INFLUENCE OF UNEXPECTED EVENTS ON DRIVING BEHAVIOUR AT DIFFERENT HIERARCHICAL LEVELS: A DRIVING SIMULATOR EXPERIMENT

T. W. Schaap (Twente University, The Netherlands), A. R. A. van der Horst (TNO, The Netherlands), B. van Arem (Twente University, The Netherlands)

t.w.schaap@utwente.nl

ABSTRACT: Computer based simulation models of human driving behaviour can be used effectively to model driving behaviour and behavioural adaptation to Intelligent Transport System (ITS). This can be a useful step in human centered design of ITS. To construct a comprehensive model of driving behaviour, the interaction between the three levels of the driving task has to be determined. This gives insight into how different driving tasks influence each other. A driving simulator experiment was conducted to determine the relationship between levels of the driving task. The influence of workload on this relationship was determined by giving subjects an additional cognitive task. Subjects had to drive many similar intersections, with two unexpected events. Their reaction on the tactical level to the compensation on the control level was measured. Participants lowered speed and increased headway after having to brake; level of unexpectedness increased this effect. Workload decreased this effect on driving speed.

1 Introduction

1.1 *Modelling behavioural adaptation to Intelligent Transportation Systems (ITS)*

Driving is and has always been a complex task. Next to controlling the vehicle, which is a complex task in itself, the driver has to determine why, when and where he wants to drive. He has to determine his route, make sure he takes the correct turns, avoids collisions with vehicles crossing his lane and keeps the appropriate distance to lead vehicles. Furthermore, many secondary tasks such as tuning the radio or talking on the phone are performed while driving. This requires constant attention, goal management and use of memory. Today, in a time with more vehicles on the road than ever [1], both industry and governments have set their focus on making driving safer and more comfortable. One of the ways to achieve this goal is through the development of Intelligent Transport Systems (ITS).

When developing ITS, the driver is not always at the center of the designing process. Therefore, it is not always guaranteed that the application will fulfill a certain user need. Furthermore, in many cases it is uncertain how the human user of ITS will react to the system. This is an important step in the designing process of ITS. Drivers may adapt their behaviour in an unexpected way, which may turn out to be both positive and negative. Determining the effects of this behavioural adaptation can be done in many ways, depending on the stage of the development process and the possible safety effects of the system [2]. A cost-effective and safe way to determine the effects of ITS is by developing a computer simulation model of driving behaviour, which can interact with such a system. We will develop a simulation model of driving behaviour based on the structure of the driving task, making it possible to develop a comprehensive driving behaviour model.

1.2 Levels of the driving task

Our computer simulation model of driving behaviour will have to meet a number of constraints [2], such as running in real-time, focusing on intersection behavior, and the possibility to build the model structure on Michon's hierarchical model of the driving task [3]. According to Michon [3], driving consists of three hierarchically ordered levels: strategic, tactical and operational. On the strategic (navigation) level, the goals of the trip are set and the route and departure time are determined. On the tactical (guidance) level, the driver has to follow the road, maintain a steady speed and keep enough distance to other vehicles. On the operational (control) level, the driver controls the vehicle by pressing the gas pedal and the brakes, turning the steering wheel and using the vehicle controls. These levels can be active at the same time and can influence each other. This is most clear at intersections, where route choice, tactical maneuvers and control tasks are equally important. This is also where the top-down influence between the levels becomes most clear. When a certain route has been chosen, the driver has to make the turns according to this route and therefore control the vehicle to do so.

On the other hand, bottom-up influence is also possible. Michon [3] expected that this would have a relation with expectations and unexpected situations. Unexpected situations can lead to a higher priority for lower level tasks when they have to take over to guarantee safety or the original task can not be performed successfully. For instance, when one drives a certain route and a street turns out to be blocked, the tactical level solution of taking a different turn will take precedence over the original route. When a driver suddenly has to brake for a crossing child, the distance to other vehicles or the next turn to take can be altered according to the outcome of the situation. In these cases, lower levels influence the outcome of higher levels.

Alexander and Lunenfeld [4] describe how primacy increases with lower level tasks, whereas complexity increases with higher level tasks. Tasks on a higher level therefore often take more time to complete and are more complex. On the other hand, lower level tasks sometimes have to take over in order to ensure safety. These latter situations are of interest for our research, because this is bottom-up influence between levels of the driving task. These are the situations in which the driver compensates for unexpected events.

Unfortunately, the hierarchical relation between the levels of the driving task, and especially the bottom-up influence resulting from this, has not yet been determined precisely, and can therefore not yet be fully integrated in a computational model of driving behaviour. Only when we know how normal driving behaviour takes place, we can make a valid and complete comprehensive model of driving behaviour, which can in turn be used to determine the effects of behavioural adaptation to ITS.

1.3 Research objective

We conducted a driving simulator experiment to determine in which situations normal top-down interaction between the levels of the driving task is overruled by bottom-up influence. This bottom-up influence can be seen as compensation for an unexpected event. In order to determine the relation between this event and the participants' reactions, we also looked at the influence of cognitive workload and at the level of unexpectedness of a situation on this bottom-up influence. We focused on the tactical level and the control level, because it is very difficult in an experimental setting to control the expectations of a group of participants on the strategic level (route and trip goals).

1.4 Hypotheses

An unexpected event will cause compensation behaviour on a lower level of the driving task, influencing higher level tasks. After a while, the effect of the unexpected event on the task will fade away. The operational level tasks that we studied were sudden braking as a reaction to a braking lead vehicle, and steering away from an approaching vehicle from the left. These operational level tasks will have an impact on following distance and intersection approach speed, as well as anticipation and lateral acceleration, which are tactical level tasks.

We expect that compensation behaviour on the operational level to a braking lead car (by braking), increases the participants' following distance, increases anticipation to the intersection (measured by minimum speed based on distance and time to intersection) and decreases overall intersection approach speed. After a number of intersections, this effect will fade away. We also expect that the level of unexpectedness has an influence on this.

We furthermore expect that compensation behaviour in reaction to an accelerating vehicle from the left decreases overall intersection approach speed as well as the distance-to-intersection and time-to-intersection of the onset of speed decrease (anticipation), and influences lateral acceleration. After a number of intersections, this effect will fade away. We also expect that the level of unexpectedness has an influence on this.

2 Method

2.1 Participants

87 subjects participated in our experiment. They were between 23 and 60 years old, had their driver's license for five years or more and drove 10.000 kilometers or more annually. Due to simulator sickness, 11 participants did not complete the experiment. 76 participants completed the experiments. An error in the data storage led to an incomplete dataset for 37 participants. 39 complete datasets were used for analysis.

2.2 Data measurement

The experiment was performed in a driving simulator of TNO Human Factors. This simulator was a fixed-based driving simulator with manual transmission (see Figure 1). The participant could control the driving simulator by means of normal vehicle controls. The road environment and other road users were projected on three screens with a total horizontal field of view of 180° and the total vertical field of view of 45°.

In order to determine the participants' workload during driving, participants had to perform a Peripheral Detection Task (PDT) [5]. Measuring workload objectively is difficult with self-report measures [6], but with the PDT, this is less of a problem. A LED light is shown to the participants randomly every 3 to 5 seconds (see Figure 1). Participants have a small switch attached to their index finger, which they have to press every time they see the LED light. Workload is determined by reaction times and the number of missed signals. As workload increases, visual attention narrows [5], which increases response time and the chance of missing a signal. If a participant did not respond to the LED light for 2 seconds or more, this was registered as a missed signal.

2.3 Experimental design

An urban layout was simulated with one long road, crossed by twenty other roads, creating 20 intersections. Subjects were instructed to drive with a maximum speed of 50 km/h and give priority to traffic coming from the right, according to Dutch traffic regulations. They had to go straight on each intersection and park the simulated car at the end of the road (see Figure 1).

The infrastructure was similar at each intersection, and the other road users always behaved similarly. A lead car drove in front of the subject the whole time. This vehicle slowed down when the subject fell too far behind, and speeded up when the subject came too close. This way, the lead distance was always between 18 and 48 meters from the bumper of the simulated car.

When the participant was approaching an intersection, a car coming from the right always crossed the intersection first, followed by a car from the opposite direction. The participant and a lead car then reached the intersection, and a car from the left yielded and crossed after they had passed the intersection. The intersection layout and the positioning of other road users, including the lead car, are depicted in Figure 1.

The experiment consisted of four experimental drives and an introduction drive. In the first experimental drive, participants only drove on standard intersections, setting their expectations about the situations to come. This was the reference condition for normal driving. After 5 standard intersections in the second drive, an unexpected event happened: the lead vehicle suddenly braked. The third drive was a reference condition again. At the eighth intersection in the fourth drive, the car from the left that had always yielded now suddenly accelerated and stopped before colliding with the participants. Both unexpected events could occur at three levels: strong, medium and mild.

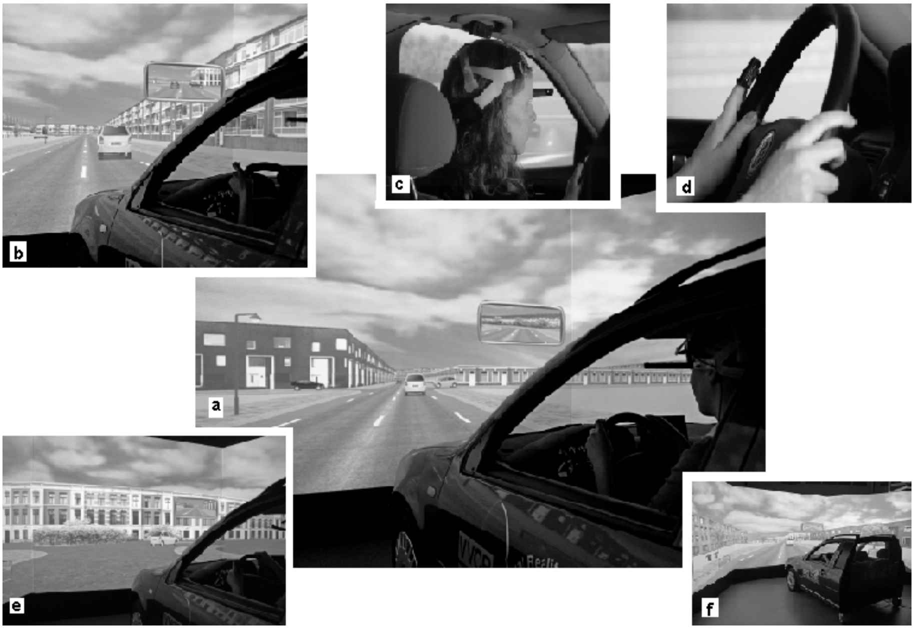

Fig.1. Experimental setup

(1a: intersection layout with traffic; 1b: lead car; 1c: LED light for PDT; 1d: switch for PDT; 1e: end of experimental drive; 1f: the TNO driving simulator)

Half of the participants were furthermore given an additional, cognitive task, to determine the effect of cognitive load on the influence between the levels of the driving task. They had to count back from a high number by steps of a certain size (ranging between 4 and 9, depending on the drive). All participants with the additional task were given exactly the same task, and they were told to do it as fast as possible, making sure that they had additional cognitive load during driving. Participants were encouraged to continuously perform the additional task and were reminded of their task after a number of seconds without an answer, but they could give their final answers at their own pace, ensuring that all participants were equally challenged.

The two levels of cognitive workload (no additional task or additional task) and the three levels of unexpectedness of the events (mild, medium, hard) leads to 6 event conditions. The event conditions were counterbalanced among participants to eliminate possible learning effects. Participants always encountered the same version (mild/ medium/ hard) of both the unexpected events, and always drove a drive without an unexpected event as the first and third drive. Participants with an additional cognitive task also had to perform this cognitive task during reference conditions.

After each drive, participants were given a break and a questionnaire, with questions related to simulator sickness, the level of predictability of the driving task and the level of difficulty of the PDT. For the participants with the counting task, additional questions were asked about the level of difficulty of this task, and whether it had influenced the participant's way of driving.

2.4 Data registration

Twenty-one variables were registered with a frequency of 256 Hz during the experiment:

1. Time (s);
2. Path number;
3. Distance to intersection (m);
4. Distance from next intersection (m);
5. Velocity (m/s);
6. Acceleration (m/s2);
7. Lateral position (m);
8. Lateral velocity (m/s);
9. Steering angle (angle);
10. Gas pedal angle (percentage of maximum pressed);
11. Brake pedal angle (percentage of maximum pressed);
12. Time headway (s);
13. Distance lead vehicle (m);
14. Velocity lead vehicle (m/s);
15. Time to intersection (s);
16. Time to collision (s);
17. Time to collision with left approaching vehicle (s);
18. Time to collision with right approaching vehicle (s);
19. Distance to intersection of lead vehicle (m);
20. Speed of lead vehicle (m/s);
21. PDT reaction time (ms);

2.5 Analysis

All recorded twenty-one variables are related to tactical level or control level driving tasks. These were used to answer the question whether, and in what way, control level compensation for an unexpected event influences tactical level task performance. In this paper, we only focus on the first unexpected event, the braking lead car. A full description of the second part of the analysis and its results will be published in [7].

First, we determined whether the standard intersections were actually seen by the participants as "expected" and the unexpected events as “unexpected”. This was determined by studying the answers given in the questionnaire and by looking at learning effects in driving. Next, we tested our hypotheses that the braking lead car would have an effect on following distance, moment and location of anticipation to the intersection and the intersection approach speed. This was tested by comparing these variables in the reference case (third drive) to the intersections directly after the event. Finally, the effects of the level of unexpectedness (mild, medium or hard braking) and of the additional cognitive task were examined.

3 Results

3.1 Expectations

The expectations of the participants were tested by studying their driving behaviour and related learning effects, and by examining their answers to selected questions of the questionnaire.

3.1.1 Learning effects in driving behaviour

A learning effect can be determined by examining the average speed on intersections. Average driving speed increases with experience, as a result of the participants' knowledge of what to expect. Indeed, a significant increase of average driving speed can be found during the experiment (p<.0001). The standard deviation of speed also tells us something about the learning effect of standard intersections: when participants get more used to situations, they know better what to expect and therefore can drive more smoothly trough these intersections. A decrease in the standard deviation of speed therefore also points to a learning effect. The standard deviation of speed decreased significantly during the experiment (p<.0001). This supports our expectation that participants were getting used to the standard intersections during the first experimental drive.

3.1.2 Answers to selected questions of the questionnaire

Participants were given a questionnaire after each experimental drive. Some questions concerned the participant's comfort during the experiment, some were related to the difficulty of the driving task, the PDT and the additional task. A third topic in the questionnaire was the predictability of other road users' behaviour in the experiment and the intersections. The answers to these questions were used to determine whether participants had expectations about the situations and whether an unexpected event was actually seen as unexpected. The answers to the questionnaire revealed that the reference conditions were seen as significantly more predictable than the drives with the unexpected events (p<.006, see Figure 2). Also, 50% of the unexpected events were explicitly mentioned in the field for additional information about the experiment. It is safe to conclude that the unexpected events were really not expected by the participants.

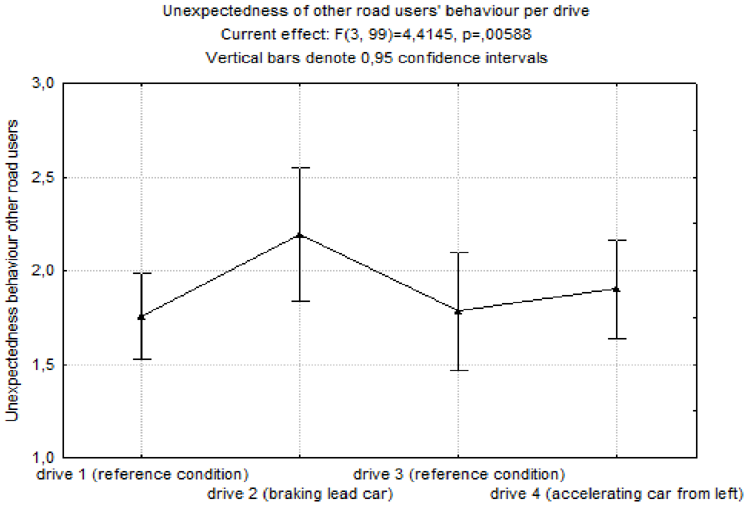

Fig.2. Level of unexpectedness per drive

3.2 *Effects of control level compensation on tactical level tasks to a braking lead vehicle*

In reaction to the braking lead vehicle, participants drove at significantly lower speeds on the directly intersections following the unexpected event than they did on the same intersections in the standard drive (p<.0018). Figure 3 shows the average speed on the intersection area (100 meters before until end of intersection) measured over 7 intersections in drive 2 (braking lead vehicle) and drive 3 (standard drive), and the interaction effects between drive and intersection (p<.001). It can be seen that overall speed for these intersections is significantly lower in the drive with the braking lead vehicle; the reaction to the braking lead vehicle (intersection 5 in drive 2) is also clear.

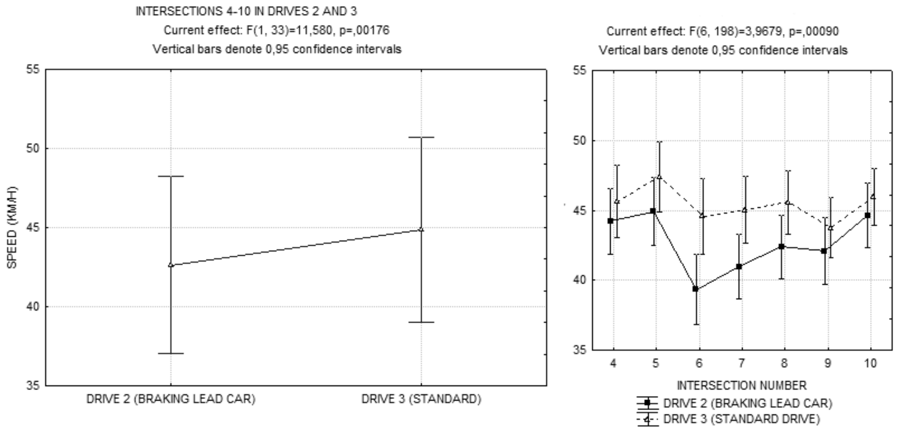

Fig.3. Average driving speed after braking lead car and in reference condition. Left: average speed in drive 2 and drive 3; Right: interaction effect between intersection number and drive. Lead car brakes at intersection 5 in drive 2

Furthermore, participants increased their headway significantly during the second drive (p<.001), compared to the reference drives.

3.3 Effects of level of unexpectedness and additional workload

The level of unexpectedness (L.O.U.) has a significant effect on the percentage of time participants drove with the minimum headway (p<.038): when the lead car would brake harder, the participants would drive less time with the minimum headway (see Figure 4).

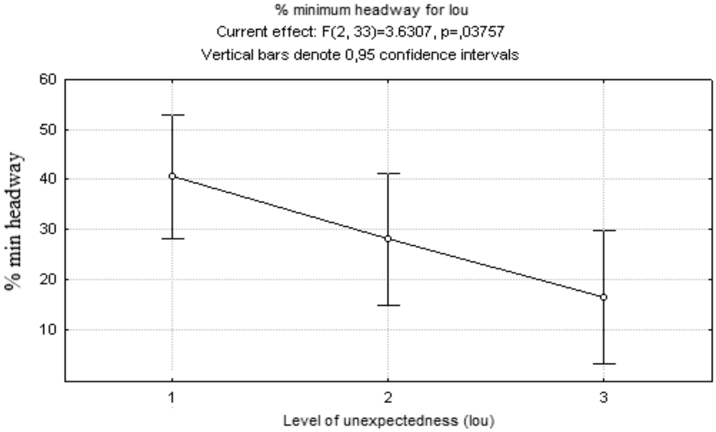

Fig.4. Effect of level of unexpectedness (lou) on % of time driven with minimum headway. 1 = least unexpected, 3 = most unexpected

There was no significant influence found on driving speed of the level of unexpectedness.

The additional task increased PDT reaction time (p<.001) and number of missed PDT signals (p<.001), and this increased workload influenced the effect that was seen on driving speed: with the additional task, the speed decrease in the second drive was significantly less than without the additional task (p<.027).

A full description of our experimental results will be published in [7].

4 Conclusions

It can be seen from our results that tactical level tasks are influenced by operational level compensation tasks in case of an unexpected event, and that this effect fades away after a certain amount of time. A significant effect of the level of unexpectedness on this influence between levels of the driving task was seen, and additional workload seems to change the relation between level s of the driving task as well. A full description of conclusions regarding the structure of the driving task and our conceptual model of intersection driving behaviour will be published in [7].

5 Acknowledgments

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