

IMPACT OF RDS-TMC RECEIVER USE ON SPEED AND OTHER DRIVER BEHAVIOUR

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The aim of the study was to assess the safety of an in-car ITS device functioning as an RDS-TMC receiver as well as to develop a measurement system and procedures for such studies.

Fifty-nine subjects participated in the studies in 1998 driving the instrumented car of VTT equipped with a device functioning like an RDS-TMC receiver. The dependent variables studied were glances to the receiver, looking behaviour at appropriate directions in order to search priority other road users, conflicts, speeds, steering wheel position and braking force.

During the trials with no turn, the number of glances to the receiver was 2.70 and the single glance time was 1.45 s, on average. In contrast to the expectations, the results did not show any age effect indicating that older subjects did not perform as well as younger subjects. Subjective assessments of workload and ease to understand the messages also showed that the subjects did not have any substantial problems with the RDS-TMC task.

The ease of the RDS-TMC task might be influenced by several factors such as the positioning of the receiver close to the driver's normal line of sight but not being obstructed by the steering wheel or obstructing the forward vision, the relatively large display and controls, the on handed use of the controls, the relatively simple information, the simple functions of the receiver with no complicated menus, and the appropriate instructions given to the subjects.

Despite all above-mentioned results, the analyses showed that the glances to the receiver influenced the occurrence of mistakes in the search of priority road users. The driving behaviour analyses also indicated potential safety problems during turning manoeuvres. The receipt of RDS-TMC messages caused a considerable reduction of speeds. This reduction was accompanied with a higher occurrence rate of strong brakings and unsafe jerks in speed. Abrupt steering wheel movements were also more frequent. The receipt of the message when performing the turning manoeuvre or just before it apparently may cause temporarily too high workload.

In the future, some changes in route and/or task design as well as the camera position for glance data collection, to enable unoccluded vision of the subject's face even during turns, will be made. The number of glances and the total glance time seemed to be the most promising variables of the glance pattern analyses.

1. INTRODUCTION

During the past years, persons active in the transport area have witnessed the increasing introduction of various new technology systems in transport. These were first called RTI (Road Transport Informatics), then transport telematics, and lately ITS (Intelligent Transport Systems) systems. High expectations on the benefits of the ITS systems have been presented whereas also many have expressed words of doubt concerning the impact of these systems. A much-discussed issue has been the safety impact of these systems.

Traffic safety evaluation of ITS applications and systems is, however, a relatively difficult task. The Field Trials guidelines for transport telematics systems (Maltby 1990) states that "A potentially difficult area to assess is how safe an RTI is likely to be in the real environment. There are three main reasons for this: (1) accidents, the direct measure of safety, are relatively infrequent occurrences in terms of vehicle kilometres, (2) large samples would be required to identify with reasonable confidence a modest worsening of safety, (3) it is often difficult to attribute the cause of an accident to a particular factor. This means that the safety aspects of RTI systems must be investigated by other means...".

The primary indicator of safety, i.e. accident rate can very seldom be used as indicator of the safety effect of an ITS system. It is seldom possible to detect changes in the number of accidents, following the introduction of an ITS device, particularly if this effect should be measured over a short period of time. Most of the safety assessments of new telematics systems (e.g. Brookhuis 1995, Kuiken 1996) have concentrated on indirect measurement of safety by applying various indicators of human performance as surrogate measures for safety. Examples of such indicators are glance patterns, glance duration, reaction times, workload, etc. The underlying rationale of this approach has been as follows, for example: because the driver needs to look at the traffic environment to conduct the primary driving task, the traffic safety is endangered if he/she looks too frequently or too long at a given in-vehicle device.

However, the safety relevance of these HMI (Human - Machine Interaction) indices remains unclear as in almost all cases no proven explicit relationships exist between current HMI indices and accident risk. On the other hand, if field trials are considered, there even is not a direct way to quantify the potential links between real accidents and HMI indices. Fortunately, research has identified a close link between conflicts and accidents (e.g. Hydén 1987).

2. OBJECTIVES AND HYPOTHESES

The aim of this study is to identify and quantify the relationships between various behavioural indices and safety by using conflicts as well as driver's errors as the surrogate measures for safety. More specifically, the study conducted in 1998 was designed to develop the measurement system and procedures as well as to make a first effort in establishing the links between the various behavioural indices. At the same time, the objective was to apply the indices in assessing the safety of an in-car ITS device functioning as an RDS-TMC receiver.

The study was built upon a set of hypotheses about how the use of an RDS-TMC receiver (times of receiving messages) would affect driving behaviour. The times of receiving messages were regarded as trial situations in comparison to control situations, i.e. situations without message receivals. The hypotheses were the following:

1. Drivers concentrate their attention more to the RDS-TMC device (more frequent and longer glances) in trial situations than in control situations.
2. The central (cognitive) and especially perceptual (visual) workload is higher in trial than in control situations.
3. Due to hypotheses 1 and 2, trial situations have in comparison to control situations:
 - more observation errors
 - more driving errors
 - longer reaction times
 - more abrupt manoeuvres
 - more conflicts i.e. higher accident risk.
4. The impacts due to higher workload are more distinctive for elderly drivers than for younger drivers.
5. Drivers compensate for the higher workload by reducing their speed and by operating the receiver at times of lower workload (e.g. on straight road sections rather than in curves or junctions).
6. By comparing the conflicts to other situations with regard to the values of various HMI and behavioural indices, it is possible to determine the ranges, within which the indices can vary without endangering safety.

The experimental design and the methods were designed to verify most of these hypotheses.

3. METHOD

Subjects performed two concurrent tasks. The primary task was to drive twice the route of 50 km normally, following the experimenter's directions. The secondary task was to read the messages provided by an in-car terminal that was designed to simulate the RDS-TMC receiver. In addition, the subjects answered to written questions before and after the experiment.

The route consisted of suburban streets; main roads and limited access highways. In order to increase the sensitivity of the measurements, most parts of the route were on suburban roads including several turns, and the great majority of the messages were presented before entering the intersections. The posted speed limit ranged from 40 km/h to 120 km/h.

The receiver shown in Figures 1 and 2 was positioned on the right side of the steering wheel, such that the visual angle from the centre of the normal fixation site on the road ahead to the centre of the receiver was approximately 29° horizontally and 18° vertically. The eye-screen distance was approximately 70 cm for a driver of about 180 cm length. The width of the receiver was 190 mm and the height of the receiver was 150 mm. The dimensions of the display were 130 mm and 95 mm, respectively. The diameter of the controls (push buttons) was 20 mm.

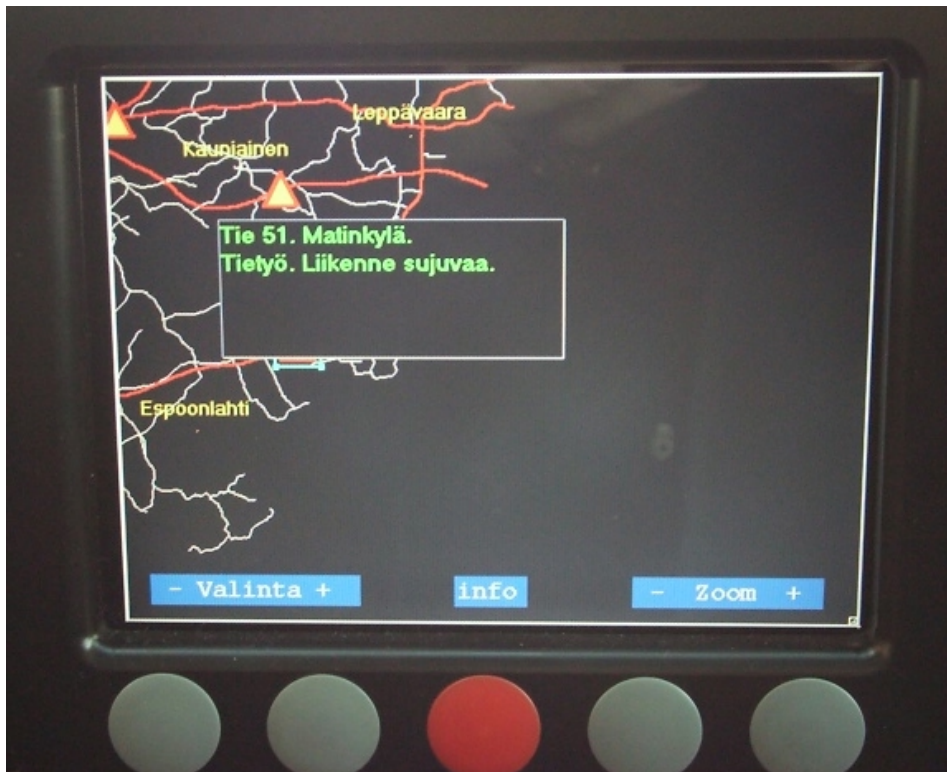


Figure 1. The receiver displaying a dynamic map, a text message and the functions of the controls.



Figure 2. The receiver and its location.

The receiver consisted of a colour display and five controls. The display showed a dynamic road map indicated by white and red lines, a light blue circle indicating the location of the test vehicle and red/yellow warning signs (triangles) indicating the location of the events. The map was controlled by GPS so that the white circle was always in the middle of the display.

The experimenter seated in the rear controlled the appearance of the events. During the experiment, the number of warning signs varied between 3 and 12. One event was "active" indicated by a square around the warning sign. The most recent event was always active but the subject was able to select which event was active between the trials.

The text messages consisted of one to three lines of text shown in a box in the middle of the display. The characters were green and 3 mm high. The text messages were typical RDS-TMC messages indicating a road, a more detailed location and an event. Following messages were used, for example:

- Road 1130. Kauklahti. Broken down vehicle. Danger of queuing traffic.
- Road 1. Salo-Helsinki. Junction Kehä II. Roadworks. Slow traffic.
- Road 1. Tarvo. Bus lane closed.
- Ring road I. Tapiola-Leppävaara. People on roadway. Warning cleared.
- Road 51. Helsinki-Kirkkonummi. Matinkylä. Roadworks. Traffic flowing freely.

The subject vehicle was a 1992 Opel Astra Caravan with manual transmission equipped with hidden measuring instruments for speed, use of brake pedal and use of steering wheel. The data collection frequency was 5 Hz. In addition, driver's eye and head movements as well as the general view in the front of the vehicle were recorded with two cameras. The first camera directed toward the driver's face was hidden among the warning lamps in the dashboard and the other camera was hidden in the grille. The data were transmitted to the videocassette recorder (VCR) and computer in the trunk.

Totally, 59 paid subjects participated in the study. However, the final data included 39 subjects. Other subjects were excluded because of technical problems resulting in insufficient data.

All the subjects were licensed drivers who volunteered for the study. The original design included equal number of young and old subjects. However, the final data included fifteen subjects between the ages 20 and 22 years (with a mean of 21.2 years) and twenty-four between the ages 60 and 69 years (with a mean of 63.8 years). Eighty percent of the subjects were males (i.e. approximately the same percentage as in every-day Finnish traffic).

Subjects' vehicle kilometrage during the previous year ranged from 6,000 km to 25,000 km (with an average of 16,100 km). The familiarity with the route among the subjects varied rather considerably. However, many subjects did not find driving unfamiliar with the test vehicle and they estimated that the driving was rather similar in comparison to their normal driving. None of these background variables differed statistically significantly between the two age groups.

There were 56 sites on the route, which was driven through twice. In all, there were thus 112 sites on the route from which 40 served as trial sites (i.e. sites with a new message) and 72 as control sites (with no new message). The trial sites included 10 turns at yield intersections (turning onto a main road), 10 turns at general rule intersections or turning onto a secondary road, 10 turns at intersections with traffic lights and 10 road sections with no turns. Correspondingly, the control sites included 18 sites of each type. Fifty percent of the turns were to the right and fifty percent to the left. The subjects did not know in advance the location of trial or control sites, and the order of the trial and control sites was randomised. Consequently, the occurrence of the next message appeared unpredictable to the subjects.

The dependent variables studied were:

- glances to the receiver (i.e. number of glances, total glance time and the time of the most prolonged glance); both the off-road time and dwell time were determined
- looking behaviour at appropriate directions in order to search priority road users (vehicles, bicyclists and pedestrians) at intersections (22 trial sites and 38 control sites)
- conflicts (severe, slight and potential conflicts)
- speed (before and after passing trial and control sites, acceleration, jerk)
- steering wheel position (standard deviation, change, jerk)
- braking force.

On the basis of earlier conflict studies conducted at VTT, we expected to obtain approximately 20 conflict situations at both trial and control sites. The earlier conflict studies were conducted at junctions with accident records indicating safety problems (Kulmala 1984). Hence, we assumed that the conflict expectancy would be approximately half of that expected on the basis of exposure alone. As a first attempt of in-vehicle conflict study, the estimate had, however, high uncertainty.

The subjects participated in the experiment individually. They were told that this study investigated how drivers assess the receiver prototype and how they comprehend the messages. Particularly, the subjects were instructed to drive safely as well as to (1) open a new message with the red button whenever it appeared, (2) assess whether the new event was located on the route (that was shown approximately at the beginning of the experiment), (3) read aloud the message, (4) indicate whether the message was understandable and (5) close the message with the red button. The location and contents of the messages were designed so that the subjects did not find out the artificiality of the RDS-TMC service during the experiment.

The subjects were asked to familiarise themselves with all controls before the start and the use of the receiver was explained thoroughly. In addition, the subjects drove a practice route during which 10 messages emerged so they could get used to the car and the use of the receiver.

The test route was driven twice (a short break between the runs). However, the location and the contents of the messages were different during the two runs. During the experiment, the experimenter in the rear launched the messages with a silent push button. The subjects were not told that the experimenter controlled the receiver. The appearance of a new message was announced by a loud voice signal.

The experiment was conducted in July and August, only in daytime between 08:30h and 16:30h without active precipitation.

Before and after driving the test route, the subjects answered to the questions concerning the mental workload. Before the experiment, the questionnaire concerned their previous driving in suburban areas. After the experiment, the questions focused on test drive. Finally, they were told that their driving behaviour was recorded during the experiment and a permission to use the data was requested.

4. RESULTS

The paper concentrates on speed choice and other forms of driving behaviour. For detailed description of results concerning glance patterns, message comprehensibility and workload, see Kulmala *et al.* 1999.

In the basic data, we had speed (km/h), steering wheel position (degrees) and brake force at 0.2 second intervals. We calculated on the basis of these data the following new variables:

- speed change between successive instants (to determine acceleration)
- the change of the speed change between successive instants (to determine jerk)
- steering wheel position change between successive instants
- the change of the steering wheel position change between successive instants (to determine "steering jerk").

As the main interest lies on using the indices for studying the safety of an RDS-TMC receiver, we concentrated on analysing the driving behaviour during the moments of receiving RDS-TMC messages. Hence, we arranged the data into the following four periods for each fixed trial and control site along the test route:

- 1) 5 ... 0.2 seconds before the site (and receipt of message at trial sites)
- 2) 0 ... 4.8 seconds after the site
- 3) 5 ... 9.8 seconds after the site
- 4) 10 ... 19.8 seconds after the site.

For the purpose of looking for situations with possible safety problems, the periods were also classified according to whether the following hold true for the period: the highest decrease of speed decrease was less than 1.44 km/h (corresponds to value of jerk -10 m/s^3). This was done according to a finding by Nygård (1998), who could identify traffic conflicts on the basis of the speed profiles of the instrumented vehicle.

4.1 Speeds

The mean speeds of drivers are shown in Figure 3. The speeds between the trial and control sites could vary due to some special conditions like driving in queue, and hence, we used the period just before passing the site as an additional control for studying the effect of the receipt of the message at the trial sites.

There was a change in speeds just after receiving the message at the sites where the vehicle is turning. This reduction of speeds was 0.9 km/h for left-turning vehicles ($p < 0.01$) and 3.4 km/h for right turning vehicles ($p < 0.001$), but could not be observed for straight driving vehicles. A larger reduction of mean speeds was observed in the later periods, i.e. 5...10 and 10...20 seconds after the message has been received. Judging from the speeds of turning situations, these periods probably coincided with the negotiating of the junctions. The changes were statistically significant ($p < 0.001$). The speed reduction was approximately 2 km/h for the straight driving, almost 4 km/h for the left turning and 6...8 km/h for right turning vehicles.

The effects on the variance of speeds were quite small, less than 0.2 km/h. An analysis of accelerations showed results corresponding to the speed analysis, i.e. larger decelerations after trial sites than control sites.

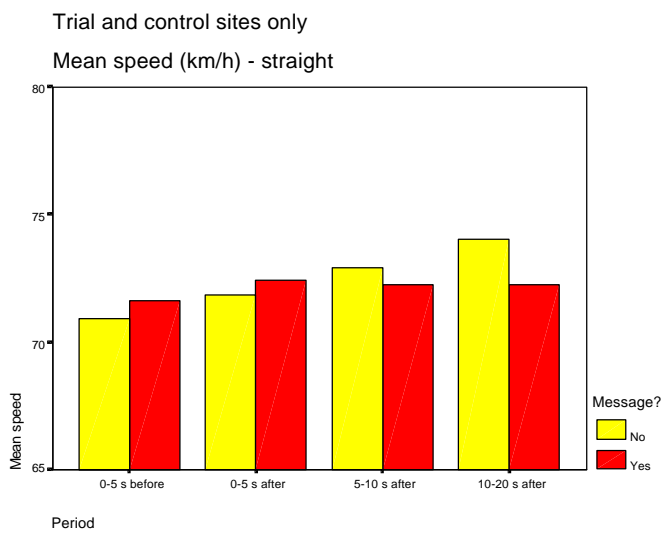
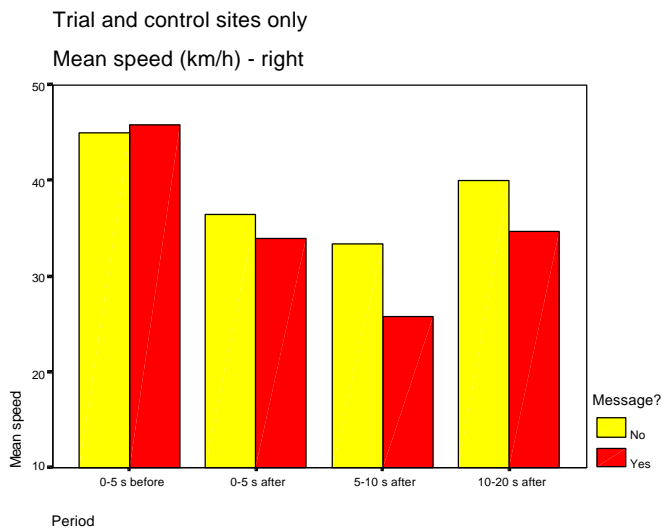
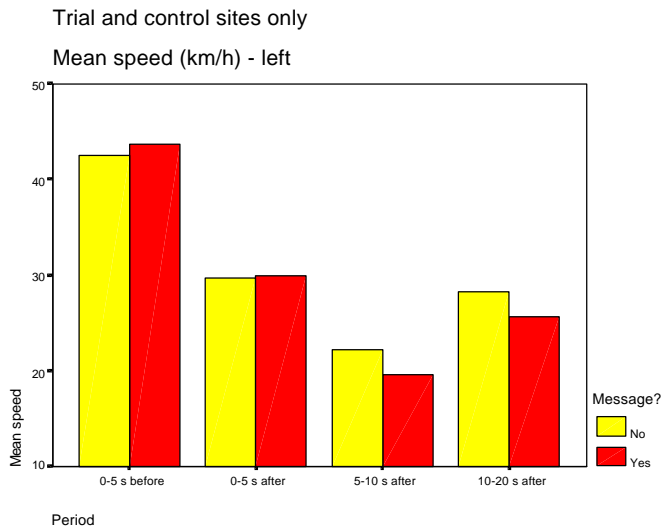


Figure 3. Mean speeds of subjects before and after passing the trial and control sites. The control sites not used as a trial sites during one of the driving rounds have been excluded.

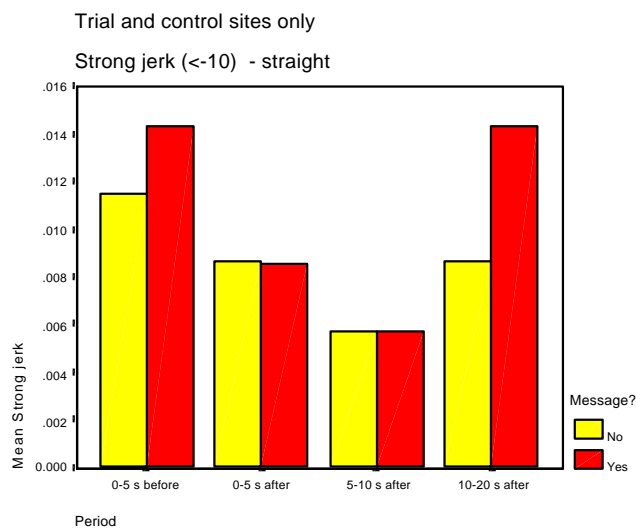
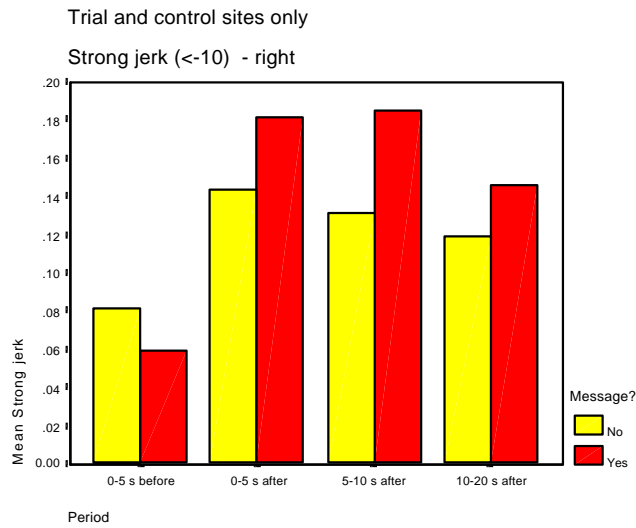
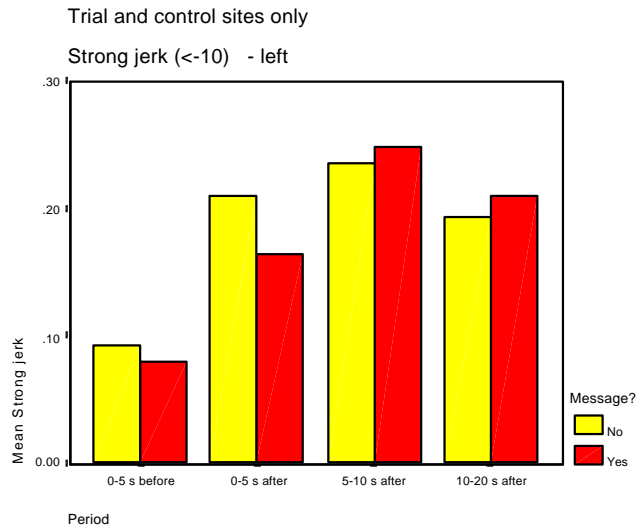


Figure 4. Proportion of strong negative jerks (stronger than -10 m/s^3) of subjects before and after passing the trial and control sites. The control sites not used as a trial sites during one of the driving rounds have been excluded.

Decelerations as such are not necessarily an indicator of safety problems, but very abrupt decelerations might be. The abruptness of the decelerations can be investigated by studying jerk (the first derivative of acceleration and the second derivative of speed). Figure 4 presents the proportion of very large negative jerks (jerk more powerful than -10 m/s^3) in the data.

It should be noted, however, that the jerks were now studied at 0.2 second intervals. According to Nygård (1998), the sensitivity of the data registration device causes some random fluctuations in the jerk values, and he used 0.4 second intervals to smoothen out the fluctuations. Hence, the jerks stronger than -10 m/s^3 were not necessarily linked to a conflict type situation but could also be linked to an otherwise strong braking. The proportion of very strong jerks seems to have increased somewhat for turning vehicles, whereas the proportion for straight driving vehicles was smaller during the first ten seconds after message receipt. None of the changes were statistically significant, however.

4.2 Steering wheel position

The steering wheel is turned especially during turning manoeuvres, and the standard deviation of steering wheel turns is very large during those manoeuvres. As an indicator of driving performance, the standard deviation of steering wheel position can be used on straight sections only (Figure 5).

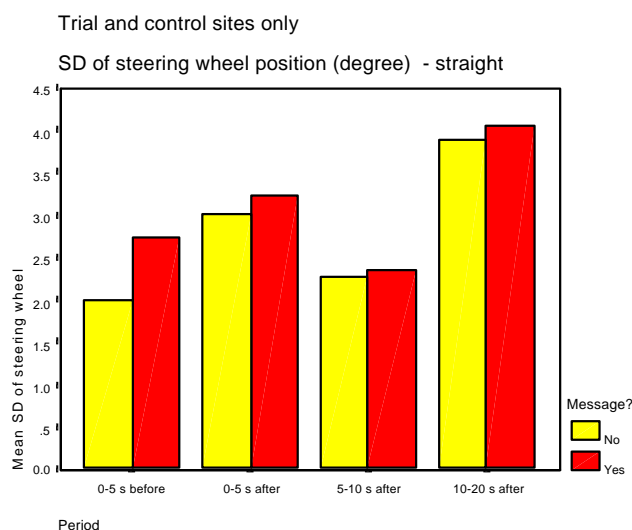


Figure 5. Mean standard deviation of steering wheel position (degree) of subjects before and after passing the trial and control sites. The control sites not used as a trial sites during one of the driving rounds have been excluded.

On straight sections, the standard deviation of steering wheel position was smaller after trial sites than after control sites when compared to the standard deviations just before passing the sites. The differences were statistically significant ($p < 0.001$).

Figure 6 shows the proportion of strong steering wheel jerks at trial and control sites. The steering wheel jerk was regarded as strong, if the jerk was stronger than $20 \text{ degrees}/0.2 \text{ sec}/0.2 \text{ sec}$. This means that in successive 0.2 second periods of observation the steering wheel position change was more rapid than $20 \text{ degrees}/0.2 \text{ seconds}$ (a rate of $100 \text{ degrees/second}$). The receipt of RDS-TMC messages seemed to have little effect on the mean maximum steering wheel jerk on straight sections.

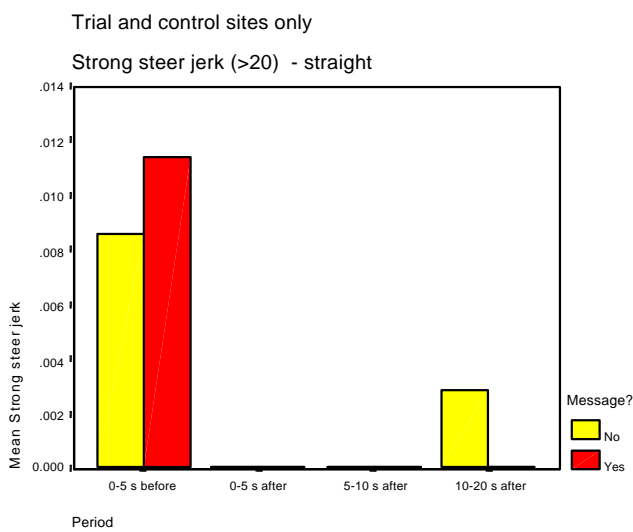
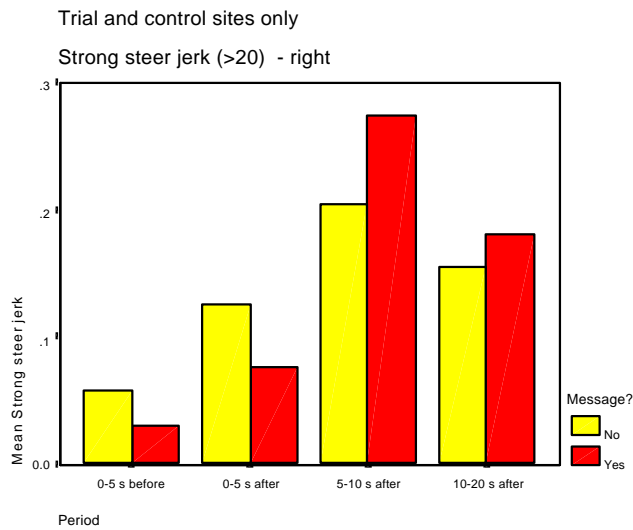
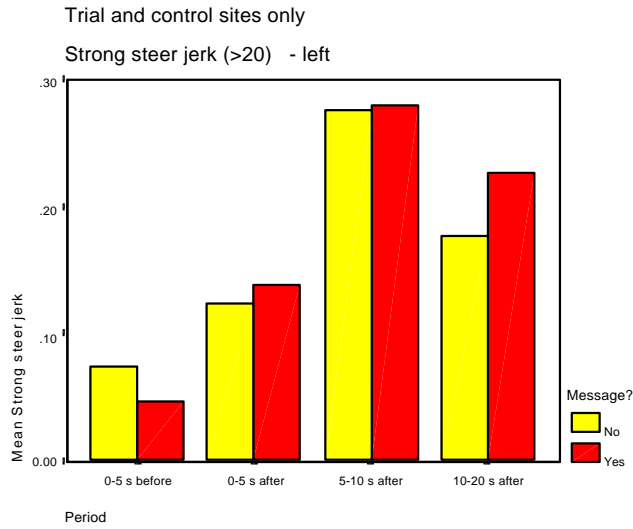


Figure 6. Proportion of strong steering wheel jerks (>20 degrees/0.2 s/0.2 s) of subjects before and after passing the trial and control sites. The control sites not used as a trial sites during one of the driving rounds have been excluded.

At sites where the subjects had to turn, however, the steering wheel jerks were stronger after passing trial sites than after passing control sites. The difference was small during the first five seconds after passing the site, but then larger 5...10 and 10...20 seconds after passing the site. The differences were statistically significant ($p < 0.001$). Results were similar for strong steering wheel jerks (Figure 12), although there were, not surprisingly, very few strong jerks on straight sections. There were more strong steering wheel jerks for turning vehicles 5...20 seconds after passing the trial site. The largest differences were statistically significant ($p < 0.05$).

4.3 Braking

The average maximum braking force was higher during the first 10 seconds at trial sites after receiving the message at trial sites than at control sites. This held for both sites where the subjects were turning and where they were driving straight on. The differences were statistically significant ($p < 0.001$).

The proportion of strong brakings at trial and control sites is presented in Figure 7. A braking was considered strong, if the brake force was greater than 25.

At trial sites where the subjects were turning, the proportion of strong brakings was higher just after passing the site i.e. after receiving a message than at control sites. These differences were not, however, statistically significant.

4.4 Conflicts

In all, the final data set contained seven conflict situations, out of which two were severe, two slight and three potential conflicts. For the definitions of the various types of situations, see, e.g. Kulmala (1984).

Out of the seven conflict situations, only four occurred at times around passing the trial and control sites. All situations occurred at control sites. Two occurred 5...10 seconds after passing the control site, and the rest two 10...20 seconds after passing the control site. The sites were located before junctions, and the conflicts occurred at the junctions. In three of the four conflict situations, the subject was turning left. In one situation, the subject was driving straight on.

The small number of conflicts made any analyses or conclusions about the safety relevance of the HMI and behavioural indices impossible.

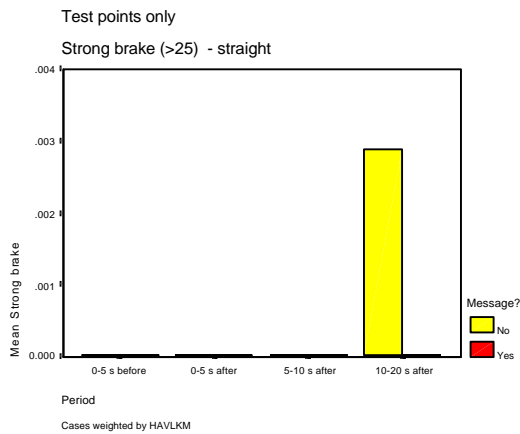
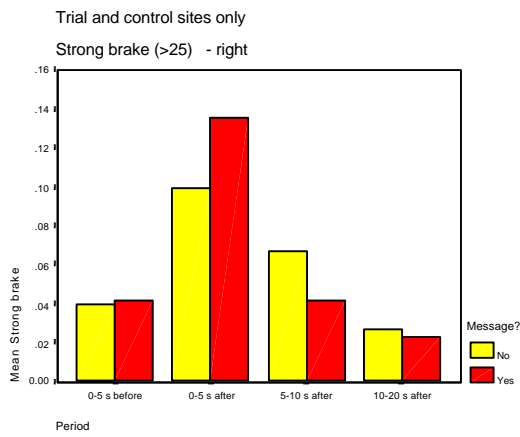
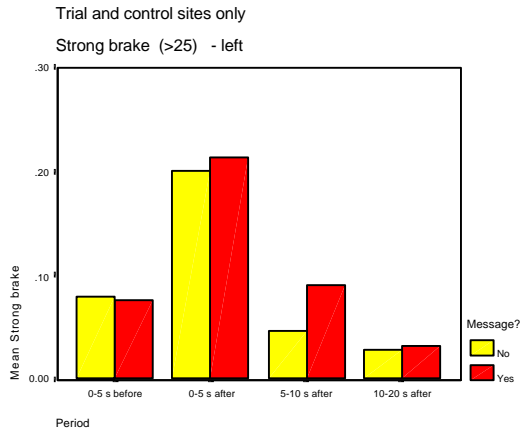


Figure 7. Proportion of strong brakings (>25) of subjects before and after passing the trial and control sites. The control sites not used as a trial sites during one of the driving rounds have been excluded.

5. DISCUSSION

The main objective of studying the relationships between HMI and behavioural indices and traffic safety as measured by the number of conflicts was not reached due to the unexpectedly low number of conflicts observed. Nevertheless, we could investigate the impacts of the use of the RDS-TMC receiver on driver behaviour, and discuss the safety implications of these findings.

Drivers' looking behaviour can be first compared to the corresponding HMI recommendations (Task Force HMI 1998). These recommendations suggest that visually displayed information should be such that the driver can assimilate it with a few glances (i.e. up to 4 for the average driver) which are brief enough (i.e. single glance time of 2 seconds, while glance times around 1 second should be the normal case) not to adversely affect driving (Task Force HMI 1998). The most reliable results of the present study - collected during the trials with no turn - indicated that the number of glances to the receiver was 2.70 and the single glance time (in terms of off-road time) was 1.45 s, on average. This comparison suggests that the information provided by the receiver was relatively easy to assimilate, although the glance time was somewhat higher than 1 second.

Second, a comparison of the present results and previously obtained from comparable studies reveal that the RDS-TMC task was easy. For example, Tijerina, Parmen and Goodman, (1998) assessed driver workload of several route guidance systems while driving. The results showed that the number of glances varied from 4 to 32 and the single glance time from 1.0 s to 3.1 s. Moreover, the data of Dingus, Antin, Hulse and Wierville (1989) showed that many tasks connected to a moving-map navigation system resulted in much more glances than the RDS-TMC task of the present study, while many conventional tasks, such as check of speed, time, or remaining fuel resulted in fewer glances. Overall, the single glance times ranged from 0.6 s to 1.7 s.

Third, the results did not show any age effect indicating that older subjects did not perform as well as younger subjects. However, many previous studies have demonstrated age-related problems in divided attention tasks involving complex or demanding conditions (see reviews by Hakamies-Blomqvist 1994, Schieber 1994). Consequently, these results suggest that the RDS-TMC task of the present study was relatively easy.

Fourth, the subjective assessments of workload and ease to understand the messages showed that the subjects did not have any substantial problems with the RDS-TMC task.

The ease of the RDS-TMC task might be influenced by several factors. These include

- the positioning of the receiver close to the driver's normal line of sight but not being obstructed by the steering wheel or obstructing the forward vision
- the relatively large display and controls
- controls could be used one handed
- relatively simple information with legible text, pictograms and map
- the simple functions of the receiver with no complicated menus
- the subjects were instructed appropriately.

Despite all above-mentioned results, the analyses showed that the glances to the receiver influenced the occurrence of mistakes done in the search of priority road

users. In comparison to the trials with no mistake, the drivers more frequently looked at the receiver and the total glance time was more substantial when a mistake happened. This result also showed that the number of glances and the glance time are the most promising variables, while the time of the most prolonged glance may be an insensitive variable.

In addition, the results on indices of driving behaviour indicate that although the RDS-TMC task was easy, it still might have negative safety consequences.

When driving straight on, the receipt of RDS-TMC messages had minor impact on driving behaviour, and sometimes small positive impacts. The steering wheel handling had less variance and strong jerks. These results corresponded well to those for glance pattern, visual search and subjective workload.

The situation was totally different during turning manoeuvres. Specifically, the receipt of RDS-TMC messages caused a considerable reduction of speeds during turning manoeuvres. This reduction was accompanied with a higher occurrence rate of strong brakings and unsafe jerks in speed. Abrupt steering wheel movements were also more frequent after receipt of RDS-TMC messages. During turning manoeuvres, the driving task is considerably more complicated than when driving straight. Therefore, the receipt of the message when performing the turning manoeuvre or just before it apparently may cause temporarily too high workload. The drivers seem to try to compensate for it by lowering their speeds but the results still indicated problems.

Unfortunately, due to data collection apparatus problems, we do not have complete data on glance patterns or visual search mistakes for turning manoeuvres. Hence, the glance pattern and visual search results can not be compared to the speed, braking and steering wheel results. It may also be that the temporarily excessive workload during turning manoeuvres is not due to just diverting the attention visually to the receiver but also due to too high cognitive workload (i.e. the knowledge that a relevant message might just have arrived but this can not be checked until after performing the turn, for example).

For continuing the studies, it is imperative that the camera position for glance data collection is altered to accommodate for unoccluded vision of the driver's face. It is necessary to make the route and/or the task more difficult in terms of the expected number of conflicts to make it possible to verify the safety relevance of the various HMI and behavioural indices.

New studies, following the afore-mentioned recommendations have been undertaken in 1999 at VTT.

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