irritation while driving may interfere with attention, perception, information processing, motor performance and make the driver more disposed to aggressive behaviour (for a review see Ullberg[7]).

Up to now, there has been little reported on long-term driver experiences with a system like the AAP. The time the system is used has a significant impact on its effects, as shown by logged data in Hjälmdahl[8], where the speed reduction decreased over time. This indicates a danger of overestimating the effects if systems are only evaluated after short-term usage. If, and how, the drivers' experiences vary over time are uncertain.

For different driver groups the AAP affects speed differently, as shown by Hjälmdahl[8]. Also, the acceptance is affected by driver characteristics, as shown by Adell et al.[9] As already discussed in Adell et al., the need for and justification of systems like AAP lie, from a societal point of view, in their safety potential[9]. From an individual driver's point of view, however, this motive for using systems in one's private car may not be obvious since the perception of traffic safety and risk is usually very vague[10]. This is demonstrated in Adell et al. where usage of the AAP only slightly improved safety according to the test drivers[9]. Differences between objectively measured effects and drivers' subjective experiences of the system are important when choosing implementation strategies or evaluating systems, as drivers' experiences may be good indicators of more objectively measured effects in some areas, while they might lead to invalid conclusions in other areas.

This paper aims at examining drivers' experiences with the AAP after long-term use with special focus on changes over time. The hypotheses to be tested are based on results from earlier studies[11-14] and are listed below as null hypotheses:

1. The AAP does not affect reported driving behaviour (speed level, compliance with speed limits, car-following distance);
2. The AAP does not affect reported travel time and fuel consumption;
3. The AAP does not affect drivers' workload;
4. The AAP does not affect drivers' distraction;
5. The AAP does not affect drivers' emotional state;
6. The AAP is used in the same way by test drivers regardless of gender, age and initial attitude towards the system.

In addition, differences between driver groups are analysed, and discrepancies between the drivers' evaluation and objectively measured effects are examined. Finally, the paper also analyses the safety implications of drivers' experiences with the AAP.

The analyses are based on data collected in the large scale field trial with AAP in Lund, Sweden[15].

2. METHOD

2.1 The active accelerator pedal

An Active Accelerator Pedal (AAP) is an ISA (Intelligent Speed Adaptation) system which assists the driver to comply with the legal speed limit. The system consists of 1) a dashboard-mounted display informing the driver of the current speed limit and 2) an active accelerator pedal exerting a counterforce if an attempt is made to exceed the speed limit. The accelerator pedal must be pressed approximately three to five times harder than normal in order to override the system. The legal speed limit is determined by GPS and an onboard digital map containing the speed limits. The vehicle does not transmit a signal of its own and can not be localised.

2.2 Experimental design

The evaluation was designed as a short/long-term usage within-subjects study, see Figure 1. The system was installed in 281 passenger cars and was kept running for between 6 and 12 months (long-term usage).

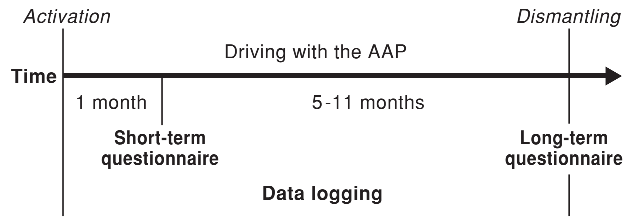

Fig. 1 Experimental design of the field trial

2.3 Participants

The 281 participants (247 private car drivers and 34 company car drivers) were recruited by questionnaires distributed to randomly selected vehicle owners in the municipality of Lund and by a request to local transport companies. The test drivers were assigned into groups according to gender, age and initial attitude towards the active accelerator pedal; positive/negative/indecisive. The initial attitude was determined by the question "*Would you think of having the following equipment in you car? A system that gives a counter force to the accelerator when the vehicle has reached the speed limit, and the speed limit cannot be overridden except in an emergency*." (*good, not good, neither*) in the recruiting questionnaire. Of the 281 who started the trial, 197 participated to the end (Table 1).

Female drivers over 65 and young drivers (18-24) were underrepresented. This was due to the fact that female drivers over 65 often do not have a car registered in their own name, and young drivers often have older cars in which it was not possible to install the AAP. Middle-aged drivers (45-64) were overrepresented.

There were some problems with technology, with two thirds of the drivers reporting some level of malfunctioning of the system during the trial. In the group of drivers reporting malfunctioning, there was an overrepresentation of company car drivers (32 of the 34 drivers). No differences in gender (X^2, p=0.29), age group (X^2, p=0.47) or initial attitude (X^2, p=0.99) could be found.

2.4 The test area

The test area included the entire city of Lund (ca. 100 000 inhabitants), where the speed limits are 30, 50 and 70 km/h. The AAP system was used in all areas except on a motorway running through the city. It could not be switched off within the test area, but could be set man-

Table 1 Test drivers starting and completing (starting/completing) the trial according to age group, gender and initial attitude towards the AAP (three drivers did not reveal their initial attitude, which is why the total sum in the table is less than 281/197)

	Age group												Total
	18-24			25-44			45-64			65≤			
	positive	negative	indecisive	positive	negative	indecisive	positive	negative	indecisive	positive	negative	indecisive	
Male	4/2	2/1	1/1	41/26	8/5	7/6	61/43	12/8	13/12	28/19	1/1	3/3	181/127
Female	5/3	0/0	0/0	26/19	12/7	3/3	28/18	5/4	12/10	5/2	1/1	0/0	97/67
Total	9/5	2/1	1/1	67/45	20/12	10/9	89/61	17/12	25/22	33/21	2/2	3/3	278/194

ually to a desired speed limit outside the test area.

2.5 Procedure

Responses were elicited by questionnaires mailed to the drivers after short-term usage (1 month) and after completion of the trial (5 to 11 months later). If no reply was received in three weeks, a reminder was sent out. As compensation for time loss and inconvenience, the drivers received 99 SEK (~10 Euro) in petrol checks twice during the trial.

2.6 Questionnaires

The questionnaires covered: driver behaviour (speed, speed limit compliance etc.), travel time, fuel consumption, driver state (workload, distraction, stress, irritation, driving enjoyment etc.) and use of the system, and contained 101 and 229 questions, respectively. Most questions were to be answered on a five-graded scale (either one sided or two-sided), but seven-graded scales and open questions were also used.

The response rate, for those answering both questionnaires, was 80% (157 of 197 drivers). There were no statistically significant differences in response rates between gender (X^2, p=0.88), age groups (X^2, p=0.22, however, drivers 18-24 were too few to be assessed), initial attitude (X^2, p=0.57), driver type (X^2, p=0.22) or malfunctioning systems (X^2, p=0.73).

2.7 Analysis

The youngest age group (18-24) included too few answers (2) and had to be excluded from the analysis.

Analysis of variance (ANOVA) was employed to analyse the data when no severe deviations from the normal distribution were found. The design 3 (age) × 2 (gender) × 3 (attitude) × 2 (driver type) × 2 (malfunctioning system) × 2 (time) or 3 (speed), with repeated measures on the last factor, was used. The main effects of the between-subject factors AGE (25-44, 45-64, 65+), GENDER, initial ATTITUDE (positive, indifferent, negative), DRIVER TYPE (company car drivers, private drivers) and MALFUNCTIONING SYSTEM (yes, no) were entered in the model. The within-subject factors TIME (short-term, long-term) or SPEED (30 km/h, 50 km/h, 70 km/h streets) were entered when at hand. If no within-subject factor was available, a univariate ANOVA was performed. Backwards elimination was used on the between-subject factors until $p<0.10$. When the Mauchly's test of sphericity indicated violations of the assumption of circular variance-covariance matrix of the dependent variable ($p>0.10$), the Greenhouse-Geisser epsilon was used to correct the degrees of freedom. Post Hoc pair-wise comparison (Tukey HSD) was used to find differences among age groups and attitudes. The single sample t-test was used to analyse differences from the answer category "unchanged".

The Wilcoxon's matched-pairs signed-rank test was employed to assess statistical difference over time when normal distribution could not be assumed, the Mann-Whitney's rank sum test to analyse effects of gender, driver type and malfunctioning system, and the Kruskal-Wallis H for differences between age groups and initial attitudes. The Post Hoc pair-wise comparison (Tukey HSD) was used to identify statistically significant differences between more than two groups.

3. RESULTS

3.1 Driver behaviour

The test drivers noticed a considerable reduction in their speeds when using the AAP (Figure 2). No significant differences in the magnitude of speed change in streets with different speed limits were reported in the short-term measurement. In the long-term, however, the effect was larger in streets with lower speed limits compared with streets with higher limits (F(1.7,249.1)=8.333, $p<0.05$). The analysis also yielded a decreasing effect over time in 50 km/h (F(1,144)=12.186, $p<0.05$) and 70 km/h streets (F(1,146)=6.019, $p<0.05$). Interaction effects between *time and attitude* showed an increasing effect over time for initially positive drivers and decreasing effect for negative drivers in 30 km/h streets (F(2,143)=3.459, $p<0.05$). The decreasing effect over time in 50 km/h streets was more accentuated for negative and indifferent drivers than for positive ones (F(2,144)=4.454, $p<0.05$). Interaction effects between *time and driver type* was found for 50 km/h (F(1,144)= 5.328, $p<0.05$) and 70 km/h streets (F(1,146)=2.990, $p<0.10$) showing that the time effect was significantly larger for company car drivers than for private car drivers. Outside the test area, where the use of the system was voluntary, the drivers also reported a reduction in speed (long term only) (Figure 2). This reduction was considerably smaller than inside the test area but yielded larger effects in streets with lower speed limits compared to streets with higher limits (F1.7, 252.6)=8.510, $p<0.05$). Interactions between *speed and driver type* showed that this pattern was more accentuated for company car drivers than for private drivers (F(1.7,252.6)=3.387, $p<0.05$).

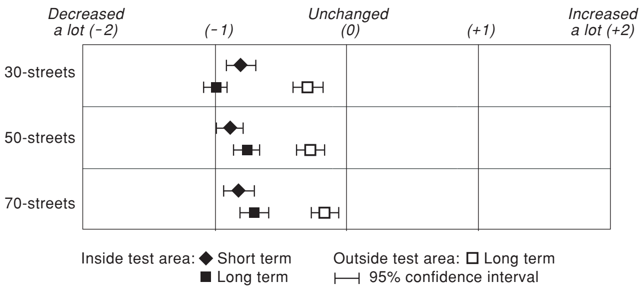

Fig. 2 The average reported changes in speeds when using the AAP

According to the test drivers it was easier to comply with the speed limit when using the AAP, see Figure 3. Higher compliance with speed limits was also reflected in a reduction in the reported risk of being fined for speeding, which decreased considerably (short-term: $M=-1.36$, $SD=0.685$, long-term: $M=-1.32$, $SD=0.708$, where −2="decreased a lot", 0="unchanged", +2="increased a lot"). Further analysis showed that drivers with a malfunctioning system found it harder to comply with speed limits in the short-term measurement (in 30 km/h

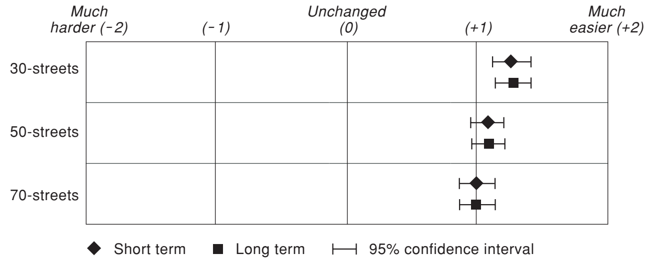

Fig. 3 How much harder/easier it had become to comply with the speed limits

streets: $U(n_1=47, n_2=105)=1818$, $p<0.05$), in 50 km/h streets: $U(n_1=47, n_2=106)=2011$, $p<0.05$), in 70 km/h streets: $U(n_1=47, n_2=106)=1929$, $p<0.05$)). It also showed a smaller effect on the risk of being fined for speeding for drivers with a malfunctioning system compared to others (short-term: $U(n_1=47, n_2=106)=2038$, $p<0.05$), long-term: $U(n_1=47, n_2=104)=1897$, $p<0.05$).

The car-following distance was in general not affected by the use of AAP, according to the drivers ($M=-0.1$, $SD=0.126$, where −3="much shorter", 0="Unchanged", +3="much longer").

3.2 Travel time and fuel consumption

The drivers' travel time increased slightly, according to themselves, when using the AAP ($p<0.05$), whereas no statistically significant change in fuel consumption was found (Figure 4). There were indications that the drivers with a malfunctioning system reported a larger increase in travel time (F(1,142)=2.889, $p<0.10$) and higher fuel consumption (F(1,143)=3.136, $p<0.10$) compared to the other drivers. Further, interactions between *time and driver type* indicated an increase in fuel consumption over time for company car drivers (F(1,143)= 3.716, $p<0.10$).

3.3 Workload

The drivers' workload was assessed by six factors

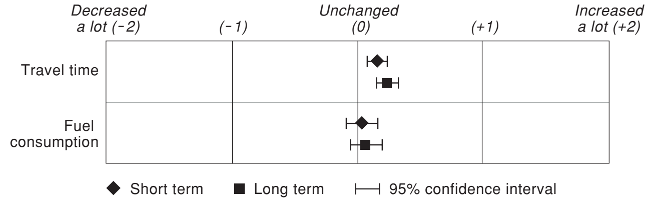

Fig. 4 Reported effects on travel time and fuel consumption while driving with the AAP compared to driving without the system

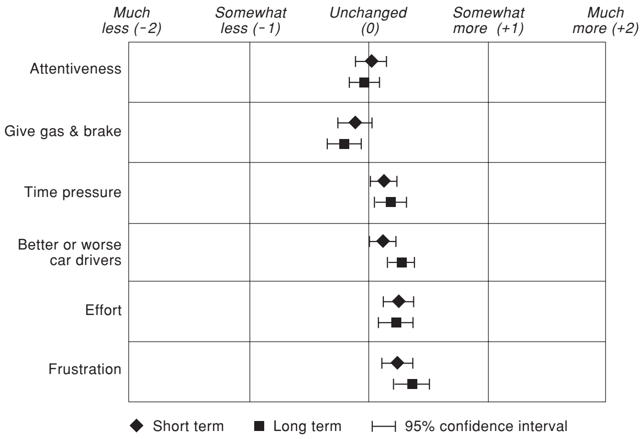

Fig. 5 Mean ratings of the six workload factors when driving with AAP for short and long terms

(based on the raw task load index, RTLX[16]). The results showed a decrease in the need to give gas and brake ($p<0.05$, long term only) an increase in time pressure, driving performance, effort and frustration ($p<0.05$) (Figure 5). The driving performance increased over time ($F(1,147)=2.980$, $p<0.10$). Statistically significant main effects of attitude were found, implying that the negative drivers felt the need to be more attentive while driving ($F(2,149)=2.440$, $p<0.10$), higher time pressure ($F(2,148)=5.698$, $p<0.05$), higher effort ($F(2,147)=4.758$, $p<0.05$) and higher frustration level ($F(2,143)=2.366$, $p<0.10$) than the positive drivers. Main effects of age groups showed that older drivers rated their performance higher than middle-aged and younger drivers ($F(2,147)=3.784$, $p<0.05$) and their frustration was lower than younger drivers ($F(2,143)=2.366$, $p<0.10$). Drivers with a malfunctioning system rated their performance lower ($F(1,147)=8.098$, $p<0.05$), their effort higher ($F(1,147)=4.758$, $p<0.05$) and their frustration higher ($F(1,143)=14.467$, $p<0.05$) than other drivers.

3.4 Distraction

The use of the AAP was not considered to be distracting by a majority of the drivers (Table 2). Nevertheless, about 6% of the drivers agreed completely with the statement that the AAP takes attention away from more important tasks while driving.

The drivers' awareness of pedestrians increased slightly (short term: $M=3.15$, $SD=0.624$, $t(155)=3.081$, $p<0.05$ and long term: $M=3.22$, $SD=0.629$, $t(153)=4.357$, $p<0.05$). However, the majority, 74% (short term) and 66% (long term), did not report a change when using the system. The analysis yielded statistically significant

Table 2 Responses to the statement: "The AAP takes attention away from more important things while driving" (long-term)

Do not agree at all (1)	(2)	(3)	(4)	Agree completely (5)	*M*	*SD*
51%	22%	13%	9%	6%	2.0	1.237

effects of attitude, showing a higher awareness among the initially positive drivers compared to the negative drivers ($F(2,145)=6.314$, $p<0.05$). The reported awareness of speed limits was not generally affected by use of the AAP. However, outside the test area (voluntary use of the system) the awareness of speed limits decreased over time ($F(1,143)=5.994$, $p<0.05$). Interaction effects between *time and attitude* showed a more accentuated effect on negative drivers ($F(2,143)=3.450$, $p<0.05$).

3.5 Emotional state

Reported changes in emotional state are shown in Figure 6. Drivers stated an increase in irritation level in the long-term measurement, reduction in driving enjoyment and increase in the feeling of obstructing the traffic behind them ($p<0.05$). Stress increased ($F(1,143)=4.165$, $p<0.05$) and driving enjoyment decreased ($F(1,144)=7.399$, $p<0.05$) over time. The analysis yielded statistically significant main effects of attitude and system malfunctioning. The negative drivers rated their stress level higher ($F(2,143)=5.416$, $p<0.05$) and driving enjoyment lower than the positive drivers ($F(2,144)=4.406$, $p<0.05$). The negative drivers experienced an increase in stress level compared to driving without the AAP ($p<0.05$). Drivers with a malfunctioning system rated their irritation ($F(1,142)=8.917$, $p<0.05$) and stress ($F(1,143)=$

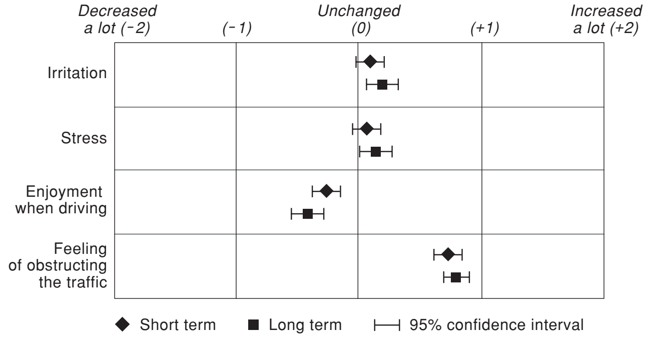

Fig. 6 Reported changes in emotional state while driving with the AAP compared to driving without the system

6.386, $p<0.05$) higher than drivers without these problems. No statistically significant increase in stress or irritation could be shown for drivers without a malfunctioning system. Interactions between *time and driver type* showed that private car drivers showed no change in stress over time while the stress of company car drivers increased ($F(1,143)=5.131$, $p<0.05$). Interactions between *time and attitude* showed that negative drivers rated their irritation higher than the positive drivers in the short term ($p<0.05$) while this difference could not be found in the long-term measurement ($F(2,142)=2.729$, $p<0.10$). Interactions between *time and gender* showed that men experienced less irritation over time and women more ($F(1,142)=3.860$, $p<0.10$).

3.6 Usage of the AAP

The drivers generally used the counter force as a support to drive at the speed limit "often", overrode the system "never" or "seldom" and lowered their speed to avoid the counter force between "seldom" and "often" after long-term use (Figure 7). The analysis showed differences between age groups (support: ($H(2)=8.140$, $p<0.05$), avoid: ($H(2)=5.042$, $p<0.10$), override: ($H(2)=11.725$, $p<0.05$)). Further post hoc analysis indicated that older drivers used the assistance of the counter force significantly less frequently ($p<0.05$) and lowered their speed to avoid the counter force more often ($p<0.10$) than younger age groups. Older drivers also overrode the system more seldom than young drivers reported ($p<0.05$).

The use of the counter force as a support to drive at the speed limit and the override rate were also affected by the drivers' attitude ($H(2)=8.044$, $p<0.05$, and $H(2)=13.530$, $p<0.05$ respectively). The post hoc test showed that negative drivers both used the support of the counter force ($p<0.10$) and over rode the system more often ($p<0.10$) than the positive drivers. The drivers with a malfunctioning system reported higher overriding rates than others ($U(n_1=47, n_2=102)=1971$, $p<0.10$).

The drivers did not report a general difference in how much they looked at the speedometer when using the AAP (short-term: $M=-0.01$ $SD=1.064$, long-term: $M=-0.19$ $SD=1.015$ where -2="much less", -1="somewhat less", 0="unchanged", +1="somewhat more", +2="much more"). The analysis yielded that men looked less at the speedometer with the use of AAP ($p<0.05$) and did so to a less extent compared to women ($F(1,150)=3.398$, $p<0.10$), and that there was a reduction over time ($F(1,150)=4.049$, $p<0.05$).

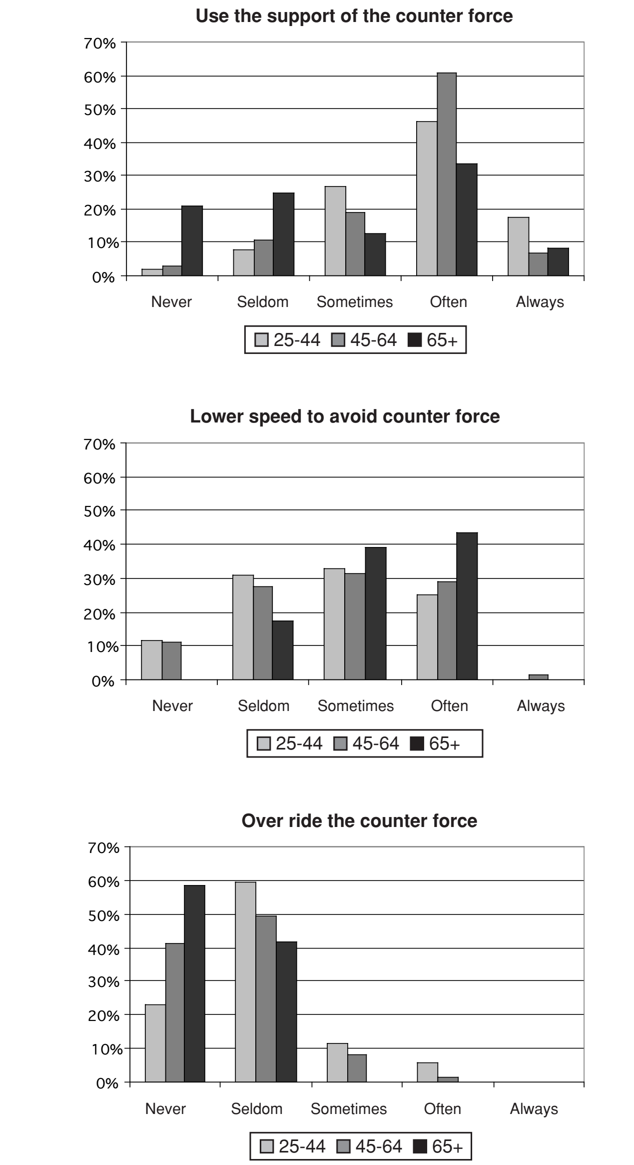

Fig. 7 The stated use of the counter force for different age groups (long-term)

4. TEST OF HYPOTHESES

Hypothesis 1: The AAP does not affect reported driving behaviour (speed level, compliance with speed limits, car-following distance).

The hypothesis can be rejected for the speed level and compliance with speed limits. The drivers experienced a considerable reduction in speed both within the test area (the AAP running) and outside (voluntary use of the AAP). According to the test drivers, the use of the AAP also made it easier to comply with the speed limits, and they experienced reduction in the risk of being fined for speeding.

The hypothesis can not be rejected for car-following distance. The test drivers did not think the car-following distance was affected by the use of the AAP.

Hypothesis 2: The AAP does not affect reported travel time and fuel consumption.

There are indications that the hypothesis can be rejected for travel time. According to the test drivers there was a small increase in travel time when using the AAP.

The hypothesis can not be rejected for fuel consumption. The drivers did not experience any significant effect of using the AAP.

Hypothesis 3: The AAP does not affect drivers' workload.

The hypothesis can be rejected. Three factors showed an increase in workload: the drivers felt a higher time pressure, higher effort and a higher frustration level, and two of the factors showed a decrease in workload: the drivers rated their performance as better with the AAP and felt the need to gas and brake less often (long term). There are, however, indications that malfunctioning of the systems may have affected the workload. Drivers without a malfunctioning system did not report higher effort or higher frustration.

Hypothesis 4: The AAP does not affect drivers' distraction.

The results did not clearly contradict the hypothesis. Most of the drivers did not report any change in distraction or awareness, however, some indications of changes were found. Six percent of the drivers found the system to be highly distracting. On the other hand, there were also results suggesting a small increase in the drivers' awareness of pedestrians. Outside the test area the awareness of speed limits decreased over time.

Hypothesis 5: The AAP does not affect drivers' emotional state.

The hypothesis can be rejected for emotional state. The drivers in general reported an increase in irritation level, reduction in driving enjoyment and increase in the feeling of obstructing the traffic. Further, the level of stress increased somewhat over time. However, malfunctioning of the system may have influenced the results, since no statistically significant increase in irritation or stress level could be found for the drivers without a malfunctioning system.

Hypothesis 6: The AAP is used in the same way by the test drivers regardless of gender, age and initial attitude towards the system.

The hypothesis can be rejected. The results showed that the younger drivers used the assistance of the counter force to drive at the speed limit system more frequently than the older drivers did. The older drivers, on the other hand, lowered their speed to avoid the counter force more often and over rode the system less frequently than the younger drivers.

The negative drivers used the assistance of the counter force more often and overrode the system more frequently than positive drivers. Men looked less at the speedometer when using the AAP compared to women.

5. DISCUSSION

5.1 Differences between short and long-term usage

In this paper two different time periods are considered, short-term (after one month of usage) and long-term (after between a further 5 to 11 months of usage). When comparing these periods, differences in the assessment of speed changes, driver performance, driving enjoyment, stress and awareness of speed limits outside the test area were found.

The speed change differed in magnitude between the two measurements. The drivers reported changes to be the same regardless of speed limits in the short term, as opposed to larger reductions in streets with lower speed limits in the long term. The driving performance was rated higher in the long-term compared to the short term. The reduction in driving enjoyment and increase in stress over time could suggest that negative emotional experiences may increase over time rather than decrease. The reported awareness of speed limits outside the test area decreased over time. This could be seen as an increase in delegation of responsibility.

All these results point to the fact that the adaptation to the system was still ongoing after one month of use. It takes more than one month of driving to get used to and incorporate a new driver support system in the driving tasks. This has to be acknowledged when evaluating driver support systems.

5.2 Differences between driver groups

Main effects of the different driver groups were found for attitude, age, gender and malfunctioning system. Most of the effects were found for driver attitude and malfunctioning systems. The attitude effect mainly influenced workload, emotional state and usage. Overall the negative drivers distinguished themselves from the positive drivers in that they experienced more difficulty with the system. Four of the six workload factors were negatively affected (attention, time pressure, effort and frustration), as were two of the four factors for emotional state (stress and driving enjoyment). The negative drivers also overrode the system more frequently than the positive drivers did. All this indicates that the driver's attitude correlates with the emotional experiences with the system rather than with the experienced changes in driving behaviour. The reasons for the attitude thus play an important role in understanding the drivers' experiences and the choice of implementation strategy.

A malfunctioning AAP system caused drivers to share similarities with the negative drivers. But they also found smaller positive effects of the system, such as decreased risk of being fined for speeding compared to drivers without these problems. This indicates clearly that improving the system would lead to changes in most areas of the drivers' experiences. The lack of interaction effects between time and malfunctioning systems suggests that technical problems influence the driver quite early in the adaptation process. This effect is also unlikely to increase or decrease over time.

Main effects of age groups were found in the usage of the system, which indicates that the older drivers perceived the counter force more as a command to lower their speed than as a support to keep the speed limit. Effects were also found on workload, which indicated that the older drivers rated their performance with the system more highly and reported lower frustration than the younger drivers did. These differences raise the concept of adaptive HMI (Human-Machine Interaction), making it possible to adapt the interface of the system to specific needs and preferences of different driver groups.

Interaction effects were mainly found between *time and driver type* and *time and attitude*. Generally, the effects showed larger changes over time for the company car drivers and the initially negative drivers. Interaction effects were focused on speed changes and emotional state.

5.3 Experienced effects vs. objectively measured effects

Differences between objectively measured effects and drivers' subjectively experienced effects have important implications for evaluation methodology and implementation strategies. The discrepancies found in this study relate to the magnitude of speed changes and car-following distances; small differences were also found in travel time and fuel consumption. Experiences regarding delegation of responsibility coincided well with the objectively measured effects.

According to the test drivers, their speed decreased while using the AAP. This is in line with the objective measurements of the test drivers' speed[15], although the perceived magnitude of the reduction in speed differs (Figure 8). Drivers experienced a larger speed reduction in streets with lower speed limits while the objective measurements showed the opposite behaviour. On 50 and 70 km/h streets, the reduction in mean speed was about 5% and the reduction in 85th-percentile was about 10%. In 30 km/h streets there was no change in mean speed and the reduction in the 85th-percentile was about 4%.

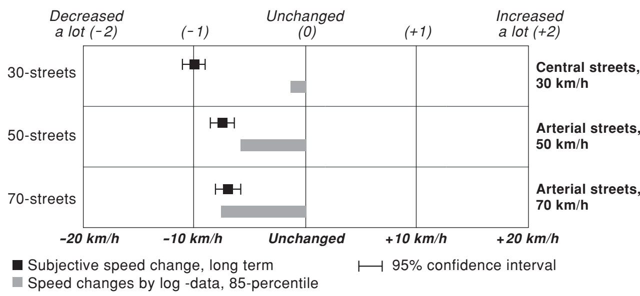

Fig. 8 The test drivers' experienced and measured speed changes. Measured results are based on (logged) data from Várhelyi et al. and show the change of the 85-percentile speeds in the long-term[15].

The car-following distance was not believed to be affected by the use of the AAP. Results from the behavioural observation show, however, an increase of the average time gap between the vehicles in car-following situations from, on average, 1.72 seconds to 1.89 seconds with the AAP[12].

The experienced travel time increased slightly with the AAP. Analysis of the logged data from the cars showed no statistically significant increase in travel time, but a modest decrease of 0.6%[15].

According to the test drivers, fuel consumption was not affected in either the short or long-term by the use of the AAP. Analysis of the logged data showed a small decrease of 1% ($p<0.10$)[17].

The awareness of speed limits outside the test area (voluntary use of the system) decreased over time and men reported that they looked less at the speedometer when using the AAP. This might indicate delegation of responsibility, as the drivers trust the system to tell them when they are speeding, thereby paying less attention to the travel speed and speed limits. This is in line with results from the behavioural observations[3]. Hjälmdahl and Várhelyi showed an increase in delegation of responsibility while using the AAP outside the test area. The drivers started forgetting to adjust the speed (both increase and decrease) when entering an area with a new speed limit[3].

The attention towards pedestrians increased somewhat when using the AAP, according to the drivers. These results are in line with the results from the behavioural observations which showed an increase in correct yielding behaviour towards pedestrians, from 88% to 96%[3].

5.4 Safety implications

The reduction in injury and fatal accidents based on lower mean speeds has been estimated to be between 8% and 32%, under the assumption that all cars are equipped with an AAP[1]. The results in this paper suggest that the changes in the drivers' workload and emotional state should also be taken into consideration when estimating the traffic safety effects.

The findings have shown an increasing workload, especially for the initially negative drivers and the drivers with a malfunctioning system. However, small increases in workload are not necessarily a safety problem, while an overload of the driver is. Nevertheless, further studies should look into this and the correlation with the negative attitude. The system also has to be developed further to eliminate any increase in workload due to malfunctioning systems.

The emotional state of the drivers deteriorated, the driving enjoyment decreased, the feeling of obstructing other traffic increased and in the long term they also felt more irritation when driving with the system compared to without. With time, stress increased and the reduction in driving enjoyment became more pronounced. These negative effects were more accentuated for the negative drivers and drivers with a malfunctioning system. These changes could potentially affect traffic safety. More investigations are needed to determine the effects on the drivers' behaviour in traffic. What is certain, though, is that these negative effects will influence the acceptance of the system and should be addressed before implementation. Still one should also bear in mind that these results reflect a situation where only relatively few cars were equipped with the AAP. Duynstee et al showed that mixing cars equipped with a system like the AAP (although a limiting system) with unequipped cars can create some irritation among both driver groups[18]. It is therefore plausible that if a majority of cars are equipped with the AAP, some of the negative effects would decrease. In particular, the feeling of obstructing other drivers and the irritation are likely to change with penetration level, but workload factors like time pressure and frustration could also be affected. Too little is known about how the subjective effects are affected by the penetration level.

This study has indicated two main areas that could affect the traffic safety potential of the AAP negatively: increased workload and deteriorating emotional state. The magnitude of the changes is not a major problem, but could potentially turn into one – at least indirectly by obstructing acceptance and thereby possibly the implementation.

6. CONCLUSIONS

The purpose of this paper is to examine drivers' evaluations of the AAP after long-term usage with special focus on changes over time, differences between driver groups, and discrepancies between the drivers' experiences and objectively measured effects. The most important findings are summarized in Table 3.

The study has shown that the drivers found the AAP to be effective in decreasing their speed and believed that their risk of being fined for speeding decreased drastically. However, the workload increased and the emotional state of the drivers deteriorated. Between-subject effects showed different ways of using the system depending on age; the younger drivers used the supporting function of the system more, while the older drivers found the counter force to be more of a command to lower their speed. The time effects have shown the importance of long-term evaluations and the interaction effects have demonstrated how, in particular, different driver types and initial attitudes affects the drivers' experiences differently over time.

Table 3 A summary of the most important findings

	Results	Main effects between driver groups	Main effects over time	Interaction effects	Difference between experienced and measured effects
Driver behaviour					
Speeds	reduction	malfunctioning system	decrease	time x attitude time x driver type	coincide but different magnitudes
Risk of being fined for speeding	reduction	malfunctioning system	no effect	no effects	not measured
Following distance	no effect	no effect	decrease	no effects	objective effects: small increase
Travel time and fuel consumption					
Travel time	increase	malfunctioning system	no effect	no effect	objective effects: small decrease
Fuel consumption	no effect	malfunctioning system	no effect	time x driver type	objective effects: small decrease
Workload					
Attentiveness	no effect	attitude	no effect	no effect	not measured
Accelerate and brake	decrease (long term)	no effect	no effect	no effect	not measured
Time pressure	increase	attitude	no effect	no effect	not measured
Better car driver	increase	age, malfunctioning system	increase	no effect	not measured
Effort	increase	attitude, malfunctioning system	no effect	no effect	not measured
Frustration	increase	age, attitude, malfunctioning system	no effect	no effect	not measured
Distraction	unclear	attitude	slight increase	time x attitude	coincide
Emotional state	worse	attitude, malfunctioning system	deteriorate	time x attitude time x gender time x driver type	not measured
Usage					
Use of the support	often	age attitude	not measured		
Override	seldom	age attitude malfunctioning system	not measured	not applicable	not measured

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