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Driving with a congestion assistant; mental workload and acceptance

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ABSTRACT

New driver support systems are developed and introduced to the market at increasing speed. In conditions of traffic congestion drivers may be supported by a "Congestion Assistant", a system that combines the features of a Congestion Warning System (acoustic warning and gas pedal counterforce) and a Stop & Go system (automatic gas and brake pedal during congestion). To gain understanding of the effects of driving with a Congestion Assistant on drivers, mental workload of drivers was registered under different conditions as well as acceptance of the system. Mental workload was measured by means of physiological registrations, i.e. heart rate, a secondary task and with the aid of subjective scaling techniques. Acceptance was measured with an acceptance scale. The study was carried out in an advanced driving simulator. Driving with the Congestion Assistant while in congestion potentially leads to decreased driver mental workload, whereas just before congestion starts, i.e. developing just noticeable, the system may add to the workload of the driver. Acceptance is generally high after experiencing the system, though not in all respects.

1. Introduction

Operator support systems have been widespread in aviation for a long time already, while active operator support in surface transportation is introduced only quite recently, at the moment facing a real proliferation. In fact, aviation has come to full automation, under certain restricted conditions, while an Automated Highway System (Congress, 1994) is yet no more than a large demonstration project to test whether full automatic driving is technically feasible. Although complete automated driving turned out to be technically possible, most available applications aim at partial supporting the driver, only taking over parts of the driver's task. Advanced cruise control systems, for instance, are provided with "intelligence" in order to detect slower driving cars ahead and adapt the speed accordingly (Hoedemaeker and Brookhuis, 1998; De Waard et al., 1999, 2004).

Systems are developed for different reasons, with different objectives, though safety is always an important issue. Systems that have safety as primary objective are expected to gain considerable savings in casualties (see Carsten and Tate, 2005). The OECD expects a reduction in casualties of some 40% after the introduction of a series of feasible safety related systems (OECD, 2003). However, the development and introduction of driver support systems in road traffic, although originally instigated by safety, has been pushed mainly by efficiency and comfort. For comparable reasons novel driver support systems face a faltering implementation. Some of them are not yet fully developed, i.e. not sufficiently tested to functionality, safety, reliability and acceptance; others are not yet introduced because of uncertainty about liability effects or cost-effectiveness, and potential unwanted behavioural effects, or even sheer lack of political courage (Brookhuis and De Waard, 2005).

Well-known examples of accepted applications are advanced cruise control (ACC) systems. Originally developed for safety enhancement, these types of systems are now found in the brochures of car manufacturers as comfort systems. Prototypes of this type of systems passed a number of tests (and improvements, see Michon, 1993, for an early discussion) and were successfully placed on the consumer market, notwithstanding the fact that they were quite expensive in the beginning. Before the actual marketing, user needs research or marketing research is indispensable, but also studies on acceptance and certainly safety effects are still necessary, even after implementation. Consumer acceptance is dependent on the attitude with respect to system safety and validity (does the system function as it should) and benefit (is there a positive cost-benefit balance), but also on the attitudes with respect to norms and on perceived control (Hof, 2005). Safety effects may originate in systems' information provision leading to (extra) mental load in potentially dangerous situations.

The present paper is part of a large study (Van Driel and Van Arem, 2006), which examined behavioural effects as well as

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workload and acceptance of a combination of relevant parts of a so-called Congestion Assistant in the form of a Congestion Warning System with a Stop & Go facility. The present paper focuses on mental workload and acceptance because these two factors are crucial for the implementation success of new systems.

1.1. Mental workload

The main reason why in recent years electronic driving aids have been developed, i.e. for safety reasons because of the unacceptable number of human victims, is primarily considered a 'human factors' case. Systems are often designed to remove human errors in the information processing that complex traffic conditions bring along. However, driver support systems almost inherently increase mental workload at the same time since they add information in those situations. For this reason, drivers' mental workload receives much interest these days, and will continue to be a hot topic in the near future. Mental workload can be expressed by the specification of the amount of information processing capacity that is used for task performance (Brookhuis and De Waard, 1993; De Waard, 1996; Brookhuis and De Waard, 2000). Workload is not only task-specific; it is also person-specific. Individual capabilities, but also motivation to perform a task, strategies applied in task performance, as well as mood and operator state, affect the experienced load.

Usually three global categories are distinguished in the field of driver mental workload, i.e. measures of task performance, subjective reports and physiological measures (Brookhuis and De Waard, 2000, 2002). The first is based on techniques of direct registration of the operator's capability to perform the driving task at an acceptable level, i.e. with respect to acceptably low accident likelihood. These measures of task performance are either directly related to vehicle handling, i.e. lateral and longitudinal vehicle control, such as steering and car following, or indirectly by means of so-called secondary or double-tasks, such as the peripheral detection task (PDT, Martens and Van Winsum, 2000), extensively reported in Van Driel and Van Arem (2006). Subjective reports of driving performance are of two kinds; observer reports that are mostly given by experts and/or self-reports by the drivers. The value of the first exists by virtue of strict protocols that limit variation as produced by personal interpretation; the second mainly lives by virtue of validation through multiple applications in controlled settings. A well-known example of the latter is the Rating Scale Mental Effort (RMSE) developed by Zijlstra (1993). Finally, physiological measures are a natural type of workload index since work demands physiological activity by definition. Physical workload but also mental workload has a clear impact on heart rate and heart rate variability (Mulder, 1992). Mental workload might increase heart rate and decrease heart rate variability at the same time but also separately.

1.2. Acceptance

Acceptance of Intelligent Transport Systems (ITS) is vital for implementation success. For instance, take-over of control in case of short headways to a lead car is less appreciated than warnings or suggestions of the appropriate action in a test of different types of Collision Avoidance Systems (Nilsson and Alm, 1991). Although drivers expect a positive safety effect by this type of anti-collision systems and other forms of ITS, they have at the same time reservations. Handing over control to a device and a fully automated braking function are evaluated as negative aspects of ITS systems (Hoedemaeker, 1996; Hoedemaeker and Brookhuis, 1998). Collision avoidance systems are not widely implemented indeed. Acceptance in this field is often captured with an acceptance scale, using a Likert scaling technique (Van der Laan et al., 1997). The outcome renders the driver's feelings in two subscales, i.e. with respect to usefulness of the system as well as how satisfied the driver was with the system.

1.3. Congestion assistance

A user needs survey was conducted to assess the perceived needs of the driver for driving assistance (Van Driel and Van Arem, 2005). The top-10 of the indicated needs for assistance is given in Table 1.

From the survey it may be concluded that there is a significant need for several forms of congestion assistance (Van Driel and Van Arem, 2006). The results served as a basis for creating a Congestion Assistant that would be able to provide the driver with help during congested traffic situations on a motorway by means of the following functions:

- Congestion warning and information: while driving upstream of a traffic jam, the driver would receive a warning about the traffic jam ahead. While driving in a traffic jam, information about the length of the jam can be displayed continuously.
- Active gas pedal: while approaching a traffic jam, participants would feel a counterforce on the gas pedal when the speed is too high considering the situation.
- Stop & Go: while driving in a traffic jam, the longitudinal driving task (regulating speed, car following) will be taken over by the system.

A driving simulator experiment was conducted to assess the impacts of the Congestion Assistant on the driver in terms of mental workload and acceptance.

2. Method

In the experiment 37 volunteers participated (7 female and 30 male). All participants were between 23 and 60-years-old, had a driving license for at least 5 years and drove regularly.

2.1. Apparatus and procedure

For the experiment the TNO moving base driving simulator at Soesterberg (NL) was used (Fig. 1). Central to the simulator was a mock-up of a standard private car (BMW 318i) with original controls (pedals, instruments, steering wheel, etc.), in automatic gear version. An interface to a number of control computers took care of data registration and in return high quality virtual environments and scenarios, as well as (counter) forces on the steering wheel and pedals that were realistically simulated.

The experiment was designed to investigate the effects of the Congestion Assistant on driving behaviour (see Van Driel et al., 2007), workload and acceptance (this paper). The participants were invited to TNO for driving in the simulator during four runs of

Table 1
Top-10 of most popular driver support functions (Van Driel and Van Arem, 2005).

Driver support function	(Great) need (%)
Warning for downstream traffic condition – motorway	90.2
Warning for downstream traffic condition – rural road	84.3
Blind spot warning during lane changing – motorway	82.1
Blind spot warning at non-signalised intersection – urban road	82.0
Blind spot warning at non-signalised intersection – rural road	79.4
Blind spot warning during lane changing – rural road	75.0
Blind spot warning at signalised intersection – urban road	73.3
Blind spot warning at signalised intersection – rural road	71.4
Warning for imminent crash	70.2
Presentation of badly visible objects on windscreen	70.0

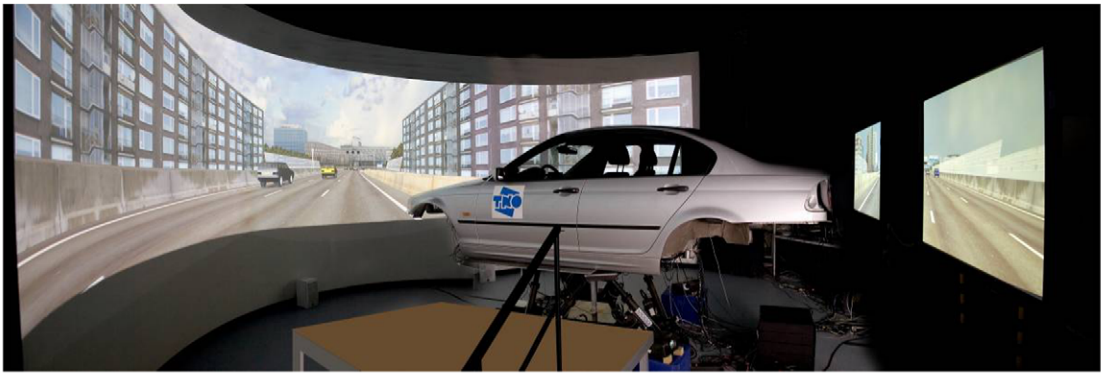

Fig. 1. A picture of the simulator mock-up of the TNO moving base simulation facility.

15 km each. Since respondents from the user needs survey indicated strong needs for help in reduced visibility situations (see Table 1), the impacts of the Congestion Assistant were studied during normal visibility and in fog. Accordingly, the experimental conditions varied with respect to 'system' (with versus without Congestion Assistant) and 'visibility' (normal versus fog). This resulted in the following four conditions:

1 without Congestion Assistant during normal visibility
2 with Congestion Assistant during normal visibility
3 without Congestion Assistant during fog
4 with Congestion Assistant during fog.

Each participant completed four experimental runs corresponding to the four conditions, comprising a 2×2 within-subjects design with the factors 'system' and 'visibility'. To avoid order and learning effects, the conditions were counterbalanced by a Latin square design (for an extensive description see Van Driel and Van Arem, 2006).

Each run included normal stretches of motorway and a traffic jam (see Table 2). The tail of the congestion was encountered after about 10 km from the start, independent of the driving lane. The traffic jam itself had a length of 3 km, implying that the participants left the traffic jam after about 13 km from the start. The Congestion Assistant supported the driver during the whole congested traffic situation. The functions of the Congestion Assistant were programmed to switch on or off at fixed points in each trial.

2.2. Human–Machine interfacing

The Congestion Assistant communicated to the driver through its interface. The interface consisted of visual, acoustic and haptic feedback. All visual feedback was given via a display (Fig. 2). It is assumed important that the driver knows the status of the Congestion Assistant at all times, therefore, the display showed which functions of the Congestion Assistant were active. The display was positioned next to the steering wheel and consisted of three icons and a textbox, see Fig. 2. The three icons represented the following three functions:

- Upper icon: congestion warning and information
- Middle icon: active gas pedal
- Lower icon: Stop & Go

The icons could be either green (active) or grey (inactive, comparable to inactive functions in regular computer software).

The haptic feedback on the active gas pedal was given when the speed was assessed by the system as too high in the approach of the traffic jam. The Stop & Go function, assuming longitudinal control completely, was activated at the beginning of the traffic jam, preceded by an acoustic warning. Specific force functions of the gas pedal can be found in Van Driel and Van Arem (2006).

Table 2
Sequence of conditions encountered in one run.

Section	Length (km)	Support from congestion assistant
Start	5	No support
Section 1: before	3.5	Congestion warning
Section 2: start congestion	1.5	Congestion warning and active gas pedal
Section 3: within congestion	3	Congestion information and stop & go
Section 4: after	2	No support

2.3. Measures

The three categories of mental workload measures (see also De Waard, 1996), physiological measures, task performance measures, self-report measures were included in the present experiment as follows;

- The first category of workload measures includes those derived from the operator's physiology, i.e. the cardiac function that can be used to measure mental workload. The contraction of the heart is produced by electrical impulses that can be measured in the form of the ECG (Electro Cardio Gram). From the ECG signal several measures can be derived, such as average heart rate and heart rate variability (Mulder, 1992). Generally, the higher the average heart rate and the lower the heart rate variability, the more mental effort has to be spent.
- All the usual primary task measures in longitudinal and lateral respect were registered, but reported elsewhere (Van Driel et al., 2007). As a secondary task performance measure, the Peripheral Detection Task (PDT), was used. This measure can be considered a low-level easy-to-automate process that requires little conscious attention (Martens and Van Winsum, 2000). The task (and instruction) is merely the detection of stimuli that were presented regularly in the periphery of the functional visual field. The idea behind it is that the functional visual field decreases with increasing workload in the primary task.
- Self-report measures are used to measure the subjectively experienced mental effort. This method is based on the operator's rating of his performance. The Rating Scale Mental Effort (RSME) is an example of a self-report measure (Zijlstra, 1993). It is a one-dimensional scale, ranging from 'no effort' to 'extreme

Fig. 2. The warning display as positioned in the simulator.

effort'. The driver has to simply indicate the amount of invested effort on the RSME.

Acceptance of the Congestion Assistant was registered before the actual driving task started, based on functional description, and after each trial in the Congestion Assistant condition, using the acceptance scaling technique (Van der Laan et al., 1997), resulting in a usefulness score and a satisfaction score.

The dependent variables with respect to workload and acceptance were:

Average heart rate (HR)
Heart rate variability (HRV)
Reaction time to PDT signals
Percentage of missed PDT signals
RSME score
Usefulness score
Satisfaction score.

3. Results

3.1. Heart rate (HR) and heart rate variability (HRV)

Analyses were performed to investigate the effects of the Congestion Assistant on workload during normal visibility and in fog. Possible differences between road sections as well as transitions from one function of the Congestion Assistant to another were taken into account. Repeated measures ANOVAs were carried out on HR and HRV using 'visibility' (normal, fog), 'system' (without, with) and 'section' (1–4) as within-subject factors. Data from six participants were not considered, because of the bad quality of their ECG signals.

The results showed a significant main effect in HR of 'section' ($F(3,81) = 13.9$, $p < 0.001$) and a significant interaction effect between 'system' and 'section' ($F(3,81) = 6.6$, $p < 0.001$). Fig. 3 shows this interaction effect. From post hoc tests it appeared that the IBI (Inter–Beat–Interval) with the Congestion Assistant was higher than without the system, but only in the traffic jam (Section 3). IBI and HR are reciprocal concepts, therefore a higher IBI score represents a lower HR score, meaning that the mental workload was lower in the traffic jam when one was driving with the Stop & Go function of the Congestion Assistant.

A significant interaction effect between 'system' and 'section' was found for HRV ($F(3,81) = 4.3$, $p < 0.01$). Fig. 4 shows this interaction effect for a specific feature of HRV. It seems that the power value around the 0.1 Hz component (Mulder, 1992), indicative for investment of mental effort, with the Congestion Assistant was higher than without the system during the transition from Section 3–4 (i.e. from in the traffic jam to after the traffic jam). With post hoc tests no effect of 'system' was found, although it might be considered an indication that switching off the Stop & Go led to decrease in mental workload as indicated by a higher HRV ($F(3,81) = 3.7$, $p < 0.06$). Perhaps the participants in a way felt relieved after resuming control.

3.2. Peripheral detection task

The average reaction time to the appearance of the PDT signals and the percentage of missed signals were used to judge the participants' mental workload while driving. Generally, the larger the reaction time and the more missed signals, the more demanding the primary task (i.e. driving safely). Analyses were performed to investigate the effects of the Congestion Assistant on workload during normal visibility and in fog. Possible differences between road sections as well as transitions between functions of the Congestion Assistant were taken into account. Data from two participants were not considered in the analyses on the percentage of missed signals, because of the considerable deviation from the rest of the data. These participants indicated after the experimental runs to have had difficulties with performing the PDT task.

The results with respect to the PDT reaction times showed a significant main effect of 'section' ($F(3,93) = 12.3$, $p < 0.001$) while an interaction effect between 'system' and 'section' was found as well ($F(3,93) = 9.6$, $p < 0.001$), see Fig. 5. From post hoc tests it appeared that the average reaction time with the Congestion Assistant was larger than without the system, but only when approaching the traffic jam (Section 2). This indicates that the

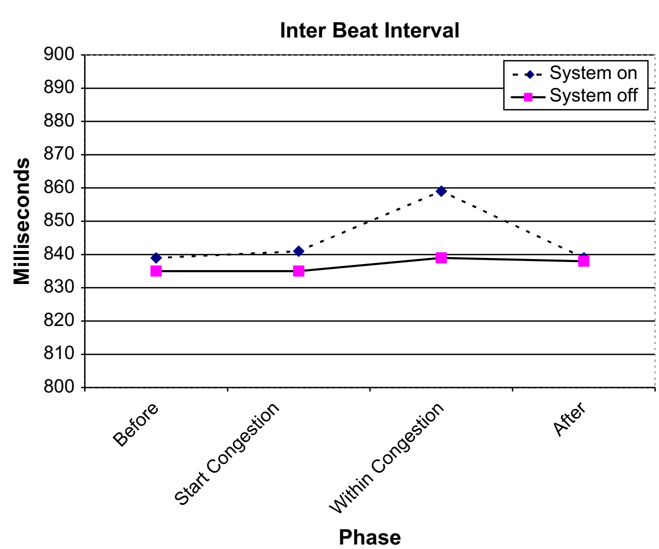

Fig. 3. Inter–Beat–Interval (IBI) as a function of 'system' and 'transition'.

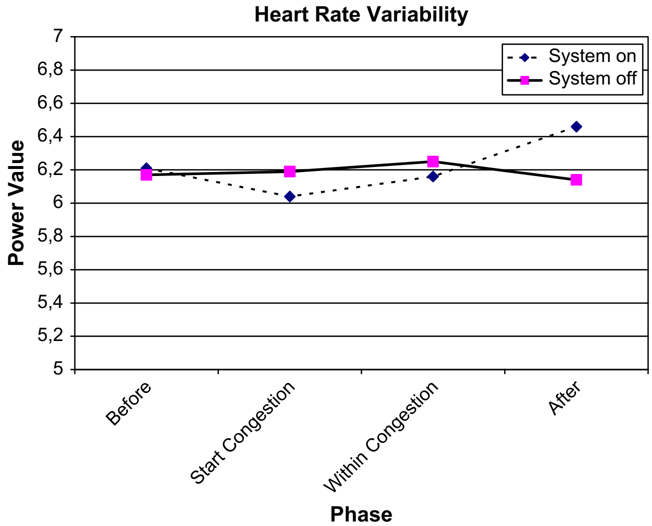

Fig. 4. Heart rate variability (HRV) as a function of 'system' and 'transition'.

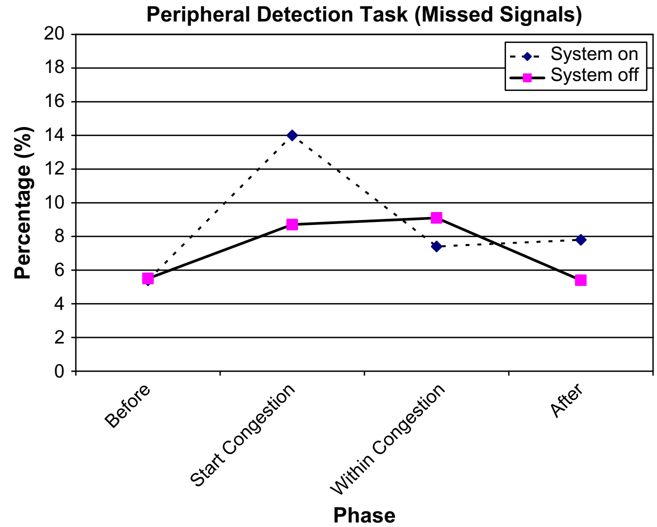

Fig. 6. Percentage of missed PDT signals as a function of 'system' and 'section'.

mental workload in the approach phase was higher than normal when one was driving with an active Congestion Assistant.

With respect to the percentage of missed PDT signals the results were similar, showing a significant main effect of 'section' ($F(3,93) = 18.6$, $p < 0.001$) and an interaction effect between 'system' and 'section' ($F(3,93) = 7.1$, $p < 0.001$), as clearly visible in Fig. 6. It appeared that when approaching the traffic jam (Section 2), the percentage of missed PDT signals with the Congestion Assistant was larger than without this system. This confirms that the mental workload in the approach phase was higher than normal when one was driving with an active Congestion Assistant.

3.3. Effort self-report

The scores on the effort self-report questionnaire, the Rating Scale Mental Effort (RSME, Zijlstra, 1993), were used to judge the participants' subjective mental workload while driving. The higher the score on the RSME is, the higher the experienced workload. Analyses were performed to investigate the effects of the Congestion Assistant on workload during normal visibility and in fog. The results showed significant main effects for both within-subject factors 'visibility' ($F(1,33) = 12.4$, $p < 0.01$) and 'system' ($F(1,33) = 16.4$, $p < 0.001$). Furthermore, a significant interaction effect was found between these factors, shown in Fig. 7. Post hoc tests revealed that more effort was put into driving in fog than driving during normal visibility, but only when one was driving without the Congestion Assistant. In fog, the experienced workload with the Congestion Assistant was lower than without the system.

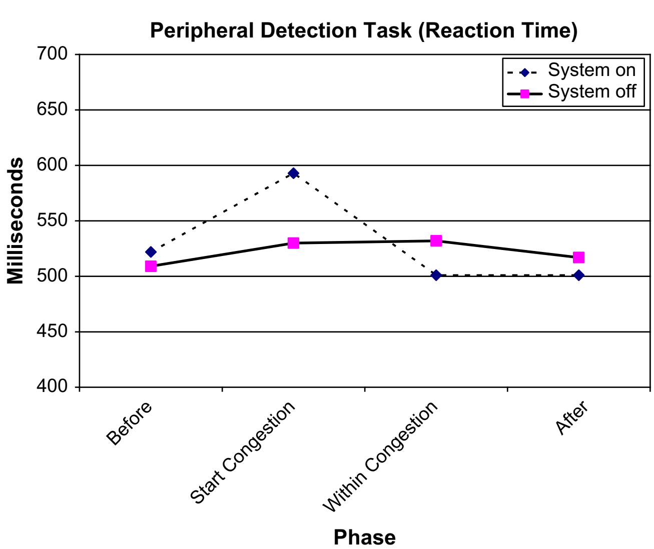

Fig. 5. Reaction time to PDT signals as a function of 'system' and 'section'.

3.4. Acceptance of the system

The results of acceptance of the Congestion Assistant concern the scores on the two acceptance subscales, usefulness and satisfaction. The influence of visibility and experience (before and after driving) on acceptance was examined as well.

Fig. 8 shows the means of the two acceptance subscales, usefulness and satisfaction, obtained by the procedure described in Van der Laan et al. (1997). Averages were calculated for the Congestion Assistant as a whole and for the three functions of the system separately. Driving with the Congestion Assistant was expected to be positive (first part, before driving), which was confirmed by the experience (second and third part). Clearly usefulness is rated higher than satisfaction for the Congestion Assistant as a whole and its separate functions. The Warning & Information function and the Stop & Go were accepted best, while

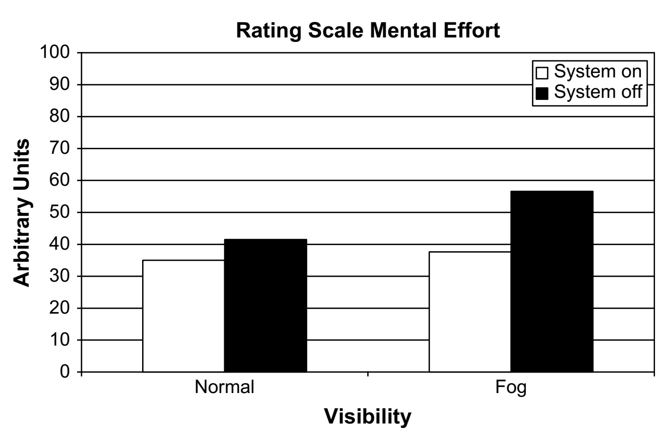

Fig. 7. RSME score as a function of 'visibility' and 'system'.

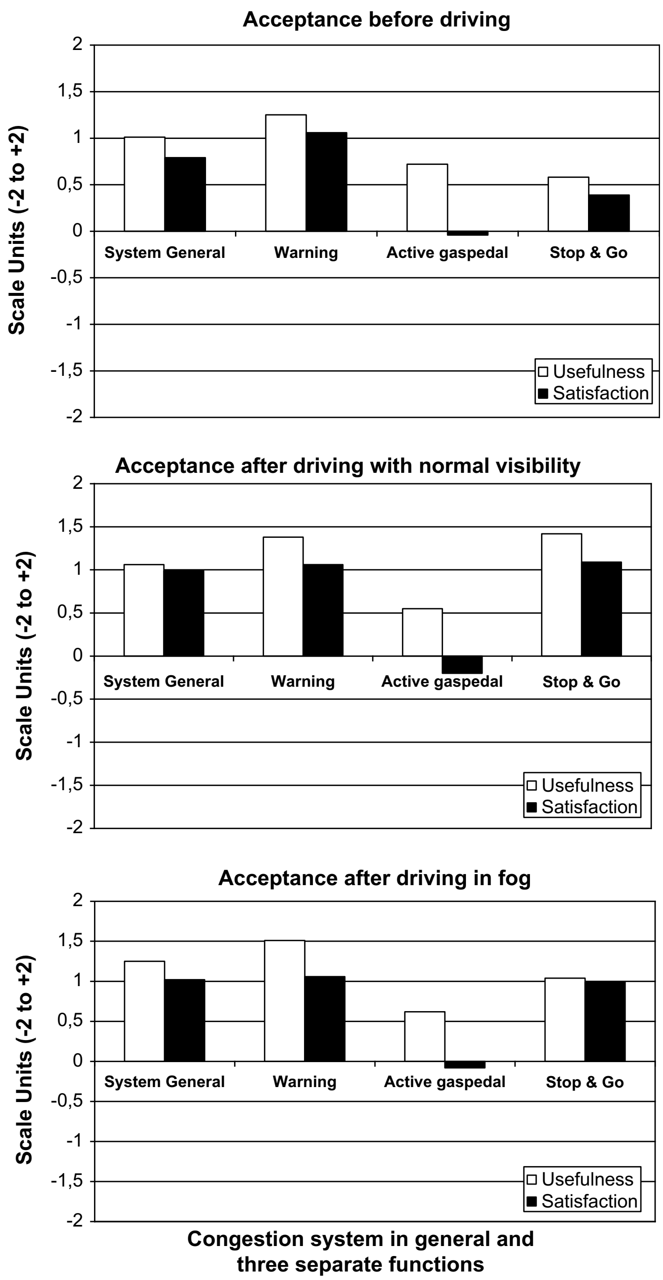

Fig. 8. Acceptance scores of the Congestion Assistant in general, and three separate functions, i.e. voice warning, haptic feedback (Active gas pedal) and automatic driving (Stop & Go).

the active gas pedal was least appreciated. The expectation that the Congestion Assistant would be accepted more in fog than during normal visibility was not clearly supported by the results. Gaining experience with the Congestion Assistant significantly increased the acceptance of the Stop & Go. Preconception (mental model based on the function description) of the system's functions showed a relative change in before and after measures in a positive direction, except for the active gas pedal feedback which turned out to be appreciated relatively negative.

4. Discussion and conclusion

It was expected that drivers would have to invest less effort in driving with the Congestion Assistant than without this system. This expectation was confirmed by the RSME data, however, this was mainly true for driving in fog. During normal visibility the Congestion Assistant did not affect the experienced workload in the sense of indicated effort. In addition to the RSME data which focus on the whole Congestion Assistant, the other workload measures (i.e. HR, HRV and PDT) showed the impacts of the separate functions of the system on mental workload. No impacts of the acoustic warning function were found. However, the workload increased when driving with the active gas pedal and decreased when driving with the Stop & Go. Furthermore, it was found from the RSME data that the participants experienced driving during normal visibility as being less effortful than driving in fog, which disappeared when one was driving with the Congestion Assistant. The other measures showed that despite the higher workload because of fog, the participants were able to perform the driving task well without having to invest extra (physiological) effort. It is clear that the results obtained by the heart rate data do not always correspond to the results from the effort scale and also from the PDT. Possibly, this has to do with differences between the measures with respect to sensitivity. The PDT may be more sensitive for visual workload. The present combination of workload measures enables to form a differentiating picture of the driver's mental workload caused by the Congestion Assistant.

The impacts of the Congestion Assistant on the various indicators of mental workload around and within the traffic jam (following the time sequence in Table 2) were as follows; when approaching the traffic jam, the workload with the Congestion Assistant was higher than without this system (based on PDT data); when driving in the traffic jam, the Congestion Assistant resulted in a lower mental workload (based on heart rate data); when entering and leaving the traffic jam, the workload with the Congestion Assistant was lower when the Stop & Go switched on respectively off (based on heart rate data).

Generally, the participants reported that they appreciated the Congestion Assistant. They thought it could increase traffic safety and efficiency, and decrease emissions, while it would assist them in some of the situations that were incorporated in the experiment. Predominantly when they were driving in fog conditions, the participants experienced a lower workload with the Congestion Assistant. The results showed that the active gas pedal was least appreciated as feedback mechanism, while the mental workload was higher with the active gas pedal than without this function. Contrarily, the Stop & Go, a comfort function that (partly) automated the driving task, was well-appreciated, also reflected in a lower workload.

Finally, since the participants in this study were first-time users, and experience will probably change with exposure, future studies should cover changes in performance, workload and acceptance with repeated exposure to the Congestion Assistant. It might well be that the high workload with the active gas pedal is a novelty factor for a large part, for example, wearing off when the system repeatedly performs fine. Subsequently, the system should be put to the test in practice, first in an instrumented vehicle to validate the simulator results, later fit out a fleet of vehicles to study the effects with different percentages of system penetration.

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