Adaptive strategies and goal management in car drivers
Cnossen, Fokeltje

IMPORTANT NOTE: You are advised to consult the publisher's version (publisher's PDF) if you wish to cite from it. Please check the document version below.

Document Version
Publisher's PDF, also known as Version of record

Publication date:
2000

Link to publication in University of Groningen/UMCG research database

Citation for published version (APA):
Chapter 5

Car driving

The previous chapter discussed some strategies of operators in dealing with high task demands in complex dynamic tasks. It indicated that operators try to preserve their primary task goal when task demands are high. In car driving, the main goal is to arrive at the planned destination while avoiding accidents. Mental task demands for car drivers mainly come from performing tasks such as map reading, tuning the car stereo, making telephone calls, processing information from an in-car route guidance system or from variable messages signs along the road. In light of the increase in in-car information systems introduced into cars, and the continuing increase in traffic volumes, the main question of this thesis is whether drivers can deal with such a high information load. This chapter will be dedicated to traffic behaviour research and examine whether behavioural adaptation to high task demands has also been observed in car drivers.

Although car driving is considered a complex dynamic task, an important difference between driving and tasks such as industrial process operation, flying an aeroplane, or air-traffic control is the nature of task environment. Operators in other complex tasks often need to infer the state of the process or the state of the environment from indirect information sources (e.g., displays) and, perhaps more important for mental task demands, have to remember this information. For the car driver, more information is visually available in the environment. Cognitive demands are thus lower for car drivers than for operators in other complex dynamic tasks. However, expertise is needed for optimal use of environmental information. The next section (5.1) will therefore not only focus on the role of the environmental cues in driving, but also discuss driving expertise. Goal management in car drivers is discussed in Section 5.2. Having set the stage for the next three chapters in which three experiments will be discussed, this chapter will end (Section 5.3) with a formulation of specific research questions that those experiments try to answer.

5.1 Complexity of the driving task

In comparison with other complex dynamic tasks such as air-traffic control or flying an aeroplane, car driving is more environmentally cued. In most other complex tasks, information about the environment and the task is often not (visually) present and needs to be inferred. An air-pilot cannot directly observe the position of the flaps in the wing, the state of the landing gear, or a fire in an engine; rather, this information needs to be inferred from displays. In contrast, most of the information necessary for driving task is available in
the environment. Obtaining situation awareness, i.e., knowing the present state of the environment and the task, is therefore less difficult for car drivers. Although information may not always be visible to car drivers (for example, the position of following cars on the road cannot be observed when the driver looks ahead), information is usually readily obtainable: changing visual focus suffices to obtain a direct up-to-date overview. Expertise is, however, needed to guide visual search: experienced drivers know where and when to expect information, and where to search for it.

5.1.1 Expertise
Expertise depends on the ability to recognise the general category of a specific situation, and on performing the appropriate actions in the appropriate situations. Experts will develop general schemata which enable the classification of the situation. This determines the general strategy to deal with the environment. The specific actions are determined by this strategy, but tuned and moulded by information from the environment so that the resulting behaviour is maximally adapted to the actual circumstances.

5.1.2 Schemata
Although traffic situations vary greatly in their specific details, car drivers often encounter the same traffic situations: negotiating intersections with minor or major roads, entering and exiting the motorway, driving a motorway, etcetera. Consistent exposure to similar traffic situations will result in the development of specific schemata. These schemata guide the perception and selection of (goal-)relevant information from the environment, the interpretation of behaviour of other traffic, the selection of actions and prediction of future traffic situations. As a result of practice, environmental cues will increasingly trigger associated behaviour, or rather, activate the subgoals to deal with the specific traffic situations. As experience grows, so does the number of schemata, which become more differentiated as well. As a result, car driving becomes increasingly more environmentally cued.

For novice drivers, it is not always obvious where information is, where it can be expected, and when to search for it. It requires considerable experience to develop information searching and noticing patterns. Novices look closer to the vehicle, and in contrast to experienced drivers do not look farther forward when their driving speed increases (Mourant & Rockwell, 1972; Neboit, 1983). Experienced drivers focus more on the horizon than novice drivers (Carter & Laya, 1998), and can use peripheral vision in lane keeping more than less experienced drivers (Summala, Lamble & Laakso, 1998).

Experienced drivers use schemata or reference situations more than novice drivers (Saad, 1996). Experienced drivers compare the actual situation against such reference or prototype situations, and base their decisions on a representation of the typical behaviour adopted in such situations. Deviations from this typical behaviour by other drivers leads to increased monitoring and adaptation of driving behaviour (e.g., increase headway). Only experienced drivers report the environmental cues on which they base these judgements, suggesting that novice drivers do not use that information or are not aware of these cues. This difference between novice and more experienced drivers is also evident in the type of errors made in visual search. Novice drivers mainly look in the wrong direction because they lack knowledge concerning which situations might become dangerous. Experienced drivers’
search patterns are based on expectations and they typically overlook dangerous situations when they occur in unusual locations. That visual search is dominated by expectations is also shown by Theeuwes (1996). Objects at unusual locations are detected later, even when they are highly salient.

The development of these schemata depends on consistent associations between environmental cues and future situations. In the Netherlands, physical appearance of motorways is rather consistent, while other roads outside of built-up areas have less consistent lay-out. This indeed impedes the development of prototypical representations: Dutch drivers have developed a prototypical representation of a “motorway”, but not of other roads (Theeuwes, 1998).

5.1.3 Expertise is specific and dependent on the environment

In Chapter 3, expert task behaviour was said to be goal-dependent and highly specific. There is indeed strong evidence that the development of expertise is highly specific. For example, Duncan, Williams, Nimmo-Smith & Brown (1993) showed that in experienced drivers, individual driving subtasks, e.g., mirror checking, overtaking, merging, were only marginally correlated with each other, indicating that each subtask develops independently from the others. Moreover, within-subtask performance was variable as well: there was no tendency to generally be a “reliable mirror checker” for example. This probably indicates that performance of specific tasks relies to a large extent on the specific environmental details encountered. Groeger & Clegg (1997) also showed that timing in gear shifting is very variable. Berthelon, Mestre & Taramino (1996) performed a study in which drivers had to assess the arrival time of a crossing vehicle at the intersection. When abstract images were used (moving dots), driving experience had no effect on decision time, but with realistic images (driving simulator), more experienced drivers were faster and more accurate in their decisions. They appeared to have gained an increased ability to select quickly the relevant cues and/or to analyse complex visual scenes. This also hints at skill specificity.

More generally, these studies indicate that in the development of a specific skill, task-specific cues become associated with task-specific actions. It appears that the specificity of expertise lies in the variability of the environment, not in the schemata themselves. As experience grows, the schemata become more differentiated to be more in tune with the environment.

Anticipation plays an important role in driving. Anticipation allows faster reactions to traffic situations and adaptation of behaviour to prevent potentially dangerous situations. Rather than reacting to dangerous situations as they occur, drivers thus prevent them from occurring. For example, drivers increase their time headway when the car in front signals to turn at the next intersection (Van Der Hulst, Meijman & Rothengatter, 1999). Drivers also increase their time headway when they anticipate that the lead car will slow down to give way to a car from the right (Van Der Hulst, Rothengatter & Meijman, 1998). When driving in fog, they also increase their time headway. In this way, car drivers increased the time available to react to potential hazards, which obviously reduces task demands.

Anticipatory actions are based on schemata. For example, the decision to overtake is not based on the momentary state but on the expected development of that situation (Saad, 1996). The expected development is part of the driver’s representation of normal behaviour.
in reference situations. The cues from the environment and such a schema enable the anticipation of future situations. In more experienced drivers, the number of schemata will be higher, and be more detailed and differentiated, allowing more anticipation in experienced drivers.

5.1.4 Summary
Thus, car driving appears be less complex than other complex dynamic tasks. Most information is readily observable in the environment, and mental schemata can be easily checked against environmental information. This reduces the demands on working memory and enables the driver to perform other tasks during driving. However, drivers thus rely heavily on visual information. Therefore, the introduction of visual in-car information systems (of which route guidance systems are an important example) has stimulated research on the effects of performing visual tasks while driving. The next section will present an overview of these results, and of other workload research in driving as well.

5.2 Goal management in car driving: a review
Car driving is a task where different goals operate at different levels of behaviour. Despite some differences with other complex tasks, car driving is clearly a complex and dynamic task. It can be assumed that trading off between goals proceeds in the same manner as in other complex tasks: preservation of the primary task goal is likely to be important in car driving as well. This review will discuss experimental results from relevant driving behaviour studies.

Car driving is a hierarchical task, and arriving safely at the planned destination is the main goal in car driving. In order to achieve the main task, subtasks aimed at satisfying subgoals have to be performed to achieve the main task goal. Thus, behaviour at the operational level (speed control, lateral control, mirror checking) is under control of goals at the tactical and strategic level. As an example, only when a driver is planning to overtake or change lane, is it necessary to check the rear-view mirror (although driver may check the mirrors to maintain a mental overview of other traffic). Driving behaviour is thus hierarchically controlled. This top-down control does not rule out bottom-up control: most tactical and operational goals in driving are mainly determined by the traffic environment, and only to a lesser extent by general goals such as being in a hurry. Goals in driving are context-dependent. For example, whether it is opportune to overtake depends on the traffic environment: only when there is a slow car in front is overtaking opportune. Many goals in driving are therefore created dynamically as a response to external events.

Drivers perform several subtasks during driving. Many subtasks are a direct part of the driving task (e.g., speed control, steering, visual search, distance keeping), but others are not (tuning the radio, picking up the car telephone). On the basis of results in other complex dynamic tasks, it can be expected that drivers will neglect the subsidiary tasks (radio and telephone handling) when task demands increase.
5.2.1 Manipulation of task demands

Task demands have been increased by a number of manipulations. Visual route guidance systems use displays to indicate the route to drive. Usually, the digitised maps indicate the current position of the driver and the route to drive, but some systems use simple arrows. The RG systems that were tested often included auditory support. Although checking a RG system is a task additional to driving, the information it presents is highly relevant for drivers. The main goal of arriving at the destination implies knowledge of the route to drive. Drivers are thus faced with a goal conflict: to arrive at the destination they need to check the system, but to perform the driving task safely, they need to look at the traffic environment. To study demands of a more cognitive nature, various working memory tasks have also been used, which are usually presented auditorily. The next two sections (5.2.2. and 5.2.3) will discuss evidence on changing of working method and giving up subsidiary activities by drivers under high task demands.

5.2.2 Change of working strategy

Speed reductions

The most important way of reducing task demands is by reducing driving speed. Many studies found that drivers reduce their driving speed when task demands increase. Lower driving speeds allow more time for information processing and are thus highly effective in reducing the demands on the driver. For example, when drivers had to operate the car stereo, time to complete a route increased, implying that driving speed was lower (Jordan & Johnson, 1993). Other studies, using direct speed measures, also found that car drivers reduced their driving speed when task demands increased. Srinivasan and Jovanis (1997) studied a number of route guidance (RG) systems and also found that in high task demand situations, drivers reduced their driving speed.

In a study by Dingus et al. (1997), a relation was found between level of demands and driving speed. Participants were required to drive with different RG information systems: visual displays, traditional paper maps, or messages by voice. The authors noted the long duration of glances at the displays of the visual RG systems, indicating high visual demands; in general, long glances are taken as evidence that the information presented is difficult to process (Fairclough, Ashby & Parkes, 1993). Interestingly, systems with the highest visual demands were associated with lowest driving speeds.

When drivers drive with a route guidance system, speed reductions are particularly found near intersections. Pohlman and Traenkle (1994) studied the effects of different RG systems on driving performance. The high visual demands of the electronic and paper maps resulted in deteriorated lateral control and in speed reductions, which were especially found near intersections. The fact that speed reductions are particularly found near intersections is not surprising. Route decisions are made near intersections and it can be assumed that the RG system will be consulted near intersections most heavily. The visual load of the RG systems will therefore be most prominent near intersections. Furthermore, it is at intersections that drivers interact with other traffic most, and attentional demands will therefore be highest there. Drivers apparently try to resolve the goal conflict by reducing driving speed allowing more time for both tasks.
Other adaptations

Noy (1989) found that car drivers increased their distance headway to the front car when driving with an in-car visual system. Interestingly, this effect was especially found when drivers were actually looking at the system, suggesting that drivers are aware of the negative effects that looking at the display have on driving performance.

Hancock, Simmons, Hashemi, Howarth & Ranney (1999) studied driver distraction by having drivers react to a digit presented on a phone display screen by pressing a key on the phone pad to indicate whether the digit was part of a memory set. The stimulus was presented as the driver approached a signalled intersection where drivers had to come to a stop if the traffic light turned red. With the distracter task, drivers started to brake later after the change of the traffic light. However, they compensated for the later detection by braking more intensely.

5.2.3 Neglect of less important tasks

Mirror checking

Checking the rear-view mirrors helps building up a mental overview of the traffic situation, but it is only a critical subtask when the goal is to change lane. Mirror checking can thus be considered a task of a relative low priority in most traffic situations. It can be expected that under high task demands drivers reduce checking their mirrors, or decide not to overtake. A number of studies support this. A number of studies examined rear-view mirror checking in drivers under high task demands. Landsdown (1997) used two different visual displays: one presented congestion information, the other route guidance (RG) symbols. Fairclough, Ashby & Parkes (1993) used two different visual RG systems: one in which an electronic map showed the route to drive, and one in which written text instructions were presented on a screen. Brookhuis, De Vries & De Waard (1991) presented participants with a mental arithmetic task over the car telephone in differing traffic densities.

All studies showed that car drivers indeed check their rear-view mirror less frequently when task demands increased. This adaptation to the task demands did not hamper traffic safety, as priority of mirror checking was probably not very high in these studies. Fairclough’s study was performed in relatively low traffic intensity, where a mental overview is easily obtained. In the study by Brookhuis, De Vries & De Waard, participants in the highest traffic condition were instructed to follow a lead car as accurately as possible, ruling out the possibility of overtaking it and strongly reducing the necessity to check the mirrors. When traffic intensity increased, participants checked their mirror less often. The mental arithmetic task reduced mirror checking in the conditions with lower traffic conditions, but not in the highest traffic conditions. Most probably, mirror checking was already of low priority because participants were following a car as accurately as possible. Landsdown’s study also strongly suggests that the reduction in frequency of mirror checking is dependent on the priority of the other task that increases task demands. Frequency of mirror checking decreased in the RG condition but not in the congestion warning condition. Apparently, participants regarded the route guidance information more important, which is not surprising, considering that route finding is an important subgoal in driving.
Other adaptations

It has also been found that drivers focus more on traffic-relevant objects when task demands increase. For example, De Waard (1991) compared the time that car drivers looked at traffic-relevant and traffic-irrelevant objects for different road sections. He found that on a combined entrance/exit section of a motorway, drivers spend more time looking at traffic-relevant objects (for example, other cars) compared with driving on a straight section of the road. Wierwille, Hulse, Fischer & Dingus (1991) showed that as traffic intensity increased, drivers looked less at the visual display on the dashboard and more at the traffic environment. Gugerty (1997) studied memory for positions of other cars. He found that as the number of cars on the road increased, the number of cars recalled decreased. However, drivers focussed more on potentially hazardous cars.

5.3 Research questions

5.3.1 Main question: goal management

The main question of this thesis refers to goal management and task strategies in car drivers. Drivers are increasingly required to deal with high information load: traffic density increases, and so do the number of in-car devices and the amount of information along the road. Traffic behaviour researchers have expressed concern about the potential information overload and distraction of drivers, which may threaten traffic safety (e.g., Verweij, 1993). From a traffic safety viewpoint, it is important to ask what drivers will do when they have to deal with more information than they are able or are willing to process. Will their priorities be with performing the driving task safely, or will they be distracted by additional information and additional tasks? This is a question of how do drivers assign priorities to subtasks, or stated differently, of how they deal with conflicts between different goals.

As was discussed in Chapter 2, driving is assumed to be a hierarchical task, with most activities confined to the tactical and operational level. Goals at the tactical level determine the goals at the operational level, and thus guide actual driving behaviour. Much of driving behaviour is in response to the environment and it can be assumed that many goals at the tactical (and strategic) level are triggered by the actual (and expected) state of the environment. It is unclear, however, how this lower-level, bottom-up control interacts with higher-level control. Ranney (1994) concluded in a review of traffic behaviour models that it is presently not established how drivers allocate their attention among the tasks at the different levels of control.

Most goal conflicts in driving behaviour thus take place at the same level, and it is not clear how drivers deal with conflicts at the same level. The literature overview in the previous chapter suggests that some tasks may be more central to the driving task than others. As route finding is part of the main goal in driving (arriving at the destination), RG information is probably more important to drivers than the news on the radio, for example. It is therefore hypothesised that some tasks are more important than others, even if they are at the same hierarchical level within the driving task. It can be assumed that important tasks in driving are route finding, collision avoidance, lateral and longitudinal control.
5.3.2 Overview of experiments

The main three strategies in dealing with high task demands appear to be investment of more effort, neglect of subsidiary tasks, and change of working methods (see Chapter 4). In order to investigate these strategies in drivers more fully, three experiments were designed and performed in a driving simulator. How do drivers assign their priorities among different subtasks: are some subtasks more important than others? Do drivers adapt their behaviour to increases in task demands? These questions are addressed in the next chapter (Chapter 6) and in Chapter 8. In the experiments discussed in Chapter 6, drivers performed various demanding subtasks at the tactical level, whereas in the experiment in Chapter 8, drivers had to weigh two conflicting subtasks at the strategic level.

Experiment 1: Conflict between goals at the same level

The first experiment, to be discussed in the next chapter (Chapter 6), dealt with the strategy to neglect subsidiary tasks. It tested the hypothesis that tasks at the same hierarchical level may have different priorities. More specifically, it tested whether route information is more important than irrelevant traffic information. Two different tasks were performed in a 2 x 2 design: using a map for route finding and processing and remembering traffic information. Task demands were furthermore varied by manipulating traffic density. It was assumed that high traffic density is a factor increasing task demands that cannot be neglected by the driver in the same way as traffic information or a map can. It was expected that driving in high traffic density would either increase the investment of mental effort or result in behavioural adaptation of the driver, for example by reducing speed. There were no expectations on how this would interact with the performance of the other tasks.

Experiment 2: Relation between driving speed and mental effort

As the previous section showed (Section 5.2.2), a rather consistent finding in the literature is that drivers reduce their driving speed when task demands increase. This was interpreted as an adaptive behavioural response: reducing speed would decrease the task demands, which in turn would reduce the need for further effort investment. However, it has never been shown directly that a reduction in driving speed does indeed reduce task demands. This was therefore the main question in the second experiment, discussed in Chapter 7: do drivers reduce their speed as an adaptive response to high task demands? The idea behind the experiment was that if reducing speed is a way of decreasing mental task demands, different driving speeds should be associated with different levels of mental effort. Drivers were therefore requested to drive with different speeds. In one condition, drivers were requested to drive as accurately as possible, complying with traffic rules, as if taking a driving test. This was expected to result in a relatively low driving speed. In the other conditions, speed was increased in two ways: in one condition, they were asked to drive as fast as possible without hampering traffic safety. In the last condition, they had to follow a lead car driving at high speed. All conditions were driven twice, once without and once with an additional memory task. It was hypothesised that drivers would neglect this subsidiary task when driving with high speeds.

Experiment 3: Conflict between main goals in driving

The question whether additional information can hamper traffic safety was addressed directly in the last experiment, discussed in Chapter 8. The objective was twofold. The first question concerned the trade-off between conflicting goals at the same level. The main goal
in driving, to arrive safely at the destination, can be divided into two parts: arriving at the
destination, and preventing accidents. A conflict was induced between the two goals of
route finding and collision avoidance. How this goal conflict is solved by drivers is an
important question, also from a traffic safety viewpoint. Drivers were presented with
auditory route guidance messages just prior to an intersection. At the same time, a car from
the left does not observe the priority rules and fails to give way to the participant. It was
expected that handling of the emergency situation would interfere with trying to remember
the route messages. It was hypothesised that the dealing with the emergency would receive
more priority.

Apart from trying to answer the question of how this goal conflict is solved by car drivers,
this experiment also explored the properties of goals and intentions. From the literature on
goals and intentions (Chapter 4), it became clear that there is no consensus regarding the
nature of intentions. They are assumed to have motivational qualities, which render them
relatively resistant to obstructions, but they are also considered declarative structures
subject to decay, for which active maintenance is required to prevent loss of intentions. The
experiment therefore also included conditions in which the emergency with the car from
left occurred after the route guidance messages had been presented. In this way, it could be
tested whether the emergency interfered with the encoding of the messages, or with the
memory or execution of the previously formed intentions. It was expected that if intentions
are remembered as declarative units, an emergency occurring when they are actively
rehearsed, might obstruct the rehearsal process, resulting in route errors.