Searching in Lists While Driving

Identification of Factors Contributing to Driver Workload

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Content

List of tables

List of figures

Summary

More and more in-vehicle systems are rapidly becoming commercially available, making the driving task more and more complex. Driving performance in such multiple-task situations depends primarily on the level of task demands imposed on the driver by certain situations. The higher the perceived task difficulty, the higher the workload level of that individual. But as performance is best under moderate workload levels (Kantowitz & Casper, 1988) and prolonged periods of high workload are experienced as uncomfortable (Hockey, 1986), individuals have to actively influence too high workload levels by investing more effort, adopting less demanding working strategies, or skipping subsidiary tasks.

The aim of this dissertation was therefore to investigate how performance varies in relation to the manipulation of specific primary- and secondary task demands and to isolate high demanding conditions. To investigate possible trade-offs between primary task (driving) and secondary task (searching in a list) performance, the effects of a standardized secondary visual search task on the primary task of driving were evaluated and compared between several conditions. For this purpose, participants had to steer a car (moving at two different velocities) along a track lane (at which they looked on from a bird-eye's perspective), presented on the left of two monitors, while searching for a particular entry in a list, presented on the right of two monitors. In separate conditions, primary task performance, secondary task performance, and subjective workload of the same straight and curved sections were measured under a variety of conditions: in the first three experiments, the effects of the position of an entry in a list, long list lengths, and short list lengths were investigated. The fourth experiment located secondary task controls on the steering-wheel (instead of 15cm to the right of the steering-wheel), and in the last experiment, stimuli of both primary and secondary tasks were merged on one single monitor. Lane deviation as well as errors served as a measure for accuracy regarding primary task performance and secondary task performance respectively. Task completion times and misses (trials that could not be completed correctly in the given time window) served as an overall measure of speed. Subjective measures served the purpose to detect small changes in subjectively experienced task difficulty, caused by variations in primary- and secondary task demands.

According to Kantowitz and Simsek (2001), a key assumption of secondary task methodology is that the primary task is uninfluenced by adding a secondary task. This assumption could not be verified in the current experiments: Even though there was a clear tendency to protect the primary task of driving, participants seemed incapable of fully prioritising the primary task of driving over the secondary search task at all times. As a consequence, lane deviations increased during more demanding situations or situations where participants were not able to extend task completion times to improve primary task accuracy, which was mainly the case during highly demanding road sections (e.g. high curve radii) and when secondary task demands increased rapidly during the last fifth of the searching period. List lengths consisting of less than eight entries had the least negative effect on driving. Furthermore, proximity of the displays improved driving performance to a greater extent than did proximity of controls. This was probably due to the fact that during situations where primary task demands increased quite unexpectedly (e.g. a change of road section) or secondary task demands became quite absorbing (during the last fifth of the search), only an increase in visual proximity could meet the requirement of being able to switch attention back to the driving task fast enough. For more stable changes in task demands, such as driving speed, participants were able to compensate for increasing task demands mainly by increasing secondary task completion times. All results showed remarkably high standard deviation values during high demanding situations, which generally speaks for a wide range of individual differences in both biological capabilities and cognitive and motor skills, as well as in motivational factors towards driving in general or the experimental situation specifically.

To draw conclusions from the preceding findings, it appears that participants were able to compensate for increasing task demands quite well by applying the twin strategies of investing more effort and adopting less demanding working strategies (extending the secondary task duration), at least up to a certain point. From this point, further increases in task demands resulted in increasing lane deviations. There is also evidence for the assumption that drivers continue performing a lower-priority task longer than is optimal, thus missing the point where they would need to switch attention to a higher-priority task again (Jamson & Merat, 2005; Jersild, 1927; Moray, 1986; Rogers & Monsell, 1995; Sheridan, 1972).

Preface

The dissertation is structured the following way: Chapter 1 gives a general introduction of the relevant theoretical issues concerning dual task performance in general and while driving in particular. Chapter 2 describes the general methods applied in the experiments. Here, all methods used in several experiments are described to avoid repetitions later when describing the particular methods of each experiment individually. Chapter 3 describes three experiments conducted to find out more about task demand levels introduced by different set-ups of secondary task design, which are then discussed at the end of the chapter. Chapter 4 describes an experiment which was set up to investigate any effects of positioning the secondary task control closer to the driver and analyses statistical differences between experiments 3 and 4. Chapter 5 describes an experiment conducted to find out more about the effects of increasing display proximity on primary- and secondary task performance and analyses statistical differences between experiments 4 and 5. The description of each of the experiments is organized as follows: a short introduction which describes the experimental goals is followed by a description of the applied methods, the results and a short discussion. Chapter 6 finally summarizes the results of all experiments and discusses participants' reactions to primary- and secondary task demands, as well as their reports about subjective experiences. Furthermore, limitations of the applied methods and directions for future research are discussed here.

Chapter 1: General introduction

Under natural conditions, actions are almost never executed in isolation, but overlap with other actions: we think while walking, we talk while driving, we make phone calls while watching TV. Consequently, the question arises how concurrently executed tasks interfere with each other (e.g. searching in lists while driving). In some cases, it does not matter if the result of concurrently executed actions is not satisfactory, because the action is by its very nature repeatable. For example, if someone becomes distracted while reading a book, he or she can simply read the respective section again. In other situations, an insufficient performance is safety-relevant, as in the case of executing additional tasks while driving. But regardless of the fact that driving is a performance-critical primary task, drivers today engage in a wider and wider variety of secondary tasks through interaction with in-car interfaces, as all manner of new in-vehicle systems are rapidly becoming commercially available, including route guidance systems, collision avoidance systems, automatic lane control, and enhanced convenience and entertainment systems. In principle, intelligent help systems in the future car can help the driver, e.g. with the task of planning a trip, finding the way to the destination, avoiding accidents, and so forth (Alm, Svidén, & Waern, 1997). But these in-vehicle information and communication devices are also changing the nature of the driving task: driving a car is becoming more and more complex as the number and variety of in-car information and communication systems is constantly increasing. Drivers take it for granted that they are able to divide their attention between the primary task of driving and secondary tasks like monitoring information displays (Piechulla et al., 2003).

On the other hand, concerns that new technologies may contribute to driver distraction and inattention are not new. “Indeed, when windshield wipers were first introduced, concerns were raised over their potential hypnotic effects on drivers.” (Harbluk, Noy, & Eizenman, 2002). Nevertheless, drivers need to keep their visual attention to the front to keep the car in its lane and to avoid obstacles, and any looking away from it, whether inside or outside the car, means an increased risk of accident (Wikman, Nieminen, & Summala, 1998). Each second that a driver moving at a velocity of 100 km/h does not concentrate on the ongoing traffic means approximately 28 m of distracted driving (Bloch, 2005). The result could be a delayed reaction to a hazard, or worse, a failure to detect it at all. Late detections of traffic conflicts have been generally cited as causal factors in a large proportion of road traffic crashes (Rumar, 1990). Numerous crash records have reported that the visual attention of the crash-involved driver was focused on controls, displays or mirrors inside the vehicle at the time of the crash (Wierwille & Tijerina, 1996). Although designers intend that these devices improve safety, it is possible that the variety and number of these vehicular enhancements might reduce safety by increasing driver workload (Kantowitz & Simsek, 2001). Thus, it is important to evaluate driver workload in the presence of this new technology and to find out what factors contribute to in-vehicle system distraction and what factors support driving performance. As yet there are not many principles and guidelines available for telematics systems (Hampton & Langham, 2005), to say nothing of regulations or restrictions on the type of equipment that may be installed into road vehicles (see Green, 2001 for an overview of existing guidelines). The existence of principles and guidelines could be potentially beneficial for the telematics industry, but it is important to remember that these documents are in their infancy and their validity has yet to be proven (Hampton & Langham, 2005). Therefore, from a safety perspective, it is helpful to obtain results on possible trade-offs between driving and secondary task performance (Kantowitz & Simsek, 2001) and to find out how future systems should be designed to minimize driver distraction. Solutions like disabling the system whilst the vehicle is in motion would work effectively, but there are situations where users need specific information while driving. Consequences might be that drivers stop their car at dangerous road sections to retrieve certain information or change a destination setting, which might be even more risky than allowing similar interaction with an in-vehicle system while driving. Sometimes the factors contributing to in-vehicle system distraction are quite clear, but technical solutions are not yet available. For example, Vollrath and Totzke (2000) found that when interacting with telematic systems, the level of visual distraction increases as a task changes from auditory, to visual, to manual. But minimizing visual and manual tasks is a solution that is currently not practical because of the technological issues of implementing voice recognition in cars (Murray, 2000; Vollrath & Totzke, 2003) and therefore, visual displays may remain integral components of telematic systems for many years. As processing capacity is not unlimited, operators have to schedule tasks and it is not yet clear what the specific departures from optimal allocation are, or how they are influenced by task properties and environmental goals. One reason why it is hard to isolate certain factors is, as shown in figure 1.1, that there are a large number of different and interacting factors influencing driving performance.

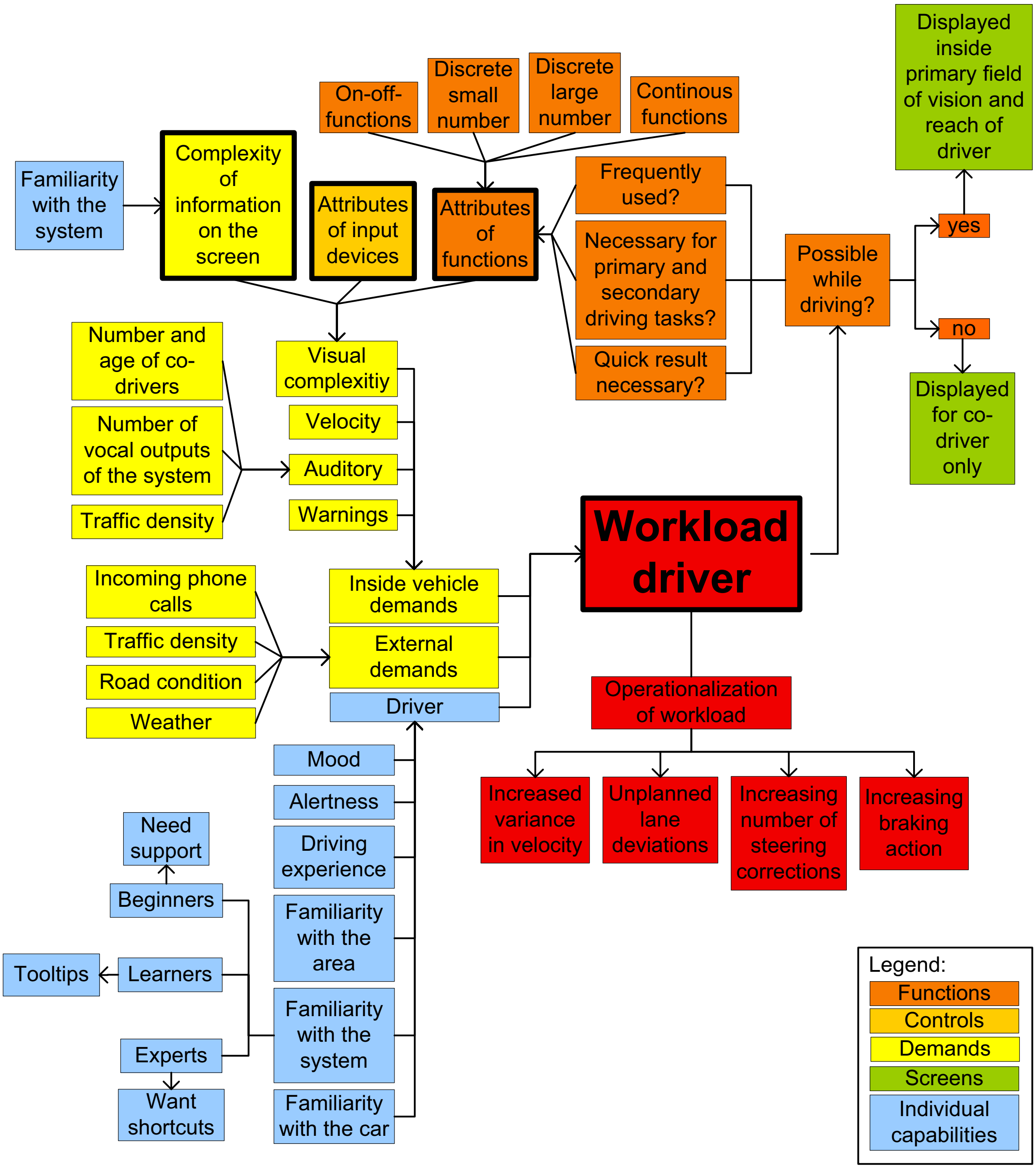


Figure 1.1 Determinants of workload level

Therefore, the goal of this dissertation was to isolate factors contributing to visual and attentional demands when executing a secondary task while driving. As examining all of the above displayed factors would be beyond the scope of a dissertation, some exemplary factors, which are supposed to be of some importance, were selected: First, the effects of different list lengths of a secondary task on driving performance shall be examined, as well as the effects of different control and display locations. Furthermore, the effects of different road appearances (straight section versus curved sections) and speed conditions on driving performance shall be investigated. And finally, the question if a secondary task imposes a constant level of task demand on an operator or if it changes during different stages of the dual task situation shall be answered.

To introduce the most relevant factors contributing to primary- and secondary- task performance in general the first chapter begins with summarizing relevant aspects of research on dual task performance (section 1.1). Section 1.2 then points out reasons for dual task performance decrements. These general criteria are then transmitted to the context of driving, where task demands on the one hand (section 1.3) and driver capability on the other (section 1.4) contribute to a general workload level (section 1.5.1), which can be suboptimal both if it is too high (if task demands far exceed driver capability) and too low (if driver capability far exceeds task demands). In these cases, drivers have to compensate for suboptimal workload levels by applying several different strategies (discussed in section 1.5.2). Section 1.5.3 introduces motivational and emotional factors that moderate driving performance on top or besides driver capability and task demands in both a short-term and a long-term manner. To give an overview of possible strategies to measure workload, section 1.5.4 summarizes common techniques of workload measurement. A section about the general aims of this dissertation (section 1.6) finally concludes the general introduction.

1.1 Determinants of dual task performance

Multiple-task performance is a frequent phenomenon in everyday life: we can easily talk while walking, exercise while watching TV, or cook while listening to the radio. But this is not true for all task configurations. As one obvious example, it is harder to read a book while driving than to eat while watching TV. Therefore, the question arises what factors determine how well two or more tasks can be executed simultaneously. Dual task performance in general depends on many factors, including task similarity (section 1.1.1), task difficulty (section 1.1.2), invested resources (section 1.1.3), efficiency of timesharing (section 1.1.4), and practice (section 1.1.5).

1.1.1 Task similarity and performance

The relevance of task similarity for dual task performance was demonstrated among others by Allport, Antonis and Reynolds (1972) and McLeod (1977). The effects of task similarity on performance can be enhancing (by cooperation) as well as degrading (by confusion). If concurrent tasks require identical processes performed by a certain processor or identical functions subserved by a common structure, this might result in a dual task facilitation. Thus, it is generally easier to perform identical movements with the two hands than different ones (Heuer, 1996a). Tasks that are integrated in one respect – meaning that they are in some way supported by identical or coordinated rather than competing processes – appear to gain more from integration in other respects (Heuer, 1996b). According to Wickens (1991), similarity of information-processing routines between two tasks leads to cooperation and facilitation of dual task performance, whereas differences between these routines lead to interference, confusion, and conflict. In this case, processes relevant for one task are activated by stimuli for a different task, producing confusion or cross-talk between the two – a mechanism labelled as *outcome conflict* by Navon (1984).

A common problem with measuring the effects of task similarity is that it is often hard to measure similarity: how similar are piano playing and poetry writing, and so forth. “Only when there is a better understanding of the processes involved in the performance of such tasks will sensible answers be forthcoming.” (Eysenck M.W. & Keane, 2005).

1.1.2 Task difficulty and performance

Performance on one or more tasks will largely depend on how difficult the task(s) are perceived. It is generally accepted that the same task will prove more difficult to some individuals than to others. Furthermore, the ease with which the same individual performs a given task on different occasions or with increasing practice may vary. Therefore, task difficulty cannot be an independent or absolute attribute of the task itself, driven by task complexity. Rather, it is set up by two major factors: the nature of the task itself (the task demands), including situational conditions under which the task is performed (icy roads for example increase task demands) on the one hand, and the individual capability of the person executing the task on the other. If the driver's capability far exceeds the demands of a complex task, the task is perceived as relatively easy (Fuller, 2005). Similarly, a simple task will be challenging if the demands exceed the driver's available capability (for further information see also chapter 1.4).

According to Kahneman (1973), task difficulty can be assessed by measuring the level of interference with a secondary task. Allport (1980) argues that this interpretation suffers from circular reasoning, as no independent measure of task difficulty would exist if task interference were a function of task difficulty and vice versa. Yet an independent measure of task difficulty "is in itself a rather difficult task" (Gopher D. & Donchin, 1986, p. 41-2), because it cannot be directly observed from its physical description, but has to be derived from the interaction between task and operator (Gopher D. & Donchin, 1986). However, as people often cope with an increase in task difficulty by increasing mental and physical effort devoted to the task (see next section), performance may remain stable nevertheless. Hence, despite a great increase in difficulty, quality of performance is no reliable measure of task difficulty (Gopher D. & Donchin, 1986). But what is generally accepted is that performing two tasks concurrently is more difficult than performing each of the two tasks alone and because engaging in more than one task entails additional demands such as coordination and avoidance of interference, task demands of the dual task situation are not the exact sum of task demands of each of the tasks when executed singularly (Müller & Krummenacher, 2002).

1.1.3 Effort and performance

The term *effort* is used for the mobilization of additional resources as a voluntary compensatory process (Mulder, 1980). Effort reflects the operator's reaction to task demands and the amount of effort being expended is considered to be one of the most important components of mental workload (De Waard, 1996). Therefore, the interaction of experienced task difficulty and performance can be widely influenced by investing more effort or 'trying harder'. Accordingly, the consequence of increasing task demands will be a decrease in performance, unless more resources are supplied to compensate. Furthermore, while investing more effort into a task of constant difficulty will improve its performance, investing more effort will be necessary to maintain a constant level of performance on a task of increasing difficulty (Wickens & Hollands, 2000). This mechanism has been labelled the *Potency Principle* by Kantowitz and Knight, Jr. (1978). On the other hand, by investing more effort performance can only be further increased until either a resource or data limit is reached. A task is said to be resource-limited when performance improves as more resources (effort) are invested and deteriorates as resources deplete. If further effort will lead to no improvement, a task is said to be data-limited (Norman & Bobrow, 1975). Norman and Bobrow (1975) visualized this interdependency of effort, task difficulty, and performance in several performance-resource functions (PRF). Figure 1.2 illustrates the functions of performance due to the amount of invested resources of three tasks A, B and C, with task difficulty decreasing from task A to C.

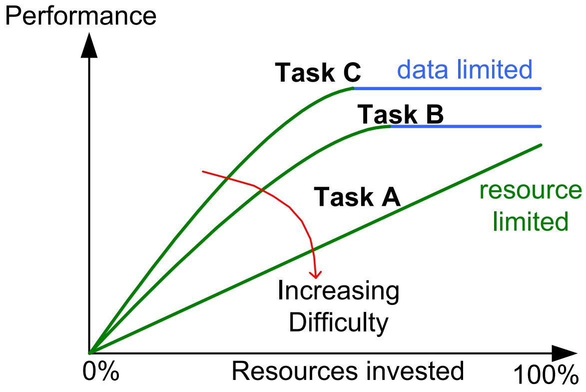


Figure 1.2 Performance-resource-function (source: Müller & Krummenacher, 2002)

Tasks that are heavily data-limited tend to be those that are very easy, highly skilled and/or well-practiced (Wickens, 1991). If a data-limit is reached, performance will simply not improve any further, but if a resource limit is reached, performance on the task will suffer if task demands are further increased, as described in figure 1.3. This phenomenon is called the *difficulty-performance trade-off* (see Wickens, 1980 for a review of literature supporting the phenomenon of difficulty-performance trade-off). For the range of task loading where the operator maintains performance, the operator is assumed to have reserve or spare capacity. A larger budget of reserve capacity is more likely to be associated with sustained performance and increased costs, while a small reserve budget of effort will typically give rise to overt decrements under stress (Hockey, 1997).

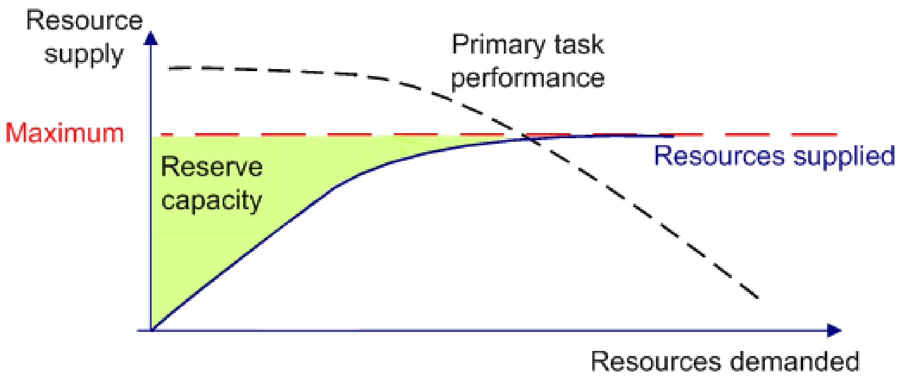


Figure 1.3 Schematic relationship among primary task resource demand, resources supplied, and performance (Source: Wickens & Hollands, 2000)

Mulder (1986) distinguishes between two types of effort: The *compensatory effort* to change current energetical resource states like fatigue or boredom, such as effort to stay alert. *Computational effort*, on the other hand, refers to controlled information processing in order to react to increasing task demands. In contrast, Hockey (1997) postulates only one kind of effort with two separate levels (an upper and a lower set-point), which is of compensatory nature, as the goal of effort management is to control the effectiveness of task behaviour in relation to changing demands. The lower set point of the two-level effort system is therefore a quite stable default for a given task environment (task demand level) and a specific person (level of skill, anticipated resource needs of the task). For more information see also section 1.5.2.1.

1.1.4 Divided attention, timesharing and performance

A further critical factor determining dual task performance is the ability to divide attention between several tasks. Dividing attention becomes necessary whenever dual tasks require physically incompatible actions, such as focussing on two different things. Consequently, the available time has to be split between the different tasks (Heuer, 1996b). Therefore, the concept of switching attention suggests a 'movement metaphor' that it should take longer to shift attention between more distant tasks than more proximate ones. This is of course true when attention is shifted between widely spaced visual sources (Wickens & Hollands, 2000).

According to Kahneman's (1973) theory of *Attention and Effort,* attention can be concentrated on one activity as well as it can be separated between several activities. Consequently divided attention research investigates whether and how attentional resources can, as an act of voluntary control, be shared among multiple loci in sensory space. Wickens (1991) postulated five mechanisms that determine success or failure of timesharing: first, good scheduling of available time; second, efficient switching between activities; third, confusion of task elements (because of their similarity); fourth, cooperation between task processes and finally, competition for task resources. Perfect timesharing accordingly defines a situation in which two tasks are performed concurrently with no decrement, even though each can be shown to interfere with the other activity (e.g., Allport et al., 1972; Shaffer, 1975; Wickens et al., 1983). Difficulties in performing two tasks simultaneously arise when both tasks require a central process of evaluation and response generation, indicated by phenomena such as the *psychological refractory period* (e.g., Heuer, 1996b; Pashler & Johnston, 1998).

While task similarity described a determinant contributing to dual task performance which is an attribute of the task itself, task difficulty introduced a dual task performance determinant which arises out of the interaction of task and operator attributes. Effort and time-sharing skills presented factors determining dual task performance which largely depend on operator motivation and skills. Skills are usually acquired by practice, a determinant discussed in the next section.

1.1.5 Practice and performance

Practice makes perfect, as the saying goes. This is especially true for dual task performance (Eysenck M.W. & Keane, 2005). Accordingly, Spelke et al. (1976, p. 229) state: “Peoples’ ability to develop skills in specialised situations is so great that it may never be possible to define general limits on cognitive capacity“. Contrary to Spelke et al. (1976), Broadbent (1982) has shown that in complex tasks practice in fact decreases dual task interference but does not eliminate it. Nevertheless, practice does improve dual task performance in several ways: first, a person develops new strategies to execute each of the tasks and in this way reduces task interference (Bahrick & Shelly, 1958; Heuer, 1996a, 1996b); second, attentional demands or other resource-demanding processes are reduced with increasing practice; and third, practice enables a more economic operating mode which requires less resources (Eysenck M.W. & Keane, 2005). While controlled information processing is serial, conscious, flexible and requires some degree of effort, automatic processing is fast, unconscious, rigid, requires almost no resources or attention, and can be performed in parallel (Schneider & Shiffrin, 1977; Shiffrin & Schneider, 1977). Accordingly, the experiments of Shaffer (1975), Allport et al. (1972), Hirst et al. (1980), Spelke et al. (1976), McLeod (1977), and Logan (1979) suggest that extensive practice on one task allows it to be performed automatically and this way it will not interfere with, or be affected by another task (Underwood & Everatt, 1996). Furthermore, performance can not only be increased by practicing the involved tasks but also by practicing strategies of optimal task prioritisation. Schneider and Fisk (1982) found that subjects could time-share an automatic and a resource-demanding letter-detection task with perfect efficiency if they received training to allocate their resources away from the automatic task (which required few resources). In the absence of this training, subjects allocated resources in a non-optimal fashion by allocating more resources to the automatic task than it needed, at the expense of the resource-limited task.

Rasmussen (1980; 1986) distinguishes three distinct categories on a continuum of automaticity. First, *skill-based behavior* involves automated schemata, consisting of well-learned procedures, thus enabling a rapid assignment of stimuli to responses in an automatic mode with a minimum investment of resources. Second, in *rule-based behavior* an action is selected by bringing a hierarchy of rules into working memory. After scanning these rules and comparing them with the stimulus conditions, the decision-maker will initiate the appropriate action. Third, *knowledge-based behavior* is invoked when entirely new problems are encountered. In this case neither rules nor automatic mapping exist and a novel plan of action has to be formulated. This might be an explanation for why mental workload imposed by driving diminishes with experience (Moss & Triggs, 1997).

Recapitulating, it can be said that practice improves dual task performance even when the tasks seem to be incompatible. According to Fitts (1966), both speed and accuracy of performance increase as subjects become more practiced at a particular task. But the improvement in performance and decrease of workload is accompanied by the disadvantage that higher levels of automation also might decrease situation awareness (Sarter & Woods, 1995). This can be attributed to a shift from dependence on external stimuli to dependence on internal stimuli with increasing practice and a reduced involvement of consciousness (Bahrick & Shelly, 1958).

To summarize the general determinants of dual task performance, task similarity can both improve and be detrimental to dual task performance. Task difficulty, i.e. certain task demands meeting particular operator capabilities, shapes a great deal of dual task performance, and performance can be generally improved by investing more effort and receiving some practice on the particular task combination. Practice not only improves performance on every task when it is executed alone, but also the ability to divide time and attention between tasks.

1.2 Reasons for dual task performance decrements

As discussed above, high skilled behaviour reduces the amount of effort that has to be invested and even high demanding tasks are perceived as relatively easy and performed at high levels of accuracy and speed. But even for those who receive extensive training (e.g., professional drivers), experiences of cognitive overload from the simultaneous use of in-vehicle navigational and infotainment systems can negatively affect performance and significantly increase driver risk (Ward et al., 2003).

Performance on two concurrent tasks is usually worse than performance on each of the tasks alone. The most important reason for this are structural constraints of the human information processing mechanism (chapter 1.2.1). Other reasons for dual task performance decrements, such as switch costs and distraction (chapter 1.2.2) or speed-accuracy trade-offs (chapter 1.2.3), are to some extent consequences of these structural constraints.

1.2.1 Structural constraints

In order to explain dual task performance decrements caused by structural constraints, the introduction of three basic concepts is required: single-channel models, capacity-sharing models, and multiple-resource models.

In *single-channel models*, the dual task performance decrement is attributed to time-sharing of a single central mechanism (Heuer, 1996b). This central mechanism processes only one stimulus at a time, analogue to the central processing unit of a computer. Consequently, the central entity is committed to one task or the other in an all-or-none fashion. Hence, the entity must be time-shared among tasks: while data from one stimulus are processed, additional stimuli are held in store until they receive access to the central mechanism. Subsequent research has focused on precisely where in the information processing sequence the single-channel bottleneck is located. Pashler (1998), for example, identified the primary bottleneck at the stage of response selection. That is, two independent responses, based on unpredictable stimulus input, cannot be selected at the same time: one or the other must be postponed.

Limited central capacity models share the general assumption of a general-purpose limited capacity central processor (GPLCP). In contrast to single-channel-models, limited capacity models assume a hypothetical central quantity that can be allocated to concurrent actions in a graded manner. Capacity is a hypothetical variable and its relation to performance is specified by the *performance-resource function* (PRF) (Norman & Bobrow, 1975). For dual task performance, capacity is characterized by three assumptions: First, the capacity supplied to the first task and the capacity supplied to the second task add up to the upper limit of capacity (capacity-sharing assumption). Second, the performance level on each task, given a certain amount of capacity supplied, is assumed to be independent of whether it is combined with a concurrent task or not. Third, the allocation of capacity to the two tasks is assumed to be at least partly under voluntary control (Heuer, 1996b, p.123). Kahneman (1973) viewed the amount of resources available at any time as limited, but this limit varies with the level of arousal, according to the inverted U-function, known as *Yerkes-*

Dodson Law (1908), which relates effectiveness of performance to arousal (see section 1.4.1 for more information).

As neither of the preceding theories were able to explain why effective time-sharing and unaffected performance could occur when a second auditory task was added to a primary visual task, Wickens (1984) proposed a *multiple-resource model*, in which different resources for different modalities are assumed. As each of them can be capacity-shared by concurrent tasks, the concurrent execution of two tasks leads to interference to that extent to which they involve similar stimulus and response modalities (visual versus auditory input), require the same processing stages (encoding and central processing vs. response processes), or access the same codes of information processing (spatial vs. verbal). In this case, there is once again the assumption of a performance-resource function, but it is multidimensional rather than two-dimensional. With regard to multiple-resource models, it is the lack of empirical support and the nature of the models that trigger criticism (Navon, 1984). According to Heuer (1996b), there is also no convincing evidence for a competition for different types of resources, as “the available data on performance tradeoffs can all be accommodated by the assumption of a single source such as generalized central capacity.” (Heuer, 1996b, p. 137).

What is common to all of the models is the assumption that almost all tasks make demands on some central entity, and that competition for this entity is a major source of dual task interference. In other words, all models include the idea that there is a finite rate at which humans can process tasks (Moray et al., 1991). Consequences arising from this assumption are described in the following two sections.

1.2.2 Switch costs and limits of divided attention

Every day we engage in several tasks, switching from one to another with little apparent effort (Huey & Wickens, 1993). But this is not true for all task configurations. It matters for example a lot, whether tasks are visual, auditory, spatial, linguistic, perceptual, or action-oriented. Obviously, it is harder (and thus more dangerous) to read a book while driving than to listen to the same book on tape (Huey & Wickens, 1993). Whenever dual tasks require physically incompatible actions (e.g. focussing on two different visual sources), the available time has to be split between the different tasks (Heuer, 1996b). When interacting with an in-car device for example, the user’s concentration is divided between activities related to driving and activities related to interacting with the device. If this interaction requires vision, a timesharing behaviour is exhibited, with the eyes being continuously shifted back and forth between the road and the in-vehicle task. Thus, task switching means ceasing the execution of one task to engage in another task. As a consequence, the task demand of two concurrently executed tasks does usually not equal the sum of task demands of each of the tasks when executed separately, as engaging in more than one task entails additional demands such as coordination and avoidance of interference (Müller & Krummenacher, 2002). This *cost of concurrence* is due to the fact that the task of time sharing itself subtracts resources of both of the tasks (Gopher D. & Navon, 1980). If these additional task demands cannot be met, task switches are associated with certain performance costs, such as time required to switch and errors due to switching. In other words, when resources are in limited supply (see chapter 1.2.1) and these limited resources are divided between two activities, one or both should receive an insufficient supply and performance should suffer (Gopher D., 1986; Wickens, 1991). Accordingly, Sumie et al. (1998) state that the need to share visual input and central processing resources between tasks while driving and concurrently performing a secondary task can degrade performance on one or both tasks.

If in-vehicle tasks requiring vision cause drivers to look less at the road ahead and look more often, for longer periods, and for more varied duration at the in-vehicle display (Victor, Harbluk, & Engström, 2005), the question arises whether drivers are aware of this change and able to react adequately. According to Piechulla et al. (2003), drivers usually are aware of the risk caused by glances away from the road and keep them short, typically around 1.6 seconds (Rockwell, 1988; Wikman et al., 1998). Correspondingly, Victor, Harbluk and Engström (2005) found that in general, drivers increase viewing time in the central road area when demands increase.

Jersild (1927), Sheridan (1972) Moray (1986), Rogers and Monsell (1995), and Jamson and Merat (2005), on the other hand, found that there is a cost for switching between tasks, and that there is a tendency to continue performing a lower-priority task longer than is optimal when the need to perform a higher-priority task arises. Tijerina et al. (1998) compared performance of destination entry with four commercially available navigation systems and found that eyes-off-the-road time was about two thirds to three fourths of the total task time when the entry was manual. But even with voice entry, participants tended to look towards the speaker of microphone and about one third of the total task time was spent looking away from the road. Consequently, in-vehicle tasks that require long eyes-off-the-road time degrade driving performance (for a review see Green, 1998). Vehicle crashes, a consequence of degraded driving performance, might be the result. Indeed, numerous crash records have reported that the visual attention of the crash-involved driver was focused on controls, displays or mirrors inside the vehicle at the time of the crash (Wierwille & Tijerina, 1996). In addition, Rumar (1990) states that late detection of traffic conflicts due to driver attention problems have been generally cited as causal factors in a large proportion of road traffic crashes. Thus, the limits of divided attention sometimes refer to our limited ability to time-share the performance of two or more concurrent tasks, and sometimes refer to the limits in integrating multiple information sources. Given the limitations of human memory, vision, physical strength, and so forth, some tasks may stretch or even exceed an operator's capacities, while other tasks impose so few demands that they may be performed concurrently with other tasks (Huey & Wickens, 1993).

1.2.3 Speed-accuracy trade-off

Switch costs not only refer to overlook or ignore certain information, they also include a trade-off between speed and accuracy of task performance which cannot be maximized at the same time when task demands increase. Task completion time (speed) and error rate (accuracy) represent two dimensions of the efficiency of processing information. In speeded performance people often make errors, and they tend to make more errors when they try to respond more rapidly. This reciprocity between time and errors is referred to as the *speed-accuracy trade-off*. Forcing the operator to commit no errors, on the other hand, could induce impossibly long task duration times, as with increasing accuracy very small changes in accuracy generate very large differences in latency, as shown in figure 1.4.

In other words, the general finding is that faster movements are made with less accuracy, and more precise movements are made more slowly. This relationship is described by a mathematical model known as Fitt´s Law (1954) and has been proven to be extremely robust (Keele, 1986) for a wide range of target types, system dynamics (e.g., displacement of the joystick controlling cursor position or velocity), control devices (e.g., computer mouse, joystick, rotary knob), and displays (e.g., computer screen, direct view of nearby or distant target) (Huey & Wickens, 1993).

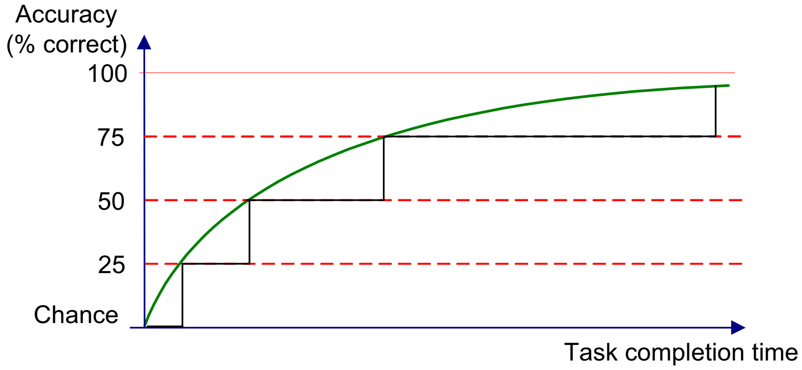


Figure 1.4 The speed-accuracy operating characteristic (source: Wickens & Hollands, 2000)

Consequently, the most important and most challenging aspect of the speed-accuracy trade-off is the ability to decide what is ‘best’ in the current situation, as some situations require rather fast responses, whereas others require rather accurate ones (for further information see chapter 1.4.2.3). According to Knight and Kantowitz (1974), participants were able to shift the form of limitation in such a way as to minimize its impact on task performance criteria. Thus, when errors were costly, only latency was affected.

Summarizing the preceding section, there are three models explaining dual task performance decrements due to structural constraints. Both single channel models and models of limited generalized central capacity explain dual task performance decrements in terms of competition for limited generalized central capacity. According to the multiple-resource model, concurrent execution of two tasks leads to interference to the extent to which they involve similar stimulus and response modalities, require the same processing stages, or access the same codes of information processing. When resources are in limited supply (an assumption which is shared by all of the models) and these limited resources are divided between two activities, one or both should receive an insufficient supply and their performance should suffer. These switch costs usually result in either decreased accuracy or increased error rate.

1.3 Task demands and driving performance

Having introduced general determinants of dual task performance and more general reasons for decrements of dual task performance, the following sections will outline these factors within the more special context of driving. First of all, the issues of task demands and driver capability shall be introduced, as they are the main determinants for how difficult an operator perceives a task. Because task demands are determined by the goal that has to be attained by means of task performance, they are – once the goal has been set – external and independent of the individual (De Waard, 1996). Increasing task demands or task complexity refers to an increase in the number of processing stages that are required to perform a specific task. Task difficulty, on the other hand, refers to the amount of resources that are required by a specific individual to perform a task. Therefore, Kantowitz (1987) has defined task complexity as a property of the task in isolation, drawing a clear dividing line from task difficulty, which is, as mentioned above, defined as the interaction between task demand and individual capability. This distinction is also shared by many other authors (e.g., Fuller, 2005; Gopher D. & Donchin, 1986; O'Donnel & Eggemeier, 1986). Therefore, in the following chapters the term *task demand* shall be used to describe the complexity of the task itself, while the term *task difficulty*, on the other hand, shall be used to refer to the complexity of a task in relation to the individual capabilities of the operator.

Factors such as visibility, road alignment, road surfaces, and curve radii contribute to driving task demands (section 1.3.1), and attributes of the in-vehicle system contribute to in-vehicle system task demands (section 1.3.2). Factors contributing to in-vehicle task demands are concerning the design of lists and menu structures (section 1.3.2.1), as well as attributes of secondary-task controls and displays (section 1.3.2.2).

1.3.1 Driving task demands

Driving task demands are determined by a host of interacting elements (Fuller, 2005). If a roadway is narrow, winding, or otherwise difficult to drive, then attentional demand of driving increases (Wierwille et al., 1991). Therefore, environmental factors such as visibility, road alignment, road marking, road signs, road surfaces and curve radii contribute to driving task demands and hence to an overall workload level (for more information see section 1.5). Environmental task demands can change both gradually or suddenly. For example, a road going up a mountain might narrow as the journey proceeds with an increase in curve radii. A blizzard, on the other hand, might change a road surface within seconds. Specific behaviour patterns of other road users might also change task demands in a sudden and unpredictable manner. Last but not least, the driver him- or herself might change task demands, e.g. by increasing the speed of the vehicle, or decreasing the distance to the leading car, etc.

1.3.2 In-vehicle system task demands

In-vehicle task demands rely heavily on how secondary task information is presented. The longer people have to avert their gaze from the road, the higher the risk of running into dangerous situations due to not having monitored the ongoing traffic. Consequently, the risk of accidents increases as well, as the stress induced by such emergency conditions sometimes leads to a speed-accuracy trade-off such that operators are forced to take rapid but not always appropriate actions. Factors contributing to the time operators divert their gaze from the road are mainly the structure of secondary task content (section 1.3.2.1) and the quality and location of how the information is displayed and controlled (section 1.3.2.2).

1.3.2.1 Design of lists and menu structure

Among the various methods designed to facilitate human-machine interaction, menu-driven interfaces have received an immense amount of use. In a typical menu task, the user must scan and scroll down a list until the target item, word, symbol, or command is located, and then press a key. According to Drury and Clement (1978) and Treisman and Gelade (1980), the number of elements to be searched has a dominant effect on search time. In other words, the architecture of a menu structure influences the complexity of a system, as in a hierarchical structure with many levels the user not only has to recognize the meaning of the options but also has to recall how to access each option (Paap & Roske-Hofstrand, 1986). Consequently, a menu should be structured in such a way that target items are reached in the minimum average time. But as the number of alternatives from which an operator must make a selection increases, the time required to respond correctly generally increases as well. At the same time, drivers are confronted with more and more information to be dealt with by in-vehicle systems. Fadier and de la Garza (2006) describe a tendency to compensate for the complexity of a system by an increasing use of procedures, instructions, safety and control systems, thus making the system even more intransparent for the user. The challenge is therefore to structure menus despite their huge amount of information in a way that requires the minimum amount of time. As it is always difficult in the product's initial design stage to assess how the system will be handled in a real-life situation, several methods have been developed to anticipate future interactions with a system, e.g. usability tests at different stages of the engineering process of a product. But these methods cannot be applied until development process has advanced to a certain point where designs of surfaces and interactions have already been implemented in some kind of prototype or simulation. Therefore it is important to find out more about general demands imposed by different designs of menu structures. As a first step, the question arises of how many alternatives to place on a menu page. The topic of how to structure menus is described in more detail in section 3.1.

1.3.2.2 Display and control of information

Quality of performance also depends on the physical characteristics and dynamics of the display and the associated control devices of an in-vehicle system. Several interacting factors contribute to in-vehicle task demands with regard to displays and control devices: the number of axes controlled; the availability of predictability and preview; the required precision; stimulus response compatibility; organization and functional grouping of information, and many more. If a display content is very complex, for example, it may require the operator's attention for an inordinate amount of time to extract relevant data (Nowakowski C., Utsui, Y., & Green, P., 2000). The same is true for display texts that are difficult to read. Text size legibility is governed by both the character height on the display and the viewing distance. Readability in general is also governed by the visual angle at which a user is looking at the display. Because the quality, format, and content of displays vary, the perceptual demands their use imposes on the driver vary as well. However, not only the format of the display itself imposes perceptual demands on the driver, the location of the displayed information (of whatever quality) contributes as well a great deal to distraction from the primary task of driving. To minimize switching distances between two objects of visual attention, head-up displays (HUD) have been introduced into the modern automobile. A HUD describes a display where the display elements are largely transparent, meaning the information is displayed in contrasting superposition over the user's normal environment. Furthermore, the information is projected with its focus at infinity. The benefit of this technology is that users neither need to move their heads nor refocus their eyes when switching attention between the instrument and the outside world, thus decreasing eyes-off-the-road and accommodation time.

As the relevant information of an in-vehicle system is usually not only displayed to the driver but also has to be adjusted, switched, stored, etc., drivers have to interact with the system by some kind of input device or control. The most important consideration for a control is its accessibility: Controls should be located within easy reach distance to the driver. Conventional in-vehicle controls are located on the centre console and are fairly easily visible, but the reach distance can be rather large. For this reason, many car manufacturers have begun to locate secondary task controls, e.g. controls of radio volume and tuning, on the steering-wheel. Not only reaching distances have a role to play, however: Changes induced by controls on the display should match the operator's expectations, which might be individually different, depending for example on the level of experience a user has (Hollands & Merikle, 1987). As a consequence, poorly designed controls, high-order system dynamics, inadequate displays, and incompatible controls and displays may make it difficult for an operator to accomplish even relatively easy tasks (Huey & Wickens, 1993). The topic of how to display and control information is discussed in more detail in chapters 4.1 and 5.1.

Recapitulating, there are several factors contributing to driving task demands, such as road and weather conditions, as well as the driving behaviour of other road participants. In-vehicle task demands on the other hand are driven by several interacting factors. Of some importance is the complexity of the information presented, as well as attributes of the displays presenting the relevant information and the controls used to manipulate the displayed information.

1.4 Capability of the driver and driving performance

As the same task will prove more difficult to one individual than to another, task demands must always be examined alongside the capability of the driver. Only the dynamic interaction of both factors determines subjectively perceived task difficulty, which again determines workload level (see chapter 1.5) and hence driving performance to a great extent.

Driver capability is constrained by the biological characteristics of the driver, such as information processing capacity and speed, reaction time, motor coordination or flexibility and strength (section 1.4.1). In addition to these characteristics, knowledge (e.g. about traffic regulations, road conditions of the current route, etc.) and skills – both control skills associated with basic vehicle control and handling skills in challenging circumstances (e.g. how to react when going into a skid) – arising from training and experience also have a role to play (section 1.4.2). A combination of biological characteristics, knowledge and skills determines the upper limit of competence of the driver and therefore constitutes underlying individual differences.

1.4.1 Biological factors

The capability of different drivers attributable to biological factors can vary both between different drivers (e.g. processing capacity and speed, reaction time, physical reach, motor coordination, strength, etc.) and within the same driver at different times (e.g. processing speed, reaction time, etc.). Due to the fact that biological factors were not subject of investigation in this dissertation, only some examples shall be mentioned at this point.

First, psychomotor and cognitive performance vary as a function of daytime due to *circadian rhythms* which refer to spontaneous rhythmic fluctuations of all bodily processes. Second, Lindenberger et al. (2000) have argued that sensory and motor processes require increasing levels of cognitive control as *age* advances, which might result in prolonged periods of higher workload. However, age is usually confounded with experience, and experience compensates some of the biological deficiencies which occur with increasing age. Third, a general impairment of driving performance is the rule when *drugs*, *alcohol*, and certain *medication* come into play. The last example for possible biological factors, *level of arousal*, shall be described in more detail as the level of arousal is closely related to workload. It is generally accepted that there is an optimal arousal level or range, both for sustaining performance and as being rewarding to the individual (Fuller, 2005). The relationship between capability and arousal is traditionally described by an inverted U-curve (see figure 1.5), with both very low and very high levels of arousal associated with rather low levels of capability, related to as the *Yerkes-Dodson Law* (Yerkes & Dodson, 1908).

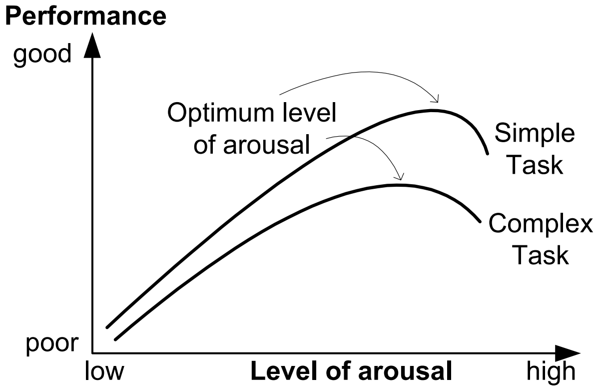


Figure 1.5 Yerkes-Dodson law (source: Wickens & Hollands, 2000)

The upward limb appears to result from an energizing process, which simply expands the amount of cognitive effort or resources mobilized for task performance. In contrast, the downward limb is the consequence of a more specific effect of high arousal on the selectivity of attention, which causes the operator to focus on a more restricted set of environmental or internal sources of information (Kahneman, 1973). While most stressors (e.g. noise) are thought to increase the level of arousal, others like sleep deprivation or fatigue will decrease it (Wickens & Hollands, 2000).

1.4.2 Knowledge and skills

Biological factors define in a manner of speaking the upper limit of performance. Up to this individually different limit, individually different levels of knowledge and skills are responsible for the fact that performance differs, not only between various people but also within one person at different times. The following section outlines some examples of knowledge and skills relevant to driving performance, such as practice (section 1.4.2.1), time-sharing skills (section 1.4.2.2), task priority management (section 1.4.2.3), situation awareness (section 1.4.2.4) and perceptual-motor skills (section 1.4.2.5).

1.4.2.1 Level of practice and experience

There are many examples proving differences in driving capability between novice and expert drivers. One is that learner drivers find it almost impossible to drive and hold a conversation, whereas expert drivers often find it fairly easy. Another example is the act of changing gear which can – after practice – occur without attending to it, and while other acts, or processes, occur at the same time (except physically incompatible actions). But it is not only the interference between tasks that is reduced with practice, also the perception and interpretation of environmental cues changes with experience. Accordingly, unexperienced drivers typically underestimate risk in comparison with more experienced drivers, and make speed regulations less as a function of critical cues in driving situations (Delhomme & Meyer, 1998; Finn & Bragg, 1986). In addition, in a study by Grayson et al. (2003), less experienced drivers had the highest levels of speed consistency across different road types, which suggests a lack of differentiation between them. Furthermore, Taylor (1964) showed that the galvanic skin response expressed as a rate per unit time was negatively correlated with driving experience. While Taylor argued that less experienced drivers must have perceived more risk than the more experienced ones, Fuller (2005) suggests that the less experienced drivers simply found the task of driving under the same conditions more difficult. This finding might go along with the fact that inexperienced drivers are more reactive in dealing with hazards, whereas experienced drivers are more likely to show anticipatory avoidance of a hazard by changing speed, direction, or focus of attention (Brown & Groeger, 1988; Quimby & Watts, 1981). Accordingly, Grayson et al. (2003) postulate that drivers differ in accident liability because they differ in their abilities to detect and recognize potential hazards, and in their abilities to respond appropriately to those hazards. One reason might be that such anticipatory processing is only possible if there is enough reserve capacity to do so. Another reason is probably that novice drivers have not yet experienced enough possible scenarios to anticipate potential outcomes of different situations.

There are several possible explanations why experienced drivers have more capacity at their permanent disposal: First, experienced drivers do not have to process the same amount of information, as they have procedural knowledge defining what to do under what circumstances and a representation of the dynamics of road and traffic scenarios, which enable a more detailed prediction of how particular scenarios will develop (Kaempf & Klein, 1994). Second, drivers familiar with a vehicle perform secondary tasks quite differently from unfamiliar drivers: the location of in-vehicle controls, for example, is retrieved from memory instead of being visually acquired, as experienced drivers rely much more on tactile feedback than looking at the control for final guidance of their hand. As a consequence, they avert their gaze from the road less frequently. Moreover, active planning of the movement to the control may be minimal, with the driver instead relying upon a stored motor program (Sumie et al., 1998). Hence, experienced drivers need less time to execute a secondary task. Another factor cutting down the duration of a dual task situation is the ability to time-share attention between two tasks which shall be discussed in the next section.

1.4.2.2 Time-sharing skills

Driving entails numerous cognitive processes, such as response selection, memory, and planning. Each of them demands attention. As humans cannot attend to all of these processes simultaneously, drivers must rapidly shift their attention from one set of processes to another. Accordingly, attention switching can be regarded as a critical aspect of the driving task, as drivers must continually shift their attention from one spatial location to another (Moss & Triggs, 1997), including reading the instrument panel or a road sign, looking over one’s shoulder to prepare for a lane change, and several more. The way operators organize their time and resources to perform these tasks has a significant impact on the workload experienced and performance achieved (Huey & Wickens, 1993). In turn, workload has an impact on switching times. Weber et al. (1986) showed that a rise in mental workload prolongs switching time. Accordingly, Kahneman et al. (1973) found a significant positive correlation between switching time and accident rate. Gopher (1982) also found that individual differences in the speed of switching between two auditory channels provides a valid predictor of differences in performing complex skills, such as those found in bus driving and aviation. To date, however, such timesharing skills have not been clearly isolated, identified, or examined (Damos & Wickens, 1980). The view that strategies in allocating and switching attention contribute to improved time-sharing performance and develop with practice is held by Kahneman et al. (1973), Gopher, Weil, and Siegel (1989), Gopher (1991), Gopher, Weil, and Bareket (1994), and Kramer, Larish, and Strayer (1995). Conversely, in a study by Moss and Triggs (1997), switching time while operating a vehicle did not vary with driving experience and was independent of road-element type. Additionally, Heuer (1996b) argues that there is little formal evidence on the development of time-sharing skills – with one exception, which is the optimization of time-sharing in monitoring several displays (Moray, 1986). Time-sharing skills in any case rely heavily on the capability to prioritize tasks adequately.

1.4.2.3 Task priority management

Under high task demands, drivers may not be able to perform all tasks simultaneously, but have to drop certain tasks as a consequence: “Attention implies withdrawal from some things in order to deal effectively with others“ (James, 1890/1950, p. 403-404). A disastrous example of when such withdrawal of attention failed in order to deal effectively with a more important task is the Eastern Airlines L1011 crash into the Everglades in 1972, where the flight crew, preoccupied with a landing gear problem, failed to monitor their altitude (NTSB, 1973). All three crew members and a jump seat occupant became totally absorbed in the diagnosis task. According to Granda et al. (1991), significant altitude deviations resulting from task neglect are a major concern in the aviation industry because of their growing frequency of occurrence. Consequently, distraction not only describes a lack of attention but also the act of attending to something irrelevant with the result of an impaired capacity to process relevant information (Rumar, 1990). Therefore, effective task performance involves selecting relevant information while ignoring irrelevant information. But how appropriate is human behaviour in selecting which task to do when?

Different components of a complex task have different functional priority with respect to the overall goals or temporal limits. One task can be highly relevant in one situation and inappropriate in another, and thus, the driving context determines to a large extent the priority of a certain task. According to Funk (cited from Chou, Madhavan, & Funk, 1996, p. 308), strategic task management involves several components. First, the initiation of tasks when appropriate conditions exist – the speed with which activities can be initiated depends on the degree of automaticity in that specific task and the degree of possible alternatives. Second, the assessment of task progress and status (task monitoring). Third, the assignment of priorities to tasks relative to their importance and urgency for the safe completion of the mission (task prioritization). Fourth, the assignment of human and machine resources to tasks so that they may be completed. Fifth, the temporary suspension of lower priority tasks, so that resources may be allocated to higher priority tasks, and the resumption of interrupted tasks when priorities change or resources become available. And finally, the termination of tasks that have been completed, that cannot be completed, or that are no longer relevant. Actions usually can be stopped rapidly, although under high stress there may be a tendency to inhibit action stopping or switching, i.e., in high stress situations, activities may persist longer than they should (Huey & Wickens, 1993).

Task priority management therefore makes the assumption that the optimal task manager will process a mental priority scale that can provide the basis for appropriately shedding tasks when workload becomes excessive, so that the operator can address high-priority tasks before those of lower priority. There appears to be little data, however, to indicate the effectiveness of subjective priority in driving task management in operational environments (Huey & Wickens, 1993). In a study by Cnossen et al. (2000), however, car drivers were found to reduce their driving speed only when primary task demands increased. Increases in secondary task demands resulted instead in skipping the subsidiary task when task demands increased beyond capability or motivation of the participants. Cnossen et al. (2000) consequently argue that drivers prioritise their tasks with respect to the main task goal, which is to arrive safely at the destination. Therefore, tasks that serve the driving task directly (e.g. route guidance system information) will receive higher priority from drivers than tasks that are less important to the driving task (Cnossen, Meijman, & Rothengatter, 2004), such as changing the radio channel for example. Wierwille et al. (1991) found that drivers did adapt to high anticipated attentional demand by increasing the proportion of time spent looking at driving-related visual areas, while decreasing the proportion of time spent observing the navigation display by about the same amount. Contrary to these findings, Moray (1986), Jersild (1927), Sheridan (1972), Rogers and Monsell (1995), and Jamson and Merat (2005) reported a tendency to continue performing a lower-priority task longer than is optimal if the need to perform a higher-priority task arises. Similarly, Dingus et al. (1997) found that drivers had more unplanned lane deviations when driving with a complex route guidance system due to inappropriately long glances at the displays. Cnossen et al. (2004) reported similar effects: even when participants had already reduced their driving speed to counteract the negative effect of map reading, they still swerved more. Jameson and Merat (2005) found that participants seemed incapable of fully prioritising the primary driving task over either a visual or cognitive secondary task.

As different components of a task may have different functional priority with changing situational contexts, one task can suddenly become highly relevant in a certain situation. Therefore, effective task management depends highly on an optimal situation awareness. Knowing what tasks are currently in the queue that need to be done (Huey & Wickens, 1993) is crucial for prioritizing the currently most important task. Therefore the next paragraph will deal with situation awareness.

1.4.2.4 Situation awareness

In a road environment there is an enormous influx of visual information, and attracting attention to driving-relevant objects is considered to be crucial, since failure to identify these objects precludes the operation of any of the processes that take place following object detection like estimation of the speed of the leading vehicle and adjustment of own speed (Theeuwes, 1991). Endsley (1995) describes situation awareness as having three hierarchical phases: the first is to perceive the status, attributes, and dynamics in the environment. Only those drivers who are aware of the surrounding traffic and the current state of in-vehicle systems are able to prioritise tasks accordingly. The second phase goes beyond simply being aware of the elements and includes the comprehension of the significance of objects and events in the current situation. “Directing attention to the appropriate aspects of the environment depends on both an understanding of the system and the physical characteristics of the environment.” (Durso & Gronlund, 1999, p. 289). The third phase is formed by the ability to project the future actions of the elements in the environment. Thus, situation awareness includes comprehending the meaning of perceived information, comparing it with operator goals, and providing projected future states of the environment that are valuable for decision making. Crundall, Underwood, and Chapman (1999), for example, showed that hazardous events redirect attention away from extra-foveal regions of the functional field of view toward the hazard at the point of fixation.

Acquiring and maintaining situation awareness becomes increasingly difficult as the complexity and dynamics of the environment increase (Endsley, 1995). Because our awareness of an evolving situation resides mostly in working memory, it degrades as resources are reallocated to competing tasks (Wickens & Hollands, 2000).

Summa summarum operators must do more than simply perceive the state of their environment; they must understand the integrated meaning of what they are perceiving in the light of their goals. Situation awareness therefore incorporates an operator’s understanding of the situation as a whole, forming a basis for decision making (Endsley, 1995).

1.4.2.5 Perceptual-motor skills

A good driving performance can only be achieved if the appropriate motor action is executed at the correct time. “Of all the skills demanded by contemporary civilization, the one of driving an automobile is certainly the most important to the individual, in the sense at least that a defect in it is the greatest threat to his life” (Gibson & Crooks, 1938, p. 453). Following other vehicles without colliding, braking and speed control, as well as the interrelationship between steering control and gaze direction, are important actions to ensure a safe arrival at the destination. As braking or following other cars were not subject of investigation in this dissertation or part of the following experiments only the topic of steering control and gaze will be addressed in the following paragraph.

Most steering-control models are based on the assumption that the “automobile driver acts as an error-correcting mechanism with permanent attention allocated to the steering task” (Godthelp, 1986, p. 211). However, as a consequence of the need to coordinate many tasks during driving (e.g., reading the instrument panel or a road sign or looking over one’s shoulder to prepare for a lane change), human steering control cannot rely on the availability of a rich and continuous stream of visual input to guide steering at every moment (Hildreth et al., 2000). Rather, it seems more likely that two processes combine to allow drivers to accurately guide their vehicles through curves (e.g., Donges, 1978; Reid L.D., 1983). The first is a “long-range process, which relies on preview and prediction of the curvature of upcoming sections of the road, perhaps allowing the establishment or activation of some pattern of likely future gross steering movement requirements” (Groeger, 2000, p.48). The second is a “short-range process, which operates in a corrective fashion, allowing the driver to modify slightly the current heading as a function of proximity to the road edge” (Groeger, 2000, p. 49). These processes operate serially rather than in parallel, and anticipatory movement is being made in the time available before a short-range correction is possible (Godthelp, 1986). Once the driver has entered the curve, the visual demand of maintaining lateral position within the lane boundaries is a linear function of the curvature of the road (Tsimhoni & Green, 1999). Thus, a controlled increase in the visual demand of driving can be attained.

To summarize the preceding sections, the upper limit of driver capability is set by their biological constitution, resulting in different reaction times, processing capacities, motor coordination, levels of strength, etc. Up to this limit, however, the level of knowledge and skills on a variety of category groups accounts for individual differences in driving performance. First of all, practice is necessary to develop all kinds of skills by deploying automated schemata, consisting of well-learned procedures, and thus decreasing dual task interference. But in addition practice enables drivers to develop situation awareness, thus being able to detect and recognize potential hazards, in order to estimate risks more adequately and to predict more accurately how the perceived scene will develop. Practice also influences the way operators organize their time and resources to perform multiple tasks, in other words their time-sharing skills. This is because one basic requirement for time-sharing skills is an optimal management of task priorities which again develops with practice. And above all, the individual fitness to drive relies heavily on overall perceptual and motor skills required for a satisfying driving performance.

1.5 Workload level and driving performance

Driving performance is – like every other multiple-task performance – determined by the overall level of workload of the driver. For this reason the term workload has to be defined in a first step (section 1.5.1). As performance is usually best under moderate workload levels, section 1.5.2. introduces several strategies which can be adopted to compensate for suboptimal workload levels. To which extent and efficiency these strategies are executed relies heavily on the current motivational and emotional state of the driver, as well as on their general attitudes towards driving (section 1.5.3). Finally section 1.5.4 introduces several methods of mental workload assessment.

1.5.1 Workload – possible definitions

“The concept of workload is examined, attempts at a definition are made, and the usual conclusion is that workload is a multidimensional, multifaceted concept that is difficult to define.” (Gopher D. & Donchin, 1986). Although or even because the term ‘workload’ has intuitive meaning for most people, the word *workload* did not appear in many dictionaries until the 1970s; and operational definitions proposed by psychologists and engineers continue to disagree about its source(s), mechanism(s), consequence(s), and measurement, but thus far, the following assumptions have been made (Huey & Wickens, 1993):

1) If the difficulty, number, rate, or complexity of the demands imposed on an operator are increased, workload is assumed to increase.
2) If errors increase or control precision degrades, workload is assumed to increase.
3) Workload reflects an operator's response to a task, rather than task demands directly.
4) If an operator feels effortful and loaded, then workload has increased even though task demands or performance have not changed.

Kahneman (1973), for example, defines mental workload as being a specification of the capacity an operator spends on task performance. Kantowitz (1988) speaks of workload as an intervening variable that cannot be directly observed but must be inferred from changes in performance and that modulates the tuning between the demands of the environment and the capabilities of the organism (Kantowitz & Simsek, 2001, p. 396). Brookhuis and de Waard (2001) define mental workload as the proportion of mental capacity that is required for task performance, determined by the interaction between the capability of the driver and the task itself, a definition which has also been suggested by O´Donnell and Eggemeier (1986). According to Gopher and Donchin (1986), workload is a label assigned to the interactive feature of task demands, the operator's overall capability (set up by biological factors and skills) and present motivational and emotional state.

Recapitulating, the interrelationship between, task demands, driver capability, and workload can be described as the following: if the driver's capability far exceeds the demands of a task, the task is perceived as relatively easy and the workload level remains rather low. Similarly, a task will be experienced as rather challenging if task demands exceed the driver's capability and workload level is increasing.

1.5.2 Compensation of suboptimal workload levels

It can generally be assumed that human performance is most reliable under moderate workload that does not change suddenly or unpredictably (Kantowitz & Casper, 1988). When workload level is too low, errors may arise from a loss of vigilance and boredom. This is the case whenever driver capability far exceeds task demands and the task is experienced as easy, or boring. According to Welford (1965), boredom is a result of a requirement to maintain attention in the absence of relevant task information, thus describing the consequences of prolonged periods of low workload. Deficient performance has also often been observed in monotonous tasks that continue without interruption for an hour or more (O'Hanlon, 1981). Thackray, Bailey, and Touchstone (1977) found that participants who had experienced high levels of boredom during a simulated air-traffic control task showed a decrement in attention over the 60-minute work period, whereas those who reported being least bored during the task showed no such decrement. For the same reason, Moss and Triggs (1997) found that switching time was faster in a dual task condition relative to a single task condition. The authors explain this finding with a rise in mental workload (and arousal) in the dual task situation to an extent where it was improving performance rather than impairing it. A finding which would have also been predicted by the Yerkes-Dodson law (1908).

When workload is too high, on the other hand, errors arise from an operator’s inability to cope with critical task demands. In these situations operators will have to invest more effort, restructure task management strategies, or accept losses in performance. The maintenance of performance stability under such demanding conditions is an active process under the control of the individual, requiring the management of cognitive resources through the mobilisation of mental effort (Hockey, 1997). Fatigue is then the consequence of continuously high levels of information load (Welford, 1965). Whereas boredom can become apparent within minutes of the onset of a monotonous task (O'Hanlon, 1981), fatigue is typically a product of hours of continuous work. Hence, both too low and too high workload levels are suboptimal and may cause decrements in performance, as shown in figure 1.6.

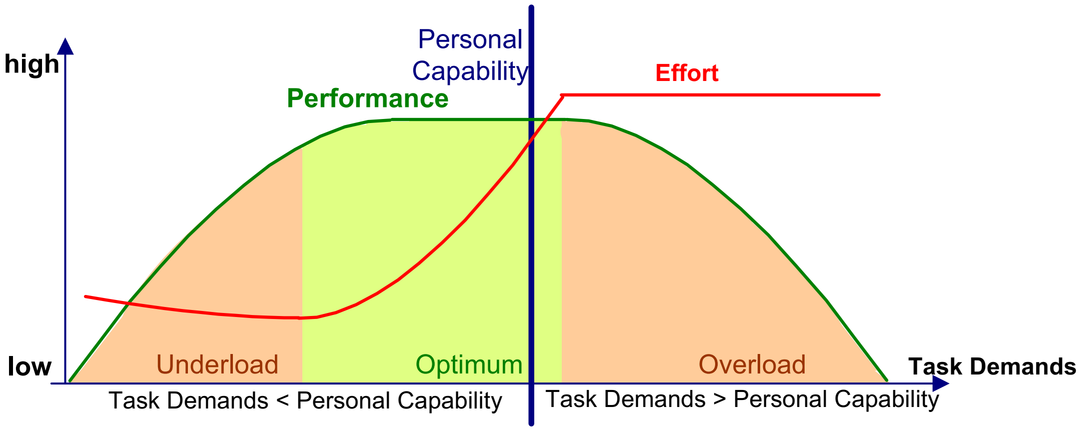


Figure 1.6 Relationship between task demands, personal capability and workload

Therefore, behavioural adaptations to different workload levels become necessary to keep workload level as close as possible to an optimum: “Given some flexibility, operators usually work homeostatically to achieve an ‘optimal level’ of workload by seeking tasks when workload is low and shedding them when workload is excessive” (Wickens & Hollands, 2000, p. 470). Other theories speak of behavioural adaptation of suboptimal levels of risk (Wilde, 1982), task difficulty (Fuller, 2005), arousal (Taylor, 1964), or safety margins (Summala, 1996). But the consequence is in all theories a suboptimal level of workload or arousal. Summala (1996, p.112) states that “whenever we cannot readily keep within our safety margin thresholds we feel our task is overloaded…”. Fuller even equates the concepts of task difficulty and workload homeostasis: “The concept of task difficulty or workload homeostasis…” (Fuller, 2005, p.467).

Summarizing, it is generally assumed that operators deal actively with task demands in complex hierarchical tasks. In order to compensate for high task demands, operators can either invest more effort in the task (section 1.3.2.1), adopt less demanding strategies that involve fewer manipulations of information or less use of working memory (section 1.3.2.2), or skip subsidiary tasks that are not essential for achieving the main task goal (section 1.3.2.3). In the latter cases, the desired level of accuracy or speed might be decreased.

1.5.2.1 Investing more effort

While investing more effort will improve performance on a task of fixed difficulty, investing more effort will be necessary to maintain a constant level of performance on a task of increasing difficulty (Wickens, 1991). “To maintain speed when the road standard (e.g. width) decreases we have to put more effort into the task…” (Summala, 1996). Maintaining performance under high effort, however, is associated with a significant cost in terms of discomfort and sustained sympathetic activation (Hockey, 1997). Consequently, management of effort not only allows and requires individuals to control the effectiveness of task behaviour in relation to changing demands but also their personal well-being. Unlike Kahneman (1973), Hockey (1997) argues that effort is not automatically increased to meet higher task demands. Rather, perception of the change in load beyond a certain level (the lower set-point) causes a shift from automated to controlled information processing (Schneider & Shiffrin, 1977; Shiffrin & Schneider, 1977). This state consequently involves an increasing demand on working memory (Baddeley, 1986). It is also equivalent to Mulder’s (1986) *computational effort* associated with task demands. From the moment when control is shifted to the supervisory controller, the individual has the chance to actively decide on either adopting a strategy to maintain task performance within acceptable limits by incurring extra costs, or adopting a strategy to accept a reduction in overt performance with no increase in cost. This makes the upper limit of the effort budget more variable due to the physiological, motivational and emotional factors of an individual (see section 1.5.3). For example, Van der Hulst, Meijman, and Rothengatter (2001) found that drivers who are fatigued become less willing to invest effort into the task. Other findings show that after prolonged driving or sleep deprivation, drivers invest less effort in their steering performance (Fairclough & Graham, 1999). Hockey (1986, p. 44-38) summarizes the affects that characterize a high arousal state as follows: “first, increased selectivity of attention in dual component tasks; second, increased speed with decreased accuracy in rapid decision-making tasks; and third, reduced working memory capacity.” Operating at higher levels of effort for any length of time is known to be uncomfortable and avoided whenever possible (Hockey, 1997). Thus, the relationship between task demands, driver capability, effort and performance is also moderated by task duration: People may be able to invest considerable effort or accept inactivity and boredom to some extent, but not for very long. As a consequence, experienced operators will pace themselves, particularly in predictable situations, working at a rate and effort level that they can maintain for the expected duration of the task. If they do not pace themselves appropriately, performance is likely to suffer as the mission progresses (Huey & Wickens, 1993). And even if performance level does not degrade, the consequences of sustained mobilization of increased effort might impose long-term costs of fatigue and possible health risks (Hockey, 1997). Hence, there is also a utility of effort conservation (Wickens & Hollands, 2000) and people may not try to achieve perfect performance or accomplish tasks immediately, but rather by rescheduling, deferring, or shedding less important tasks in order to achieve acceptable performance and maintain a reasonable level of workload for the duration of the task (Huey & Wickens, 1993). The moment workload level starts to exceed a certain level, less demanding working strategies can be adopted, a strategy introduced in the next section.

1.5.2.2 Adoption of more or less demanding working strategies

Because the driving task is a self-paced task (Taylor, 1964), driving task demands are to a certain extent under the control of the driver through selection of driving speed, distance to the car in front, or frequency of rear-mirror checking. A number of studies have shown that drivers adopt less demanding strategies by changing their driving behaviour when task demands increase. For example, it has been found that drivers increase their distance to the car in front when performing additional tasks (Noy, 1989) or being fatigued (van der Hulst et al., 2001). Or they reduce their driving speed when task demands increase (e.g., Cnossen et al., 2004; Dingus et al., 1997; Jamson & Merat, 2005; Pohlmann & Traenkle, 1994). In Summala's hierarchical model of behavioural adaptation, driving speed also plays an important role to keep time margins at a constant level (Summala, 1996, p.112): "To maintain speed when the road standard (e.g. width) decreases we have to put more effort into the task, or slow down…". According to Fuller (2005), speed choice is the primary solution to the problem of keeping task difficulty within selected boundaries. Consequently, speed choice would also be deployed in order to increase workload in situations of mental underload. Correspondingly, Summala (1996), Brown (1994) and Brookhuis et al. (1991) pointed out that a drowsy driver may increase speed and consequently task demand in order to get over the drowsy state. Other strategies to reduce current workload levels concern the handling of the secondary task, e.g. adopting the less demanding working strategy of prolonging the duration of the secondary task. Jordan and Johnston (1993), for example, found that the time to complete a route increased when drivers had to operate the car stereo and Summala (1996) predicts an increased time spent on additional tasks, to keep workload at a constant level. Furthermore, strategies will also differ between individuals, and some strategies will be more effective and require less effort to reach the same level of performance (De Waard, 2002). But there is also evidence for drivers not adapting compensatory behaviour to deal with suboptimal workload levels as well. In a study of Alm and Nilsson (1995), drivers did not increase their distance to the car in front sufficiently to accommodate for increased reaction time due to their performing a secondary task, even though they did have the opportunity to do so.

1.5.2.3 Skipping subsidiary tasks

If adopting less demanding working strategies is still not sufficient to meet very high task demands, subsidiary tasks have to be skipped. Research has also shown that when engaged in a secondary task like a telephone task (Recarte & Nunes, 2003), or an auditory memory task (Brookhuis et al., 1991), drivers not only slow down or increase time headway to a vehicle in front, but also reduce mirror and speedometer inspections. But Pohlman and Traenkle (1994) also report that drivers deviated from their lane more when they drove using a complex visual route guidance system than when driving with a common paper map. Obviously, a major problem with skipping subsidiary tasks is to determine which tasks are least important, as discussed in the section of task prioritisation. Another explanation might be that drivers do not have the time to make such decisions when task demands exceed certain levels. As mentioned above, in these situations drivers tend to make fast decisions at the cost of accuracy. In other words, they react spontaneously without thinking.

Cnossen et al. (2004) and Hockey (1997), on the other hand, argue that operators are generally able to protect high-priority task goals, and it can be assumed that the preservation of the primary task goal is also important in an everyday skill such as car driving. Correspondingly, Landsdown (1997), Fairclough et al. (1993), and Brookhuis et al. (1991) found that drivers reduced their rear-view mirror checking when task demands increased while driving with a visual route guidance system in an experimental setting which largely reduced the need to check the mirrors, which was not the case during situations where task demands were high and checking the mirrors was important (De Waard, 1991). Knight and Kantowitz (1974) reported as well that participants were able to prioritize the more important task. Thus, when errors were costly, only latency was affected.

Nevertheless, distraction from the main driving task is one of the most important causes of accidents (Rumar, 1990; Sprenger, 1999). According to Shelton (2001) and Utter (2001), 25-30% of all vehicle accidents result from driver distraction or inattention. Verwey (1993) even speaks of 30-50% of accidents in which driver distraction plays a role. Where compensatory adjustments cannot be made, performance suffers. In a simulator study in which drivers were instructed to maintain speed at 70mph, Stanton and Young (2002) found that as mental workload increased, situational awareness decreased. As suggested by Wickens and Hollands (2000), quality of performance does deteriorate, such as a loss of control of lane positioning or situation awareness. In this case, low priority task elements may be dumped (such as mirror checking), and in more extreme cases, high priority tasks, such as looking ahead, may also suffer. An explanation of disruption in cognitive performance following a loss of control is that attentional resources are mobilized by thoughts which have no link to the task (Seibert & Ellis, 1991).

Furthermore, as compensatory activity entails costs, which are aversive (Hockey, 1986), a shift to a low effort mode of control will occur as soon as changes in task demands permit. However, it is possible that this shift to a lower effort mode also occurs in situations where task demands do not permit it, but where the operator is exhausted or not willing to endure the aversive state any longer. In a study by Holding (1983), participants were – after prolonged work – more likely to choose a task method requiring low effort, even though it entailed more risk of error. Apparently, fatigue seems to cause a shift towards a preference of activities requiring less effort, or less use of high level control actions (Hockey, 1997).

Recapitulating, increasing task demands can be met by either investing more resources, adopting less demanding working strategies, or ”as a last step”, skipping subsidiary tasks. Investing more effort, thus operating at high levels of workload, is known to be uncomfortable and avoided whenever possible. Consequently, people may not always try to achieve perfect performance at high costs, but rather achieve acceptable performance and maintain a reasonable level of workload for the duration of the task. To keep workload levels within these accepted boundaries, drivers adopt several strategies which might differ in efficiency and costs. Probably the most common strategy is to reduce or increase driving speed in order to compensate for too high or too low workload levels respectively. If adopting less demanding working strategies is still not sufficient to meet very high task demands, subsidiary tasks have to be skipped. Here the problem arises to decide on which task to protect and to come to a decision while time pressure is still at a moderate level. Otherwise, operators will tend to make fast decisions at the cost of accuracy. If it is not possible to increase or decrease workload levels as required, drivers may either drop high priority tasks as well or, in more extreme cases, lose control of the vehicle if workload level is too high, or become distracted or tired if it is too low.

1.5.3 Modulating variables of driving performance

Together, biological factors and acquired skills through training and experience determine the upper limit of competence of the driver. And it is the subjectively perceived task difficulty which arises out of the dynamic interface between the demands of the driving task and the capability of the driver which determines driver workload and consequently, driving performance (Fuller, 2005). But although workload and performance are clearly related, their relationship is more complex, as biological factors, knowledge and skills do not necessarily predict the level of performance at each point in time, because performance is vulnerable to several modulating variables, such as a general attitude towards driving (section 1.5.3.1), motivation (section 1.5.3.2), and emotion (section 1.5.3.3). General attitudes, and the resulting motivational factors as well as different emotional states eventually determine what operators do with their skills in a specific situation. “Human performance is subject to considerable change and variation, a fact often overlooked by psychologists in the development of formal models of performance.” (Hockey, 1986, p. 44-2). These models typically assume that motivation, arousal, emotion or fatigue do not alter the pattern of behaviour, only its level of efficiency (Hockey, 1986).

1.5.3.1 Personality and attitudes towards driving

Ever since Tillman and Hobbs (1949) stated that “a man drives as he lives”, there has been interest in the driver’s personality as an underlying causal factor in driver behaviour. Eysenck (1947) structured the personality along different dimensions, which he gained from factor analysis, and he described extraverted individuals as having relatively low levels of endogenous arousal and actively seeking external stimulation in order to drive their arousal levels up. Correspondingly Taylor (1964) assumes that drivers adopt a certain level of anxiety that they wish to experience when driving, and then adjust their driving behaviour accordingly to maintain it. Zuckerman (1979) postulated the personality trait of sensation-seeking, which is defined by “the need for varied, novel, and complex sensations and experiences and the willingness to take physical and social risks for the sake of such experience.” (Zuckerman, 1979, p. 10). Individuals high in sensation-seeking are more likely to speed, overtake more and adopt shorter distances to the car in front. Sensation-seeking is more prominent in young males, the group of drivers that is also most frequently represented in traffic accident statistics (Heino, van der Molen, & Wilde, 1996). One major problem with studies of individual differences and driving style is that they have usually been based on a correlative design where some personality questionnaires are related to driving inventories; this kind of study, based only on questionnaires, is easily biased by the effects of social desirability caused by self-deception and/or impression management (Lajunen & Summala, 1995). Correspondingly, Wilde (1994) postulated that the relationship between collision involvement and personality is generally weak and inconsistent.

There are several alternative theories accounting for differences in performance between drivers. In his risk homeostasis theory, Wilde (1982), for example, assumes that people have a target risk level which guides their behaviour and which they gain through weighing up the costs and benefits of alternative actions. This means that a perceived risk which is higher than the target risk the driver is willing to accept leads to behavioural changes which will reduce the perceived risk (safer driving). On the other hand, a perceived risk lower than the target risk will lead to behavioural changes which will increase the perceived risk (more dangerous driving). Therefore, risk homeostasis theory would also predict that, as safety features are added to vehicles and roads, drivers tend to increase their exposure to collision risk because they feel better protected. Furthermore, risk homeostasis theory relates very well to general attitudes as different drivers will weigh up costs and benefits in different ways. So does Fuller’s theory of task difficulty homeostasis (2005), as it implies individual differences in preferred levels of task difficulty. In his theory he assumes that drivers attempt to maintain a certain level of task difficulty and that risk of collision is generally not relevant in the decision-making loop. However, he also states that task difficulty and feelings of risk appear to be very highly related (Fuller, 2005).

Furthermore, individually preferred levels of risk and general attitudes towards driving will not only influence the actual behaviour of an individual while driving, but also decision making in situations before getting behind the wheel, such as buying a vehicle with particular features like Anti-lock Braking Systems (ABS), Adaptive Cruise Control (ACC), Electronic Stability Programs (ESP), Automatic Lane Control (ALC), etc., in contrast to simply buying a car with air condition only.

1.5.3.2 Motivation

Motivational factors determine what drivers eventually do with their skills (Lajunen & Summala, 1995). However, because of the difficulty of observing intra-individual transient variations of motivation, little is known about this topic (Delhomme & Meyer, 1998). According to Fuller (2005), performance is very much determined by the extent to which the driver is motivated to allocate the resources needed to carry out the task in such a way that capability is maintained above task demand.

Generally there are two different kinds of motivation distinguishable to explain driver motivation or certain behaviour: the motivation to avoid negative consequences, and the motivation to seek positive results. People are more likely to try to meet performance standards if their job or personal safety are on the line than if the consequence of poor performance is simply a ‘bad score’. In addition, operators may act less conservatively, take more risks, and try new techniques when failure does not have any direct consequences (Huey & Wickens, 1993, p.58). Incentives, on the other hand, can be seen as having the effect of maintaining a task set, or orientation towards current work goals. This will benefit any task where distraction or loss of interest tends to occur (Hockey, 1986).

Furthermore, performance may generally be influenced (sometimes impaired, sometimes increased) by the presence of others (Zajonc, 1965). People might drive faster according to the desire to ‘show-off’ to peers, or might drive slower in order to provide a comfortable ride for an elderly passenger. For this reason, it may well be crucial to know which skills are more sensitive to the effects of transient motivational factors, particularly when drivers are novices (Sivak, 1981). One skill that is very sensitive to the effects of motivational factors is obviously adaptive speed control: when choosing speed regulations, novice drivers are more dependent on their motivational state at that moment than more experienced drivers (Delhomme & Meyer, 1998). Different motivations may also compete with each other, e.g. the need to provide a comfortable ride for an elderly passenger, while not having much time available for the journey. In moments when priority is given to the goal of arriving on time, a driver might accelerate and then slow down again upon remembering not to scare the grandmother. Overt performance is therefore assumed to be driven by internally-maintained states, determined by both long-term and short-term goals. These determine output criteria for behaviour such as how fast to work, how much monitoring of accuracy is required, the order in which actions are executed, etc. According to Hockey (1997), the upper limit of invested effort is a function of individual differences in the perceived value of task goals in the response to challenge, in the capacity for sustained work, and in the tolerance of aversive states associated with high levels of workload. For activities which are more unpredictable or more critical in terms of outcomes the upper limit of the effort budget may be increased. Behavioural stability remains high under these conditions, and effort well within reserve limits, though the overall level of mental activity is increased (Hockey, 1997). Additionally, the upper set-point of the effort budget is likely to change under the influence of short-term factors such as fatigue (Holding, 1983) and prevailing affective states (Ellis H.C. & Ashbrook, 1988).

1.5.3.3 Emotion and stress

When identifying types of tasks and task characteristics that result in overload there are two phenomena to be considered: eyes-off-the-road and mind-off-the-road (Green, 2000). Mind-off-the-road refers to situations where the driver is thinking about something other than the road situation, which can occur when the driver is listening to a long or complex auditory message or when the driver is daydreaming. In other words, distraction can be exogenous (produced by external objects or events irrelevant to driving) as well as endogenous (produced by the driver’s own thoughts or cognitive activity unrelated to the driving task) (Gulian et al., 1989; Recarte & Nunes, 2003). Thoughts associated with emotional states can inspire or impair performance. Whether happy or sad, any thoughts that divert selective attention away from task-relevant processing can interfere with performance (Seibert & Ellis, 1991). For example, a driver might find him- or herself at the wheel following a happy or unhappy event related to work, or their social or family life. McMurray (1970) found that people involved in divorce proceedings have double the accident rate of control motorists. Anger and anxiety degrade working memory capacity (Hockey, 1986) and because our awareness of an evolving situation largely resides in our working memory, situation awareness also degrades as a result (Wickens & Hollands, 2000).

The above mentioned subjectively different risk estimation may as well influence performance: one who does not realize the risk or danger of a particular situation will experience less stress than one who does (Coyne & Lazarus, 1980). Consequences could be differences in the allocation of attention, changes in corresponding decision making (e.g. choosing a more risky alternative) or in carrying out a particular decision (Delhomme & Meyer, 1998) – with different outcomes.

Recapitulating, motives and emotions serve as general modulators and affect driving performance in a rather unspecific way. Thus, strong positive as well as strong negative emotions may affect driving performance. Motives can vary, not only between drivers, but also within the same driver at different times: they include both transient motivational and more permanent personality factors and general attitudes towards traffic and safety.

To summarize the preceding sections, driving performance depends on three groups of influencing factors (see figure 1.7): first, the workload level, which arises out of the dynamic interface of task demands on the one hand and driver capability on the other; second, variables such as motivational and emotional states, or the general attitude towards driving, which modulate driving performance in a more implicit way; and third, the more or less successfully used strategies to compensate for suboptimal levels of workload.

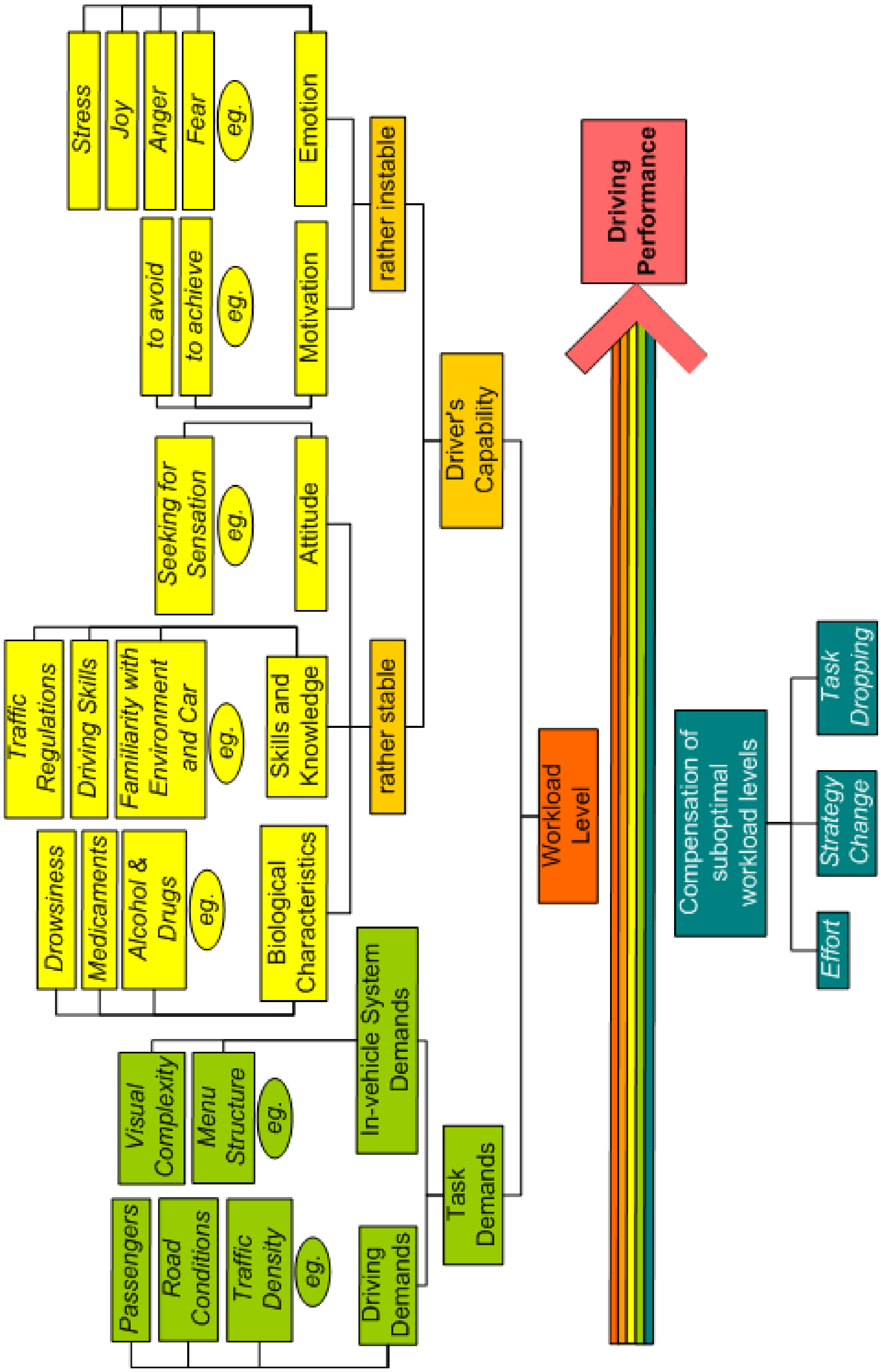


Figure 1.7 Determinants of driving performance

1.5.4 Assessment of mental workload

According to McDowd et al. (1991), workload measures fall into one of the following categories: objective performance measures (primary and secondary task performance), subjective measures, and physiological measures. Objective performance measures include two major types of measures: The primary task measurement techniques assess workload by examining certain aspects of the operators capability to perform a required task (e.g., lane keeping), and some aspect of the task is varied to increase task loading (e.g. road curvature or driving speed). The secondary task methodology provides an index of workload through analysis of the operator’s capability to perform an additional task or function concurrently with the primary task (O'Donnel & Eggemeier, 1986; Williges & Wierwille, 1979). Ideally, the operator maintains a constant level of performance on the primary task, and the workload level required for the primary task is inferred by comparing performance of the secondary task alone and the multi-task situation. However, in situations of high workload, concurrent tasks (e.g. steering and using a navigation system) may interfere with each other and degrade the performance of one or more tasks (Green, Lin, & Baian, 1994). Furthermore, people often cope with an increase in task demands by increasing mental and physical effort devoted to the task, and performance may thus remain stable. Hence, despite a great increase in task demands, performance measures will not reflect any change and be insensitive to the increase in workload, while other measures, such as self-reported ratings or physiological measures, may well give an indication of increased workload (De Waard, 2002). This interrelationship is illustrated in figure 1.8.

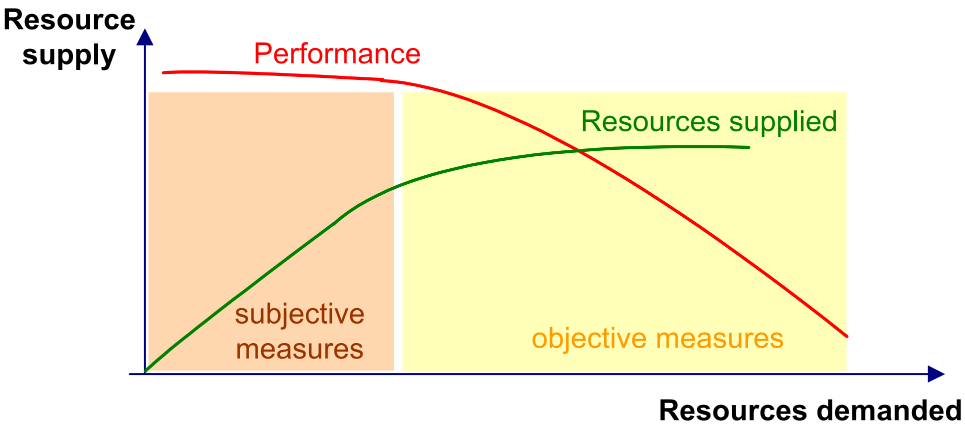


Figure 1.8 Areas of subjective and objective measures of workload

Accordingly, Cnossen et al. (2000) have stated that car drivers can achieve a high level of task performance when performing a number of tasks concurrently, even in difficult driving situations, but that this is associated with high costs. Therefore, the second class of workload measures is set up by subjective workload assessment techniques which require the operator to provide judgements of the experienced level of workload or effort, which are in turn associated with performance of a task or system function (Moray, 1988; O'Donnel & Eggemeier, 1986; Williges & Wierwille, 1979). Subjective perception of workload is hypothesized to be influenced by the amount of invested resources and to be dominated by the demands on working memory imposed by the processing (Yeh & Wickens, 1988). Therefore, if an operator feels effortful and loaded, then workload has in fact increased, even though task demands or performance have not changed. According to de Waard (2002), drivers can easily assess their workload and report it. Correspondingly, Green et al. (1994, p.3) state: “To date, subjective measures have given the most consistent results”. Subjective techniques range from ad-hoc surveys to highly formalized methods such as the Subjective Workload Assessment Technique (SWAT) (Reid G.B., Shingledecker, & Eggemeier, 1981) and the Task Load Index (NASA-TLX) (Hart & Stavelend, 1988). They include structured single dimensional rating scales (Wierwille & Casali, 1983), as well as multidimensional assessment techniques (O'Donnel & Eggemeier, 1986). The disadvantage of subjective measures usually is that the operator’s statement might be influenced by other biases like dislike of the task or the operator’s reluctance to report that the task was difficult.

The third class of techniques is formed by physiological workload assessment techniques, which provide a measure of workload through analysis of the operator’s physiological response to manipulations of task or system demands. Measures explored include transient and steady-state evoked cortical response (Donchin, 1981), heart rate and heart rate variability (Mulder, 1980), and rate of eye blinks (Stern, Walrath, & Goldstein, 1983). Tsimhoni and Green (Tsimhoni & Green, 1999) furthermore list the technique of visual occlusion, which was first proposed by Senders, Kristofferson, Levison, Dietrich, and Ward (1967). With the visual occlusion technique, workload levels are assessed by shutting off visual input for time periods of different lengths, thus estimating the visual demand of different driving conditions by measuring degradation of performance.

1.6 General aims of this dissertation

Regardless of the fact that driving is a performance-critical primary task, drivers engage in a wide variety of secondary tasks through interaction with in-car interfaces. Consequently, the question arises how concurrently executed task interfere with each other (e.g. searching in lists while driving). But although it is possible to prescribe an optimal allocation schedule to tasks as a function of their importance or their cost of non- or inaccurate completion, it is not yet clear what the specific departures from optimal allocation are, and how these departures are influenced by task properties and environmental goals (Huey & Wickens, 1993). Therefore, the overall goal of this dissertation is to isolate factors which contribute to driver workload in such multiple-task driving situations and those which might have a facilitating effect on driving performance. In the light of the previous thoughts the following issues were addressed in this dissertation:

1) What effects does an additional task, namely finding an entry in a list have on driving performance under varying conditions?
2) How many entries should a secondary task list consist of to guarantee an optimal driving performance?
3) Where should input devices be located to guarantee an optimal driving performance?
4) What influence does the display location of the list have on driving and list performance?
5) How does performance vary along with manipulation of the difficulty of each the primary and the secondary task? I.e., how do task completion times, error rates, and lane deviation vary as a function of list length, driving speed, curve radii and direction, control and display location?
6) How do these measures co-vary with subjective measures of workload?

These issues were investigated in the following six experiments. The first, a pilot experiment, was conducted to help make decisions concerning experimental settings of the subsequent experiments.

Chapter 2: General methods

In this chapter, methods that are similar for several of the experiments shall be described to avoid iterations later in the text. The first section (2.1) discusses the advantages and disadvantages of simulated studies in general and the advantages and disadvantages of high-cost and low-cost simulators in particular. The sample of all experiments is described in section 2.2, followed by descriptions of the general experimental setup (2.3), the general procedure (2.4) and of data analysis (2.5).

2.1 Simulating reality

From a research perspective, field studies with instrumented vehicles are often regarded as the ultimate validation stage for assessing behavioural models, safety measures, new designs of road infrastructure or vehicle equipment (Santos et al., 2005). However, there are several reasons in favour of using driving simulation rather then in-vehicle testing:

1. **Safety:** some research (e.g. effects of alcohol on driving performance) is too hazardous to be conducted in vehicles on the road.
2. **Equipment cost:** experiments using simulators can be conducted at less cost and more quickly than constructing roadworthy systems.
3. **Experimental control:** during on-road testing, many conditions, such as surrounding traffic, weather, etc. cannot be controlled. Simulators allow the design of experiments where specific chains of events are easily created and repeated, and can be kept equivalent for all participants in the experiment, therefore producing more consistent and reliable results.

For these reasons, driving simulators are usually considered as a much more practical research tool. However, a common reservation against driving behaviour data gathered from simulators concerns the validity and reliability of the data (De Waard et al., 1999; Farber, 1999). The supposed weakness of most simulators is the fact that they can only partly simulate all stimuli received in a real environment which is especially true for low cost simulators. Hence, as participants experience first of all a lack of risk in a simulator, they might drive in a less realistic manner. Possibly for this reason, lane keeping was less precise in the simulator than on the road in studies conducted by Reed and Green (1995) and Sumie et al. (1998). To guarantee a good transfer of results, the logical conclusion would be to develop a simulator as similar to a natural environment as possible, so that the operator becomes unaware of the mediating technology and the fact of being in a car that is actually not moving at all (Lombard, 2002). To become involved in the virtual environment and starting to feel like being part of an artificial, computer created environment is called *feeling of presence* (Kalawsky, Bee, & Nee, 1999). The first question that now arises is what the requirements of such a realistic driving simulator are. The answer to this question is far from trivial and even if it was known, details in the technical implementation of angles of the visual field, spatial and temporal resolutions, feedback parameters of the driving interfaces, dynamic variables of the virtual vehicle, etc. would be extremely difficult to realize, if not impossible. In any event, the costs of such a simulator would undoubtedly be immense. Therefore, the key question is whether a powerful and high cost simulator as described provides empirical data that are almost as reliable and valid as the data gained from studies with instrumented vehicles. According to Groeger (2000), gaze patterns and the aspects of the road that influence them are quite different in actual and simulated driving, even with very sophisticated simulation. Results from studies comparing simulator and on-road conditions are inconsistent, probably because driving simulators vary substantially in quality, representing a range from “simple single screen, PC-based laboratory instruments, to advanced graphics, wide-screen, fixed-based mock-ups, while a moving base version of the latter is only affordable for a happy few research institutes.” (Santos et al., 2005, p. 136). Thus, while Kurokawa and Wierwille (1990) showed that task completion time was significantly longer in the simulator than on the road, Sumie et al. (1998) found no difference in task time measures between the simulator and on-the-road driving. Wooldridge et al. (2000) conducted experiments in a driving simulator, on a test track, and on a public road to examine visual demand of road geometry. Results showed that the effects of curve radius on visual demand were similar for all three test conditions. Therefore, the selection of a particular simulator set-up should be based on an evaluation of research goals, the nature of the driving tasks and the expected behavioural outputs (Santos et al., 2005, p. 137). For example, if deriving absolute driving performance measures is a goal in itself, the ‘physical correspondence’ (Blaauw, 1982) between driving performance in the simulator and the real-world should be a first priority – in this case, only high cost simulators come into question. However, if the aim is to obtain consistent results, for instance, with relatively obvious performance measures, e.g., on driving impairment by a secondary task, then a low to medium cost system should prove satisfactory (Santos et al., 2005). The results of a study conducted by Reed and Green (1995) which compared driving performance on-road and in a low-cost simulator support this theory. Although the absolute values of driving performance measures were different in the simulator and on the road, driving performance in the simulator was sensitive to both a within-subject factor and a between-subjects factor. Therefore, the simulator has been shown to produce driving performance measures with a visually demanding secondary task with good relative validity, which suggests that the simulator can be used to assess the relative performance degradations that would be associated with alternative interface designs for in-vehicle driver aids (Reed & Green, 1995). For this reason, a low-cost simulation has been found sufficient for the purposes of this dissertation.

2.2 Participants

Participants were recruited from a list of volunteers provided by the Max Planck Institute for Cognition and Neural Sciences in Munich. All together 84 paid volunteers participated in one pilot and five main experiments in equal numbers of males and females. Their age ranged from 20-36 years (mean: 26.4, SD=2.7years). All participants had normal or corrected-to-normal vision and a driver's licence for at least two years (mean: 7.6, SD=4.1). Mean kilometres driven per annum was 5322 (SD=7636). Mean daily computer usage was 4.4 hours (SD=3.0). The following demographic data was obtained for each participant: sex, age, years of education, handedness, driving and computer experience (for detailed information see Appendix A).

2.3 General experimental setup

This section starts with a description of the technical equipment used in the experiments (section 2.3.1). Section 2.3.3 then describes the stimuli presented on the two monitors, followed by a description of the applied controls (section 2.3.3).

2.3.1 Apparatus

The experimental apparatus consisted of five components (see figure 2.1).

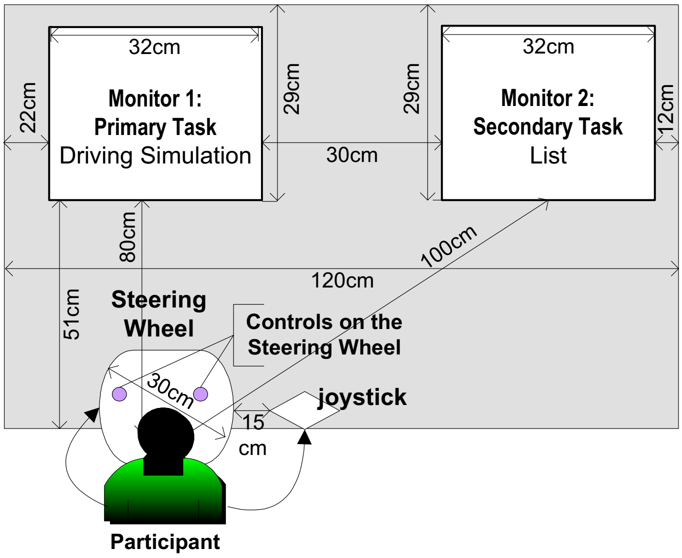


Figure 2.1 Outline of experimental apparatus

The first component, a 17-inch monitor with a refresh rate of 85Hz, displayed the track lane. This monitor was positioned approximately 80cm in front of the participant. The display image was 32cm (800pixel) in width and 24cm (600pixel) in length. The second component, again a 17-inch monitor with a refresh rate of 85Hz and a display image of 32cm (800pixel) in width and 24cm (600pixel) in length, displayed an alphabetically sorted list of different lengths. The two monitors were placed in a parallel line in front of the participant on a 120cm x 80cm table. Each monitor was 51 cm away from the front edge of the table and with a distance of 30cm between them. Participants looked straight on the left monitor and at a viewing angle of approximately30 degrees on the right one.

The third component, a *thrustmaster*® forced feedback steering-wheel with a diameter of 30cm was mounted on the front edge of the table in front of the left monitor. It controlled the lateral position of the car in all experiments and in experiments 4 and 5 cursor movement in the list as well.

The fourth component, a commercial gaming joystick, was mounted on the front edge of the table in front of the left monitor, 15cm to the right of the steering-wheel. It controlled cursor movement in experiments 1 to 3. Time constant of both steering-wheel and joystick (i.e., the rate at which the joystick could follow a stepwise input signal) was 20msec.

The final component, a personal computer (Pentium 4, 1.7GHz, 256MB memory) with a *kubuntu* interface based on a LINUX operating system, controlled the visual displays, the controls, the task prompts, and the log files.

2.3.2 Stimuli

2.3.2.1 Primary task and track setup

In all experiments the stimuli on the left monitor consisted of a red car on a 3.2cm (80 pixel) wide grey road on a green background. The centre of the car was positioned approximately 4.8cm (120 pixel) above the lower edge of the screen and participants had a bird's eye view on the scene (see figure 2.2 and 2.5). Under natural conditions, drivers simultaneously control steering and speed. But, as driving is a self-paced task (Taylor, 1964), adjustments of driving speed provide a very flexible and rapid means of controlling workload level. Correspondingly, Hoyos (1986) reported that drivers used compensatory speed reductions as demand increased. Hence, adding speed control would permit a greater range of actions and lead to a greater variability of results. For this reason, participants could not alter the speed of the car and the driving task was limited to steering control only with the goal of producing more consistent results. However, since driving speed is closely related to workload and because high speeds require more of the drivers' visual capacity (Sumie et al., 1998), different driving performance results can be expected following a change in a preset driving speed. Consequently, two driving speed settings were used in the following experiments. As the position of the car was fixed on the screen, speed conditions were simulated by moving the road behind the car at two different rates: 3.8cm (95 pixel) per second in the slow condition and 5.4cm (135 pixel) per second in the fast condition.

The track itself was composed of 13 different types of track elements to vary road complexity levels. Seven track elements were classified as low demanding track elements with one straight element and six elements with a moderate curve radius between 0cm and 4.8cm (120pixel). The remaining six track elements were sharp curves classified as highly demanding track elements with a curve radius between 6.4cm (160pixel) and 9.6cm (240pixel), as displayed in figure 2.2. Each track element covered 9/10 of the screen in the vertical dimension which equalled approximately 21.6cm (540pixel).

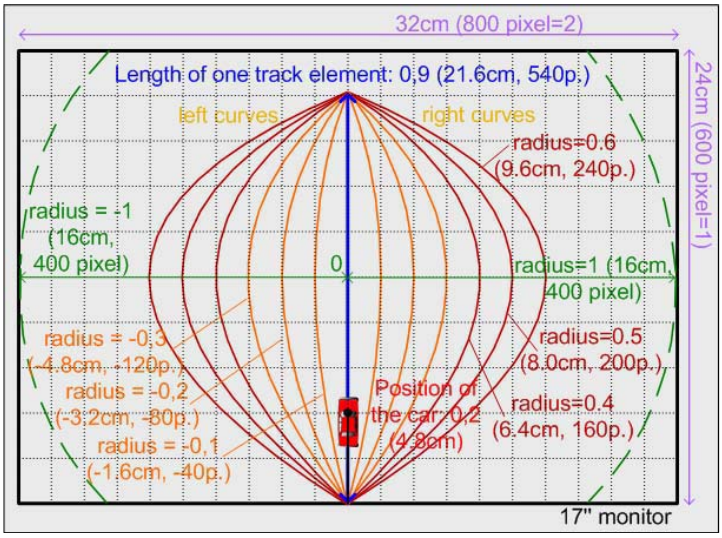


Figure 2.2 Screen dimensioning

Moderate and sharp curves could be either right or left bends. Each of the 13 road-element types was used approximately six times within a single track. Only experiment 2 made an exception: Here, each road-element type was used approximately eight times within a single track, due to an extended track length, as experiment 2 entailed a longer task duration because of a secondary task with a maximum list length of 104 entries. In order to not unnecessarily extend the duration of all of the experiments and avoid secondary task demands dropping below a certain point for the other four experiments, only the track length of experiment 2 was expanded at the expense of restricted comparability. Thus, the entire track consisted of 114 track elements in experiment 2 and 90 track elements in all other experiments.

In order to analyse the effects of varying task demands, each trial (presentation and search of one letter-digit-combination; see below for more information) consisted of either high or low demanding track sections only. For this purpose, each three to four either low or highly demanding track sections were combined in a group (see figure 2.3-1. and 2.3-2.), thus producing 24 groups in equal numbers of both low and highly demanding track section groups (see figure 2.3-3.).

Again, experiment 2 was an exception due to higher secondary task completion times. Here, one additional track section was added to each group so that they consisted of four to five track sections each (instead of three to four). The number of track sections in each group was varied in order to preclude anticipation of secondary task prompts which were displayed at the very beginning of each group or trial.

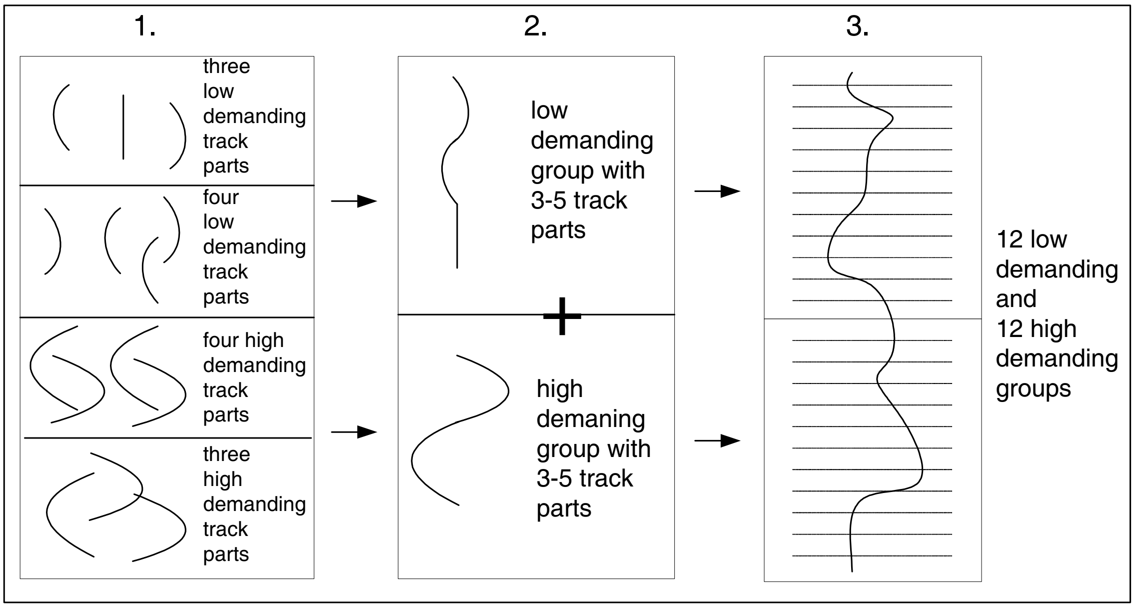


Figure 2.3 Construction of tracks

Therefore a task prompt appeared not regularly at for example the beginning of every third track section, but rather it appeared either every third or forth track section (see Appendix C for detailed information). Consequently, the track course in each condition consisted of 24 task prompts or trials (12 ‘short’ and 12 ‘long’ trials). To avoid fatigue effects each condition was separated in two experimental runs, lasting between approximately five minutes each in experiment 2 and approximately four minutes each in all other experiments. These split conditions were then presented to the participants in random order.

The track lane of each bisected condition started out with three low demanding track sections displaying no secondary task prompt at all to give participants time to become familiar with the task situation. The data from these track sections was later eliminated from the log files. At the beginning of all other groups, a letter-digit-combination was presented at the beginning of the first track section of a group as a starting signal for the participant to initiate the search (for detailed information on task prompts see chapter 2.3.2.3). For data analysis, the split halves were reunited again (see chapter 2.5).

Recapitulating, the following independent primary task variables were manipulated in the experiments (see table 2.1).

Table 2.1 Overview of independent primary task variables

Factor	Description	Possible values
Velocity of the car	cm/pixel per second	0 - 200
Curve radius	Radius of track section	0 - 9.6cm/240 pixel
Direction of curvature	Straight track sections, right turns and left turns	

2.3.2.2 Secondary task and list setup

According to Manes and Green (1997), every additional level in a menu increases the number of extra keystrokes. Thus, in their study the mean number of extra keystrokes was greater for a menu structure consisting of three levels with four entries each than for a menu structure consisting of two levels with eight entries on each level. The menu in the following experiments had only one menu level to minimize complexity and ease analysis of the keystroke data. In all experiments, stimuli on the right screen consisted of four entries which were part of an alphabetically sorted list. The selected one of the four visible entries was highlighted by a red selection bar (cursor) and was thus displayed as yellow text on a red background, as illustrated in figure 2.4a. The other three entries were displayed as yellow text on blue background. Each entry consisted of one letter and one digit (e.g. D1). The text size of the entries amounted to approximately 3.2 cm (100pt).

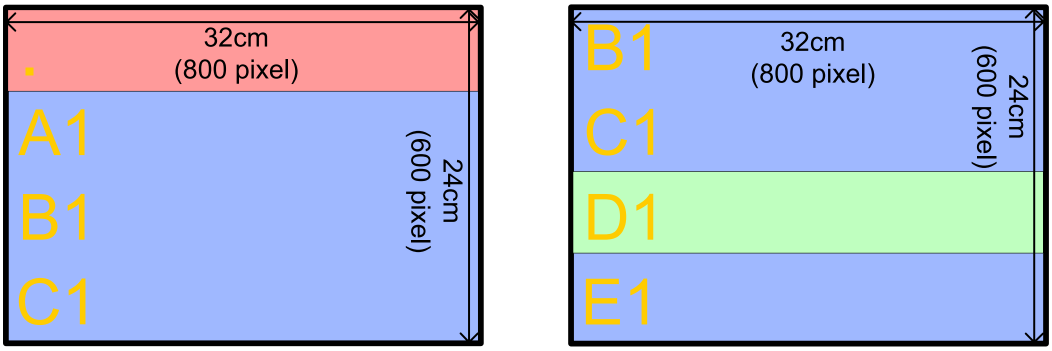


Figure 2.4 a) False or none affirmation and **b)** correct affirmation of an entry

Possible navigation directions in the list were an up- or downwards movement only. The selection bar moved at a speed of seven entries per second, which could not be altered by the participants. When navigating down, the cursor moved downwards up to the last entry displayed on the screen. It then stayed on that position while the list entries moved upwards behind the selection bar until the end of the list was reached.

When reversing the movement direction, the cursor moved up to the first displayed entry and stayed there until the beginning of the list was reached. Meanwhile, the list entries were moving down behind the selection bar. In order to minimize complexity and ease analysis of the keystroke data, the selection bar did not wrap around (i.e., jump from the last item to the first or vice versa).

If a list item had been confirmed correctly, the selection bar highlighted in a green colour (see figure 2.4b) and then jumped back on the first entry of the list (see figure 2.4a).

If a list item had been affirmed incorrectly, the selection bar highlighted in a red colour and remained on the current entry (see figure 2.4a). The participant could now continue the search until the correct entry had been affirmed or time was up. In this case the cursor jumped on the first list entry as well to ensure that the participant started a new search from the first entry again. This ‘arbitrary’ behaviour of the cursor was pointed out to the participants at the beginning of each experiment and they could become familiar with it during the training trials. All tasks were in principal manageable in the given time window, which was expanded for experiment 2 in order to manage searches in lists with a maximum length of 104 entries.

Recapitulating, the following independent secondary task variables were manipulated in the experiments (see table 2.2).

Table 2.2 Overview of independent secondary task variables

Factor	**Description**	**possible values**
Searching period	Progress of the search	1st, 3rd, and 5th fifth of total search time
List length	Total number of list entries	2, 4, 8, 26, 52, 78, 104 entries
List position	Position of the target entry in the list	1st, 2nd, and 3rd third of the list
Control location	Distance of secondary task control to the operator	15 cm right to the steering-wheel and on the steering-wheel
Display location	Experimental set-up with one or two screens	

2.3.2.3 Task prompts

All experiments included dual task conditions as well as single task conditions, which did not include any task prompts at all. In all dual task conditions the starting signal for the secondary task was introduced at the beginning of each trial, thus presenting each new task prompt at a fixed location in the track lane. The task prompt was displayed right above the car on the left monitor and showed one specific entry of the alphabetical list presented on the right monitor (see figure 2.5).

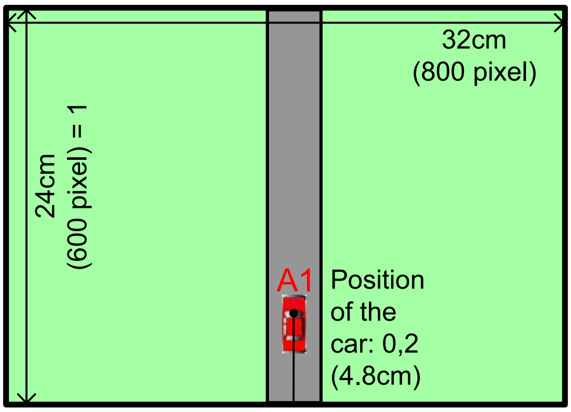


Figure 2.5 Presentation of the target list stimuli (task prompts)

The presentation of the task prompt on the left monitor was synchronized with a jump of the cursor on the first entry in the list presented on the right monitor. The first and the last entry of a list were never displayed as a task prompt due to their exceptional position at the 'edge' of the list. Thus, participants were not immediately able to affirm the first list entry or scroll all the way down to the last list entry without having to look at the list. The letter-digit-combination remained above the car until the correct list entry had been confirmed, or switched to a new letter-digit-combination if the participant did not manage to affirm the correct list entry in the required time window.

2.3.3 Controls

Stimuli on the left monitor were in all experiments controlled by the steering-wheel. Turning the steering-wheel to the left and right produced a turn of the car to the left and right respectively up to a maximum angle of 80 degrees.

Two different input devices (the joystick and the keys on the steering-wheel) were used to control stimuli on the right monitor. In experiments 1-3, stimuli on the right monitor were controlled via the joystick, which was positioned 15cm to the right of the steering-wheel (see figure 2.6). The time constant of the joystick (i.e., the rate at which the joystick could follow a stepwise input signal) was 20msec. Pulling the joystick down or pushing the joystick up provoked a down or up movement of the cursor in the list. Pressing the button at the back of the joystick affirmed the currently selected list entry.

In experiments 4 and 5 stimuli on the right monitor were controlled via keys on the steering-wheel (see figure 2.6): two four-way-navigation keys, one positioned on the right half, the other positioned on the left half of the steering-wheel and two buttons right below the four-way-navigation keys. Pressing either four-way-navigation key on the upper or lower press point produced an upwards or downwards movement of the cursor in the list respectively. To confirm a currently selected list entry either of the two small buttons right below the navigation-keys had to be pressed.

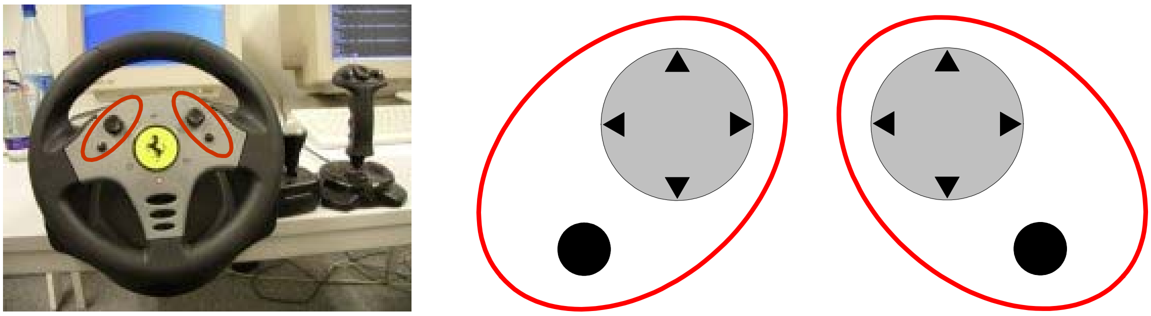


Figure 2.6 Controls on the steering-wheel

2.4 General procedure

After filling out a short biographical questionnaire (see Appendix A) participants were seated in front of the steering-wheel approximately 80cm away from the left monitor.

Training phase. In all experiments, the training phase consisted of two training periods. First, participants practiced steering the car with the aim of keeping the car in the center of the track lane. Subsequently, some exemplary letter-digit combinations were displayed above the car on a straight road and participants practiced navigating in the list. Each of the training periods lasted approximately two minutes.

Instructions. Before starting the test phase, participants were instructed to keep the red car as close to the center of the grey track lane as possible and prioritize the driving task at all times. In the driving-only condition, participants were instructed to drive in the centre of the lane. In the dual task condition, participants were instructed – after perceiving the task prompt – to switch their attention back and forth between the driving task and the search in the list until the displayed target item had been confirmed correctly, but to prioritize the driving task at all times. They were also informed about the ‘arbitrary’ behaviour of the cursor, jumping on the first entry of the list at the moment a new task prompt appeared. The relevant instruction was reinforced before each bisected condition and participants were told whether the car was moving at low or high velocity.

Test phase. Primary task (driving) and secondary task (list searching) were performed both concurrently and alone at two different speeds. This resulted in 20 bisected conditions in experiment 2 and 16 bisected conditions in all other experiments, which were performed in randomized order and consisted of 12 trials each. Details are described at the appropriate places for each experiment (chapters 3, 4 and 5). After each bisected condition participants were required to rate their self-assessed extent of invested effort and perceived interference of the dual task situation during the preceding condition on a five-point rating scale (for more information see Appendix A). In addition, they had to approximate their prioritisation of tasks on a bipolar scale from -10 (fully prioritizing the list task) and +10 (fully prioritizing the driving task). To avoid fatigue effects, the test phase was interrupted for a short break after half of the bisected conditions had been completed. At the end, participants answered a questionnaire about driving and computer experience (see Appendix A) and were paid for their services.

2.5 Data analysis

In the following experiments primary task, secondary task and subjective measures were chosen to assess workload measures, as physiological workload assessment techniques require specialized equipment which is still substantially more expensive than the collection of primary task performance, secondary task performance or subjective measures of mental workload (Kramer, 1991). In addition, findings show that the same manipulations which give rise to physiological changes will typically create subjective assessments of higher effort (Yeh and Wickens, 1988).

In order to gain the relevant data, driving performance and secondary task performance were recorded every 20msec. The according output log files included the following data (at each time stamp):

- ideal position of the car on the x-axis (center of the road)
- actual position of the car on the x-axis
- actual position of the car on the y-axis
- type of track section
- declination angle of the car (with the y-axis being the 0° position)
- letter-digit-combination currently displayed (if so)
- list entry currently selected
- key stroke (none, incorrect and correct) and
- trial duration

For minimum and maximum values of these categories see table 2.3.

Table 2.3 Minimum and maximum values of dependent variables

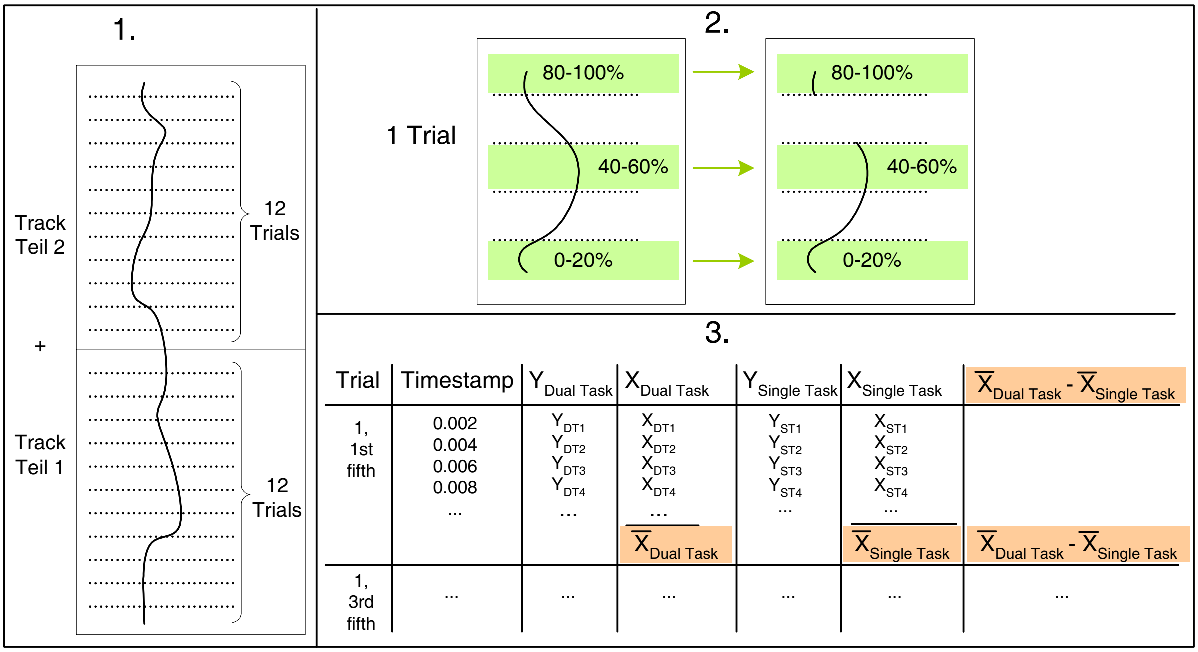
Variable	Minimum and maximum values
Ideal and actual position on the x-axis	7.3cm (182pixel) and 24.2cm (604pixel) from the left side of the screen
Position on the y-axis	0 cm (pixel) and 1200cm (30000pixel) in exp. 2 / 960cm (24000pixel) in all other experiments
Current angle	-80° and +80° (vertical line equaled 0°)
Type of track section	radius between 0 cm (pixel) (straight track sections) and 9.6cm (240 pixel) (sharpest right and left turns)
Display of task prompt	boolean: off and on
List item selected	A1 and Z4
Key stroke	none (0), incorrect (1) and correct (2)

Four dependent measures were then computed from the log files: deviation from the ideal route as a measure for accuracy of primary task (section 2.5.1), task completion time (speed of secondary task completion); percentage of missed trials (speed of secondary task completion); and number of extra keystrokes (accuracy of secondary task) which served as secondary task performance measures (section 2.5.2).

2.5.1 Driving performance (primary task)

Primary task measurement techniques assess workload and distraction by examining primary task performance, e.g. lane keeping. Consequently, driving performance was measured by lateral position in the lane.

Lane deviation. In a first step, the bisected tracks were reunited again (see figure 2.7-1.). The deviation of the target route was then computed by subtracting the x-value of the actual position from the x-value of the ideal position (namely the center of the road) at each time stamp which was done both for the data of the single task and the data of the dual task conditions. In a second step, all data was eliminated from the log files which was logged in dual task conditions during periods where no task prompt was displayed and accordingly no dual task situation existed, which was the case for the distance driven after having confirmed the correct entry.



Trial	Timestamp	$Y_{\text{Dual Task}}$	$X_{\text{Dual Task}}$	$Y_{\text{Single Task}}$	$X_{\text{Single Task}}$	$\bar{X}_{\text{Dual Task}} - \bar{X}_{\text{Single Task}}$
1, 1st fifth	0.002 0.004 0.006 0.008 ...	Y_{DT1} Y_{DT2} Y_{DT3} Y_{DT4} ...	X_{DT1} X_{DT2} X_{DT3} X_{DT4} ...	Y_{ST1} Y_{ST2} Y_{ST3} Y_{ST4} ...	X_{ST1} X_{ST2} X_{ST3} X_{ST4} ...	
			$\bar{X}_{\text{Dual Task}}$		$\bar{X}_{\text{Single Task}}$	$\bar{X}_{\text{Dual Task}} - \bar{X}_{\text{Single Task}}$
1, 3rd fifth	...	...	...	...	...	...

Figure 2.7 Data analysis for lane deviation

From this data, only the first, the intermediate and the last twenty percent of y-values of each dual-task trial were kept for further statistical analysis to allow a better comparability between the results of more and less time-consuming trials (see figure 2.7-2.). From the remaining data the y-values of the dual task situation were matched with the equivalent trial in the driving-only condition and mean lane deviation values of the single task condition (baseline value) were subtracted from the according mean lane deviation values of the dual task condition for each fifth of the search regarding one trial (see figure 2.7-3.).

From these concatenated log files spreadsheets were created summarizing the data for each condition and participant. All main effects and interactions between the factors were then assessed by carrying out a series of repeated measures ANOVA, corrected for sphericity violations where necessary by use of the Greenhouse-Geisser (1959) modification. As the factors ‘direction of curvature’ and ‘curve radius’ were derived from the same variable (track section type), two separate repeated measures ANOVAs were executed for lane deviation.

Finally a t-test for a single sampling was executed to find out whether the difference between mean lane deviation in the dual task situation and in the single task situation was positive and significantly different from zero (i.e., lane deviation in the dual task situation being significantly higher than in the single task situation).

2.5.2 List performance (secondary task)

A direct measure of secondary task difficulty is the number of tasks which could not have been completed correctly. The number extra keystrokes (false positive answers) is also an important measure with respect to the fact that choosing a wrong menu item in a commercial in-vehicle system leads the user into a wrong branch of the menu tree one level down. As a result, the user has to execute several steps to ‘undo’ the action: he/she has to press the ‘back-button’ or ‘back-entry’ to move one level up again and then recommence the search for the desired entry. In this way, the time for searching in the menu has somewhat tripled, entailing a significant rise in distraction potential. Extra keystrokes were generally due to the participant either selecting an incorrect item believing it was correct or selecting a wrong item by accident (slipping). For completed trials, the amount of time required to utilize the displayed information in order to perform the required task is interesting as well to be able to investigate possible speed-accuracy trade-offs. Consequently, list performance was measured based on the percentage of unsuccessful task completions (misses) on the one hand and task completion time and number of extra keystrokes for successfully completed trials on the other.

Misses. All trials which were not successfully completed in the given time window were treated as misses. As the track behind the car moved faster during the fast driving speed conditions, there was less time to complete a task. Therefore, the shortest possible time window of the fast condition was taken as a general maximum time window for both the slow and the fast condition. In other words, all successfully completed trials in the slow condition which lasted longer than this maximum time window were also treated as misses. All main effects and interactions between the factors were then assessed by carrying out a repeated measures ANOVA, corrected for sphericity violations where necessary by use of the Greenhouse-Geisser (1959) modification.

Task completion time. The mean task completion time of successfully completed trials (within the maximum time window) was calculated for each participant from the extracted log files. All main effects and interactions between the factors were then assessed by carrying out a repeated measures ANOVA, corrected for sphericity violations where necessary by use of the Greenhouse-Geisser (1959) modification.

Extra keystrokes (false positive answers). The number of extra keystrokes was counted for each successfully completed trial. All main effects and interactions between the factors were then assessed by carrying out a repeated measures ANOVA, corrected for sphericity violations where necessary by use of the Greenhouse-Geisser (1959) modification. For an overview of all dependant variables see table 2.4.

Table 2.4 Dependent variables

Measure	Description	Rationale
Lane deviation	Average and maximum deviation of the centre of the lane (absolute value)	Indicates primary driving task decrements
Misses	Trials not competed correctly in the given time window	Yields error data for each condition
Task completion time	Time elapsing between the display of the letter-digit-combination and the correct affirmation	Provides the true time needed to complete a task, indicating how well participants perform
Extra keystrokes	Number of unnecessary button presses per trial	Indicates how efficiently and directly each trial was completed

2.5.3 Subjective ratings of workload

Subjective measures were assessed after each bisected condition. Participants were required to estimate the subjective level of workload they experienced during the preceding trial. For this purpose, they rated their self-assessed overall effort during the preceding condition and the degree of interference caused by the secondary task on a five-point rating scale. Furthermore, they assessed their allocation of attention on a bipolar scale between -10 (fully prioritizing the list task) and +10 (fully prioritizing the driving task). For detailed information see Appendix A.

The mean estimated values of perceived effort, secondary task interference, and attention allocation were calculated for each condition. All main effects were then assessed by carrying out a series of repeated measures ANOVA, corrected for sphericity violations where necessary by use of the Greenhouse-Geisser (1959) modification. According to Bortz (1999, p.26), the data gained from so called per fiat measures, e.g. questionnaires, rating scales, etc. can be treated as metric, thus allowing for the entire statistical apparatus to be deployed for statistical analysis. This procedure is based on the assumption that the validation of a hypothesis is likely to be exacerbated by the adoption of an incorrect level of measurement.

Chapter 3: List length and position in the list

The following chapter begins with an introduction of relevant theories and studies concerning the structure of menus (section 3.1) which was investigated in the three experiments described in this chapter. Section 3.2 describes a pilot experiment conducted to help make decisions about the experimental set-up of the subsequent experiments. Section 3.3 then describes the first experiment, executed to investigate the effect of list position of a secondary task target entry, followed by experiment 2 which was carried out to learn more about the effects of long lists on performance measures (section 3.4). The goal of experiment 3 was to cross-check whether primary task performance improves with shorter list lengths of the secondary task (section 3.5). Sections 3.3, 3.4, and 3.5 start out with a short introduction of experimental goals, followed by a description of experimental methods and results and conclude with a short discussion of the particular experiment. Section 3.6 finally summarizes the findings of all three experiments.

3.1 Theoretical background

According to Fadier and de la Garza (2006), designers must, from a legal standpoint, take necessary steps to ensure that future equipment usage has been anticipated and entails no safety endangering consequences for the persons who will use it.

The longer people have to avert their gaze from the road, the higher the risk of running into dangerous situations due to not having monitored the ongoing traffic. As a result, the risk of accidents increases as well, as the stress induced by such emergency conditions sometimes leads to a speed-accuracy trade-off such that operators are disposed to take rapid but not always appropriate actions.

According to Drury and Clement (1978) and Treisman and Gelade (1980), the number of elements to be searched in a list has a dominant effect on search time. Therefore, a menu should be structured in such a way that target items are reached in the minimum average time. As the number of alternative choices among which an operator must select increases, the time required to respond correctly generally increases

as well. According to the Hick-Hyman Law (Hick, 1952; Hyman, 1953), response latency increases linearly as the logarithm of the number of alternatives is increased.
In a typical menu task, the user must scan and scroll down a list until the target item, word, symbol, or command is located, and then press a key (identity match). In the letter-search task developed by Neisser (1963) for example (see figure 3.1), subjects scan a vertical column of random three- or five-letter sequences until they detect the target letter. Within each search, the time will be directly proportional to the distance of the item from the top of the menu.

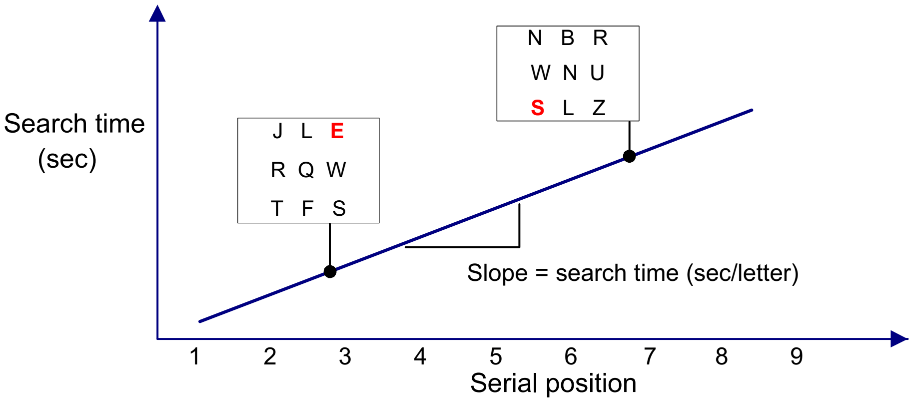


Figure 3.1 Neisser’s letter search paradigm (source: Neisser, 1963)

Several in-vehicle systems on the market utilize hierarchical menu architectures. The safety and usability of such in-vehicle menu systems is very much in question, however. In spite of or in addition to the above mentioned arguments, the question of what makes an in-vehicle menu system too distracting to be used while driving has not as yet been answered satisfactorily. According to Manes and Green (1997), hierarchical menus are too complicated for drivers to learn, even when they devote their full attention to the interface. Additionally, because of their complexity, only younger drivers with computer experience are able to understand the basic concept. If hierarchical systems were not utilized, however, huge amounts of information would have to be organized in long lists, which might aggravate orientation as well. Therefore, the major emphasis of hierarchical organization must be on the proper balance of menu breadth (the number of items one must scan on a given menu) and menu depth (the number of menus one has to pass through to get to the desired information), because it is these elements that effect search time and selection accuracy. For example, the decision whether 64 menu entries are best arranged in one level with 64 entries (1x64) or three levels with four items each (4x4x4) depends on the particular logical groupings of menu items, the space available for each menu, the type and location of the control used to select items, and the time available for users to read through the menu (Manes & Green, 1997). Miller (1980; 1981) proposed that selecting an item from a menu is a linear function of the number of choices on the screen at any given time. In his experiment, there were at each level of the menu 2, 4, 8, or 64 choices, but the number of end nodes, 64, remained constant. The results showed that a menu hierarchy of two levels had the fastest task completion time, produced the fewest number of errors, showed the least amount of variability, and was the easiest to learn. Accordingly, the recommendation for display design was that an expansion in breadth was better than an expansion in depth.

However, Paap and Roske-Hofstrand (1986) have suggested that the organization of items on a given menu may be the more important variable for optimizing speed and accuracy of selection. With a well-defined organization, there need not necessarily be a difference between a deep menu structure (a few items on many menus) and a broad menu structure (many items on a few menus or even a single menu) in terms of the number of items scanned. Indeed, the deeper structure could even require the user to scan more items than would be required on a single, well-structured menu (Mehlenbacher, Duffy, & Palmer, 1989). Thus, the organization of the items on the menu, rather than the depth of the menus, becomes the key determinant of the efficiency of a search.

There are two basic strategies for organizing items on a menu: alphabetical grouping, and grouping based on semantic or functional relationships between the menu items (Mehlenbacher et al., 1989). Landauer and Nachbar (1985) found that mean selection times for entries in menus consisting of words (from four to 14 characters long) were twice as high as for menus consisting of integers (from 1 to 4096). The menus in this experiment were well structured (ordered), which was not the case for the menus in Miller´s experiment. There is also evidence that research that evaluates search efficiency with different menu organization might have difficulties to demonstrate indisputably that, for example, categorical organization is superior to alphabetical organization (Hollands & Merikle, 1987; Mehlenbacher et al., 1989), because the mental organization of the operator is an important factor as well. As McDonald et al. (1983) suggest, categorical organization may be most effective when users have knowledge of a particular subject domain. Conversely, an alphabetically organized menu would be the best choice when users do not have a well-formed mental organization of the subject domain.

In two experiments conducted by Müsseler (1994), participants had to find names in a hierarchical menu. In the first experiment, participants were instructed to find matching items using a graphical user interface and a mouse, while in the second experiment, participants used keyboard shortcuts to retrieve items from a drop down menu. The factors which had the biggest impact on selection time were the number of groupings in the submenu and whether the menu item was overt or covert.

To summarize the above-mentioned findings, factors concerning menu or list structure that are assumed to influence the duration of eyes off the road are (among others) the complexity of the menu tree (the number of menu levels) and each of its branches (the total number of entries in one menu level), the complexity of the entries, the number of entries visible on the screen and accordingly text size, and the position of the target entry in the list.

The aim of the following pilot and three main experiments was to investigate the effects of list length and position of the target entry in an alphabetically ordered list on driving performance, task completion time, and error rate, under a slow and a fast driving condition. The pilot experiment was conducted to help reach decisions about the set-up of the subsequent experiments (described in section 3.2). In the first main experiment, the position of the target entry in a 26-entry list was altered (described in section 3.3). In the second experiment, the total number of list entries of rather long lists (with a maximum of 104 entries) was varied (described in section 3.4) and in the third experiment, the total number of list entries of rather short lists (with a maximum of eight entries) was altered (described in section 3.5). Moreover, in all three experiments the effects of curve radius, direction of curvature, and progress of the search on driving performance were investigated as well. See table 3.1 for an overview.

Table 3.1 Factors investigated in experiments 1-3

Factor	Description	Possible values
Velocity of the car	cm/pixel per second (pps)	3.8cm (95pixel) per sec in the slow condition and 5.4cm (135pixel) per sec in the fast condition
Direction of curvature	Direction of the turn	straight track section, left turn, right turn
Curve radius	Radius of track section	-9.6cm (-240pixel) = sharpest left turn, +9.6cm (240pixel) = sharpest right turn
Searching period	Progress of the search	1st, 3rd and 5th fifth of the searching period
List length		26 entries in exp. 1, 26, 52, 78, and 104 entries in exp. 2, 2, 4, and 8 entries in exp. 3
List position	Position of the target entry in the list	1st, 2nd and 3rd third of the list (only investigated in exp.1)

3.2 Pilot experiment

A pilot experiment was conducted to help make decisions about the set-up of the subsequent experiments, namely to adjust the two levels of car velocity, the maximum value of curve radius, the number of entries displayed in each condition, and the speed of cursor movement in the secondary task list.

3.2.1 Participants

Four paid (€16) volunteers participated in the experiment in equal numbers of males and females. Their age ranged from 26-30 years (mean: 27.3, SD=1.6). All participants were right handed, had normal or corrected-to-normal vision and had held a driver’s licence for at least seven years (mean: 8.5, SD=1.1). Mean kilometres driven per annum were 35050 (SD=38360). Mean daily computer usage was 4.8 hours (SD=1.5).

3.2.2 Experimental setup

Apparatus. The experimental apparatus consisted of the PC, two 17-inch monitors, the steering-wheel, and the joystick. The two monitors were placed in a parallel line in front of the participant on a 120 cm x 80 cm table. Each monitor was 51 cm away from the front edge of the table and with a distance of 30 cm between them. Participants were seated in front of the steering-wheel at an approximate distance of 80 cm to the left of the two monitors. The distance to the right monitor amounted to 1m, which participants were looking at from an angle of approximately 30 degrees. The joystick was mounted on the table at a distance of 15cm to the right of the steering-wheel.

Stimuli on the left monitor. Each bisected block consisted of 45 track sections, starting out with three low demanding track sections without a task prompt. These were followed by six low demanding and six highly demanding track section groups including a task prompt in randomized order. The number of track sections in each group varied between three and four (for further information see Appendix C). 18 of the track sections were straight track sections, 36 were left turns and 36 were right turns. Track sections were moving behind the car at 3.2cm (80pixel) per second in the slow condition and 4.8cm (120pixel) per second in the fast condition. The stimulus to start the secondary task was presented right above the car on the left screen.

Stimuli on the right monitor. On the right screen four entries of an alphabetical list with a total of 26 entries were displayed in all dual task conditions (for further information see Appendix D). Text size of the displayed entries amounted to approximately 3.2 cm (100pt). One list entry consisted of one Latin letter between ‘A’ and ‘Z’ and the digit ‘1’, e.g. D1.

Controls. Stimuli on the left monitor were controlled by the steering-wheel. Stimuli on the right monitor were controlled by the joystick with a push button. Navigation in the list was possible via pushing the joystick up or pulling it down. Confirmation of an entry was executed by pressing the push button at the back of the joystick.

3.2.3 Procedure

After filling out a biographical questionnaire participants were seated in front of the steering-wheel approximately 80 cm away from the left monitor and completed the training phase. Participants were instructed to keep the red car as close to the middle of the grey track lane as possible and prioritize the driving task at all times.

After the general instructions, participants performed 16 bisected conditions (representing eight conditions) in randomized order. Three secondary task types (three different positions of the target entry in the list) and one control (non-task) condition were employed at two different speed levels (see table 3.2).

Table 3.2 Overview of experimental design of the pilot experiment

	Driving only	Target entries located in the 1st third of the list	Target entries located in the 2nd third of the list	Target entries located in the last third of the list
Slow	1	2	3	4
Fast	5	6	7	8

Each bisected condition consisted of 12 trials and was instructed in written format (see Appendix B). After each bisected condition, participants estimated effort and interference of the dual task situation experienced during the preceding condition (for more information see Appendix A). The test phase was interrupted for a short break after half of the experimental runs had been completed. At the end participants answered the questionnaire about driving and computer experience (see Appendix A) and were paid for their services.

3.2.4 Pilot results and discussion

The following decisions were made concerning driving task (section 3.2.4.1) and list selection task set-up (section 3.2.4.2), based on pilot experiment results.

3.2.4.1 Driving task

Levels of car velocity. The first decision was made based on a repeated measures analysis of variance (ANOVA), which showed no significant effects of velocity [$F(1,15)=1.579$, $p>0.3$, $\varepsilon=1.0$], and statements of participants in the questionnaire presented at the end of the experiment, describing both the slow and the fast condition as rather slow. This result was also reflected in the subjective estimation of effort, which showed almost no increase in subjectively estimated workload levels in the fast condition compared to the slow condition. Therefore, both speed conditions were raised by 0.6cm (15pixel) per second from 3.2 to 3.8cm/sec (80 to 95 pixel/sec) in the slow condition and from 4.8 to 5.4cm/sec (120 to 135 pixel/sec) in the fast condition.

Maximum curve radius. To decide on the maximum curve radius very sharp curves with radii up to 12.8cm (320pixel) were included in the experiment to estimate a limit of feasibility. Based on consistent subjective ratings and lane deviation measures (mean lane deviation value of 5.4pixel during moderate curves compared to 11.1pixel during sharp curves), curves with a radius higher than 9.6cm (240pixel) were eliminated from the track. This was true for right and left turns with a radius of 11.2cm (280pixel) and of 12.8cm (320pixel). Accordingly the number of track sections was reduced to 13 (from formerly 17).

3.2.4.2 List selection task

Number of entries displayed. The pilot experiment was started with the easy condition of four entries displayed. This setting was kept for the subsequent experiments, as results revealed no evidence against this set-up.

Velocity of Cursor Movement. The majority of the trials could not be completed successfully due to the fact that the cursor movement was too slow. Therefore, the speed of the cursor was increased from five to seven entries per second.

Summarizing the lessons learned from the pilot experiment concerning primary task demands, the level of car velocity was increased after both performance measures and subjective ratings revealed a task demand level which was obviously too low. Furthermore, the maximum curve radius was decreased after performance measures indicated that the two curves with the highest radii were too demanding. Concerning secondary tasks, cursor speed was increased as a disproportionate number of trials could not have been completed successfully. The number of displayed entries was judged as appropriate and therefore kept for further experiments.

3.3 Experiment 1: List position

3.3.1 Introduction

As pointed out in chapter 1, the goal of the design of any secondary task should be to minimize the time of eyes-off-the-road. If the number of elements to be searched in a list has a dominant effect on search time (Drury & Clement, 1978; Treisman & Gelade, 1980), then list elements positioned at the beginning of the list should result in shorter task completion times than those required for searching entries positioned at the end of the list. Furthermore, performance in the slow conditions is expected to be higher than in the fast conditions, as task demands are supposed to increase with increasing vehicle speed. For these purposes three different secondary task types and one control (non-task) condition were employed at two different speed levels of the car (see table 3.3).

Table 3.3 Overview of experimental design of experiment 1

	Driving only	**Target entries located in the 1st third of the list**	**Target entries located in the 2nd third of the list**	**Target entries located in the 3rd third of the list**
Slow	1	2	3	4
Fast	5	6	7	8

3.3.2 Method

3.3.2.1 Participants

Sixteen paid (€16) volunteers participated in the experiment in equal numbers of males and females. Their age ranged from 20 to 31 years (mean: 23.2 years, SD=2.9 years). All participants were right handed, had normal or corrected-to-normal vision and had held a driver’s licence for at least 4 years (mean: 5.5 years). Mean kilometres driven per annum was 2125 (SD: 2497). Mean daily computer usage was 2.8 hours (SD: 2.6).

3.3.2.2 Experimental setup

Apparatus. The applied apparatus was equivalent to that in the pilot experiment.

Stimuli on the left monitor. Each bisected condition consisted of 45 track sections, starting out with three low demanding track sections without a task prompt. These were followed by six low demanding and six highly demanding track section groups in randomized order which included a task prompt. The number of track sections in each group varied between three and four (for further information see Appendix C). 18 of the track sections were straight track sections, 36 were left turns and 36 were right turns. Track sections were moving behind the car at 3.8cm (95pixel) per second in the slow condition and 5.4cm (135pixel) per second in the fast condition. The stimulus to start the secondary task was presented right above the car on the left screen.

Stimuli on the right monitor. Stimuli on the right monitor did not differ from those displayed in the pilot experiment.

Controls. Applied controls were the same as in the pilot experiment.

3.3.2.3 Procedure

Experimental procedure was similar to that of the pilot experiment.

3.3.3 Results

Data from log files were prepared for further statistical analysis according to the description given in section 2.5.

3.3.3.1 Driving performance (primary task)

Lane deviation. Two repeated measures analysis of variance (ANOVA) were computed on lane deviation. For the first one a 3x2x3x3 factorial design with the factors list position (1st third, 2nd third, 3rd third), velocity (slow, fast), direction of curvature (straight sections, left turns, right turns), and searching period (0-20% of the search, 40-60% of the search, 80-100% of the search) was used. For the second a 3x2x2x3 factorial design with the factors list position (1st third, 2nd third, 3rd third), velocity (slow, fast), curve radius (moderate curves, sharp curves), and searching period (0-20% of the search, 40-60% of the search, 80-100% of the search) was used.

According to the first analysis, neither the main effects of position in the list [F(2,30)=0.653, p>0.5, ε=0.759] nor of velocity [F(1,15)=2.833, p>0.1, ε=1.0] were significant. The main effects of direction of curvature [F(2,30)=6.461, p<0.02, ε=0.551], and searching period [F(2,30)=17.355, p=0.001, ε=0.542], however, were significant, as was the interaction between the two factors [F(4,60)=6.315, p=0.006, ε=0.468], indicating that the effect of searching period was not distributed equally across the different track section types, as displayed in figure 3.2. Lane deviation was lowest for straight track parts (mean of 2.2 pixel, SD=2.3), higher for left turns (mean of 4.1 pixel, SD=5.4) and highest for right turns (mean of 4.6 pixel, SD=5.6). The difference between straight track parts and right turns was significant (p=0.046). Concerning searching periods, lane deviation was lowest during the first fifth of the search (mean of 0.8 pixel, SD=2.2), higher for the third fifth of the search (mean of 3.5 pixel, SD=4.1) and highest for the last fifth of the search (mean of 6.5 pixel, SD=7.2). All of the differences were significant (p<0.01).

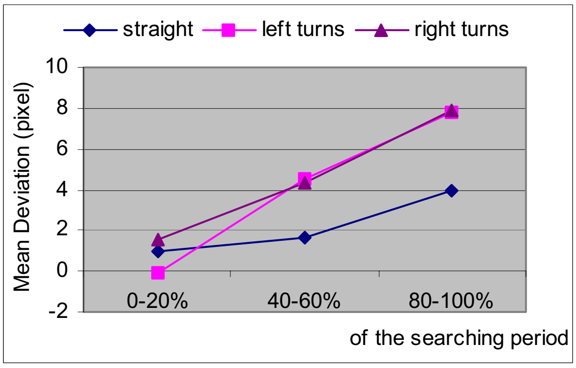


Figure 3.2 Effects of searching period on lane deviation (dual task minus single task values) – experiment 1

Performance was generally better during single task conditions than during dual task conditions, as the overall mean value of lane deviation (dual task values minus single task values) was positive (3.6 pixel, SD=4.4) and significantly (p=0.005) different from zero.

According to the second analysis, neither the main effects of position in the list [F(2,30)=2.66, p>0.08, ε=0.759] nor of velocity [F(1,15)=2.819, p>0.1, ε=1.0] were significant, as was any of the interactions. But the main effects of curve radius [F(1,15)=5.035, p=0.04, ε=1.0] and searching period [F(2,30)=16.934, p<0.001, ε=0.529] were significant. Lane deviation was significantly higher (p=0.04) for sharp curves (mean of 4.6 pixel, SD=5.8) than for moderate curves (mean of 3.5 pixel, SD=4.4).

3.3.3.2 List performance (secondary task)

Percentage of misses. A repeated measures analysis of variance was computed on the percentage of failed trials. A 3x2x2 factorial design with the factors list position (1st third, 2nd third, 3rd third), velocity (slow, fast) and curve radius (moderate curves, sharp curves) was used. According to the analysis, neither the main effect of velocity [F(1,15)=0.857, p>0.3, ε=1.0] nor the main effect of curve radius [F(1,15)=0.246, p>0.6, ε=1.0] was significant, as were none of the interactions. Only the main effect of list position [F(2,30)=6.145, p=0.014, ε=6.145] was significant. The percentage of misses was lowest for searches in the first third of the list (mean of 0.7% misses, SD=1.5), higher for searches in the second third of the list (mean of 2.0% misses, SD=3.5) and highest for searches in the last third of the list (mean of 4.4% misses, SD=4.8). All of the differences were significant (p<0.02).

Task completion times. A repeated measures analysis of variance was computed on task completion times of correctly completed trials using a 3x2x2 factorial design with the factors list position (1st third, 2nd third, 3rd third), velocity (slow, fast) and curve radius (moderate curves, sharp curves). According to the analysis, the main effect of velocity was not significant [F(1,15)=0.045, p>0.8, ε=1.0]. Neither was any of the interactions. The main effects of list position [F(2,30)=369.211, p<0.001, ε=0.656] and curve radius [F(1,15)=36.603, p<0.001, ε=1.0], however, were significant. Task completion times were lowest for searches in the first third of the list (mean of 4.6s, SD=0.7) and higher for both searches in the second (mean of 6.4s, SD=0.6) and the last third of the list (mean of 8.1s, SD=0.7). All of the differences were significant (p<0.001). Task completion times were also significantly (p=0.008) longer for sharp curves (mean of 8.6s) than for moderate curves (mean of 7.8s).

Extra keystrokes (false positive answers). A 2x3x2 repeated measures analysis of variance with the factors velocity (slow, fast), list position (1st third, 2nd third, 3rd third) and curve radius (moderate curves, sharp curves) revealed no significant main effects for either of the factors velocity [F(1,15)=0.266, p>0.6, ε=1.0], list position [F(2,30)=2.151, p>0.1 ε=0.631], or curve radius [F(1,15)=0.537, p>0.4, ε=1.0]. None of the interactions became significant as well. The mean number of extra keystrokes for all correctly completed trials was 0.12, the maximum was 7. The percentage of all error-free completed trials amounted to 91.0%.

3.3.3.3 Subjective ratings

Self-estimated effort. A one-way repeated measures analysis of variance (ANOVA) with the factor velocity (slow, fast) revealed a significant main effect of velocity [F(1,15)=7.604, p=0.015, ε=1.0]. The subjectively estimated effort was significantly lower (p<0.05) in the slow condition (mean value of 1.7) than in the fast condition (mean value of 2.0).

Ratings of interference of secondary task. A one-way repeated measures analysis of variance (ANOVA) with the factor velocity (slow, fast) revealed a significant main effect of velocity [F(1,15)=4.697, p<0.05, ε=1.0]. The subjectively caused by the secondary task was significantly lower (p=0.015) in the slow condition (mean value of 1.2, SD=0.8) than in the fast condition (mean value of 1.5, SD=0.5).

Subjective estimation of task priority. A one-way repeated measures analysis of variance (ANOVA) with the factor velocity (slow, fast) revealed no significant main effect of velocity [F(1,15)=0.229, p>0.6, ε=1.0].

For an overview of the results of experiment 1 see table 3.4.

Table 3.4 Results of Experiment 1. Mean values of lane deviation (pixel), misses (%), secondary task duration times (sec), error rate, subjective ratings of effort, secondary task interference, and attention allocation (with standard deviation in parenthesis).

Objective measures

	Lane deviation *(pixel)*		***Misses*** (%)	***Secondary task completion times*** (sec)	***Number of extra keystrokes***
	(ANOVA 1)	*(ANOVA 2)*			
List position					
1st third	3.7 (4.6)		0.7 (1.5)	4.6 (0.7)	1.5 (2.5)
2nd third	3.7 (5.1)		2.0 (3.5)	6.4 (0.6)	1.1 (1.6)
3rd third	3.4 (3.8)		4.4 (4.8)	8.1 (0.7)	1.2 (1.8)
Velocity					
Slow	3.0 (3.8)		2.0 (1.7)	6.3 (0.7)	1.3 (2.1)
Fast	4.2 (5.4)		2.7 (3.7)	6.4 (0.6)	1.3 (1.8)
Direction of curvature					
Straight sections	2.2 (2.3)				
Left turns	4.1 (5.4)				
Right turns	4.6 (5.6)				
Curve radius					
moderate		3.5 (4.4)	2.5 (2.0)	6.0 (0.5)	1.2 (2.2)
sharp		4.6 (5.8)	2.2 (3.5)	6.8 (0.7)	1.4 (1.7)
Searching period					
0-20% of search	0.8 (2.2)				
40-60% of search	3.5 (4.1)				
80-100% of search	6.5 (7.2)				
Overall	3.6 (4.4)		2.3 (2.5)	6.3 (0.6)	1.3 (1.9)

Subjective measures

	Ratings of effort	***Ratings of secondary task interference***	***Ratings of attention allocation***
Velocity			
Slow	1.2 (0.8)	1.7 (0.6)	5.2 (3.0)
Fast	1.5 (0.5)	2.0 (0.8)	5.4 (3.2)

3.3.4 Discussion experiment 1

Direction of curvature, curve radius and the current state of the search had significant increasing effects on lane deviation values, as well as the interaction between searching period and direction of curvature (ANOVA 1). Surprisingly, results revealed neither a significant main effect of velocity nor of list position on lane deviation. One possible explanation is that both factors did not change throughout one trial (presentation of one target item), thus giving participants enough time to adopt workload decreasing working strategies. Correspondingly, list position did have a significant impairing effect on secondary task performance (percentage of missed trials). Supposing that entries positioned at the end of a list impose higher secondary task demands on the operator than do entries at the beginning of the list, it appears that participants did compensate for increasing task demands by prolonging the duration of the secondary task. Consequently, it can be assumed that list position did very well increase secondary task demands, because drivers were only able to compensate for them by neglecting secondary task performance. Drivers followed this strategy even up to a point where they could not manage to confirm the correct entry in the given time window. In other words, primary task performance was kept relatively constant at the cost of increasing task completion times and an increasing rate of misses (see figure 3.3).

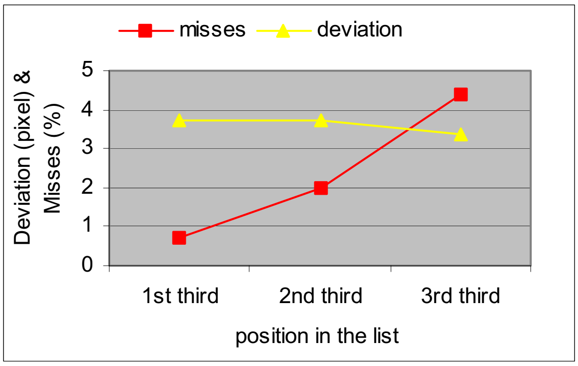


Figure 3.3 Speed-accuracy trade-off between primary (dual task minus single task values) and secondary task – experiment 1

Concerning correctly completed trials the last fifth of the searching period had clear decreasing effects on driving performance which might have resulted from the fact that identifying the target entry required more concentration than just scanning the entries to check if the target item is approaching. In these situations participants appeared incapable of monitoring the driving environment which also explains the significant effect of curve radius on lane deviation, as sharp curves allow only very short periods of inattention which is probably not the case for moderate curves or straight track sections. Interestingly, only the difference between right turns and straight track sections became significant (but not the difference between left turns and straight track sections), an effect which could possibly result from small involuntary movements of the arms when looking to the right in order to scan the list (Heuer & Klein, 1999a, 1999b; Heuer & Klein 2001; Klein & Heuer, 1999). Furthermore, curve radius did not only have a significant effect on lane deviation, it also degraded secondary task performance (task completion times), thus indicating a strong increase in task demands. Stretching out secondary task completion times evidently did not suffice to compensate for increasing task demands induced by sharp curves, thus forcing participants to compromise primary task performance. Another plausible explanation is the fact that curve radius changed quite frequently (with entering any new track section), hence not allowing participants to react to a rather short-term increase in task demands by prolonging the secondary task.

None of the investigated factors had significant effects on the number of extra keystrokes, implicating that participants in this experiment prioritized on accuracy by compromising secondary task completion speed and accuracy (resulting in long task completion times and high rates of misses). The result that list length had a significant effect on secondary task completion times appears to be trivial due to the increased times required to scroll to the end of a list of 26 entries compared to the task completion times when target entries were located at the beginning of the list.

Subjective ratings of experienced effort and secondary task interference revealed a significant effect of velocity. Apparently, participants protected primary task performance by investing more effort, when speed was at a higher level.

To investigate whether participants are able to apply the above mentioned strategies to cope effectively for even longer lists, experiment 2 implements four different list lengths. Starting out with the length of a German alphabet (26 entries) in the least demanding condition, list lengths were then doubled (52 entries), trebled (78 entries), and finally quadrupled (104 entries) for the remaining three higher demanding conditions.

3.4 Experiment 2: List length

3.4.1 Introduction

With the results of experiment 1 indicating that there are no significant differences in primary task performance measures between several positions in a list of a certain length, the question arises, whether introducing different list lengths will show an effect on primary and secondary task performance or whether participants are also able to cope for these changes in secondary task demands. Longer lists are hypothesized to impose higher task demands on the driver than shorter lists as more entries have to be searched to find the target item. Moreover, it shall be investigated whether longer lists increase task demands to an extent where speed conditions have an effect not only on subjective ratings but also on driving performance. For these purposes four different secondary task types and one control (non-task) condition were employed at two different speed levels (see table 3.5).

Table 3.5 Overview of experimental design of exp. 2

	Driving only	List with 26 entries	List with 52 entries	List with 78 entries	List with 104 entries
Slow	1	2	3	4	5
Fast	6	7	8	9	10

3.4.2 Method

3.4.2.1 Participants

Sixteen paid (€24) volunteers participated in the experiment in equal numbers of males and females. Their age ranged from 23 to 34 years (mean: 27.4, SD=3.0). All participants were right handed, had normal or corrected-to-normal vision and had held a driver’s licence for at least four years (mean: 8.6, SD= 2.6). Mean kilometres driven per annum was 6369 (SD=6714). Mean daily computer usage was 3.7 hours (SD=2.4).

3.4.2.2 Experimental setup

Apparatus. The applied apparatus was equivalent to the one used in experiment 1.

Stimuli on the left monitor. Each bisected condition consisted of 57 track sections, starting out with three low demanding track sections without a task prompt. These were followed by six low demanding and six highly demanding track section groups in randomized order which included a task prompt. The number of track sections in each group varied between four and five (for further information see Appendix C). 26 of the track sections were straight track sections, 44 were left turns and 44 were right turns. Track sections were moving behind the car at 3.8cm (95pixel) per second in the slow condition and 5.4cm (135pixel) per second in the fast condition. The stimulus to start the secondary task was presented right above the car on the left screen.

Stimuli on the right monitor. On the right screen four entries of an alphabetical list were displayed. The total amount of list entries varied between 26, 52, 78 and 104 entries in the four dual task conditions. Text size of the displayed entries amounted to ca. 3.2 cm (100pt). One list entry consisted of one Latin letter between ‘A’ and ‘Z’ and:

- the digit ‘1’ (e.g. ‘D1’) in the list with 26 entries,
- the digits ‘1’ or ‘2’ (e.g. ‘D1’ or ‘D2’) in the list with 52 entries,
- the digits ‘1’, ‘2’ or ‘3’ (e.g. ‘D1’, ‘D2’ or ‘D3’) in the list with 78 entries,
- the digits ‘1’, ‘2’, ‘3’ or ‘4’ (e.g. ‘D1’, ‘D2’, ‘D3’ or ‘D4’) in the list with 104 entries.

Controls. Applied controls were the same as in experiment 1.

3.4.2.3 Procedure

After filling out a biographical questionnaire, participants were seated in front of the steering-wheel approximately 1m away from the left monitor and completed the training phase. Participants were instructed to keep the red car as close to the middle of the grey track lane as possible and to prioritize the driving task at all times. After the general instructions, participants performed 20 bisected conditions (representing ten conditions) in randomized order. Four secondary task types (26, 52, 78, 104 entries in the list) and one control (non-task) condition were employed at two different speed levels (see table 3.5). Each bisected condition consisted of 12 trials and was instructed in written format (see Appendix B). After each bisected condition participants estimated effort and interference of the dual task situation during the preceding condition (for more information see Appendix A). The test phase was interrupted for a short break after half of the experimental runs had been completed. At the end, participants answered the questionnaire about driving and computer experience (see also Appendix A) and were paid for their services.

3.4.3 Results

Data from log files were prepared for further statistical analysis according to the description given in chapter 2.5.

3.4.3.1 Driving performance (primary task)

Lane deviation. Two repeated measures analysis of variance (ANOVA) were computed on lane deviation. For the first one a 4x2x3x3 factorial design with the factors list length (26, 52, 78, 104 entries), velocity (slow, fast), direction of curvature (straight sections, left turns, right turns) and searching period (0-20% of the search, 40-60% of the search, 80-100% of the search) was used. For the second a 4x2x2x3 factorial design with the factors list length (26, 52, 78, 104 entries), velocity (slow, fast), curve radius (moderate curves, sharp curves), and searching period (0-20% of the search, 40-60% of the search, 80-100% of the search) was used. According to the first analysis, neither the main effects of list length [$F(3,45)=2.071$, $p>0.14$, $\varepsilon=0.625$] nor of velocity [$F(1,15)=1.134$, $p>0.3$, $\varepsilon=1.0$] were significant. The main effects of direction of curvature [$F(2,30)=6.866$, $p=0.004$, $\varepsilon=0.998$] and searching period [$F(2,30)=45.476$, $p<0.001$, $\varepsilon=0.677$], however, were significant. Concerning direction of curvature, lane deviation was lowest for straight track parts (mean of 1.6 pixel, SD=1.1), higher for left turns (mean of 2.2 pixel, SD=1.5) and highest for right turns (mean of 2.5 pixel, SD=1.7). The difference between straight track parts and right turns was significant ($p=0.008$). Lane deviation was also lowest during the first fifth of the search (mean of 0.3 pixel, SD=1.0), and higher for both the third (mean of 2.1 pixel, SD=1.5) and the last fifth of the search (mean of 3.9 pixel, SD=2.2). All of the differences were significant ($p<0.001$). Furthermore, the interaction between list length and searching period was significant [$F(6,90)=6.466$, $p<0.001$, $\varepsilon=0.583$], as well as the interaction between direction of curvature and searching period [$F(4,60)=4.821$, $p=0.002$, $\varepsilon=0.767$], indicating that the effects of searching period were not equally distributed across all list lengths or track section types.

Performance was also generally better during single task conditions than during dual task conditions, as the overall mean value of lane deviation (dual task minus single task values) was positive (2.1 pixel, SD=1.4) and significantly (p<0.001) different from zero.

The second analysis revealed neither a significant main effect of list length [F(3,45)=1.431, p>0.2, ε=0.935] nor of velocity [F(1,15)=1.455, p>0.2, ε=1.0]. The main effect of curve radius [F(1,15)=5.629, p=0.031, ε=1.0] and searching period [F(2,30)=32.132, p<0.001, ε=0.71], however, were significant, as was the interaction between list length and searching period [F(6,90)=3.577, p=0.022, ε=0.488]. Lane deviation was significantly higher (p=0.031) during trials with sharp curves (mean of 2.2 pixel, SD=1.2) than during trials with straight track parts and moderate curves (mean of 2.7 pixel, SD=1.3).

3.4.3.2 List performance (secondary task)

Misses. A repeated 4x2x2 measures analysis of variance with the factors list length (26, 52, 78, 104 entries), velocity (slow, fast), and curve radius (moderate curves, sharp curves) revealed no significant main effects of velocity [F(1,15)=2.58, p>0.1, ε=1.0] and curve radius [F(1,15)=1.238, p>0.2, ε=1.0]. The main effect of list length [F(3,45)=7.715, p=0.006, ε=0.489] however was significant, as was the interaction between list length and curve radius [F(3,45)=3.724, p=0.043, ε=0.581], indicating different effects of curve radius depending on the number of entries in the list. The percentage of misses was lowest for searches in a list of 26 entries (mean of 0.8% misses, SD=1.8) and higher for searches in lists with 52 entries (mean of 2.3% misses, SD=5.2), 78 entries (mean of 5.7% misses, SD=8.2), and 104 entries (mean of 8.9% misses, SD=12.1). The differences between list lengths of 52 and 78 entries (p=0.019) and 52 and 104 entries (p=0.047) were significant.

Task completion times. A 4x2x2 repeated measures analysis of variance with the factors list length (26, 52, 78, 104 entries), velocity (slow, fast) and curve radius (moderate curves, sharp curves) revealed no significant main effect of velocity [F(1,15)=0.46, p>0.8, ε=1.0]. The main effects of list length [F(3,45)=281.261, p<0.001, ε=0.931] and curve radius [F(1,15)=48.812, p<0.001, ε=1.0], however, were significant, as was the interaction between the two factors [F(3,45)=8.502, p<0.001, ε=0.781], indicating that the effect of curve radius on task completion times was not equal for all list lengths. Task completion times were lowest for a list length of 26 entries (mean of 6.4s, SD=1.7) and higher for list lengths of 52 entries (mean of 8.8s, SD=1.7), 78 entries (mean of 10.4s, SD=1.7), and 104 entries (mean of 11.8s, SD=1.4). All of the differences were significant ($p<0.001$).

Extra keystrokes (false positive answers). A repeated measures analysis of variance was computed on extra keystrokes. A 2x4x2 factorial design with the factors velocity (slow, fast), list length (26, 52, 78, 104 entries) and curve radius (moderate curves, sharp curves) was used. According to the analysis, the main effects of velocity [$F(1,15)=1.552$, $p>0.2$, $\varepsilon=1.0$] and list length [$F(1,15)=1.798$, $p>0.1$, $\varepsilon=0.819$] were not significant, nor was any of the interactions. Only the main effect of curve radius [$F(1,15)=6.579$, $p<0.03$, $\varepsilon=1.0$] was significant. The number of extra keystrokes was significantly higher during sharp curves (mean of 1.0, SD=0.6) than for moderate curves (mean of 0.7, SD=0.4). The mean number of extra keystrokes for all correctly completed trials was 0.07, the maximum was 3. The percentage of all error-free completed trials amounted to 93.0%.

3.4.3.3 Subjective ratings

Self-estimated effort. A 4x2 repeated measures analysis of variance with the factors list length (26, 52, 78, 104 entries) and velocity (slow, fast) revealed no significant main effect of list length [$F(3,45)=1.47$, $p>0.2$, $\varepsilon=0.765$]. But the main effect of velocity [$F(1,15)=35.984$, $p<0.001$, $\varepsilon=1.0$] was significant with the subjectively estimated effort being significantly lower ($p<0.001$) in the slow condition (mean value of 1.4, SD=0.8) than in the fast condition (mean value of 2.0, SD=0.7). The interaction between the two factors was not significant [$F(3,45)=0.296$, $p>0.8$, $\varepsilon=0.857$].

Ratings of secondary task interference. A 4x2 repeated measures analysis of variance with the factors list length (26, 52, 78, 104 entries) and velocity (slow, fast) revealed no significant main effect of list length [$F(3,45)=1.746$, $p>0.17$, $\varepsilon=0.897$]. The main effect of velocity [$F(1,15)=72.824$, $p<0.001$, $\varepsilon=1.0$], however, was significant. The subjectively estimated effort was significantly lower ($p<0.001$) in the slow condition (mean value of 1.9, SD=0.7) than in the fast condition (mean value of 2.7, SD=0.6). The interaction between the two factors was not significant [$F(3,45)=0.273$, $p>0.8$, $\varepsilon=0.927$].

Subjective estimation of task priority. A 5x2 repeated measures analysis of variance with the factors list length (no list, 26, 52, 78, and 104 entries) and velocity (slow, fast) revealed both significant main effects of list length [$F(4,60)=68,152$, p<0.004, ε=0.852] and velocity [F(1,15)=7.225, p=0.017, ε=1.0]. The differences in subjectively estimated allocations of attention between the different conditions were significant only between the no list condition and all list conditions (p<0.001). See figure 3.4 for the distribution of attention. The interaction between the two factors was not significant [F(3,45)=0.581, p>0.6, ε=0.739].

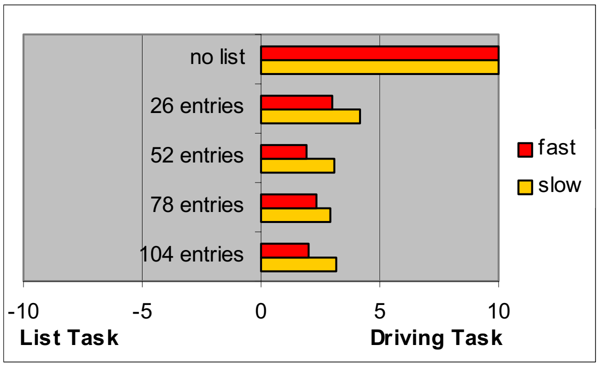


Figure 3.4 Distribution of attention allocation – experiment 2

For an overview of the results of experiment 2 see table 3.6.

Table 3.6 Results of Experiment 2. Mean values of lane deviation (pixel), misses (%), secondary task duration times (sec), error rate, subjective ratings of effort, secondary task interference, and attention allocation (with standard deviation in parenthesis)

Objective measures

	Lane deviation *(pixel)* *(ANOVA 1)*	*(ANOVA 2)*	***Misses*** (%)	***Secondary task completion times*** (sec)	***Number of extra keystrokes***
List length					
26 entries	2.4 (1.2)		0.8 (1.8)	*6.4 (1.7)*	0.9 (0.7)
52 entries	2.4 (1.3)		2.3 (5.2)	8.8 (1.7)	1.0 (0.7)
78 entries	1.8 (1.9)		5.7 (8.2)	10.4 (1.7)	0.6 (0.5)
104 entries	1.8 (1.9)		8.9 (12.1)	11.8 (1.4)	0.7 (0.6)
Velocity					
Slow	1.9 (1.2)		3.8 (5.6)	9.4 (1.3)	0.7 (0.5)
Fast	2.3 (1.7)		5.0 (7.4)	9.4 (1.8)	0.9 (0.5)

Objective measures (continued)

	Lane deviation *(pixel)*		***Misses*** (%)	***Secondary task completion times*** (sec)	***Number of extra keystrokes***
	(ANOVA 1)	*(ANOVA 2)*			
Direction of curvature					
Straight sections	1.6 (1.1)				
Left turns	2.2 (1.5)				
Right turns	2.5 (1.7)				
Curve radius					
moderate		2.2 (1.2)	4.8 (5.9)	8.8 (1.6)	0.7 (0.4)
sharp		2.7 (1.3)	4.1 (7.1)	9.9 (1.6)	1.0 (0.6)
Searching period					
0-20% of search	0.3 (1.0)				
40-60% of search	2.1 (1.5)				
80-100% of search	3.9 (2.2)				
Overall	2.1 (1.4)		4.4 (6.4)	9.4 (1.6)	0.8 (0.4)

Subjective measures

	Ratings of effort	***Ratings of secondary task interference***	***Ratings of attention allocation***
List length			
26 entries	1.5 (0.8)	2.1 (0.8)	3.6 (2.1)
52 entries	1.7 (0.7)	2.3 (0.7)	2.5 (2.0)
78 entries	1.7 (0.8)	2.3 (0.6)	2.6 (2.5)
104 entries	1.8 (0.9)	2.4 (0.7)	2.6 (2.5)
Velocity			
Slow	1.4 (0.8)	1.9 (0.7)	3.8 (2.2)
Fast	2.0 (0.7)	2.7 (0.6)	4.7 (1.8)

3.4.4 Discussion experiment 2

Direction of curvature, curve radius and the current state of the search had significant decreasing effects on driving performance, as well as the interaction between searching period and direction of curvature (ANOVA 1). Unexpectedly, results revealed neither a significant effect of velocity nor of list length on driving performance.

Only the interaction between list length and searching period became significant (see figure 3.5). As large numbers of entries in a list possibly entail longer ways to the target item, participants had obviously not reached the critical part at the end of the search during the medium 40-60% of the search when searching in lists with 104 entries. Consequently, lane deviation increased significantly only when entering the last fifth of the search. Contrary, in a rather short list of 26 entries a participant might have already been close to the target item during 40% and 60% of the search resulting in a significant increase of lane deviation already at this state. Medium list lengths of 52 and 78 entries, however, show a continuous rise in lane deviation throughout all of the searching periods. This finding strengthens the assumption that secondary task demands do not become intrusive before getting close to the target item in the list, thus forcing the participant to focus on the list in order to select the correct item (identity match).

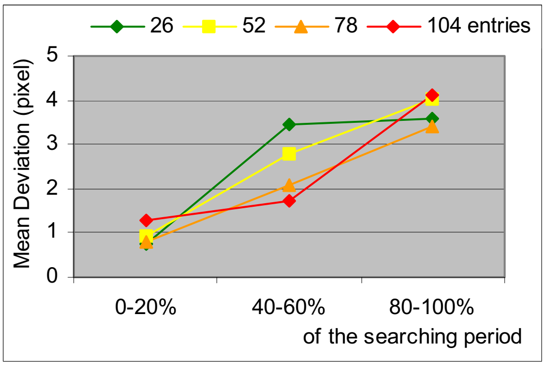


Figure 3.5 Interacting effects of list length and searching period (dual task minus single task values) – experiment 2

Interestingly, driving performance was generally worst for a list length of 26 entries, and decreased with increasing list lengths, even though not significantly. At the same time list length did have a significant effect on the percentage of trials which could not have been completed correctly in the given time window, as shown in figure 3.6). Apparently participants traded off secondary task completion speed and primary task accuracy, as higher values of lane deviation were accompanied by lower rates of misses and vice versa. In other words, the relatively constant level of driving performance was achieved at the cost of a significantly increasing rate of misses. Hence, list length had a significant effect on secondary task completion times despite the effect of increasing search times required by increasing list lengths.

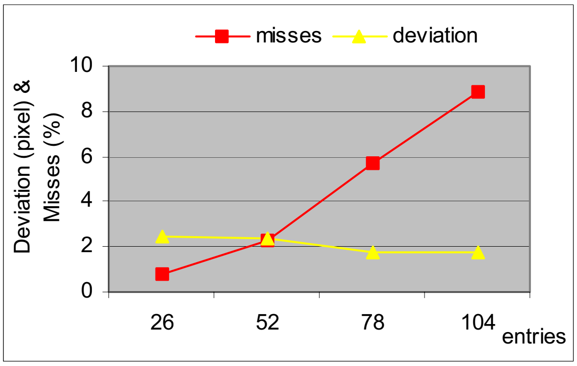


Figure 3.6 Speed-accuracy trade-off between primary (dual task minus single task values) and secondary task – experiment 2

More interestingly velocity had as well a significant effect on secondary task performance (task completion times) with trials requiring more time to be completed during fast conditions. But participants could obviously compensate completely for increasing task demands of higher speed levels by increasing secondary task completion times, thus effectively protecting driving performance. Direction of curvature as well as the interaction between direction of curvature and searching period (ANOVA 1) had a significant effect on driving performance. As in experiment 1, only the difference between right turns and straight track sections became significant, an effect which could possibly result from small involuntary movements of the arm when looking to the right in order to scan the list (Heuer & Klein, 1999a, 1999b; Heuer & Klein 2001; Klein & Heuer, 1999). Curve radius, however, did not only have a significant effect on lane deviation, it degraded secondary task performance (error rate) as well, thus indicating a strong increase in task demands. Apparently, participants reacted to increasing driving task demands by neglecting the secondary task of list search, a strategy which seems not to be efficient enough to avoid compromising driving task performance. Subjective ratings of experienced effort and secondary task interference revealed a significant effect of velocity, indicating that participants protected primary task performance by investing more effort, when speed was at a higher level.
As performance measures did not differ clearly from those of experiment 1, experiment 3 was conducted to cross-check whether primary task performance improves with shorter lists.

3.5 Experiment 3: Short list

3.5.1 Introduction

With the results of experiments 1 and 2 indicating that there is no significant difference in primary task performance measures between several positions in a list of a certain length and different list lengths, the question arises, whether introducing very short list lengths will have an enhancing effect on primary and secondary task performance. As less entries have to be searched in short lists, it is assumed that short lists impose fewer secondary task demands on the driver. The question arises whether a critical number of list entries can be identified from which on task demands start to increase in a performance degrading manner. Therefore, one control (non-task) condition and three secondary task types were implemented in the following experiment: a list with two entries, which introduces the possibility of having the entire list displayed on the screen, a list with four entries which requires to scroll one entry down in order to reach the last position and finally a list with eight entries, which forces the user to scroll down the list in order to reach most of the entries. Each condition was again presented at two different speed levels (see table 3.7).

Table 3.7 Overview of experimental design of experiment 3

	Driving only	List with 2 entries	List with 4 entries	List with 8 entries
Slow	1	2	3	4
Fast	5	6	7	8

3.5.2 Method

3.5.2.1 Participants

Sixteen paid (€16) volunteers participated in the experiment in equal numbers of males and females. Their age ranged from 20 to 34 years (mean: 25.9, SD=4.2). All participants were right handed, had normal or corrected-to-normal vision and had held a driver’s licence for at least two years (mean: 8.0, SD=4.1). Mean kilometres driven per annum was 7263 (SD=7286). Mean daily computer usage was 3.8 hours (SD=2.6).

3.5.2.2 Experimental setup

Apparatus. The applied apparatus was similar to that of the preceding experiments.

Stimuli on the left monitor. Stimuli on the left monitor were equivalent to those of the preceding experiments.

Stimuli on the right monitor. On the right screen four entries of the list were displayed (for further information see Appendix D). Due to the fact that the list was very short the first and the last entry of the list were blank lines containing only one dot (see figure 2.4a). Especially for the list with two entries these blank lines were essential to ensure that participants had to take a look at the list. The total amount of searchable list entries varied between two, four and eight entries in the three dual task conditions. One list entry consisted of one Latin letter between:

- ‘A’ and ‘B’ and the digit ‘1’ (e.g. ‘B1’) in the list with two entries,
- ‘A’ and ‘D’ and the digit ‘1’ (e.g. ‘D1’) in the list with four entries,
- ‘A’ and ‘H’ and the digit ‘1’ (e.g. ‘H1’) in the list with eight entries.

Text size of the displayed entries amounted to approximately 3.2 cm (100pt).

Controls. Applied controls were the same as in the preceding experiments.

3.5.2.3 Procedure

After filling out a biographical questionnaire, participants were seated in front of the steering-wheel approximately 1m away from the left monitor and completed the training phase. Participants were instructed to keep the red car as close to the middle of the grey track lane as possible and prioritize the driving task at all times. After the general instructions, participants performed 16 bisected conditions (representing eight conditions) in randomized order. Three secondary task types (2, 4, 8 entries in the list) and one control (non-task) condition were employed at two different speed levels (see table 3.8). Each bisected condition consisted of 12 trials and was instructed in written format (for detailed information see Appendix B). After each bisected condition participants estimated effort and interference of the dual task situation during the preceding trial (see Appendix A). The test phase was interrupted for a short break after half of the experimental runs had been completed. At the end, participants answered the questionnaire about driving and computer experience (see Appendix A) and were paid for their services.

3.5.3 Results

Data from log files were prepared for further statistical analysis according to the description given in chapter 2.5.

3.5.3.1 Driving performance (primary task)

Lane deviation. Two repeated measures analysis of variance (ANOVA) were computed on lane deviation. For the first one a 3x2x3x3 factorial design with the factors list length (2, 4, and 8 entries), velocity (slow, fast), direction of curvature (straight sections, left turns, right turns), and searching period (0-20% of the search, 40-60% of the search, 80-100% of the search) was used. For the second one a 3x2x2x3 factorial design with the factors list length (2, 4, and 8 entries), velocity (slow, fast), curve radius (moderate curves, sharp curves), and searching period (0-20% of the search, 40-60% of the search, 80-100% of the search) was used. According to the first analysis, neither the main effects of velocity [F(1,15)=2.553, p>0.1, ε=1.0] nor of direction of curvature [F(2,30)=2.22, p>0.1, ε=0.826] were significant. But the main effects of list length [F(2,30)=7.959, p=0.007, ε=0.636] and searching period [F(2,30)=37.781, p<0.001, ε=0.846] were significant. Lane deviation was lowest for a list length of two entries (mean of 1.2 pixel, SD=0.9), higher for a list length of four entries (mean of 1.4 pixel, SD=0.8) and highest for a list length of eight entries (mean of 2.6 pixel, SD=1.8). The differences between list lengths of two and eight entries (p=0.026) and between four and eight entries (p=0.039) were significant. Moreover, lane deviation was lowest during the first fifth of the search (mean of 0.2 pixel, SD=0.9), higher for the third fifth of the search (mean of 1.7 pixel, SD=1.3) and highest for the last fifth of the search (mean of 3.2 pixel, SD=1.4). All of the differences were significant (p<0.003). Also, the interactions between list length and searching period [F(4,60)=4.786, p=0.011, ε=0.575], between velocity and searching period [F(2,30)=3.513, p=0.043, ε=0.975], and direction of curvature and searching period [F(4,60)=3.53, p=0.012, ε=0.852] were significant, indicating that the effects of different searching periods were not equally distributed along the different list lengths, speed conditions or directions of curvature. Performance was generally better during single task conditions than during dual task conditions, as the overall mean value of lane deviation (dual task minus single task values) was positive (1.7 pixel, SD=0.9) and significantly (p<0.001) different from zero.

According to the second analysis, neither the main effects of velocity [F(1,15)=2.889, p>0.1, ε=1.0] nor of curve radius [F(1,15)=0.306, p>0.5, ε=1.0] were significant, but the main effects of list length [F(2,30)=6.875, p=0.13, ε=0.617] and searching period [F(2,30)=42.166, p<0.001, ε=0.855] were, as was the interaction between the two factors [F(4,60)=6.328, p=0.006, ε=0.472].

3.5.3.2 List performance (secondary task)

Misses. A 2x3x2 repeated measures analysis of variance with the factors velocity (slow, fast), list length (2, 4, and 8 entries) and curve radius (moderate curves, sharp curves) revealed no significant main effects for either of the factors velocity [F(1,15)=2.87, p>0.1, ε=1.0], list length [F(2,30)=0.522, p>0.5, ε=0.714], or curve radius [F(1,15)=1.667, p>0.2, ε=1.0], nor for any of the interactions.

Task completion times. A 3x2x2 repeated measures analysis of variance with the factors list length (2, 4, and 8 entries), velocity (slow, fast) and curve radius (moderate curves, sharp curves) revealed no significant main effect of curve radius [F(1,15)=0.379, p>0.5, ε=1.0]. The main effects of list length [F(2,30)=134.23, p<0.001, ε=0.894] and velocity [F(1,15)=6.467, p=0.023, ε=1.0], however, were significant, as well as the interaction between velocity and curve radius [F(1,15)=8.318, p=0.01, ε=1.0], as displayed in figure 3.7.

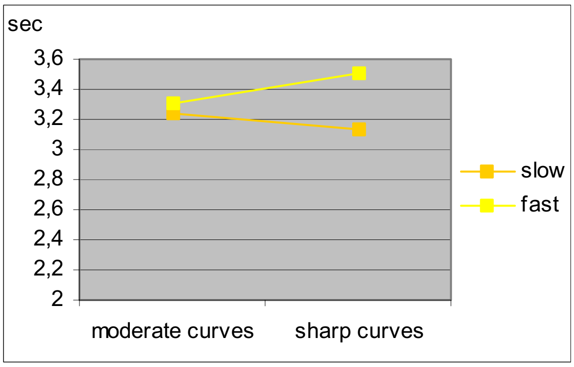


Figure 3.7 Effects of velocity and curve radius on task completion times – experiment 3

Task completion times were lowest for a list length of two entries (mean of 2.5s, SD=0.6) and higher for both a list length of four (mean of 3.2s, SD=0.7) and eight entries (mean of 4.2s, SD=0.8). All differences were significant (p<0.001).

Extra keystrokes (false positive answers). A 2x3x2 repeated measures analysis of variance (ANOVA) with the factors velocity (slow, fast), list length (2, 4, and 8 entries), and curve radius (moderate curves, sharp curves) was computed on extra keystrokes. According to the analysis the main effects of velocity [F(1,15)=2.684, p>0.1, ε=1.0] and list length [F(2,30)=0.277, p>0.3, ε=0.683] were not significant, nor were any of the interactions. Only the main effect of curve radius was significant [F(1,15)=8.715, p=0.01, ε=1.0] with the mean number of extra keystrokes being significantly higher during trials consisting of sharp curves (mean of 0.7, SD=0.7) than during those consisting of straight track parts and moderate curves (mean of 0.5, SD=0.6). The mean number of extra keystrokes for all correctly completed trials was 0.05, the maximum was 2. The percentage of all error-free completed trials was 95.0%.

3.5.3.3 Subjective ratings

Self-estimated effort. A 4x2 repeated measures analysis of variance (ANOVA) with the factors list length (no list, 2, 4, and 8 entries) and velocity (slow, fast) revealed significant main effects of both list length [F(3,45)=34.974, p<0.001, ε=0.782] and velocity [F(1,15)=5.535, p<0.04, ε=1.0]. The subjectively estimated effort was lowest for the single task condition (mean value of 0.4, SD=0.6) and higher for the dual task situations of two (mean value of 0.9, SD=0.6), four (mean value of 1.2, SD=0.7) and eight list entries (mean value of 1.7, SD=0.6). All of the differences were significant (p<0.005), except the difference between a list length of two and four entries (p>0.06). The subjectively estimated effort was significantly lower (p<0.04) in the slow condition (mean value of 0.9, SD=0.5) than in the fast condition (mean value of 1.2, SD=0.6). The interaction between the two factors was not significant [F(3,45)=0.418, p>0.7, ε=0.749].

Ratings of secondary task interference. A 3x2 repeated measures analysis of variance (ANOVA) with the factors list length (2, 4, and 8 entries) and velocity (slow, fast) revealed significant main effects of both list length [F(3,45)=40.419, p<0.001, ε=0.957] and velocity [F(1,15)=13.196, p=0.002, ε=1.0]. The subjectively estimated interference of the secondary task was lowest for a list length of two entries (mean value of 1.2, SD=0.7) and higher for both a list length of four (mean value of 1.7, SD=0.9) and eight entries (mean value of 2.3, SD=0.7). All of the differences were significant (p<0.003). The subjectively estimated effort was also significantly lower (p=0.002) in the slow condition (mean value of 1.6, SD=0.6) than in the fast condition (mean value of 1.9, SD=0.8). The interaction between the two factors was not significant [F(3,45)=0.519, p>0.6, ε=0.826].

Subjective estimation of task priority. A 4x2 repeated measures analysis of variance (ANOVA) with the factors list length (no list, 2, 4, and 8 entries) and velocity (slow, fast) revealed that the main effect of velocity [F(1,15)=1.024, p>0.3, ε=1.0] was not significant, nor was the interaction between velocity and list length [F(3,45)=0.748, p>0.5, ε=0.68]. The main effect of list length [F(3,45)=29.412, p<0.001, ε=0.684], however, was significant. All of the differences in subjectively estimated allocations of attention between the different conditions were significant (p<0.04). See figure 3.8 for the distribution of attention allocation.

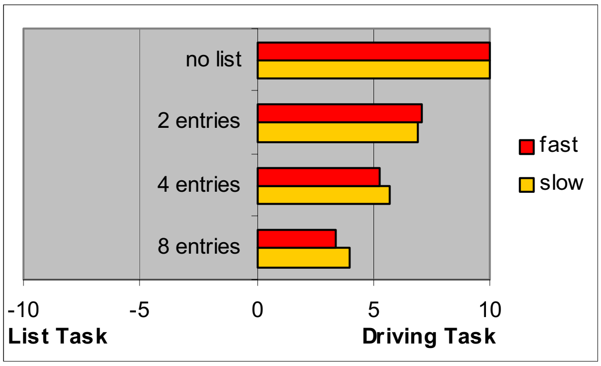


Figure 3.8 Distribution of task priority – experiment 3

For an overview of the results of experiment 3 see table 3.8.

Table 3.8 Results of Experiment 3. Mean values of lane deviation (pixel), misses (%), secondary task duration times (sec), error rate, subjective ratings of effort, secondary task interference, and attention allocation (with standard deviation in parenthesis)

Objective measures					
	Lane deviation *(pixel)*		***Misses*** (%)	***Secondary task completion times*** (sec)	***Number of extra keystrokes***
	(ANOVA 1)	*(ANOVA 2)*			
List length					
2 entries	1.2 (0.9)		0.1 (0.5)	2.5 (0.6)	0.6 (0.6)
4 entries	1.4 (0.8)		0.4 (1.1)	3.2 (0.7)	0.5 (0.5)
8 entries	2.6 (1.8)		0.5 (1.6)	4.2 (0.8)	0.7 (1.0)

Objective measures (continued)

	Lane deviation *(pixel)* *(ANOVA 1)*	*(ANOVA 2)*	***Misses*** (%)	***Secondary task completion times*** (sec)	***Number of extra keystrokes***
Velocity					
Slow	1.5 (0.7)		0.1 (0.3)	3.2 (0.6)	0.5 (0.7)
Fast	2.0 (1.3)		0.6 (1.3)	3.4 (0.7)	0.7 (0.7)
Direction of curvature					
Straight sections	1.5 (0.7)				
Left turns	1.7 (1.3)				
Right turns	2.0 (1.0)				
Curve radius					
moderate		1.8 (1.2)	0.2 (0.5)	3.3 (0.6)	0.5 (0.6)
sharp		1.9 (1.0)	0.5 (1.2)	3.3 (0.8)	0.7 (0.7)
Searching period					
0-20% of search	0.2 (0.9)				
40-60% of search	1.7 (1.3)				
80-100% of search	3.2 (1.4)				
Overall	1.7 (0.9)		0.3 (0.8)	3.3 (0.7)	0.6 (0.6)

Subjective measures

	Ratings of effort	***Ratings of secondary task interference***	***Ratings of attention allocation***
List length			
no list	0.4 (0.6)	-	*10.0 (0)*
2 entries	0.9 (0.6)	1.2 (0.7)	7.0 (2.9)
4 entries	1.2 (0.7)	1.7 (0.9)	5.6 (3.5)
8 entries	1.7 (0.6)	2.3 (0.7)	3.7 (3.4)
Velocity			
Slow	0.9 (0.5)	1.6 (0.6)	6.7 (2.2)
Fast	1.2 (0.6)	2.0(0.8)	6.4 (2.5)

3.5.4 Discussion experiment 3

List lengths of eight entries and higher and the current state of the search had significant decreasing effects on driving performance, as well as the interaction between the two factors (both ANOVAs). In addition, the interactions between searching period and velocity (ANOVA 1), as well as between searching period and direction of curvature (ANOVA 1) were significant. These results strengthen the assumption that the current status of the search represents the strongest impairing effect on driving performance. As participants have to concentrate more on the secondary task when reaching the target item in the list in order to identify it, they apparently could not control driving task demands at the same time. Furthermore, several task demands evidently added up to a performance degrading point. Thus, with a secondary task containing only two or four entries in the list, increasing demands during the progress of the search could still be compensated. The moment, participants were required to scroll in the list of eight entries, effects of searching period show much stronger decreasing effects on driving performance, as displayed in figure 3.9.

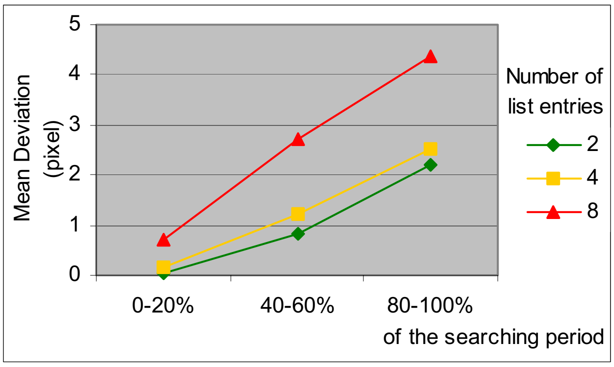


Figure 3.9 Effects of list length and searching period on lane deviation (dual task minus single task values) – experiment 3

Neither direction of curvature nor curve radius had a significant effect on driving performance in this experiment any more. Obviously, shorter list lengths enabled participants to compensate for rather frequently changing factors as well, thus also decreasing the general rate of misses. Only curve radius did have an effect on the number of extra keystrokes which was significantly higher during sharp curves. Again, participants appeared to compensate for increasing primary task demands by accepting errors and hence longer task completion times in order to protect primary task performance. List length as well as velocity had a significant effect on secondary task completion times, although there were almost no misses any more in experiment 3. This effect of list length is interesting as is can not be explained completely by the increased amount of time required for searching a list two entries longer or shorter than the other. Thus, being forced to observe moving entries on the screen appears to cause the increase in task demands, rather than the length of the list itself. Interestingly, having to scroll down one entry only for the last item of a list (as it was the case for a list length of four entries) still takes significantly longer than choosing between motionless entries on the screen (as it was the case for a list length of two entries).

Subjective ratings of experienced effort and secondary task interference revealed significant effects of list length and velocity. Apparently participants protected driving task performance by investing more effort, when speed was at a higher level or list length was increasing. But concerning list length, investing more effort was obviously not sufficient to prevent increases in lane deviation. List length had also a significant effect on subjective ratings of attention allocation, indicating that participants were well aware of the fact that they were compromising primary task performance.

3.6 Discussion experiments 1, 2, and 3

Lane deviation as well as errors served as a measure for accuracy regarding primary task performance and secondary task performance respectively. Task completion times and misses served as an overall measure of speed. Subjective measures served the purpose to detect small changes in subjectively experienced task difficulty, caused by variations in primary- and secondary task demands.

Summarizing the results of the preceding experiments, lane deviation was significantly effected by searching period and the interaction of direction of curvature and searching period in all three experiments. Direction of curvature and curve radius had furthermore a significant effect on lane deviation in experiments 1 and 2 only, while list length effected lane deviation in experiment 3 only. The interaction between list length and searching period affected lane deviation in experiments 2 and 3 and the interaction between velocity and searching period had a significant effect on lane deviation in experiment 3 only. Error rate was significantly effected by curve radius in experiments 2 and 3 only. Misses occurred only in experiments 1 and 2, being significantly effected by list position (experiment 1) and list length (experiment 2). More generally, task completion times were significantly effected by list length in all experiments, by curve radius in experiment 1 and by velocity in experiments 2 and 3. Ratings of subjectively experienced effort and secondary task interference revealed a significant effect of velocity in all three experiments and a significant effect of list length in experiment 3. In the following sections each of the effects of driving speed, list length, direction of curvature, curve radius and searching period on lane deviation, error rate, misses and task completion times, as well as on subjective experiences shall be discussed in detail.

The effect of driving speed. Driving performance was relatively unaffected by speed variations throughout all three experiments. But there was a significant effect of driving speed on the list task concerning task completion times for all list lengths in experiment 2 and for the list lengths of four and eight entries in experiment 3. It appears that taking more time to complete the list task was participants' reaction to an increase in workload induced by a faster movement of the car. They prolonged the secondary task in order not to compromise the driving task. These results are in a line with predictions of Hockey's compensatory control model (1997), where he claims that a driver prioritizes tasks with the protection of the main task goal. The increase in mental workload, however, became obvious in the subjective ratings of effort.

The effect of list length. Task demands increased in a manner detrimental to driving performance for list lengths of eight entries and higher. Consistently, only the differences between eight entries and shorter lists in experiment 3 had a significant effect on lane deviation. The comparatively low values in lane deviation for experiment 2 (see figure 3.10) can be partly explained by the fact that participants had more time to complete the secondary task: As the time window to complete a trial in experiment 2 was approximately 4s longer than in all other experiments, due to a maximum list length of 104 entries which entailed longer task durations. Accordingly, the higher lane deviations in experiment 1 indicate the performance loss caused by a higher time pressure.

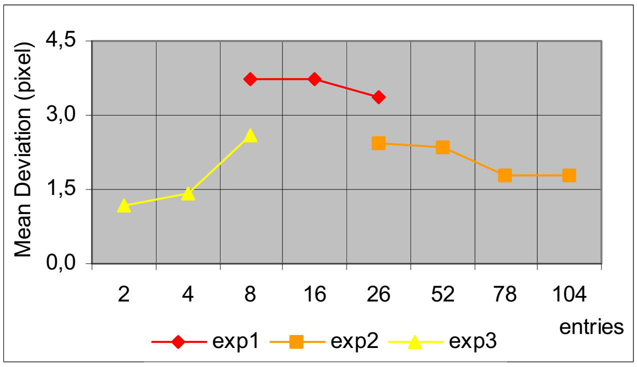


Figure 3.10 Effect of list length on lane deviation (dual task minus single task values) – experiments 1-3

The decrease in lane deviation for lists longer than 52 entries, however, has to be explained in another way, as time pressure is expected to increase again with a large number of entries in the list. Apparently, very long lists allowed participants to implement efficient switching strategies and schedule tasks more efficiently. Furthermore, participants protected primary task goals (lane deviation did not differ significantly between the different list lengths) by prolonging the duration of the secondary task. Thus, the high percentages of misses for longer list lengths in experiment 2 are another explanation for the rather low lane deviation values (see figure 3.11). In other words, participants efficiently protected primary task performance by prolonging secondary task durations.

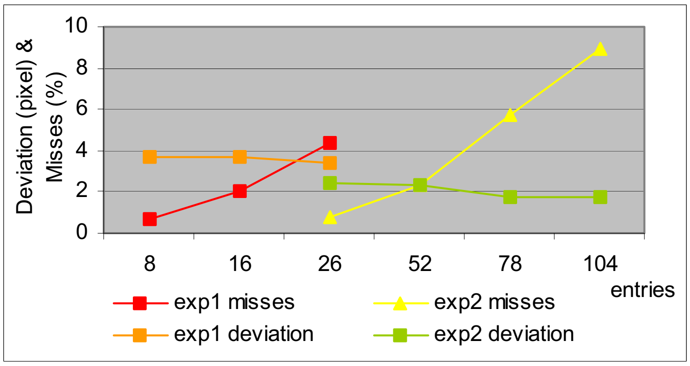


Figure 3.11 Speed (misses) – accuracy (lane deviation: dual task minus single task values) trade-off in experiments 1 and 2

The effect of direction of curvature. Right turns appeared to be the most challenging track type. Concerning the effect of direction of curvature on driving performance there was only a significant difference between straight track sections and right turns (not between straight track sections and left turns) in experiments 1 and 2. With a shorter list length in experiment 3, the additional visual demand of right turns could obviously be compensated for, as curvature had no significant effect on lane deviation. In other words, the additional visual demand of right and left turns could be better compensated for when participants were concurrently working on a secondary task with a maximum of eight entries, as a list length shorter than eight entries kept task demands in a manageable margin. Assuming that both driving on curved sections and increased list lengths contribute to overall task demands, keeping task demands of one of the two factors rather low should naturally result in better primary- and secondary task performance. As the influence of car manufacturers on roadway arrangements is usually rather low, list lengths should be kept rather short.

The effect of curve radius. Curve radius entailed a decrease of driving performance in experiments 1 and 2 only. As well, task duration was increased in experiment 1 and extra keystrokes rose significantly when driving on sharp curves in experiments 2 and 3. It appears that in experiment 1 participants prioritized accuracy of both primary and secondary task (by prolonging task duration), while in experiments 2 and 3 participants accepted a higher error rate, probably caused by keeping glances to the secondary task display short in order to protect driving performance. But results also show that, independent of strategy choice, participants always aimed at protecting performance of the driving task. Overall, the extra keystroke data suggests that participants were quite efficient, with the vast majority of trials being successfully completed with no errors at all, or with two or less extra keystrokes.

The effect of searching period. The current status of the search, rather than list length itself, had the greatest effect on driving performance in all three experiments: mean lane deviation was smallest during the first 20% of the search, higher between 40% and 60% of the search and worst during the last 20% of the search. Concerning the first 20% of the search primary task performance did almost not differ at all from the single task situation in all three experiments with lane deviation measures being only slightly above zero. Not until the search proceeded to the point where participants draw near the target entry in the list, performance decreased.

Significant interactions. The interaction between searching period and direction of curvature had significant effects on driving performance in all three experiments. Here again the assumption suggests itself that the task demands of curved road sections and advanced searches added up and exceeded the capability of participants to cope with increased task demands. Furthermore, both factors changed their current state rather quickly, thus requiring fast reactions.

The interaction between searching period and list length showed significant effects on driving performance in experiments 2 and 3. Concerning experiment 3, the interaction is quite linear predictable, as eight entries in a list impose higher task demands on the driver than do two and four entries. Concerning experiment 2, the interaction appears a bit more complex (see figure 3.5): while driving performance degrades steadily for list lengths of 52 and 78 entries, lane deviation while searching in a list with 26 entries increases with a great leap during 40-60% of the search, not changing noteworthy any more during the last fifth of the search. For searches in a list with 104 entries it appears the other way round: driving performance stays rather unaffected until during the last fifth of the search performance begins to decrease significantly. As mentioned above, large numbers of entries in a list possibly entail longer ways to the target item, so that participants had not reached the critical part at the end of the search during the medium 40-60% of the search.

In experiment 3 also the interaction between searching period and speed became significant with conditions of high velocity having a stronger decreasing effect on lane deviation than did slow conditions. The differences between both speed conditions enlarged with the progression of the search, indicating that, although speed never became a significant main factor concerning driving performance, it does very well contribute to overall task demands.

Conclusions. Although participants were instructed to not compromise the driving task while performing a display-related secondary task they did so nevertheless, causing variations in driving performance measures. Adding a secondary task significantly degraded driving performance in all three experiments with current status of the search showing the strongest effect on driving performance. The increased task demands induced by long list lengths, on the other hand, could obviously be compensated by stretching out the duration of the secondary task, thus protecting performance of the driving task. Therefore, if increasing task completion times do not constitute a problem (the requirement of scrolling is probably not a viable alternative if the application places a main focus on rapid search and retrieval), quite large amount of data can very well be structured on one menu level which is alphabetically sorted.

Furthermore, participants could obviously adapt quite well to factors which remained quite stable throughout a trial (e.g. list length and velocity), while factors changing rather frequently (e.g. curve radius) increased task demands in a performance degrading manner.

In the following two experiments, it shall be investigated whether an increase in control and display proximity might improve the positive effects of short list lengths any further. As mentioned above, the goal of the design of any secondary task should be to minimize the time of eyes-off-the-road. As experiment 3 still showed degrading primary task performance effects for list lengths of eight entries it shall be investigated whether the location of the secondary task controls close to the operator or increasing the proximity between the display of primary- and secondary task stimuli might reduce this impairing effect.

Chapter 4: Control location

The following chapter begins with an introduction of relevant theoretical issues concerning control location (section 4.1). Section 4.2 starts out with a short introduction of experimental goals, followed by a description of experimental methods and results and concludes with a short discussion of the particular experiment. Section 4.3 finally summarizes and compares the findings of experiments 3 and 4.

4.1 Theoretical background

There are several issues that have to be taken into account when discussing the advantages and disadvantages of different controls and control locations, e.g. reaching distance, closeness between various controls, closeness and compatibility to the related displays, and experience with the relevant control. The most important consideration for a control is its accessibility: Controls should be located as close to the driver as possible (within easy reaching distance). Conventional in-vehicle controls are located on the centre console and are thus easily visible, but the reaching distance is rather large. According to Sumie et al. (1998), the steering-wheel is therefore a better choice for accessibility to minimize hand-reach distance. Violations of this so called *proximity compatibility principle* have frequently been reported by participants in driving experiments – as summarized by Nowakowski et al. (2003): "First, drivers noted that controls frequently used together were located far apart. Second, drivers noted that often buttons for frequent tasks or critical tasks while driving (map zoom, scrolling, or destination entry) were often located with the furthest reaches".

At the same time human beings show a strong intrinsic tendency to move or orient towards the source of stimulation (Simon, 1969). Given the predominance of this effect, it is not surprising that *stimulus-response compatibility* is best accomplished when controls are located next to the relevant displays (Wickens & Hollands, 2000), perfectly realized for example in touch-screen displays or with a mouse pointer. Thus, finding the optimal control location entails a dilemma, as controls in a driving environment cannot be located as close as possible to the driver and at the same time as close as possible to the display they are controlling, as in this case the display would have to be mounted on the steering-wheel. One potential solution to this control location dilemma is to make the controls easy to locate and menu selections so apparent from the display that minimal visual guidance is needed, which is possible using steering-wheel-mounted controls (Sumie et al., 1998).

Independent of where controls are located operators have a set of general expectancies about how the display will respond to a particular control activity which are based on experiences gained during previous uses of similar systems. These expectancies are defined as *movement compatibility* or *cognitive-response-stimulus compatibility* (Wickens & Hollands, 2000). *Movement compatibility* is strongly governed by the *principle of movement proximity*, a principle also known as the *Warrick principle* (Warrick, 1947). It asserts that the closest part of the moving element of a control should move in the same direction as the closest part of the moving element of a display. Violations against the *principle of movement compatibility* usually cause a shift from automated to controlled information processing and therefore an increase in mental workload. For example, if operators perceive the system responding to their control movement in what they think is the opposite direction, they are forced to trigger a further - unnecessary - control action (Wickens & Hollands, 2000).

Moreover, one control might serve the requirements of a particular task and environment better than another. Card et al. (1978) suggested for example that a mouse is the best control device when both speed and accuracy are taken into consideration. The space constraints required by a mouse pad, on the other hand, make the mouse a poor choice for use in a limited-area work space such as a vehicle cab (Baber, 1997). The costs and benefits of different sorts of manual control devices for cursor positioning depend, in part, on a large number of anthropometric and biomechanical factors that are beyond the scope of this dissertation.

Another important issue concerns the familiarity of drivers with their vehicles. Those very familiar with the controls in their car perform secondary tasks quite differently to drivers who are less familiar with them. As experienced drivers rely much more on tactile feedback than looking at the control for final guidance of their hand, the location of a control is retrieved from memory rather than being visually detected. Consequently, experienced drivers avert their gaze from the road less frequently and active planning of the movement to the control may be minimal, with the driver instead relying upon a stored motor program (Sumie et al., 1998). Hence, experienced drivers need less time to execute a secondary task.

To recapitulate, several factors concerning control location are assumed to influence task completion times and the duration of eyes-off-the-road, but while some findings are quite consistent, others are oppositional. The aim of the following experiment was therefore to investigate the effects of control location on driving performance, task completion time, and error rate, under a slow and a fast driving condition. Furthermore, in the effects of curve radius, direction of curvature, and progress of the search on driving performance were investigated as well. See table 4.1 for an overview.

Table 4.1 Factors investigated in experiment 4

Factor	**Description**	**Possible values**
Velocity of the car	cm/pixel per second (pps)	3.8cm (95pixel) per sec in the slow condition and 5.4cm (135pixel) per sec in the fast condition
List length		2, 4, and 8 entries
Direction of curvature	Direction of the turn	straight track section, left turn, right turn
Curve radius	Radius of track section	-9.6cm (-240pixel), sharpest left turn, +9.6vm (240pixel), sharpest right turn
Searching period	Progress of the search	1st, 3rd and 5th fifth of the searching period
Control location	Position of secondary task controls	15 cm to the right of the steering-wheel (exp. 1, 2, 3) and on the steering-wheel (exp. 4, 5)

4.2 Experiment 4: Steering-wheel-mounted controls

4.2.1 Introduction

As discussed above, the perfect position of the secondary task controls is subject to a dilemma: secondary task controls should be located as close to the display as possible and at the same time in easy reach distance for the driver. But in a driving environment it is usually not possible to meet both requirements at the same time. It is assumed, that controls located as close to the driver (in easy reach distance) as possible on the steering-wheel allow a more intuitive navigation through secondary task contents, thus being very strongly related to induced changes on the screen. In addition, time to reach the control is assumed to decrease. Accordingly, it can be hypothesized that locating the controls close to the operator will have a decreasing effect on lane deviation, as well as on task completion times. Experimental settings of experiment 3 were retained to ensure comparability between the experiments.

4.2.2 Method

4.2.2.1 Participants

Sixteen paid (€16) volunteers participated in the experiment in equal numbers of males and females. Their age ranged from 21 to 36 years (mean: 28.8, SD= 3.5). All participants were right handed, had normal or corrected-to-normal vision and had held a driver’s licence for at least three years (mean: 10.7, SD=3.5). Mean kilometres driven per annum was 10000 (SD=9865). Mean daily computer usage was 5.3 hours (SD=3.2).

4.2.2.2 Experimental setup

Apparatus. The experimental apparatus consisted of the PC, two 17-inch monitors, and the steering-wheel. Participants were seated in front of the steering-wheel at an approximate distance of 80cm to the monitor.

Stimuli. Stimuli were similar to those of experiment 3.

Controls. Stimuli on the left monitor (navigation of the car) were controlled by turning the steering-wheel to the left or right. Stimuli on the right monitor (navigation in the list) were controlled by two four-way navigation keys and two press buttons mounted on the steering-wheel. Moving the cursor up or down in the list was possible by pressing the up- or down press point of either one of the two four-way navigation keys which reacted identical (see figure 2.6). Confirmation of a list entry was executed by pressing one of two press buttons, which were located right below the four-way navigation keys and reacted identical as well.

4.2.2.3 Procedure

The applied procedure was similar to that of experiment 3.

4.2.3 Results

Data from log files were prepared for further statistical analysis according to the description given in chapter 2.5.

4.2.3.1 Driving performance (primary task)

Lane deviation. Two repeated measures analysis of variance (ANOVA) were computed on lane deviation. For the first one a 3x2x3x3 factorial design with the factors list length (2, 4, and 8 entries), velocity (slow, fast), direction of curvature (straight sections, left turns, right turns), and searching period (0-20% of the search, 40-60% of the search, 80-100% of the search) was used. For the second one a 3x2x2x3 factorial design with the factors list length (2, 4, and 8 entries), velocity (slow, fast), curve radius (moderate curves, sharp curves), and searching period (0-20% of the search, 40-60% of the search, 80-100% of the search) was used. The first analysis revealed significant main effects of list length [$F(2,30)=12.306$, $p<0.001$, $\varepsilon=0.884$], direction of curvature [$F(2,30)=5.187$, $p=0.024$, $\varepsilon=0.692$], and searching period [$F(2,30)=62.81$, $p<0.001$, $\varepsilon=0.68$]. Lane deviation was lowest for a list length of two entries (mean of 0.7 pixel, SD=0.7), and higher for both a list length of four (mean of 1.4 pixel, SD=0.6) and eight entries (mean of 1.8 pixel, SD=0.8). The differences between the list lengths of two and four entries ($p=0.009$) and two and eight entries ($p=0.002$) was significant. Lane deviation was furthermore lowest for straight track sections (mean of 0.8 pixel, SD=1.1), higher for left turns (mean of 1.6 pixel, SD=0.9) and highest for right turns (mean of 1.7 pixel, SD=0.8). Finally, lane deviation was lowest during the first fifth of the search (mean of -0.2 pixel, SD=0.5), and higher for both the third fifth of the search (mean of 1.5 pixel, SD=0.9) and the last fifth of the search (mean of 2.7 pixel, SD=0.9). All of the differences were significant ($p<0.001$).

Only the main effect of velocity [F(1,15)=0.587, p>0.4, ε=1.0] was not significant. A significant interaction between velocity and searching period [F(2,30)=7.67, p=0.002, ε=0.988], however, shows that velocity did have a significant effect when regarded against searching period, as displayed in figure 4.1.

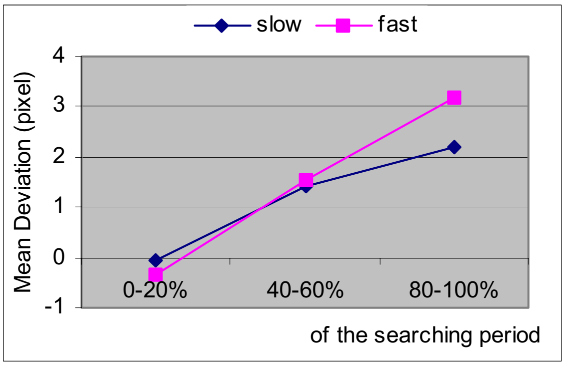


Figure 4.1 Effects of velocity and searching period on lane deviation (dual task minus single task values) – experiment 4

Performance was generally better during single task conditions than during dual task conditions, as the overall mean value of lane deviation (dual task minus single task values) was positive (1.3 pixel, SD=0.5) and significantly (p<0.001) different from zero.

According to the second analysis the main effect of velocity [F(1,15)=1.254, p>0.4, ε=1.0] was also not significant. The significant interactions between velocity and searching period [F(2,30)=6.557, p=0.004, ε=0.871] and velocity and curve radius [F(1,15)=5.007, p=0.041, ε=1.0] however show again that velocity did have a significant effect when regarded against searching period or curve radius. Furthermore, the main effects of list length [F(2,30)=13.926, p<0.001, ε=0.891], curve radius [F(1,15)=5.146, p=0.039, ε=1.0], and searching period [F(2,30)=55.877, p<0.001, ε=0.75] were significant, as were the interactions between searching period and list length [F(4,60)=4.098, p=0.005, ε=0.722], and searching period and curve radius [F(2,30)=6.314, p=0.005, ε=0.992], indicating that effects of searching period were not equal across all list lengths or curve radii. Concerning curve radius, lane deviation was higher in trials consisting of sharp curves (mean of 1.7 pixel, SD=0.9) than in trials consisting of straight track parts and moderate curves (mean of 1.2 pixel, SD=0.6).

4.2.3.2 List performance (secondary task)

Misses. A repeated measures analysis of variance (ANOVA) was computed on the percentage of failed trials. A 2x3x2 factorial design with the factors velocity (slow, fast), list length (2, 4, and 8 entries) and curve radius (moderate curves, sharp curves) was used. According to the analysis none of the independent variables increased the number of missed trials significantly, as none of the main effects of velocity [F(1,15)=0.0, p=1.0, ε=1.0], list length [F(2,30)=1.901, p>0.1, ε=0.5] or curve radius [F(1,15)=1.667, p>0.2, ε=1.0] was significant, nor was any of the interactions.

Task completion time. A 3x2x2 repeated measures analysis of variance with the factors list length (2, 4, and 8 entries), velocity (slow, fast) and curve radius (moderate curves, sharp curves) revealed neither a significant main effect of curve radius [F(1,15)=0.84, p>0.7, ε=1.0] nor of velocity [F(1,15)=3.141, p>0.09, ε=1.0]. None of the interactions was significant either. Only the main effect of list length [F(2,30)=100.813, p<0.001, ε=0.804] was significant, indicating that even with the control devices being close to the operator, task completion times were lower for a list length of two entries (mean of 2.2s, SD=0.8) than for list lengths of four (mean of 3.0s, SD=0.9) and eight entries (mean of 4.1s, SD=1.1). All differences were significant (p<0.001). To find out more about possible main effects in the separate list conditions, three separate 2x2 repeated measures analysis of variance with the factors velocity (slow, fast) and curve radius (moderate curves, sharp curves) were computed on task completion times for each of the three list lengths. For a list of two entries none of the main effects of velocity [F(1,15)=1.275, p>0.2, ε=1.0] or curve radius [F(1,15)=1.121, p>0.3, ε=1.0] was significant, which was also true for a list length of eight entries (velocity: [F(1,15)=0.862, p>0.3, ε=1.0], curve radius: [F(1,15)=1.602, p>0.2, ε=1.0]). For a list length of four entries, however, the main effect of curve radius [F(1,15)=2.768, p>0.1, ε=1.0] was not significant, but the main effect of velocity [F(1,15)=4.828, p=0.044, ε=1.0] was. For searches in a list with four entries the task completion time was significantly longer in the slow condition (mean of 3.2s, SD=1.1) than in the fast condition (mean of 2.9s, SD=0.8).

Extra keystrokes (false positive answers). A 2x3x2 repeated measures analysis of variance was computed on extra keystrokes with the factors velocity (slow, fast), list length (2, 4, and 8 entries) and curve radius (moderate curves, sharp curves). According to the analysis none of the main effects of velocity [F(1,15)=0.447, p>0.5, ε=1.0], list length [F(2,30)=2.395, p>0.1, ε=0.992] or curve radius [F(1,15)=2.113, p>0.1, ε=1.0] was significant, indicating that neither of the factors increased task demands to an extend where secondary task error rate increased. Neither did any of the factors interact significantly. The mean number of extra keystrokes for all correctly completed trials was 0.06. The maximum was 3. The percentage of all error-free completed trials was 94.6%.

4.2.3.3 Subjective ratings

Self-estimated effort. A 4x2 repeated measures analysis of variance with the factors list length (no list, 2, 4, and 8 entries) and velocity (slow, fast) revealed significant main effects of list length [F(3,45)=31.568, p<0.001, ε=0.792] and velocity [F(1,15)=25.568, p<0.001, ε=1.0], but the interaction between the two factors was not significant [F(3,45)=0.583, p>0.6, ε=0.93]. The subjectively estimated effort was lowest for the single task condition (mean value of 0.8, SD=0.9), and higher for the dual task situations of two (mean value of 1.0, SD=0.8), four (mean value of 1.2, SD=0.8) and eight list entries (mean value of 1.8, SD=0.8). All differences were significant (p<0.04), except the one between list lengths of two and four entries (p>0.8). The self-estimated effort was significantly lower (p<0.001) in the slow condition (mean value of 1.0, SD=0.7) than in the fast condition (mean value of 1.4, SD=0.8). The effects of list length and velocity on self-estimated effort are shown in figure 4.2.

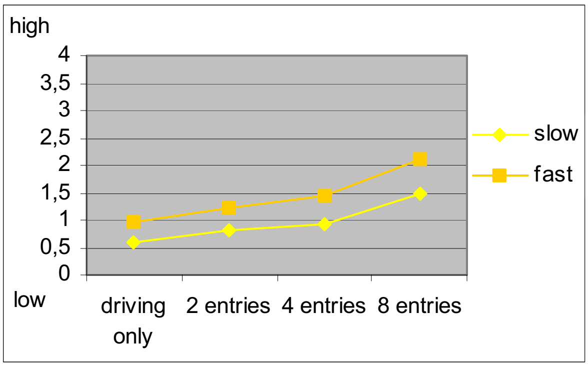


Figure 4.2 Effects of velocity and list length on self-estimated effort – experiment 4

Ratings of secondary task interference. A repeated measures analysis of variance was computed on subjective ratings of secondary task interference. A 3x2 factorial design with the factors list length (2, 4, and 8 entries) and velocity (slow, fast) was used. According to the analysis the main effects of list length [F(3,45)=70.471, p<0.001, ε=0.59] and velocity [F(1,15)=26.272, p<0.001, ε=1.0] were significant, as was the interaction between the two factors [F(3,45)=5.771, p=0.002, ε=0.725]. The subjectively estimated secondary task interference was lowest for a list length of two entries (mean value of 1.3, SD=0.8), and higher for both a list length of four (mean value of 1.8, SD=0.9) and eight entries (mean value of 2.4, SD=0.9). All of the differences were significant (p<0.005). The subjectively estimated effort was significantly lower (p<0.001) in the slow condition (mean value of 1.2, SD=0.6) than in the fast condition (mean value of 1.6, SD=0.7). The longer the list the higher the interfering effect of velocity was rated.

Subjective estimation of task priority. A 4x2 repeated measures analysis of variance with the factors list length (no list, 2, 4, and 8 entries) and velocity (slow, fast) revealed a significant main effect of list length [F(3,45)=33.307, p<0.001, ε=0.704], implying that the priority on the driving task was rated higher the less entries there were in the list. All differences were significant (p<0.02), except the difference between the list lengths of two and four entries (p>0.5). The main effect of velocity [F(1,15)=4.428, p>0.05, ε=1.0] was marginally not significant. Neither was the interaction between the two factors [F(3,45)=1.511, p>0.2, ε=0.766]. See figure 4.3 for the distribution of attention allocation.

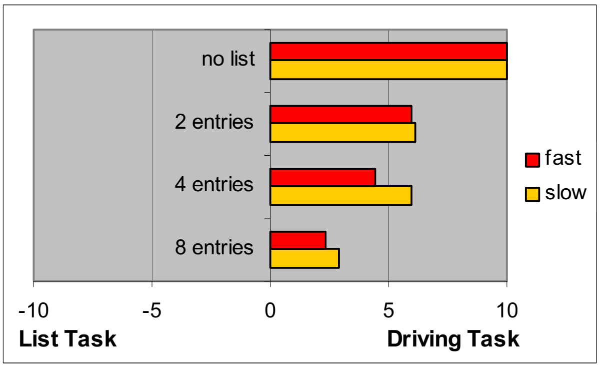


Figure 4.3 Distribution of task priority – experiment 4

For an overview of the results of experiment 4 see table 4.2.

Table 4.2 Results of Experiment 4. Mean values of lane deviation (pixel), misses (%), secondary task duration times (sec), error rate, subjective ratings of effort, secondary task interference, and attention allocation (with standard deviation in parenthesis)

Objective measures

	Lane deviation *(pixel)* *(ANOVA 1)*	*(ANOVA 2)*	***Misses*** *(%)*	***Secondary task completion times*** (sec)	***Number of extra keystrokes***
List length					
2 entries	0.7 (0.7)		0.1 (0.5)	2.2 (0.8)	0.5 (0.5)
4 entries	1.4 (0.6)		0.1 (0.5)	3.0 (0.9)	0.7 (0.7)
8 entries	1.8 (0.8)		0.5 (1.6)	4.1 (1.1)	0.8 (0.7)
Velocity					
Slow	1.1 (1.0)		0.3 (1.0)	3.0 (0.8)	0.6 (0.7)
Fast	1.4 (0.8)		0.3 (0.7)	3.2 (1.0)	0.7 (0.5)
Direction of curvature					
Straight sections	0.8 (1.1)				
Left turns	1.7 (0.9)				
Right turns	1.8 (0.8)				
Curve radius					
moderate		1.2 (0.6)	0.4 (1.4)	3.1 (0.9)	0.8 (0.5)
sharp		1.7 (0.9)	0.1 (0.3)	3.1 (0.9)	0.6 (0.6)
Searching period					
0-20% of search	-0.2 (0.5)				
40-60% of search	1.5 (0.9)				
80-100% of search	2.7 (0.9)				
Overall	1.3 (0.5)		0.3 (0.9)	3.1 (0.9)	0.7 (0.5)

Subjective measures

	Ratings of effort	***Ratings of secondary task interference***	***Ratings of attention allocation***
List length			
no list	0.8 (0.9)		*10.0 (0.0)*
2 entries	1.0 (0.8)	1.3 (0.8)	6.0 (3.0)
4 entries	1.2 (0.8)	1.8 (0.9)	5.2 (2.5)
8 entries	1.8 (0.8)	2.4 (0.9)	2.6 (4.1)

Subjective measures (continued)

	Ratings of effort	*Ratings of secondary task interference*	*Ratings of attention allocation*
Velocity			
Slow	1.0 (0.7)	1.2 (0.7)	6.2 (2.4)
Fast	1.4 (0.8)	1.6 (0.6)	5.7 (2.0)

4.2.4 Comparative statistical analysis between experiments 3 and 4

In experiment 3 the secondary task control was located 15cm to the right of the steering-wheel while in experiment 4 secondary task controls were mounted on the steering-wheel. In order to compare results between the two experiments, a series of analysis of variance (ANOVA) was executed for the different dependent variables. Data from log files were prepared for further statistical analysis according to the description given in chapter 2.5.

4.2.4.1 Driving performance (primary task)

Lane deviation. To compare lane deviation measures between experiments 3 and 4, two separate analysis of variance (ANOVA) were computed on lane deviation. For the first one a 2x3x2x3x3 factorial design with one between participant factor (*control location*: 15cm to the right of the steering-wheel, on the steering-wheel) and four within participant factors (*list length:* 2, 4, and 8 entries; *velocity:* slow, fast; *direction of curvature:* straight sections, left turns, right turns; *searching period:* 0-20% of the search, 40-60% of the search, 80-100% of the search) was used. For the second one a 2x3x2x3x3 factorial design with one between participant factor (*control location*: 15cm to the right of the steering-wheel, on the steering-wheel) and four within participant factors (*list length:* 2, 4, and 8 entries; *velocity:* slow, fast; *curve radius:* moderate curves, sharp curves; *searching period:* 0-20% of the search, 40-60% of the search, 80-100% of the search) was used.

According to the first analysis, there was no significant main effect of control location for any of the factors list length [F(2,60)=1.7, p>0.1], velocity [F(1,30)=0.197, p>0.6], direction of curvature [F(2,60)=1.246, p>0.2], or searching period [F(2,60)=0.27, p>0.7], nor for any of the interactions. The same was true for the second analysis (list length: [F(2,60)=1.422, p>0.3], velocity; [F(1,30)=0.143, p>0.7], curve radius:

[F(1,30)=1.078, p>0.3], searching period: [F(2,60)=0.196, p>0.8]). Here again, control location had no significant main effect on either of the interactions.

4.2.4.2 Secondary task performance

Three comparative analysis between experiments 3 and 4 were computed on percentage of misses, task completion times and extra keystrokes via a 2x2x3x2 repeated measures analysis of variance (ANOVA) with one between participant factor (*control location**:*** 15cm to the right of the steering-wheel, on the steering-wheel) and three within participant factors (*velocity:* slow, fast; *list length:* 2, 4, and 8 entries; *curve radius:* moderate curves, sharp curves).

The comparative analysis on the percentage of missed trials revealed no significant main effect of control location for any of the factors list length [F(2,60)=0.221, p>0.8], velocity [F(1,30)=3.333, p>0.07], or curve radius [F(1,30)=2.455, p>0.1], nor for any of the interactions. The same was true for the comparative analysis on task completion times which also revealed no significant main effect of control location for any of the factors list length [F(2,60)=0.394, p>0.6], velocity [F(1,30)=0.449, p>0.5], or curve radius [F(1,30)=0.26, p>0.6], nor of any of the interactions. But the comparative analysis on extra keystrokes revealed a significant main effect of control location for the factor velocity [F(1,30)=7.458, p=0.01], indicating that participants made less errors in the slow condition in experiment 3. But there was neither a significant main effect of control location for the factors list length [F(1,30)=0.686, p>0.5] nor for the factor curve radius [F(2,60)=0.148, p>0.7]. Control location had no significant main effect on either of the interactions as well.

4.2.4.3 Subjective ratings

Two comparative analysis between experiments 3 and 4 were computed on self-estimated effort and ratings of attention allocation via a 2x4x2 repeated measures analysis of variance (ANOVA) with one between participant factor (*control location**:*** 15cm to the right of the steering-wheel, on the steering-wheel) and two within participant factors (*list length:* no list, 2, 4, and 8 entries; *velocity:* slow, fast). The comparative analysis of self-estimated effort revealed a significant main effect of control location for the factor velocity [F(1,30)=27.23, p<0.001], indicating that the fast condition was rated more effortful in experiment 4. But there was no significant main effect of control location for the factor list length [F(3,90)=2.204, p>0.09], which was also true for the interaction between the two factors. The comparative analysis of attention allocation revealed a significant main effect of control location for the factor velocity [F(1,30)=4.994, p=0.033] as well, indicating that there was a higher priority on the driving task in experiment 4 during both speed conditions. But there was no significant main effect of control location for the factor list length [F(3,90)=0.455, p>0.7], nor for the interaction between the two factors.

A comparative analysis between experiments 3 and 4 was computed on ratings of secondary task interference via a 2x3x2 repeated measures analysis of variance (ANOVA) with one between participant factor (*control location*: 15cm to the right of the steering-wheel, on the steering-wheel) and two within participant factors (*list length:* 2, 4, and 8 entries; *velocity:* slow, fast). It also revealed a significant main effect of control location for the factor velocity [F(1,30)=39.395, p<0.001], indicating that secondary task interference was rated higher in both the slow and the fast condition in experiment 3. But there was no significant main effect of control location for the factor list length [F(3,90)=0.093, p>0.9], nor for the interaction between the two factors.

4.2.5 Discussion experiment 4

List lengths of four entries and higher, sharp curves, right and left turns, and advanced searching periods had significant decreasing effects on driving performance in experiment 4. As in the preceding experiments searching period had a strong effect on driving performance. But obviously, task demands during the first 20% of the search dropped to such an extent that performance was better in the dual task situation than in the single task condition, a finding also reported by Moss and Triggs (1997). In the second ANOVA searching period interacted significantly with list length and velocity, implying that higher demanding conditions of both factors were adding up to a performance degrading overall task demand level. The same was probably true for the interactions between curve radius and velocity (ANOVA 2), as well as between searching period and velocity (in both ANOVAs), with driving performance during the last fifth of the search being inferior in the fast condition compared to the slow condition. List lengths had furthermore a significant effect on secondary task completion times which again cannot be completely explained by the physical requirement of increased searching times due to prolonged scrolling times. Apparently, lists requiring any scrolling at all resulted in an increase of secondary task demands. There were no misses and no significant effects on error rates which implies that participants were facing a smaller need for compensation strategies, indicating that overall task demands remained at a manageable level. Subjective ratings of experienced effort and secondary task interference revealed significant effects of list length and velocity. Apparently participants protected primary task performance by investing more effort, when speed was at a higher level. But as list length had a significant effect on driving performance as well, prolonging the secondary task was obviously not sufficient, an effect of which participants were obviously well aware, as list length had also a significant effect on subjective ratings of attention allocation.

4.3 Discussion experiments 3 and 4

Summarizing the results of experiments 3 and 4, driving performance was significantly effected by list length and searching period and the interaction between both factors, as well as by the interaction between velocity and searching period. Direction of curvature and curve radius had a significant effect on driving performance in experiment 4 only. Furthermore, statistical analysis revealed significant interactions between curve radius and searching period and between velocity and curve radius in experiment 4 and between direction of curvature and searching period in experiment 3. Error rate was significantly effected by curve radius in experiment 3. Significant effects on misses, however, did not occur in any of the experiments. More generally, task completion times were significantly effected by list length in both experiments, as well as by velocity in experiment 3. Ratings of self-estimated effort and secondary task interference revealed significant effects of velocity and list length in both experiments. As no other variables were altered, the differences between experiment 3 and 4 are mainly due to the decrease in reaching distance of the secondary task controls. In the following sections each of the effects of driving speed, list length, direction of curvature, curve radius and searching period on lane deviation, error rate, misses and task completion times, as well as on subjective experiences shall be discussed.

The effect of driving speed. Driving performance was relatively unaffected by speed variations in both experiments. This was also true for task completion times where speed had only a significant effect in experiment 4 on task completion times of lists with four entries. The conclusion is that an increase of overall workload caused by changes in velocity during these experiments was not high enough to require an extension of task completion times. Nevertheless, fast trials were in both experiments rated to be significantly more effortful and the lists as more distracting than in the slow trials, reflecting a rise in subjectively assessed mental workload. Furthermore, there were significant differences in subjective ratings between experiments 3 and 4 concerning self-estimated effort, secondary task interference and attention allocation: While ratings of secondary task interference were significantly higher in both speed conditions in experiment 3, self-estimated effort was higher for the slow condition in experiment 4, indicating that task demands dropped under an optimal level. In addition, speed became a relevant factor when interacting with other factors, such as searching period or curve radius. Interestingly, there was also a significant effect of control location on velocity concerning error rates, revealing that participants made more errors during the slow condition of experiment 4 while error rates were equal between both experimental settings during the fast condition. This could either be due to different reactions of the controls or would be another indication for the hypothesis that performance decreases under very low task demands as well, due to a suboptimal level of arousal.

The effect of list length. Driving performance was best for two entries and lowest for eight entries in both of the experiments. But, as displayed in figure 4.4, both for rather low and rather high task demands, increased control proximity had an increasing effect on driving performance.

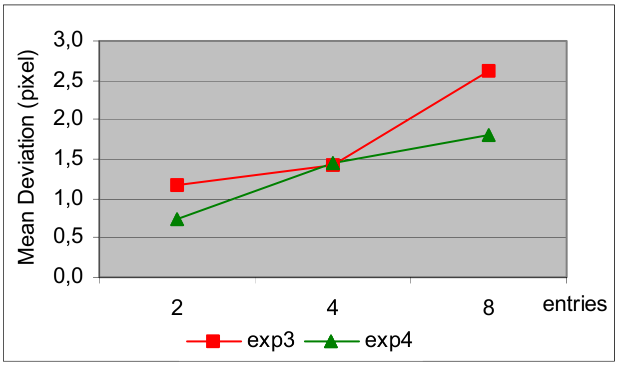


Figure 4.4 Effect of list length on lane deviation (dual task minus single task values) – experiment 4

This finding corresponds with those by Kantowitz et al. (1984) where performance was worse and workload was higher for a four-choice task than for a two-choice task in the context of simulated flight.
Task completion times were slightly longer in experiment 3 for all of the list lengths. Furthermore, the more entries in a list, the more effortful the trial was rated and the more interference was attributed to the lists. But neither of the differences in experiments 3 and 4 concerning effects of list length on primary and secondary task performance or subjective ratings became significant.

The effect of direction of curvature. The type of road segment also influenced driving performance significantly. But while in experiment 3 driving performance decreased rather linear across straight sections, left turns and right turns respectively, increased control proximity in experiment 4 apparently had a clear facilitating effect on straight sections as well as a slight enhancing effect on right turns, although the effect did not become significant (see figure 4.5).

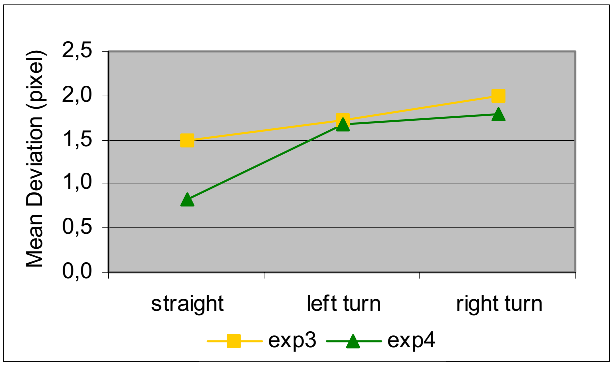


Figure 4.5 Effects of direction of curvature on lane deviation (dual task minus single task values) – experiments 3 and 4

The effect of curve radius. The effect of curve radius on driving performance was significant in experiment 4 only. Here again, only during the low demanding condition of moderate curves the change in control location did have a facilitating effect on driving performance, which did not differ significantly from experiment 3 though. The number of extra keystrokes was relatively unaffected by variations of curve radius throughout both of the experiments, which might be explained by an overall decrease in task demands.

The effect of searching period. Again, the current status of the search had the greatest effect on driving performance in both of the experiments. Mean lane deviation was smallest during the first 20% of the search, higher between 40% and 60% of the search and worst during the last 20% of the search. But differences between the two experimental settings were only marginal with a slight increase during the last fifth of the search, not reaching level of significance, though. For the first fifth of the search, performance was also very close to (or even better than) performance in the single task situation. As it can generally be assumed that human performance is most reliable under a moderate workload level (Kantowitz & Casper, 1988), one explanation for this result might be that task demands in the single task situation already dropped below an optimal level, thus resulting in a situation where participants were in a state of mental underload.

Conclusions. Although participants were instructed to not compromise the driving task while performing a display-related secondary task they did so nevertheless, causing variations in driving performance measures. Adding a secondary task significantly degraded driving performance in both experiments. List length as well as curvature and searching period had still significant decreasing effects on driving performance. Thus, increasing the proximity of secondary task controls, enabling drivers to leave their hands on the steering-wheel, could obviously not eliminate the performance impairing effects of list length, curvature and searching period. Contrary, experimental results revealed only a small advantage of locating the controls on the steering-wheel, which might partly be explained by the fact that the joystick in experiment 3 was rather big and therefore easy to find without having to look at it. Furthermore, a distance of 15cm is still rather low compared to some distances of secondary task controls drivers will experience in the car. There were also no other instruments located around the control to become confused with as it would possibly be the case in an in-vehicle environment.

As a consequence of these findings, stimuli presentation of primary and secondary task were converged on one single monitor in the next experiment to see whether this would lead to fewer decrements in driving performance. It was supposed that participants need less time to switch attention forth and back between primary and secondary task when stimuli are very close to each other, an assumption which should especially apply for the last fifth of the search, where participants have to concentrate more on the secondary task in order to identify the target item.

Chapter 5: Display location

The following chapter begins with an introduction of relevant theoretical issues concerning display location (section 5.1). Section 5.2 starts out with a short introduction of experimental goals, followed by a description of experimental methods and results and concludes with a short discussion of the particular experiment. Section 5.3 finally summarizes and compares the findings of experiments 4 and 5.

5.1 Theoretical background

A general withdrawal of visual attention occurs whenever drivers move their eyes away from the road. Whether it impairs object and event detection, and thus vehicle control, depends on the frequency and duration of glances away from the road. If a display is very complex for example, it may capture the operator's attention for an inordinate amount of time to extract relevant data (for further information on display complexity see also chapter 1.3.2.2). The resulting impairment also depends on the direction of glances, which varies according to the location of the in-vehicle display: the longer the driver looks away from the road, and the further away from the road the glances are directed, the more likely it is that the driver will miss some safety critical information from the road ahead (Lamble, Laakso, & Summala, 1999; Summala, Nieminen, & Punto, 1996). In other words, as the concept of switching attention suggests a "movement metaphor", it should take longer to shift attention between tasks presented on more distant displays than between more proximate ones (Wickens & Hollands, 2000). Accordingly, a display located close to the driver's forward field of view should decrease visual search cost and time necessary to move attention from one information source to the other. Thus, less distraction from the driving task and an increased driving performance should be the result. High spatial proximity should also enhance parallel processing between the two channels and consequently facilitate divided attention, which would be perfectly implemented by a display that could superimpose a view of, for example, the speedometer on the view of the road (Goesch, 1990; Tufano, 1997). These displays are called head-up display (HUD), which describes a display where the display elements are largely transparent, meaning that the information is displayed in contrasting superposition over the user's normal environment. Furthermore, the information is projected with its focus at infinity. The benefit of this technology is (as mentioned above) that users neither need to move their heads nor refocus their eyes when switching attention between the instrument and the outside world. It was designed to ensure that information inside and outside an aircraft could be processed simultaneously without visual scanning. Expected advantages of this technique are, for example, a decreased eyes-off-the-road time, as well as a decreased accommodation time. Accordingly, Sojourner and Antin (1990) and Martin-Emerson and Wickens (1997) found a HUD advantage relative to head-down presentation of the same information. Conversely, Kloke (2005) found no HUD advantage for reading velocity displays in comparison to a head-down speedometer. But Kloke also states that this effect can not necessarily be generalized to other in-vehicle tasks, as these are usually not located in the ergonomically favourable position of the speedometer and display a far greater amount of information. But Liu (2003) also expresses doubts about whether the HUD can really serve its function in reducing the time needed to shift attention from the road when attending to information displayed in front. Although spatial proximity will allow parallel processing, it certainly will not guarantee it, a concern which has also been reported by other authors. In an experiment by Neisser and Becklen (1975), for example, participants watched a video display on which two games were presented simultaneously, one superimposed over the other. Neisser and Becklen found that while monitoring one game, participants failed to see events in the other game and had difficulties in detecting events in two games at once, even when these were unusual or novel. Just as well may a pilot become engrossed in processing instrument information on the HUD while ignoring critical cues from outside the aircraft, a phenomenon actually observed in experiments by Fischer, Haines, and Price (1980) and Larish and Wickens (1991). It appears that close proximity in space may increase confusion between those items that are momentarily the desired focus of attention and those that are not. This failure of focused attention is caused by competition for processing resources between close objects in space (Wickens & Hollands, 2000). For this reason more distant displays might be a superior solution for any task type which requires focused attention.

To recapitulate, factors concerning display proximity are assumed to influence the duration of eyes-off-the-road, but it is not necessarily clear in which direction.

The aim of the following experiment was therefore to investigate the effects of display location on driving performance, task completion time, and error rate, under a slow and a fast driving condition. Furthermore, the effects of curve radius, direction of curvature, and progress of the search on driving performance were investigated as well. See table 5.1 for an overview.

Table 5.1 Factors investigated in experiment 5

Factor	**Description**	**Possible values**
Velocity of the car	cm/pixel per second (pps)	3.8cm (95pixel) per sec in the slow condition and 5.4cm (135pixel) per sec in the fast condition
List length		2, 4, and 8 entries
Direction of curvature	Direction of the turn	straight track section, left turn, right turn
Curve radius	Radius of track section	-9.6cm (-240pixel), sharpest left turn, +9.6vm (240pixel), sharpest right turn
Searching period	Progress of the search	1st, 3rd and 5th fifth of the searching period
Display location	Display location of primary and secondary task	on two monitors (exp. 1, 2, 3, 4) and on one monitor (exp. 5)

5.2 Experiment 5: One monitor

5.2.1 Introduction

As discussed above, it should take longer to shift attention between more distant displays than more proximate ones. The resulting impairment of driving performance should therefore be more distinct in situations where the distance between the display of primary- and secondary task stimuli is rather high. On the other hand, stimuli presented too close together might become confused with each other. In experiment 5 stimuli of the secondary task were displayed on the right side of the monitor which also displayed the primary task. Thus, both primary- and secondary task stimuli were presented on one monitor (see figure 5.1). Experimental settings of experiment 3 and 4 were retained to ensure comparability between the experiments.

5.2.2 Method

5.2.2.1 Participants

Sixteen paid (€16) volunteers participated in the experiment in equal numbers of males and females. Their age ranged from 21 to 32 years (mean: 26.9, SD=2.7). All participants were right handed, had normal or corrected-to-normal vision and had held a driver's licence for at least two years (mean: 8.4, SD=2.9). Mean kilometres driven per annum was 7858 (SD=10642). Mean daily computer usage was 5.9 hours (SD=3.0).

5.2.2.2 Experimental setup

Apparatus. The experimental apparatus consisted of the PC, one 17-inch monitor, and the steering-wheel. Participants were seated in front of the steering-wheel at an approximate distance of 80cm to the monitor.

Stimuli. Both the track lane and the list were presented on one monitor. The area for displaying the track lane was 20cm (500pixel) wide and 24cm (600pixel) high (see figure 5.1). Each bisected block consisted of 45 track sections, starting out with three low demanding track sections without a task prompt. These were followed by six low demanding and six highly demanding track section groups including a task prompt in randomized order. The number of track sections in each group varied between three

and four (for further information see Appendix C). 18 of the track sections were straight track sections, 36 were left turns and 36 were right turns. Track sections were moving behind the car at 3.2cm (80pixel) per second in the slow condition and 4.8cm (120pixel) per second in the fast condition. The stimulus to start the secondary task was presented right above the car on the left screen.
The area for displaying the list was 12cm (290pixel) wide and 24cm (600pixel) high and displayed four entries of the list (see figure 5.1). The setup of the list was similar to that of experiments 3 and 4.

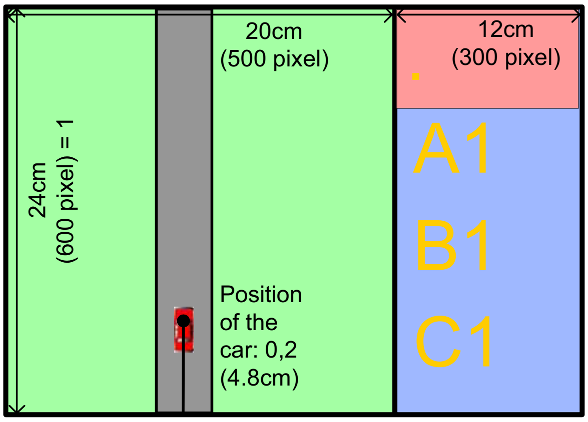


Figure 5.1 Presentation of stimuli – experiment 5

Controls. Controls used for navigating the car and in the list were identical to those used in experiment 4.

5.2.2.3 Procedure

Procedure was similar to that of experiments 3 and 4.

5.2.3 Results

Data from log files were prepared for further statistical analysis according to the description given in chapter 2.5.

5.2.3.1 Driving performance (primary task)

Lane deviation. Two repeated measures analysis of variance (ANOVA) were computed on lane deviation. For the first one a 3x2x3x3 factorial design with the factors list length (2, 4, and 8 entries), velocity (slow, fast), direction of curvature (straight sections, left turns, right turns), and searching period (0-20% of the search, 40-60%

of the search, 80-100% of the search) was used. For the second one a 3x2x2x3 factorial design with the factors list length (2, 4, and 8 entries), velocity (slow, fast), curve radius (moderate curves, sharp curves), and searching period (0-20% of the search, 40-60% of the search, 80-100% of the search) was used. According to the first analysis, only the main effect of velocity [F(1,15)=0.029, p>0.8, ε=1.0] was not significant. The main effects of list length [F(2,30)=4.866, p=0.015, ε=0.967], direction of curvature [F(2,30)=10.53, p=0.002, ε=0.669], and searching period [F(2,30)=46.597, p<0.001, ε=0.702], however, were significant. Lane deviation was lowest for a list length of two entries (mean of 0.4 pixel, SD=0.4) and higher for both a list length of four (mean of 0.8 pixel, SD=0.6) and eight entries (mean of 0.8 pixel, SD=0.6), but only the difference between two and four entries was significant (p=0.031). Concerning direction of curvature, lane deviation was lowest for straight track sections (mean of 0.1 pixel, SD=0.7) and higher for both left (mean of 0.8 pixel, SD=0.8) and right turns (mean of 1.2 pixel, SD=0.5). The differences between right turns and straight track sections (p=0.001) and right and left turns (p=0.035) were significant. Furthermore, the interaction between list length and direction of curvature [F(4,60)=3.072, p=0.023, ε=0.651] was significant, indicating that the effects of direction of curvature were not equally distributed across the list lengths (see figure 5.2).

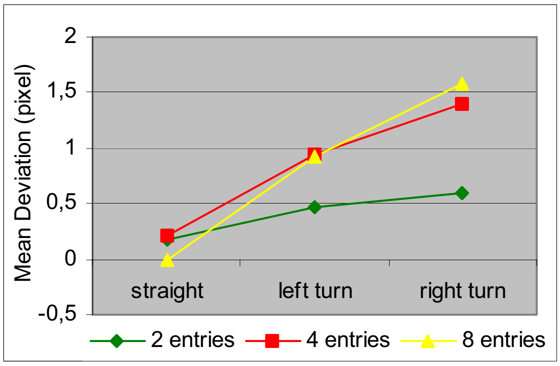


Figure 5.2 Effects of direction of curvature and list length on lane deviation (dual task minus single task values) – experiment 5

Lane deviation was also lowest during the first fifth of the search (mean of -0.05 pixel, SD=0.4), higher for the third fifth of the search (mean of 0.8 pixel, SD=0.4) and highest for the last fifth of the search (mean of 1.3 pixel, SD=0.7). All differences were significant (p<0.003). Furthermore, the interactions between list length and searching period [F(4,60)=3.493, p=0.012, ε=0.734] and between direction of curvature and searching period were significant [F(4,60)=8.301, p<0.001, ε=0.677]. Thus, the effects of searching period were not equally distributed across the different curve types and list lengths. Performance was generally better during single task conditions than during dual task conditions, as the overall mean value of lane deviation (dual task minus single task values) was positive (0.7 pixel, SD=0.4) and significantly (p<0.001) different from zero.

According to the second analysis, neither the main effect of velocity [F(1,15)=0.049, p>0.8, ε=1.0] nor the main effect of curve radius [F(1,15)=1.632, p>0.2, ε=1.0] was significant. The main effects of list length [F(2,30)=6.036, p=0.006, ε=0.896] and searching period [F(2,30)=51.423, p<0.001, ε=0.682], however, were significant. In addition, the interactions between velocity and searching period [F(2,30)=3.548, p=0.041, ε=0.829], between list length and searching period [F(4,60)=3.395, p=0.031, ε=0.667], and between curve radius and searching period [F(2,30)=5.491, p=0.009, ε=0.937] were significant, indicating once more a strong influence of searching period on primary task performance.

5.2.3.2 List performance (secondary task)

Misses. A 2x3x2 repeated measures analysis of variance (ANOVA) with the factors velocity (slow, fast), list length (2, 4, and 8 entries), and curve radius (moderate curves, sharp curves) revealed no significant main effects for either of the factors velocity [F(1,15)=4.355, p>0.05, ε=1.0], list length [F(2,30)=0.894, p>0.4, ε=0.742] or curve radius [F(1,15)=2.143, p>0.1, ε=1.0], nor of any of the interactions.

Task completion times. A 3x2x2 repeated measures analysis of variance (ANOVA) with the factors list position (2, 4, 8 entries), velocity (slow, fast) and curve radius (moderate curves, sharp curves) revealed that the main effect of curve radius was not significant [F(1,15)=1.108, p>0.3, ε=1.0]. The main effects of list position [F(2,30)=53.935, p<0.001, ε=0.722] and velocity [F(1,15)=8.579, p=0.01, ε=1.0], however, were significant, as was the interaction between velocity and curve radius [F(1,15)=5.169, p<0.04, ε=0.808], as displayed in figure 5.3.

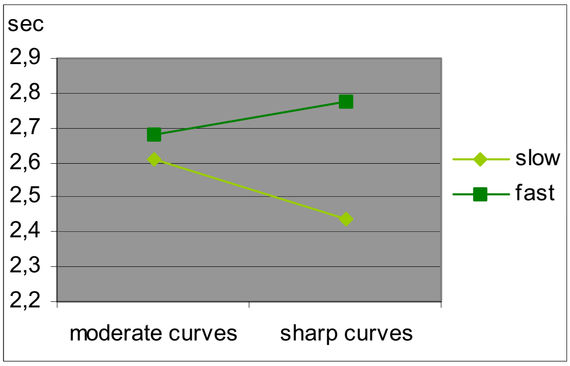


Figure 5.3 Effects of velocity and curve radius on task completion times – experiment 5

Task completion times were lowest for a list length of two entries (mean of 2.0s, SD=0.6) and higher for both a list length of four entries (mean of 2.5s, SD=0.7) and eight entries (mean of 3.3s, SD=1.0). All differences were significant (p<0.001).

Extra keystrokes (False positive answers). A 2x3x2 repeated measures analysis of variance with the factors velocity (slow, fast), list length (2, 4, and 8 entries), and curve radius (moderate curves, sharp curves) revealed no significant main effects of list length [F(2,30)=0.467, p>0.6, ε=0.767], curve radius [F(1,15)=0.0, p=1.0, ε=1.0] or velocity [F(1,15)=1.344, p>0.2, ε=1.0], nor for any of the interactions. The mean number of extra keystrokes for all correctly completed trials was 0.05 with a maximum of 2. The percentage of all error-free completed trials was 95.8%.

5.2.3.3 Subjective ratings

Self-estimated effort. A 4x2 repeated measures analysis of variance (ANOVA) with the factors list length (no list, 2, 4, and 8 entries) and velocity (slow, fast) revealed no significant main effect of velocity [F(1,15)=2.432, p>0.1, ε=1.0]. But the main effect of list length [F(3,45)=5.352, p=0.012, ε=0.634] was significant, as was the interaction between the two factors [F(3,45)=4.048, p=0.012, ε=0.904], indicating a higher effort level for all list lengths in the fast condition. The subjectively estimated effort was equal for the single task condition (mean value of 0.7, SD=0.7) and the dual task situation with a list of two entries (mean value of 0.7, SD=0.5), higher for the dual task situation with a list of four entries (mean value of 0.9, SD=0.5) and highest for a dual task situation with a list of eight entries (mean value of 1.2, SD=0.6). The differences between list lengths of two and four entries (p=0.009) and two and eight list entries (p=0.003) were significant.

Ratings of interference of secondary task. A 3x2 repeated measures analysis of variance (ANOVA) with the factors list length (2, 4, 8 entries) and velocity (slow, fast) revealed significant main effects of list length [F(2,30)=13.912, p<0.001, ε=0.71] and velocity [F(1,15)=30.18, p<0.001, ε=1.0]. The subjectively estimated interference of the secondary task was lowest for a list length of two entries (mean value of 0.9, SD=0.6), and higher for both a list length of four (mean value of 1.0, SD=0.6) and eight entries (mean value of 1.4, SD=0.6). The differences between list lengths of two and eight entries (p=0.004) and four and eight entries (p<0.001) were significant. The subjectively estimated effort was significantly lower (p<0.001) in the slow condition (mean value of 0.9, SD=0.4) than in the fast condition (mean value of 1.3, SD=0.5). The interaction between the two factors was not significant [F(2,30)=0.822, p>0.4, ε=0.694].

Subjective estimation of task priority. A 4x2 repeated measures analysis of variance (ANOVA) with the factors list length (no list, 2, 4, 8 entries) and velocity (slow, fast) revealed a significant main effect of list length [F(3,45)=28.596, p<0.001, ε=0.549]. All differences were significant (p<0.02), except the one between two and four entries (p>0.5). The main effect of velocity [F(1,15)=1.39, p>0.2, ε=1.0] was not significant, nor was the interaction between the two factors. See figure 5.4 for the distribution of attention allocation throughout the different conditions.

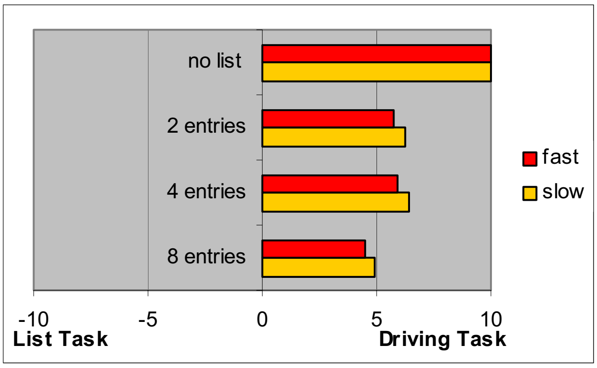


Figure 5.4 Distribution of task priority – experiment 5

For an overview of the results of experiment 5 see table 5.2.

Table 5.2 Results of Experiment 5. Mean values of lane deviation (pixel), misses (%), secondary task duration times (sec), error rate, subjective ratings of effort, secondary task interference, and attention allocation (with standard deviation in parenthesis)

Objective measures

	Lane deviation *(pixel)*		***Misses*** (%)	***Secondary task completion times*** (sec)	***Number of extra keystrokes***
	(ANOVA 1)	*(ANOVA 2)*			
List length					
2 entries	0.4 (0.4)		0.0 (0.0)	2.0 (0.6)	0.6 (0.5)
4 entries	0.8 (0.6)		0.4 (0.0)	2.5 (0.7)	0.5 (0.5)
8 entries	0.8 (0.6)		0.4 (1.1)	3.3 (1.0)	0.5 (0.4)
Velocity					
Slow	0.7 (0.5)		0.0 (0.0)	2.5 (0.7)	0.6 (0.5)
Fast	0.7 (0.7)		0.5 (0.7)	2.7 (0.7)	0.5 (0.4)
Direction of curvature					
Straight sections	0.1 (0.7)				
Left turns	0.8 (0.8)				
Right turns	1.2 (0.5)				
Curve radius					
moderate		0.7 (0.3)	0.2 (0.3)	2.6 (0.6)	0.5 (0.4)
sharp		0.9 (0.7)	0.3 (0.4)	2.6 (0.8)	0.5 (0.5)
Searching period					
0-20% of search	-0.05 (0.4)				
40-60% of search	0.8 (0.4)				
80-100% of search	1.3 (0.7)				
Overall	0.7 (0.4)		0.3 (0.3)	2.6 (0.7)	0.5 (0.4)

Subjective measures

	Ratings of effort	***Ratings of secondary task interference***	***Ratings of attention allocation***
List length			
no list	*0.7 (0.7)*		10.0 (0.0)
2 entries	0.7 (0.5)	0.9 (0.6)	6.0 (3.0)
4 entries	0.9 (0.5)	1.0 (0.6)	6.1 (2.9)
8 entries	1.2 (0.6)	1.4 (0.6)	4.7 (3.4)

Subjective measures (continued)

	Ratings of effort	*Ratings of secondary task interference*	*Ratings of attention allocation*
Velocity			
Slow	0.8 (0.5)	0.9 (0.4)	6.9 (2.5)
Fast	1.0 (0.5)	1.3 (0.5)	6.6 (2.1)

5.2.4 Comparative statistical analysis between experiments 4 and 5

In experiment 4 primary and secondary task were presented on the left and on the right of the two monitors respectively. Experiment 5 on the other hand presented the stimuli of both primary and secondary task on the left monitor only. In order to compare results between the two experiments, a series of analysis of variance was executed for the different dependent variables.

5.2.4.1 *Primary task performance*

To compare lane deviation measures between experiments 4 and 5, two separate analysis of variance (ANOVA) were computed. For the first one a 2x3x2x3x3 factorial design with one between participant factor (*display location*: two monitors, one monitor) and four within participant factors (*list length:* 2, 4, and 8 entries; *velocity:* slow, fast; *direction of curvature:* straight sections, left turns, right turns; *searching period:* 0-20% of the search, 40-60% of the search, 80-100% of the search) was used. For the second one a 2x3x2x3x3 factorial design with one between participant factor (*display location*: two monitors, one monitor) and four within participant factors (*list length:* 2, 4, and 8 entries; *velocity:* slow, fast; *curve radius:* moderate curves, sharp curves; *searching period:* 0-20% of the search, 40-60% of the search, 80-100% of the search) was used.

According to the first analysis, there was no significant main effect of display location for any of the factors list length [F(2,60)=2.81, p>0.06], velocity [F(1,30)=0.558, p>0.4], or direction of curvature [F(2,60)=0.406, p>0.6]. There was, however, a significant main effect of display location for the factor searching period [F(2,60)=13.098, p<0.001], indicating an enhancing effect of display location particularly for the last fifth of the searching period. Display location had no significant main effect on either of the interactions. According to the second analysis, there was no significant main effect of display location for any of the factors list length [F(2,60)=3.13, p>0.05], velocity [F(1,30)=0.74, p>0.3], or curve radius [F(2,60)=1.066, p>0.3], nor for any of the interactions. But there was again a significant main effect of display location for the factor searching period [F(2,60)=9.347, p<0.001].

5.2.4.2 Secondary task performance

Three comparative analysis between experiments 4 and 5 were computed on percentage of misses, task completion time and extra keystrokes via a 2x2x3x2 repeated measures analysis of variance (ANOVA) with one between participant factor (*display location*: two monitors, one monitor) and three within participant factors (*velocity:* slow, fast; *list length:* 2, 4, and 8 entries; *curve radius:* moderate curves, sharp curves). The comparative analysis on percentage of missed trials revealed no significant main effect of display location for any of the factors list length [F(2,60)=0.608, p>0.5], velocity [F(1,30)=3.14, p>0.08], or curve radius [F(1,30)=3.462, p>0.07], nor for any of the interactions. This was also true for the comparative analysis on extra keystrokes (list length: [F(2,60)=2.785, p=0.07], velocity: [F(1,30)=1.408, p>0.2], curve radius: [F(1,30)=1.342, p>0.2]). None of the interactions became significant either. The comparative analysis on task completion times revealed also no significant main effect of display location for the factors velocity [F(1,30)=0.698, p>0.4], and curve radius [F(1,30)=0.191, p>0.6]. There was, however, a significant main effect of display location for the factor list length [F(2,60)=3.959, p<0.03], as well as for the interaction between the factors list length and velocity [F(2,60)=4.237, p<0.02].

5.2.4.3 Subjective Ratings

Two comparative analysis between experiments 4 and 5 were computed on self-estimated effort level and attention allocation via a 2x4x2 repeated measures analysis of variance (ANOVA) with one between participant factor (*display location*: two monitors, one monitor) and two within participant factors (*list length:* no list, 2, 4, and 8 entries; *velocity:* slow, fast). The comparative analysis of self-estimated effort revealed a significant main effect of display location for the factor list length [F(3,90)=3.013, p=0.034], indicating that the self-estimated effort levels were lower in experiment 5. But there was no significant main effect of display location for the factor velocity [F(1,30)=3.977, p=0.055], nor for the interaction between the two factors

[F(3,90)=1.659, p>0.1]. The comparative analysis of attention allocation revealed no significant main effect of display location for any of the factors velocity [F(1,30)=5.272, p>0.5] or list length [F(3,90)=2.19, p>0.09], nor for the interaction between the two factors. A third comparative analysis between experiments 4 and 5 was computed on subjective ratings of secondary task interference via a 2x3x2 repeated measures analysis of variance (ANOVA) with one between participant factor (*display location***:** two monitors, one monitor) and two within participant factors (*list length:* 2, 4, and 8 entries; *velocity:* slow, fast). It revealed a significant main effect of display location for the factor list length [F(3,90)=8.813, p>0.001], indicating that subjective ratings of secondary task interference were lower in experiment 5. But there was no significant main effect of display location for the factor velocity [F(1,30)=1.06, p>0.3], nor for the interaction between the two factors [F(3,90)=1.371, p>=0.2].

5.2.5 Discussion experiment 5

List lengths of four entries and higher, right and left turns, as well as advanced searching periods had significant decreasing effects on driving performance. Interestingly, there was almost no difference in driving performance between secondary tasks with four and eight entries in the list, indicating that any scrolling at all increased task demands. List length also interacted in a significant manner with direction of curvature in the first ANOVA and with searching period in both ANOVAs. In both cases secondary tasks with list lengths of four and more entries were clearly more vulnerable to increasing task demands of the factors direction of curvature or searching period than searches in a list of two entries only. As in the preceding experiments searching period had a strong effect on driving performance. Concerning the results of the medium and last fifth of the search, increasing display proximity could apparently not eliminate decreases in driving task performance. Furthermore, significant interactions between searching period and list length (both ANOVAs), searching period and velocity (ANOVA 2), searching period and curve radius (ANOVA 2), and searching period and direction of curvature (ANOVA 1) indicate that advanced searches contribute a great deal to overall task demands. Obviously, task demands of either factor added up until overall task demands reached a level which participants could not compensate for any more by investing more effort or prolonging secondary task completion time, thus forcing them to compromise driving performance. This effect can be excellently demonstrated with the exemplary interaction of direction of curvature and searching period: there was almost no difference between the various types of track sections during the first 20% of the search, as displayed in figure 5.5. During 40 and 60% of the search only right turns appeared to have a degrading effect on driving performance and finally, during the last fifth of the search both right and left turns decreased driving performance measures.

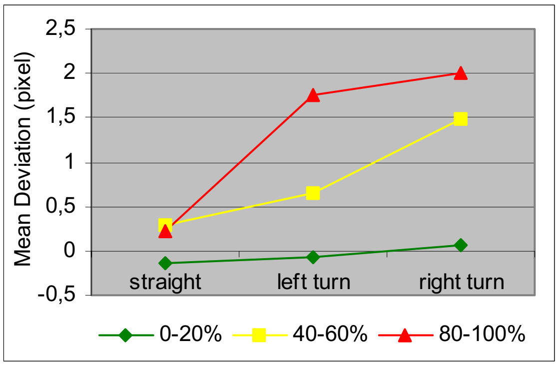


Figure 5.5 Effects of searching period and direction of curvature on lane deviation (dual task minus single task values) – experiment 5

Results revealed no driving performance decreasing effect of curve radius but a degrading effect on secondary task performance, as task completion times increased significantly when driving on sharp curves and simultaneously searching in lists with two and four entries. This was also true for the factor velocity, as well as the interaction between velocity and curve radius for all list lengths. Apparently, higher task demand levels of the factors driving speed and curve radius could be compensated by stretching out the secondary task, thus protecting driving performance. List length had also a significant effect on secondary task completion times which again cannot be completely explained by the physical requirement of increased searching times due to prolonged scrolling times. Nevertheless, it appears that the requirement to scroll is the performance impairing variable, causing an increase of secondary task demands. There were no misses and no significant effects on error rates which implies that participants compensated less by neglecting the secondary task, which again implies that overall task demands remained at a manageable level. Subjective ratings of experienced effort, secondary task interference, and task priority revealed significant effects of list length only. But the strategy to protect primary task performance by investing more effort was obviously not sufficient to cope for the demand increasing influence of list length, as list length had also a degrading effect on primary task performance. But again, participants seemed to be aware of this effect. Velocity did only have a significant effect on estimations of secondary task interference, implicating that participants still noticed a disturbing effect of increased task demands due to an increase in velocity.

5.3 Discussion experiments 4 and 5

Summarizing the results of experiments 4 and 5, driving performance was significantly effected by list length and searching period and the interaction of both factors, as well as by the interaction of velocity and searching period. Furthermore, statistical analysis revealed a significant effect of direction of curvature on driving performance in both experiments, while curve radius effected driving performance in experiment 4 only. The interaction between curve radius and searching period, however, was significant in both experiments. In addition, the interactions between direction of curvature and searching period and between list length and direction of curvature affected driving performance significantly in experiment 5 only, while the interaction between velocity and curve radius became significant only in experiment 4. Percentage of missed trials and error rates were not effected by any of the factors in either experiment. More generally, task completion times were significantly effected by list length in both experiments, as well as by curve radius in experiment 5. Ratings of subjectively experienced effort and secondary task interference revealed significant effects of velocity and list length in both experiments. As no other variables have been changed, the differences between experiment 4 and 5 are mainly due to the increased proximity of displayed information. In the following sections each of the effects of driving speed, list length, direction of curvature, curve radius and searching period on lane deviation, error rate, misses and task completion times, as well as on subjective experiences shall be discussed in detail.

The effect of driving speed. Driving performance was relatively unaffected by speed variations in both experiments. Concerning differences in task completion times between experiments 4 and 5, however, driving speed did have a significant effect when interacting with list length, thus indicating that task demands of list length and velocity added up. Nevertheless, fast trials were in both experiments rated to be significantly more effortful and the lists to be significantly more distracting during fast trials, reflecting a rise in subjectively assessed mental workload, but there was no significant difference between the two experiments, however. Only concerning subjective estimates of attention allocation display location did have a significant effect on velocity, indicating a higher priority on the driving task for both velocities in experiment 5. Or, in other words the difference between the two velocity levels on attention allocation vanished in experiment 5.

The effect of list length. Primary task performance was best for two entries and worst for eight entries in both of the experiments (see figure 5.6), but the difference between four and eight entries did not become significant anymore in experiment 5.

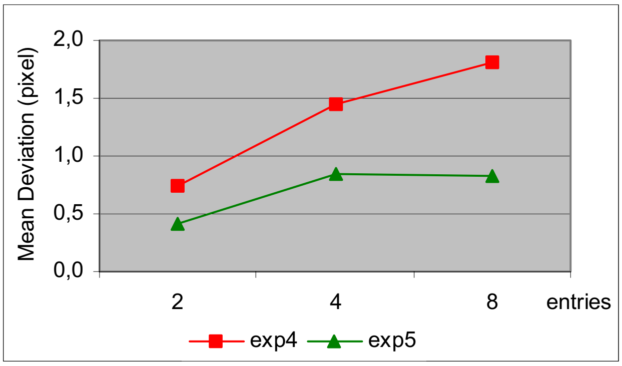


Figure 5.6 Effect of list length on lane deviation (dual task minus single task values) – experiments 4 and 5

The differences between experiments 4 and 5 concerning the effect of list length on driving performance did not become significant. But there were significant differences between experiments 4 and 5 concerning the effect of list length on task completion times, being significantly shorter in experiment 5 for all list lengths. Again, the more entries in a list, the more effortful the trial was rated and the more interference was attributed to the lists, both ratings being significantly higher in experiment 4. Thus, increasing display proximity did significantly shorten task completion times and decrease ratings of effort and interference throughout the different list lengths.

The effect of direction of curvature. The type of road segment also influenced primary task performance significantly in both experiments. But although driving performance was superior in experiment 5 for all of the track sections (see figure 5.7), the difference did not become significant, indicating that an increased display proximity could not compensate for problems related to switching attention back and forth fast enough in order to react efficiently to rapidly changing track sections.

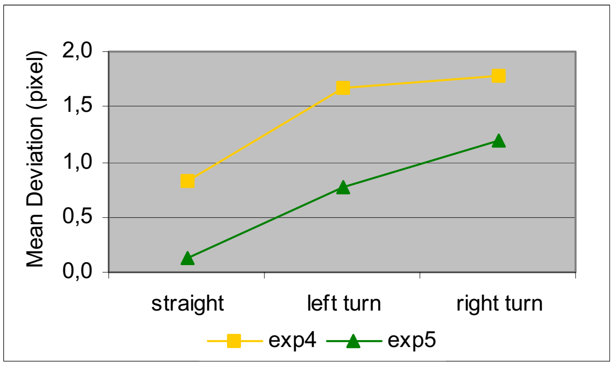


Figure 5.7 Effects of direction of curvature on lane deviation (dual task minus single task values) – experiments 4 and 5

The effect of curve radius. Curve radius did have a significant effect on driving performance, but not on task completion times in experiment 4. Conversely, curve radius had a significant effect on task completion times but not on driving performance in experiment 5. Therefore, either participants in experiment 5 balanced potential driving performance losses by prolonging secondary task completion times, while participants in experiment 4 failed to do so or overall task demands were less in experiment 5. Furthermore, the interaction between curve radius and speed had a significant effect on task completion times in experiment 5, but not on lane deviation, indicating that an increase in display location decreased primary task demands to a level where participants could compensate for them completely by increasing task completion times. Statistical comparisons between the experiments revealed no significant differences concerning the effect of curve radius on driving performance. The number of extra keystrokes was also relatively unaffected by variations of curve radius throughout both of the experiments and there was no significant difference between the two experimental settings.

The effect of searching period. Once more, the current status of the search had the greatest effect on driving performance in both of the experiments. Driving performance was best during the first 20% of the search, degraded between 40% and 60% of the search and became worst during the last 20% of the search. During the first fifth of the search there were only marginal differences in driving performance between the two experimental settings and performance was even better in the dual task situation than in the single task situation. The differences between experiments 4 and 5 then increased during the third and the last fifth of the search. As displayed in figure 5.8 and revealed by statistical comparisons between the two experiments, increased display proximity in experiment 5 had a significant advantage compared to experiment 4 concerning the effects of searching period on primary task performance, particularly for the last period of search. These results are in a line with the assumption that it should take longer to shift attention between more distant displays than more proximate ones (Wickens & Hollands, 2000). Because visual demand increases during the last searching period, only minimizing the distance between the two tasks had an enhancing effect on driving performance.

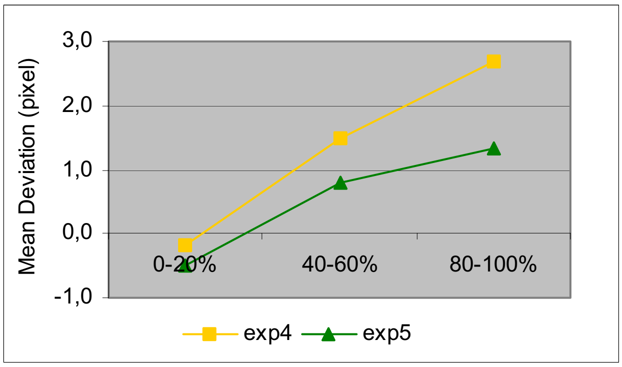


Figure 5.8 Effects of searching period on lane deviation (dual task minus single task values) – experiments 4 and 5

Furthermore, the dual task situation was generally rated to be more effortful than the single task situation in both experiments.

Conclusions. Although participants were instructed to not compromise the driving task while performing a display-related secondary task they did so nevertheless, causing variation in driving performance measures. Adding a secondary task significantly degraded driving performance in both experiments. Increasing the proximity of displays could not eliminate this performance impairing effect but had a significant improving effect on driving performance losses during the last fifth of the search. List length as well as curvature still had significant decreasing effects on driving performance in both experiments, indicating that an increase of display proximity could not eliminate the performance degrading effects of increasing task demands of either factor. Thus, changes in road surfaces and the need to scroll in the list obviously still impose task demand levels that could still not be compensated by switching forth and back between primary and secondary task more quickly due to decreased distances between the two information locations. On the other hand, experiments 4 and 5 also showed examples where the dual task situation was superior to the single task situation, indicating that overall task demands in the single task situation dropped below an optimal workload level. Consequently, making tasks too easy apparently entails the opposite effect from which was intended, namely decreasing driving performance measures. Compared to experiment 4, increasing the proximity of displays increased both accuracy (lane deviation) and speed (task completion times), as shown in figure 5.9.

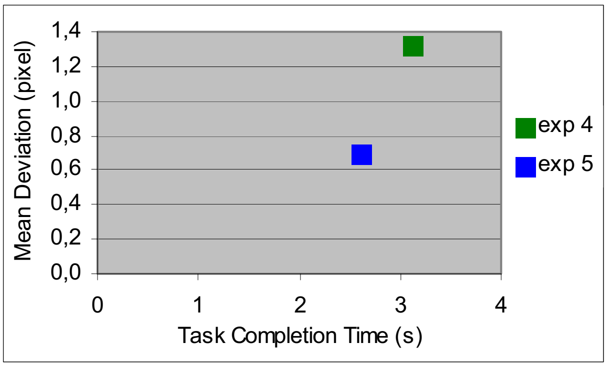


Figure 5.9 Speed – accuracy trade-offs (experiments 4 and 5)

Chapter 6: General discussion

This chapter first summarizes the results of all five experiments (section 6.1). Afterwards participants' reactions to primary task demands (section 6.2) as well as to secondary task demands (section 6.3) shall be discussed. These findings are completed by addressing participants' subjective experiences (section 6.4). Sections 6.5 and 6.6 outline some general thoughts and interpretations of the results concerning topics like speed-accuracy trade-offs and task prioritisation (section 6.5) and the influence of different workload levels (section 6.6). Furthermore, some methodological limitations of the experiments (sections 6.7) and implications for future research (section 6.8) will be discussed. Section 6.9 finally summarizes the general discussion.

6.1 Summary of results

The preceding experiments examined the effects on driving and secondary list task performance in two different speed conditions, seven different list length conditions, two control location conditions, and two display location conditions. Performance was assessed in simulated driving conditions varying in both primary and secondary task demands. The general aim of this dissertation was to isolate factors impairing driving performance. It was assumed that a factor becomes performance impairing when levels of task demands, caused by this specific factor, could not be compensated by any of the strategies adopted to decrease workload level. The aim of the first experiment was to investigate the effects of the position of an entry in the list on primary and secondary task performance. No significant differences could be found between the different positions of a specific entry in either the first, second, or last third of an alphabetically ordered list of 26 entries total. But results provided support for the hypothesis that participants adopted several different strategies in order to protect driving performance, e.g. by prolonging task completion times, even up to the point where target items could not be confirmed correctly at all, or by accepting a higher error rate on secondary task performance, or by accepting higher levels of workload. The second experiment was conducted to find out whether participants are still able to apply these strategies effectively when list lengths increase up to a maximum of

104 entries. Again, results revealed no significant effects of list length on primary task performance. Apparently participants were still able to compensate for increasing task demands by implementing the above mentioned strategies in order to protect driving performance. To cross-check whether primary task performance improves with shorter lists, experiment 3 was conducted with a maximum list length of eight entries. Here, significant differences concerning decreases in driving performance could be found between the list lengths of two, four, and eight entries. As shorter lists seemed to improve driving performance, experiment 4 was set up to investigate possible further increasing effects of positioning the secondary task control closer to the driver. But except for error rates and subjective ratings there was no significant increase in performance between experiments 3 and 4 due to the increased proximity of controls. Assuming that these results were caused by the rather great distance between the two monitors, requiring rather long times for switching attention, experiment 5 was conducted to find out, whether the degrading effects of a secondary task on driving performance could be eliminated by increasing display proximity. Although impairing effects on driving performance could not be deleted completely, there was a driving performance improving effect, especially during the last fifth of the search. In the following, results are summarized concerning driving performance (section 6.1.1), menu selection performance (section 6.1.2), and subjective experiences (section 6.1.3).

6.1.1 Driving performance

Driving performance was relatively unaffected by driving speed variations throughout all experiments. In experiments 3, 4, and 5, however, significant interactions between car velocity and searching period indicated that driving speed only caused a performance degrading effect, when overall task demands were already high. List length, however, did effect driving performance, being best at list lengths shorter than eight entries. Searching in lists with eight and more entries had a degrading effect on driving performance, which tended to level off once list length exceeded 52 entries (see figure 6.1). Only the differences between two, four and eight entries were significant, the differences between all other list lengths (26, 52, 78 and 104 entries) had no significant effect on driving performance, indicating that beyond a certain list length driving performance remains quite steady. Interestingly, searching entries in the first eight entries of a list of 26 entries degraded driving performance more strongly than searching entries in a list of eight entries total, as displayed in figure 6.1.

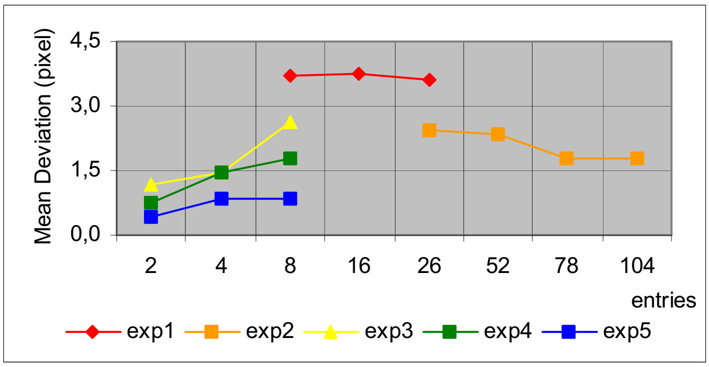


Figure 6.1 The effect of list length on driving performance (dual task minus single task values) – all experiments

The inferior results of experiment 1 compared to experiment 2 were largely caused by a higher time pressure, as time windows to complete the secondary task were increased in experiment 2. The increase in driving performance for lists longer than 52 entries, however, has to be explained in another way. Apparently, very long lists allowed participants to implement efficient switching strategies and to schedule tasks more economically. In addition, participants might possibly have protected primary task goals better in experiment 2 by prolonging the duration of the secondary task (see section 6.1.2).

Furthermore, driving performance was, as anticipated, best during straight track sections. But surprisingly, it was worse during right turns than during left turns (see figure 6.2).

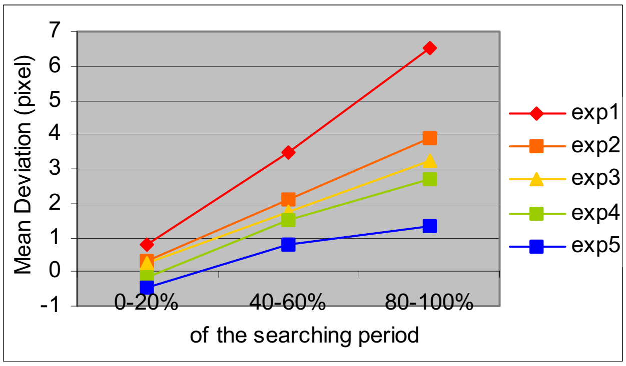


Figure 6.2 The effect of searching period on driving performance (dual task minus single task values) – all experiments

The difference between straight track sections and right turns was significant in experiments 1, 2, and 5, whereas the difference between right and left turns was significant in experiment 5 only. Neither increasing the proximity of secondary task controls nor decreasing the distance between displayed information had a significant improving effect on driving performance concerning the effects of direction of curvature. The same was true for effects of curve radius. Although driving performance was better in trials with straight track parts and moderate curves than in trials with sharp curves, an effect which was significant in experiments 1, 2, and 4, neither changing the location of secondary task controls nor an increase in display proximity could significantly increase driving performance measures during both moderate and sharp curves. The current status of the search showed the most persisting effect on driving performance throughout all experiments. Concerning the first 20% of the search results did hardly differ in driving performance during the dual task and the driving-only condition (as values are around zero), the mean lane deviation of experiments 4 and 5 even being below the value of the driving-only condition (see figure 6.2). During the medium fifth of the search, the differences started to increase and reached a maximum during the last fifth of the search. Furthermore, searching period interacted significantly with direction of curvature (experiments 1, 2, 3, 5), list length (experiments 2, 3, 4, 5), velocity (experiments 3, 4, 5), and curve radius (experiments 4, 5), indicating a very strong increase in task demands during the last period of the search up to a driving performance degrading level. Thus, task demand level did not remain constant throughout the duration of the secondary task, rather it appears that not before approaching the target item driving performance decreases, an effect which was persistent throughout all experiments. Only the increase in display proximity had a significant enhancing effect, particularly concerning the last fifth of the search.

Nevertheless, as all measures were gained by subtracting the mean single task value from the mean dual task value, overall mean lane deviation being positive and significantly different from zero reveals a general impairing effect of the secondary task on driving performance, as displayed in figure 6.3.

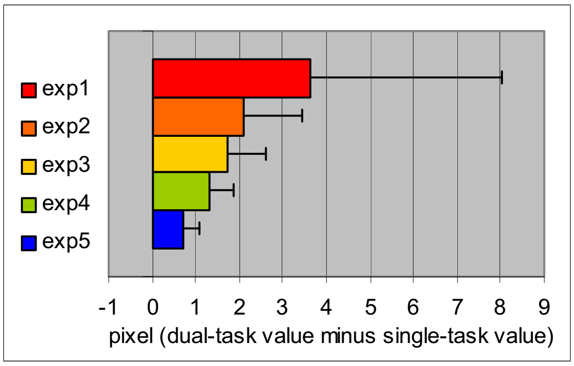


Figure 6.3 Overall driving performance (mean lane deviation: dual task minus single task values) – all experiments

The overall duration of the dual task situation did apparently not degrade driving performance, at least not for very short task durations of only a couple of seconds, which were the case for all experiments. Otherwise, mean lane deviation must have been generally higher in experiments with a more time consuming secondary task (experiment 2) than in all other experiments, which was not the case (see figure 6.1). Accordingly, Tsimhoni (2003, p. 1) states: “Longer in-vehicle tasks may not necessarily impose higher visual demands on the driver”.

6.1.2 Menu selection performance

Increasing list lengths were accompanied by a significant rise in the percentage of misses in experiments 1 and 2, as participants were (due to the increased list length) under high time pressure to complete the list task.. This finding indicates that constant driving performance measures were only possible at the cost of high task completion times and hence, high rates of misses. Task completion times of correctly completed trials were significantly effected by either curve radius (experiments 1 and 5) or speed (experiments 2 and 3). As driving speed was never a factor causing decreasing effects on driving performance, the strategy of prolonging secondary task completion times was quite effective. Concerning curve radius, however, the strategy of prolonging secondary task duration times prevented primary task performance losses in experiment 5 only. Due to the increased time pressure in experiment 1 participants were apparently not able to implement this strategy powerfully enough. While increasing the reaching distance to the secondary task controls did not significantly affect task completion times, an increase in proximity of the displayed information did result in shorter task completion times, an effect which was especially articulate for list lengths of four and eight entries. Furthermore, error rates were significantly influenced by curve radius (experiments 2 and 3). In all other experiments none of the factors influenced error rate. Contrary, most trials were completed without any errors at all, as shown in figure 6.4.

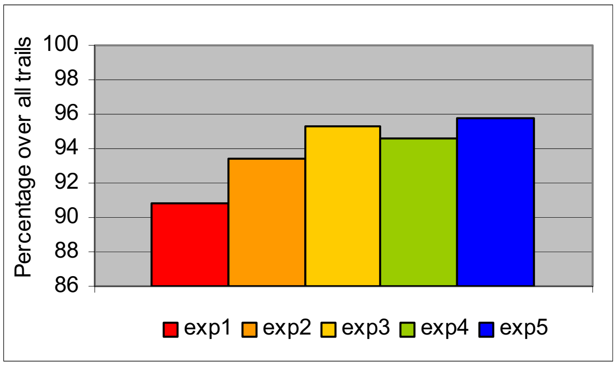


Figure 6.4 Percentage of trials completed without any errors – all experiments

Apparently, making errors was tried to be avoided if possible, although it had no other consequence than having to continue the search. In a real driving environment, however, making errors would entail being forced to back up in the menu and select the correct entry, thus entailing longer task duration times and at least two separate periods of approaching an entry instead of one, accompanied by all related negative effects of this last part of the search on driving performance.

6.1.3 Subjective experience

Fast conditions were generally reported to require significantly more effort than slow conditions, except in experiment 5, where this difference was not significant. Concerning subjective ratings of secondary task interference, fast conditions were reported to be significantly more interfering than slow conditions throughout all experiments. This finding indicates that although velocity did not effect driving performance in any of the experiments, task demands increased nevertheless, but could be compensated by 'trying harder'. List lengths had a significant effect on self-estimated effort, as well as on subjective ratings of secondary task interference in experiments 3, 4 and 5. The patterns of reported effort and interference due to the secondary task were quite similar (see figure 6.5), indicating that an increase in perceived interference also resulted in an increase of effort level. Experiment 2, with a maximum of 104 list entries, was rated highest.

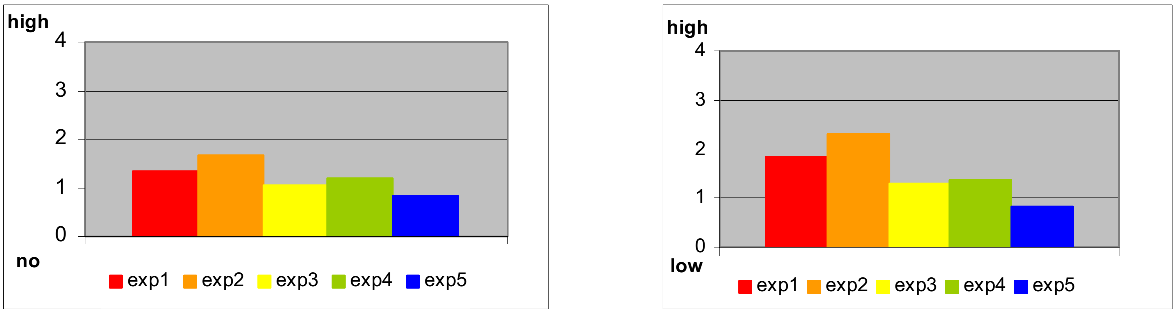


Figure 6.5 a) Distribution of effort **b)** and secondary task interference

According to participants' estimations, allocation of attention was significantly effected by list length in experiments 2, 3, 4, and 5, indicating that there was a higher priority on the driving task the less entries there were in the list. Accordingly, prioritising the primary task of driving was most endangered in experiment 2, where list lengths exceeded 26 entries.

6.2 Reaction to primary task demands

Primary task demands were varied by implementing 13 different track section types and two different levels of driving speed. The type of road section changed rather frequently, thus imposing a more varying level of task demands on the driver, while speed variations represented a rather stable level of task demands, as it did not change during one single condition.

6.2.1 Direction of curvature

As expected, driving performance was best on straight track parts. One explanation for this result is of course the increased visual demand imposed by curved track sections. But surprisingly, right turns tended to decrease performance to a greater extent than left turns, so an additional explanation must be found. It is a widespread everyday observation that turning the head to the left or right while driving a car or riding a bicycle is associated with a certain risk of turning the steering device as well (Klein & Heuer, 1999). There have been occasional reports of accidents in which a vehicle ran off the road, but more typical are small lane deviations from the proper course (Heuer & Klein, 1999a, 1999b). Klein and Heuer (1999) also conducted two experiments which showed that when the head was in an eccentric position, iso-directional rotations of a steering device were always of longer amplitude and longer duration until peak excursion than rotations in the opposite direction, which might be an explanation for the larger lane deviations during right turns, as turning the steering-wheel to the right was an iso-directional movement to turning the head to the right in order to search the list.

There is also the possibility that small shoulder movements induced by rotations of the head are partly propagated to the hands (Klein & Heuer, 1999). Thus, the movement of the head looking to the right might have been transmitted to the hands, inducing a same-direction rotation of the steering-wheel (Heuer & Klein, 1999a). In some cases, this movement might even have compensated for a possible deviation to the left. Structural constraints on the coordination of movements of the head and of the arms are quite complex, however, and the net result of the possible contributions is therefore hard to predict (Heuer & Klein, 1999b). Last but not least, evidence regarding the relationship between movements of the head and of the arms is also less clear because these are rarely studied (Heuer & Klein, 1999b).

But in the case that small shoulder movements induced by rotations of the head are partly propagated to the hands on the steering-wheel, thus causing lane deviations in the same direction, increases in display proximity should decrease this effect, which was not the case in these experiments. Therefore, maybe even directing one’s gaze to the right might have caused such small movements being propagated to the hands.

6.2.2 Curve radius

Increasing curve radii increase the visual demand of the driving task, as fast motor reactions are required (steering) to not run off the road. Consequently, in situations where the visual demand of driving increased, participants could not afford to look away from the road for long periods of time. As they did so nevertheless, driving performance was worse during trials consisting of sharp curves than during trials consisting of straight track sections and moderate curves, a finding which is consistent with the key finding of a visual occlusion study conducted by Tsimhoni and Green (2001), who found a linear relationship between the mean visual demand for a curve (the fraction of time the road was visible) and the inverse radius of curvature. This might also be an explanation why locating the controls on the steering-wheel did not have the expected enhancing effect on driving performance during more demanding trials. In these situations of increased visual demand only a decrease in display proximity could provide a little support. Even despite an increase in display proximity participants could not compensate for changes in curve radius probably because these occurred very frequently, not giving enough time to redirect attention to the primary task and execute the proper reaction.

6.2.3 Driving speed

Although participants could not control driving speed, the two different levels of velocity had no significant effect on driving performance in any of the experiments. Nevertheless, driving speed did effect secondary task completion times and subjectively estimated workload levels. Therefore, it appears that driving speed increases task demands to an extent which could be handled by participants via increasing effort or prolonging the secondary task. The reason for this might be that higher speed levels increase time pressure, thus requiring faster information processing which can be met by increasing effort as long as no unexpected events occur. Conversely, speed – by increasing or decreasing time pressure of the task(s) – introduces the possibility of varying the level of perceived task difficulty. Therefore, speed appears to be a tool for regulating workload level, an idea which has been previously suggested (e.g., Cnossen et al., 2004; Dingus et al., 1997; Fuller, 2005; Pohlmann & Traenkle, 1994).

6.3 Reaction to secondary task demands

According to Kantowitz and Simsek (2001), a key assumption of secondary task methodology is that the primary task is uninfluenced by addition of the secondary task. This argument tends to hold for airplane pilots because they are highly trained to set the priority on flying the plane (e.g., Bartolussi et al., 1986), but must be evaluated anew when vehicle drivers become the test population. To this end, secondary task demands were varied by implementing seven different list lengths, two different control locations, and two different display locations.

6.3.1 List length

The number of searchable entries in the list did not change during one single condition in all experiments. Thus, participants did not have to adapt to a changing number of entries as would be the case in a common hierarchical menu. Nevertheless, there were significant performance differences between the number of list entries in short lists. The most obvious explanation for this is that shorter lists (with two and four entries) impose less task demands on the operator. Another explanation might be the number of displayed entries on the screen, which was four in all experiments. As the first position in the list was not yet a searchable list entry, only the list with two entries appeared on the screen in its entirety. In order to access the last entry of a list of four entries participants only had to scroll one item down. The necessity of scrolling further than this obviously entailed more visual demand, thus degrading driving performance. Motor demands imposed by navigating through the list via a control might have added to an increase in task demands as well, especially when participants passed the target item in the list and had to change direction of cursor movement. In keeping with this proposition, Rauch, Totzke, and Krüger (2004) suggest that information systems for use during driving should access deep menu structures, implying that with a deeper menu structure, the number of list entries on each level is reduced. However, this advantage probably holds only for an overall quantity of data small enough to not require many levels in menu hierarchy, as the navigation problem (i.e., getting lost or using an inefficient pathway to the goal) becomes more and more treacherous as the depth of the hierarchy increases (Paap & Roske-Hofstrand, 1986). Furthermore, while MacGregor, Lee, and Lam (1986) suggest that a minimum of eight alternatives per page is optimal, with some indication that the optimal could be considerably greater than eight, their results were not gained in a driving environment. An explanation why differences between list lengths of more than eight entries did not become significant might be that participants reacted to increased list lengths by extending the duration of the secondary task: as overall task demands were apparently higher for longer lists, the strategy of extending the duration of the secondary task had to be used excessively in experiments 1 and 2, indicated by high percentages of missed trials. But, as rather little changes in driving performance between the different list lengths or list positions reveal, quite successfully: While driving performance remained relatively constant throughout the four different list lengths in experiment 2 and the three different list positions in experiment 1, misses increased significantly. Jordan and Johnston (1993) and Summala (1996) report similar findings.

6.3.2 Location of secondary task controls

The effect of increasing the proximity of secondary task controls to the driver by locating them on the steering-wheel was smaller than expected. The enhancing effect occurred only during less demanding situations and did not become significant. The moment task demands increased (mainly due to increasing curve radii), any advantages vanished: task completion times were not shorter and lane deviations were not less frequent or smaller in amplitude. Only the effect of car velocity on error rate, self-estimated effort and subjective ratings of secondary task interference and attention allocation was significantly effected by control location, indicating that at least subjectively experienced workload levels decreased during fast conditions. Apparently, reaching distances are not a major factor effecting driving performance.

6.3.3 Display proximity

The proximity compatibility principle (Barnett & Wickens, 1988; Wickens & Andre, 1990; Wickens & Carswell, 1995) suggests that a task requiring high processing proximity should be designed with high display proximity. In other words, if two information sources are used to a high extent within the same task, the according display components should be located close together (defined in spatial terms, i.e. cm). Furthermore, Wierwille (1993a; 1993b) suggests that single ‘check glances’ with a duration of about 300ms do not have a degrading affect on driving performance and although it is true for visual tasks that only one single object can be focused at the time, other objects in the surrounding area of this focused object may be covered by indirect vision (Alm et al., 1997; Wickens & Carswell, 1995). If these assumptions were correct, then driving performance in experiment 5 should have been superior to all other experimental settings, as both the driving task and the list task were displayed on only one monitor, thus increasing the proximity between the two sources of information to a maximum. This was indeed the case for the factor searching period, as driving performance improved significantly (especially during the last fifth of the search). It was also true for the effects of list length on task duration times, self-estimated effort and subjective ratings of secondary task interference. Furthermore ratings of attention allocation revealed that there was a significantly higher priority on the driving task during fast trials in experiment 5. Thus, increasing the display proximity showed some improving effects on driving performance but could not account for increasing task demands imposed by frequently changing road conditions.

6.3.4 Searching period

The closer the participant got to the target item when navigating in the list, the higher the task demands (revealed by significant driving performance losses). Apparently, executing a secondary task while driving, namely searching in a list, does not impair driving homogenously at any point of the search. Evidently, the increase in visual demand of the secondary task in order to locate a specific item in the list (contrary to just roughly scanning the visible entries for the current position in the alphabet) is responsible for the significant rise in secondary task demands and hence for decreases in driving performance. In these situations, participants were obviously too focused on the secondary task to detect changing task demands of the driving task, thus being incapable of executing a proper reaction fast enough. Furthermore, late discovers of changes in primary task demands might have caused quick, but less accurate reactions, thus causing higher lane deviation measures in the experiments. In real driving environments similar reactions might even resulted in a loss of vehicle control.

6.4 Subjective experience

Drivers' self reports revealed their ability to recognise decreases in driving performance when executing various secondary tasks while driving. They also demonstrated a clear increase in effort and secondary task interference when task demands increased. The values varied along the different conditions as participants could only react to increasing task demands by prolonging the secondary task duration which was quite effective to protect driving performance but did obviously not reduce workload levels. The strategy to decrease task demands in a more rapid manner would possibly be the reduction of speed which was not possible in these experiments. Furthermore, participants seemed to be well aware of driving performance degrading shifts in task priority towards the secondary task.

6.5 Speed-accuracy trade-offs and task prioritisation

Examining the effects of possible speed-accuracy trade-offs was possible only for the variables of car velocity, list length and curve radius. The variable of direction of curvature could not be evaluated for task completion times (and consequently misses), as there were no trials consisting of straight track parts, right or left turns only. The reason why no such trials existed was to prevent predictability of the oncoming track. The conventional wisdom is that when workload increases, drivers increase the length of time they take to complete tasks in order to protect accuracy of the first priority task. In other words, task completion times of a secondary task are supposed to increase when overall task demands increase and accuracy of a primary task has to be protected. This prediction was true in most cases, but not in all. Except for the factor curve radius in experiment 1, the factors becoming significant for task completion times never appeared as factors that degraded driving performance at the same time. One possible explanation would be that task demands only rose to levels that either degraded driving performance or extended task duration time, but not both. This explanation in turn implies that participants incorrectly prioritized the secondary task when only primary task performance was degraded. But as participants very well did prolong secondary task completion times to protect primary task performance for some factors a closer look should be taken at other reasons possibly explaining this phenomenon. Obviously, increasing task demands of some factors could be compensated by stretching out the secondary task and others could not. Therefore, the conclusion is that participants were able to extend task completion times for those factors which did not change very frequently, such as velocity and list length. On the other hand, prolonging task completion times was apparently not applicable to react properly to increasing task demands that changed quite frequently, such as direction of curvature and curve radius, and performance suffered as a result.

Concerning task prioritisation, participants could correctly prioritize tasks in the queue only to a limited extend: In the last experiment display proximity was increased to a maximum, thus enabling the participant to switch attention forth and back quite fast and easily. For this reason it should have been possible to allocate attention in a manner not degrading to driving performance. Apparently, it is not the requirement of an increase in concentration on the secondary task alone which is responsible for the degrading effect on driving performance, but also the fact that at this stage of secondary task execution obviously interruptions are either not feasible or not conducted. This mechanism probably applies particularly when priorities change quickly and unexpected. “Attention implies withdrawal from some things in order to deal effectively with others“ (James, 1890/1950, p. 403-404), a guideline which seems not adaptable in the mentioned situation. For what reasons ever operators become absorbed by the secondary task, they proceed with executing the secondary task, ignoring or not noticing the need to switch attention to the higher priority task, a finding consistent with those of Jersild (1927), Sheridan (1972) Moray (1986), Rogers and Monsell (1995), and Jamson and Merat (2005). A disastrous example of this phenomenon is the above mentioned airline crash into the Everglades in 1972, where the flight crew, preoccupied with a landing gear problem, failed to monitor their altitude (NTSB, 1973). Consequently, distraction not only describes a general lack of attention but also the act of attending to something irrelevant with the result of an impaired capacity to process relevant information (Rumar, 1990).

6.6 Workload levels

If the perceived task difficulty is too low, which is the case when personal capability exceeds task demands (Fuller, 2005), performance suffers due to boredom or suboptimal levels of arousal. With increasing task demands, performance improves up to the point where reserve capacity is exhausted. This turning point can be raised under exceptional circumstances up to a physical limit. If task demands far exceed personal capabilities, performance suffers once more. As shown in figure 6.6, lane keeping was best during the fast condition when driving on straight track sections in all experiments.

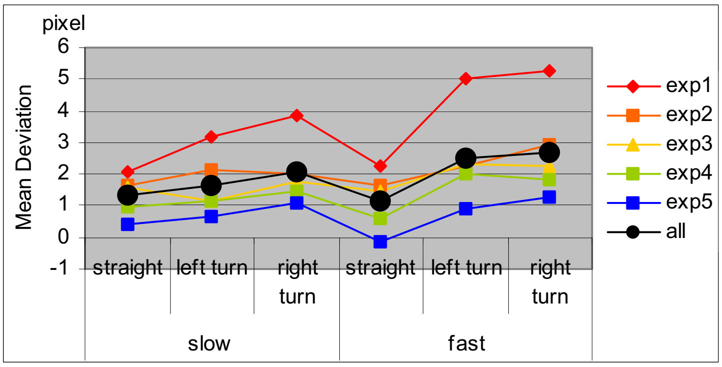


Figure 6.6 Effects of speed and direction of curvature on lane deviation (dual task minus single task values) – all experiments

One possible explanation is that driving on straight track sections at slow speed might not have been challenging enough for participants, thus provoking lane deviations due to a lack of concentration. This finding is in the line with that of Moss and Triggs (1997) and would also imply that there is a danger of making streets and cars too safe, because drivers might tend to increase speed to overcome a level of underload (Brookhuis et al., 1991; Brown, 1994), thus possibly compromising safety. Another reason that speaks against making driving and related tasks too easy is that people simply feel more safe than they actually are and underestimate levels of risk. For example, since hands-free use of mobile phones while driving was implicitly declared to be 'safe' by legalizing it, people who previously would not have used a mobile phone while driving might now begin to do so. Moreover, people may use their mobile phones in a broader range of driving situations, e.g. bad weather, high speeds, dense traffic, etc. and engage in longer conversations on the phone (Tijerina, 2001). Thus, the absolute risk of becoming involved in an accident increases, because the risk of using the hands-free mode might still be less than talking on the mobile phone without it, but it is still higher than not talking on the phone at all. Risk homeostasis theory (Wilde, 1982) also predicts that, as safety features are added to vehicles and roads, drivers tend to increase their exposure to collision risk because they feel better protected. Additionally, levels of mental underload entail suboptimal levels of arousal (Fuller, 2005), and consequently compromising safety, e.g. because drivers become less willing to invest effort (van der Hulst et al., 2001). An exemplary situation for road conditions possibly causing such mental underload situations would be driving overland in the United States or Canada which means driving on roads going only straight for hundreds and hundreds of kilometers. Possibly also sitting in a car with automatic gear shift (as travelling in the USA) might have a kind of hypnotizing effect on the driver, thus slowing down reaction times, leaving the driver incapable of reacting fast enough to sudden changes (e.g. an animal crossing the street).

Above all, the rather high standard deviations indicate that optimal workload levels are a very individual subject. Thus, just simplifying the driving task does not provide a solution. Rather, it seems preferable to give drivers the possibility to actively keep workload within acceptable boundaries. This could be realized, for example, by training drivers to estimate levels of risk correctly, thus enabling them to adjust speed, distance to the vehicle in front, etc. accordingly. For secondary tasks, the ability to prolong the task as long as necessary also appears to be important to avoid states of mental overload. As in the case of mental overload usually low priority task elements (e.g. mirror checking) are dumped until, in more extreme cases, high priority tasks (e.g. looking ahead), also suffer, minimizing the visual and attentional demands in general and hence the intrusiveness of secondary tasks on driving to support an optimal allocation schedule are essential criteria for driving safety, even if some more highly skilled drivers may become bored as a result.

Recapitulating the last section, increases in workload level became first apparent in the subjective ratings of the participants. Above all, driving speed is the factor to be mentioned because fast conditions were rated more effortful and intervening than slow conditions throughout all experiments, but never became a significant factor concerning lane deviations. Investing more effort was usually accompanied by adopting the less demanding working strategy of exceeding task completion times, which was in these experiments the only possibility participants had, as they could not influence the velocity of the car in order to decrease task demands. Because there were no subsidiary tasks that could be skipped (as for example rear mirror checking), driving performance decreased when task demands further increased at that point. Furthermore, high values of standard deviations speak for a wide range of individual differences in both biological capabilities and skills, as well as in motivational factors towards driving in general or the experimental situation in particular and hence in mental workload.

6.7 Generalizability to real driving situations

As experiments were not conducted on the road it is not clear how results of the different experimental settings translate to everyday driving. Due to the lack of perceived risk, participants may have performed the driving task in a less realistic and more erratic manner, possibly having made manoeuvres which could not be executed on the road, such as unrealistically large and fast steering-wheel motions when a lane-keeping error was detected – an action which would have caused a loss of vehicle control in reality. But, according to Fuller’s theory of task difficulty homeostasis (2005), subjective risk estimates are not a determinant of driver decision making, except in the profound sense of motivating the continuous avoidance of a certain catastrophe. Assuming that participants did not drive in an especially risky manner due to the simulator situation, results should prove valid. In Fuller's model, task difficulty arises out of the dynamic interface between the demands of the driving task and the capability of the driver. Limits of generalizing results to real driving conditions would therefore result from differences in task demand levels, supposing that the overall capability of a participant remains stable over a certain period of time. For example – since curve radii of the simulated road were probably larger than they would be on a real road – keeping the vehicle centred in the lane might have been more difficult. As a consequence, the deviation of the target road might be much larger than on a real road. Sumie et al. (1998) found similar results in a simulator validation study. However, the purpose of the simulator in many human factors studies is to detect differences in performance produced by changes in task loading. Accordingly, the results of a study conducted by Reed and Green (1995) to compare driving performance on-road and in a low-cost simulator show that although the absolute values of driving performance measures were different (e.g. lane keeping was less precise) in the simulator than on the road, driving performance in the simulator was sensitive to both a within-subject factor and a between-subjects factor. Thus, it can be assumed (and the above reported results support this assumption) that relative performance degradations that are associated with alternative interface designs for in-vehicle driver aids could be assessed. Blaauw (1982) showed that a fixed-base simulator could differentiate between inexperienced and experienced drivers with greater sensitivity than an on-road test. Reed and Green (1995) also found that subjects who performed well on the road also generally performed well in the simulator.

Other factors limiting generalization of the results concern the lack of oncoming traffic, the bird's eye view on the driving task (which is not a realistic view on the road), the lack of speed control, the lack of visual cues of depth, etc.; in short, the *feeling of presence* or “the subjective experience of being in one place or environment even when one is physically in another situation” (Witmer & Singer, 1998, p.225). For example, drivers could go off the road without noticing, as there were no off-road cues like steering-wheel shake due to surface changes, or off-road sounds in the simulator. However, it is generally assumed that the most important aspect for the validity of a simulator for a specific task is the correspondence between the behaviour of the human operator in the simulator and in the real, operational system (Blaauw, 1982). “The value of a simulator depends on its ability to elicit from the operator the same sort of response that he would make in the real situation” (Rolfe et al., 1970, p. 761). Thus, the feeling of presence becomes important only for the reason of possibly increasing behavioural correspondence, which has in any case not been proven: The interaction between a *feeling of presence* and performance in a virtual world is not obvious, nor is it a simple causal relationship (Singer et al., 1995). In fact, even opposite effects have been found (Ellis S.R., 1996), showing that as soon as redundant information from displays of air traffic control displays was removed (thus reducing the feeling of presence), an increase in performance of the system operators was found. But in these experiments, it is nonetheless possible that the lack of a feeling of presence in the reduced environment of the driving task might have increased boredom, thus degrading performance.

Concerning the construction of the lists, there are also several factors to be mentioned possibly limiting a generalization of the results. First, the list did not include real words but consisted only of a letter and a digit, which did not transmit any meaning and might have increased processing time but decreased the required time for reading an entry. Furthermore, the task required an accurate match of a displayed letter-digit-combination, whereas in a real hierarchical structured menu tree (frequently not structured in a way which would appear logical for the operator), the user would also have to recall where certain entries are located and how to get there, or search different categories. Thus, in a menu with more than one level, operators are not ‘guided’ by an alphabetical order on one single level, as they were in the preceding experiments, but would have to keep in mind a ‘map’ of the menu tree and memorize a certain pattern of steps necessary to execute a certain function. According to Paap and Roske-Hofstrand (1986) the navigation problem of getting lost or using an inefficient pathway to the target entry becomes more and more treacherous as the depth of the hierarchy increases.

On top of individual differences regarding capabilities, motivational differences might also be a possible explanation for the high standard deviations during more demanding task settings. Due to different attitudes towards driving or the experimental situation in general and more variable short term goals during the experimental situation, e.g. to give one’s best or to not care about the results at all, performance exhibits clear differences as well. Attitudes toward the experiment and its anticipated goals have probably also contributed to differences in the results by influencing the level of individually invested effort. This is in a line with Hockey (1997), who assumes in his *compensatory control model* that the upper limit of invested effort is a function of individual differences in the perceived value of task goals, in the response to challenge, in the capacity for sustained work, and in the tolerance of aversive states associated with high levels of workload. Therefore, it is to be expected that the specifics of the task and driving conditions during the task, driver motivation, fatigue, and similar factors, all have a considerable influence on the variability of task outcomes (Tijerina, Parmer, & Goodman, 1999).

In the light of this discussion, a direct transfer of the results to real driving situations is therefore not possible, but findings about direction and magnitude of different influencing factors on driving performance could be gained nevertheless.

6.8 Directions for future research

Factors examined in this dissertation were driving speed, direction of curvature, curve radius, searching period, position of the target list entry in the list, list length, location of control and location of display (for an overview see table 6.1).

Table 6.1 Overview of factors investigated

Factor	Description	Possible values
Driving speed	cm/pixel per second (pps)	3.8cm (95pixel) per sec in the slow condition and 5.4cm (135pixel) per sec in the fast condition
Curve radius	Radius of track section	-9.6cm (-240pixel), sharpest left turn, +9.6vm (240pixel), sharpest right turn
Direction of curvature	Direction of the turn	straight track section, left turn, right turn
Searching period	Progress of the search	1st, 3rd and 5th fifth of the searching period
List length		26 entries in exp. 1, 26, 52, 78, and 104 entries in exp. 2, 2, 4, and 8 entries in exp. 3, 4, 5
List position	Position of the target entry in the list	1st, 2nd and 3rd third of the list (only investigated in exp.1)
Control location	Position of secondary task controls	15 cm to the right of the steering-wheel (exp. 1, 2, 3) and on the steering-wheel (exp. 4, 5)

Factor	Description	Possible values
Display location	Display location of primary and secondary task	on two monitors (exp. 1, 2, 3, 4) and on one monitor (exp. 5)

Other factors still to be investigated are predictability of the oncoming road (position of the car on the screen), road width, text size and hence the number of entries displayed on the screen, structure of menu entries, complexity of list entries, type of control, and angle at which the operator looks at the display (for an overview see table 6.2).

Table 6.2 Overview of factors still open for investigation

Factor	Description
Predictability of the oncoming road (sight distance)	Position of the car on the screen 0 (upper edge of the screen) to 1 (lower edge of the screen)
Road width	Track size Minimum of 40 pixel (equals width of the car)
Number of entries on the display and text size	2, 4, 8, 10 …
Complexity of list entries	Increasing the number of letters and digits, order of number and letters
Type of control	Effect of different control types on lane deviation, task completion times and error rate, e.g. scrolling wheel of a computer mouse
Angle of view	Angle at which the operator looks at the display 45°, 90°…

In a first step it is important to become aware of the general contribution to overall task demands of the single factors. In a second step it could be investigated whether some factors might have potentials to influence the level of workload or decrease the tendency to stick longer to secondary task execution than optimal (e.g. increasing text size during high demanding driving situations).

Furthermore, it would be interesting to investigate the extent to which these outcomes will improve with practice. Expanding the current conditions should include an investigation of the effects of secondary task control and display location for lists longer than eight entries as well. A related question would then be whether eight entries still remains the critical list length when the number of displayed entries is increased. In general, factors increasing the tendency to become absorbed by the secondary task should be further investigated.

6.9 Conclusions

Participants apparently did attempt to protect driving performance as best as they could. Nevertheless, executing a secondary task while driving resulted in driving performance losses. But these were not of constant magnitude along the dual task situation, rather they increased with advanced searching periods reaching a peak at the end of the search just before the correct entry had been selected and confirmed. Thus, any arrangements preventing drivers to focus too much on the secondary task would be helpful to improve driving performance.

Furthermore, it appears that it is not possible to isolate particular factors which contribute more to performance losses than others, but that increasing demands of one single factor or several factors together add up until an individually different limit had been exceeded and driving performance degraded. High standard deviations argue for clear individual differences concerning this upper limit. Accordingly, task demands were not assessed as equally difficult, which was especially true for high task demands. With decreasing task demands, standard deviations decreased as well. Therefore, drivers should take some time to find out more about factors which make a secondary task difficult particularly for them and receive quite some practice on coping for those factors. Just as well as the correct interaction between gear-shifting, accelerating and coupling has to be practiced until performance meets demands, the execution of secondary tasks while driving should be practiced as well. Secondary tasks could also be offered in adjustable versions, so that drivers could configure them according to their personal needs. This could regard text size, as well as menu structure or acoustic outputs. However, all options to help drivers to keep workload on moderate levels should be utilized, including possibilities to increase workload levels.

Appendix

Appendix A: Questionnaires

Demographic Questionnaire

1) Alter: ________________	2) Geschlecht O weiblich O männlich
3) Händigkeit? O links O rechts O beidhändig	4) Wohnort? ________________________
5) Schulabschluss? O Hauptschule O Realschule O Gynmasium O Hochschule (Universität/Fachhochschule)	6) Berufsausbildung/Studium? ______________________________
7) Momentane Tätigkeit? ______________________________	

Subjective measures

1) Hat die Bearbeitung der Listenaufgabe Sie in der Ausübung der Fahraufgabe behindert?
O ja, sehr
O ja, etwas
O manchmal
O eher nicht
O etwas anstrengend

2) Als wie anstrengend haben Sie es empfunden, zusätzlich zur Fahraufgabe einen Eintrag aus der Liste heraus zu suchen?
O sehr anstrengend
O anstrengend
O mittel anstrengend
O etwas anstrengend
O gar nicht anstrengend

3) Wie würden Sie die Verteilung Ihrer Aufmerksamkeit einschätzen?

◄――――――――――――|――――――――――――►

Priorität auf Listenaufgabe Priorität auf Fahraufgabe

Questionnaire of driving and computer experience

1) Was ist Ihnen in der Simulation besonders leicht gefallen?

2) Was hat Ihnen in der Simulation Schwierigkeiten bereitet?

3) Was würden Sie gegebenenfalls ändern?

4) Entsprach die Schwierigkeit der Fahraufgabe in etwa der einer realen Autofahrt?

○ die Realität ist deutlich schwerer
○ die Realität ist etwas schwerer
○ Realität und Simulation sind gleich schwer
○ die Simulation ist etwas schwerer
○ die Simulation ist deutlich schwerer

5) Arbeiten Sie an Ihrem Arbeitsplatz mit einem Computer?

○ mehrmals täglich
○ mehrmals wöchentlich
○ mehrmals monatlich
○ weniger als einmal im Monat
○ nie

6) Wie lange arbeiten Sie durchschnittlich am Tag mit Ihrem Computer?

ca. _______Stunden pro Tag

7) Welcher Art sind die Arbeiten, die Sie mit dem Computer erledigen? (Hier sind Mehrfachantworten möglich)

○ Schreibarbeit
○ Dateneingabe
○ Datenverwaltung
○ Programmierung
○ Arbeit mit aufgabenbezogener Software (auch mehrere Programme)
○ andere Tätigkeiten (kurzes Stichwort: _________________________)

8) Nutzen Sie in Ihrer Freizeit einen Computer?

○ mehrmals täglich
○ mehrmals wöchentlich
○ mehrmals monatlich
○ weniger als einmal im Monat
○ nie

9) Spielen Sie Spiele am Computer oder an Spielkonsolen?

○ mehrmals täglich
○ mehrmals wöchentlich
○ mehrmals monatlich
○ weniger als einmal im Monat
○ nie

10) Wenn ja, welche Art Spiele bevorzugen Sie? (Hier sind Mehrfachantworten möglich)

O Egoshooter / First Person Shooter (z.B. Unreal, Quake)
O Strategiespiele (z.B. Die Siedler, Age of Empires)
O Simulationen (z.B. Flugsimulator, F1 Racing)
O Sportspiele (z.B. Fußball, Basketball)
O Umsetzungen von Gesellschaftsspielen (z.B. Mühle, Schach, Kartenspiele)
O andere Spiele (kurze Kategorisierung/Name: __________________________)

11) Besitzen Sie einen Führerschein?

O ja seit wann? __________
O nein

12) Wie oft fahren Sie Auto?

O mehrmals täglich
O mehrmals wöchentlich
O mehrmals monatlich
O weniger als einmal im Monat
O nie
ungefähre Kilometeranzahl pro Jahr: ______km

13) In welchem Maße sind Sie mit PKW-Navigationssystemen vertraut?

O sehr vertraut (Sie benützen oft ein PKW-Navigationssystem)
O vertraut (Sie haben manchmal die Möglichkeit, ein PKW-Navigationssystem zu benützen)
O ein wenig vertraut (Sie haben ein- bis dreimal ein PKW-Navigationssystem benützt)
O gar nicht vertraut (Sie haben noch nie ein PKW-Navigationssystem benützt)

14) Wie oft suchen Sie bei einem PKW-Navigationssystem einen Namen oder Musiktitel aus einer Liste heraus?

O mehrmals täglich
O mehrmals wöchentlich
O mehrmals monatlich
O weniger als einmal im Monat
O nie

Appendix B: Instructions

General Instructions

Im den folgenden Experimenten sollen Sie in einer Fahrsimulation mit dem Lenkrad ein rotes Auto steuern, welches auf dem linken Monitor erscheint. Halten Sie bitte das rote Auto möglichst **in der Mitte der Fahrbahn**, welche ebenfalls auf diesem Monitor zu sehen ist. Die Geschwindigkeit des Autos und die Anzahl der Einträge in der Liste kann dabei von Versuch zu Versuch variieren. Von Zeit zu Zeit erscheint ein Schriftzug - der sich aus einem Buchstaben und einer Zahl zusammensetzt - direkt über Ihrem Auto. Wenn der Schriftzug erscheint, suchen Sie bitte aus einer alphabetisch sortierten Liste den angezeigten Schriftzug heraus. Diese Liste wird auf dem zweiten Monitor rechts von Ihnen angezeigt.
Ihre Hauptaufgabe besteht während des gesamten Experiments darin, das Auto möglichst genau in der Mitte der Fahrbahn zu halten.

Instructions for single task conditions

Im folgenden Experiment sollen Sie in einer Fahrsimulation mit dem Lenkrad ein rotes Auto steuern. Das Auto erscheint auf dem linken Monitor auf einer Fahrbahn.
Ihre Aufgabe besteht darin, das rote Auto möglichst in der Mitte der Fahrbahn zu halten, welche ebenfalls auf diesem Monitor zu sehen ist.

Instructions for dual task conditions

Im folgenden Experiment steuern Sie in einer Fahrsimulation mit dem Lenkrad ein rotes Auto, welches auf dem linken Monitor erscheint. Sie sollen das rote Auto möglichst in der Mitte der Fahrbahn halten, welche ebenfalls auf diesem Monitor zu sehen ist. Von Zeit zu Zeit erscheint ein Schriftzug - der sich aus 1 Buchstaben und 1 Zahl zusammensetzt - direkt über Ihrem Auto. Wenn der Schriftzug erscheint, suchen Sie bitte aus einer alphabetisch sortierten Liste den angezeigten Schriftzug heraus. Diese Liste wird auf dem zweiten Monitor rechts von Ihnen angezeigt. Mit Hilfe des Joysticks können Sie die Markierung auf- und ab bewegen. Wenn Sie den angezeigten Buchstaben gefunden haben, klicken Sie bitte mit dem Zeigefinger auf den Knopf hinten am Joystickgriff. Wenn Sie richtig lagen, wechselt die Farbe der Markierung auf grün und die Markierung springt auf den ersten Eintrag der Liste, also „A1“. Wenn Sie den falschen Eintrag angeklickt haben, ändert sich die Farbe der Markierung nicht und sie bleibt auf genau diesem Eintrag stehen. Sie haben dann weiterhin die Möglichkeit, den richtigen Eintrag herauszusuchen. Wenn Sie den richtigen Eintrag in der dafür vorgesehenen Zeit nicht finden, springt die Markierung ebenfalls wieder auf "A1", da nun eine neue Buchstaben-Zahlen-Kombination angezeigt ist und gesucht werden muss. Ihre Hauptaufgabe besteht aber weiterhin darin, das Auto möglichst genau in der Mitte der Fahrbahn zu halten.
Hinweis: Ziel dieses Versuchs ist es nicht, möglichst viele Listeneinträge richtig gefunden zu haben, sondern beide Aufgaben so gut wie möglich zu bewältigen, wobei im Zweifelsfall immer der Navigation des roten Autos die Priorität gegeben werden sollte.

Appendix C: Track Setup

Experiment 1, 3, 4 and 5:

		part 1			**part 2**		
Nr	**Curve radius**	**Direction of curvature**	**Radius (in pixel)**	**Task Prompt**	**Direction of curvature**	**Radius (in pixel)**	**Task Prompt**
1	low	straight	0		straight	0	
2	low	right turn	0.2		right turn	0.2	
3	low	left turn	-0.3		left turn	-0.3	
4	low	straight	0.1	X	straight	0.1	X
5	low	straight	0.1		right turn	0.3	
6	low	left turn	-0.3		right turn	0.2	
7	low	right turn	0.2		straight	0.1	
8	high	right turn	0.4	X	left turn	-0.6	X
9	high	left turn	-0.6		right turn	0.5	
10	high	right turn	0.6		right turn	0.4	
11	high	left turn	-0.5	X	left turn	-0.5	X
12	high	right turn	0.4		left turn	-0.4	
13	high	right turn	0.5		right turn	0.5	
14	high	right turn	0.6		right turn	0.6	
15	low	right turn	0.3	X	left turn	-0.3	X
16	low	straight	-0.1		right turn	0.3	
17	low	straight	0		left turn	-0.2	
18	high	right turn	0.4	X	right turn	0.4	X
19	high	left turn	-0.4		left turn	-0.5	
20	high	left turn	-0.6		left turn	-0.6	
21	high	left turn	-0.5		left turn	-0.4	
22	low	right turn	0.2	X	straight	0	X
23	low	left turn	-0.3		left turn	-0.3	
24	low	left turn	-0.2		left turn	-0.3	
25	low	straight	0.1		right turn	0.2	
26	high	left turn	-0.4	X	right turn	0.5	X
27	high	left turn	-0.4		left turn	-0.5	
28	high	right turn	0.5		right turn	0.6	
29	low	left turn	-0.2	X	straight	0	X
30	low	right turn	0.2		right turn	0.2	
31	low	right turn	0.3		straight	-0.1	
32	low	left turn	-0.3	X	right turn	0.3	X
33	low	left turn	-0.2		straight	-0.1	
34	low	straight	-0.1		left turn	-0.2	
35	high	left turn	-0.4	X	right turn	0.6	X
36	high	right turn	0.5		left turn	-0.6	
37	high	left turn	-0.6		right turn	0.5	
38	high	right turn	0.6		left turn	-0.4	
39	high	right turn	0.4	X	left turn	-0.6	X
40	high	right turn	0.6		right turn	0.4	
41	high	left turn	-0.5		left turn	-0.5	
42	low	straight	-0.1	X	right turn	0.2	X
43	low	left turn	-0.2		left turn	-0.2	
44	low	straight	0		straight	0	
45	low	right turn	0.3		right turn	0.3	

Experiment 2:

		part 1				**part 2**		
Nr	**Curve radius**	**Direction of curvature**	**Radius (pixel)**	**Task Prompt**		**Direction of curvature**	**Radius (pixel)**	**Task Prompt**
1		straight	0			straight	0	
2		right turn	0.2			right turn	0.2	
3		left turn	-0.3			left turn	-0.3	
4	low	straight	0.1	X		straight	0.1	X
5	low	straight	0.1			right turn	0.3	
6	low	left turn	-0.3			right turn	0.2	
7	low	right turn	0.2			straight	0.1	
8	low	straight	0.1			left turn	-0.2	
9	high	right turn	0.4	X		left turn	-0.6	X
10	high	left turn	-0.6			right turn	0.5	
11	high	right turn	0.6			right turn	0.4	
12	high	right turn	0.6			left turn	-0.5	
13	high	left turn	-0.5	X		left turn	-0.5	X
14	high	right turn	0.4			left turn	-0.4	
15	high	right turn	0.5			right turn	0.5	
16	high	right turn	0.6			right turn	0.6	
17	high	left turn	-0.6			right turn	0.4	
18	low	right turn	0.3	X		left turn	-0.3	X
19	low	straight	-0.1			right turn	0.3	
20	low	straight	0			left turn	-0.2	
21	low	straight	-0.1			straight	0.1	
22	high	right turn	0.4	X		right turn	0.4	X
23	high	left turn	-0.4			left turn	-0.5	
24	high	left turn	-0.6			left turn	-0.6	
25	high	left turn	-0.5			left turn	-0.4	
26	high	right turn	0.4			right turn	0.6	
27	low	right turn	0.2	X		straight	0	X
28	low	left turn	-0.3			left turn	-0.3	
29	low	left turn	-0.2			left turn	-0.3	
30	low	straight	0.1			right turn	0.2	
31	low	left turn	-0.3			left turn	-0.3	
32	high	left turn	-0.4	X		right turn	0.5	X
33	high	left turn	-0.4			left turn	-0.5	
34	high	right turn	0.5			right turn	0.6	
35	high	left turn	-0.4			right turn	0.5	
36	low	left turn	-0.2	X		straight	0	X
37	low	right turn	0.2			right turn	0.2	
38	low	right turn	0.3			straight	-0.1	
39	low	straight	0			right turn	0.2	
40	low	left turn	-0.3	X		right turn	0.3	X
41	low	left turn	-0.2			straight	-0.1	
42	low	straight	-0.1			left turn	-0.2	
43	low	straight	0			straight	0.1	
44	high	left turn	-0.4	X		right turn	0.6	X
45	high	right turn	0.5			left turn	-0.6	
46	high	left turn	-0.6			right turn	0.5	
47	high	right turn	0.6			left turn	-0.4	
48	high	right turn	0.5			left turn	-0.5	
49	high	right turn	0.4	X		left turn	-0.6	X
50	high	right turn	0.6			right turn	0.4	
51	high	left turn	-0.5			left turn	-0.5	
52	high	left turn	-0.5			left turn	-0.6	
53	low	straight	-0.1	X		right turn	0.2	X
54	low	left turn	-0.2			left turn	-0.2	
55	low	straight	0			straight	0	
56	low	right turn	0.3			right turn	0.3	
57	low	right turn	0.2			straight	-0.1	

Appendix D: List Setups

Experiment 1:

Pos.	26 entr.
1	A1
2	B1
3	C1
4	D1
5	E1
6	F1
7	G1
8	H1
9	I1
10	J1
11	K1
12	L1
13	M1
14	N1
15	O1
16	P1
17	Q1
18	R1
19	S1
20	T1
21	U1
22	V1
23	W1
24	X1
25	Y1
26	Z1

Experiment 2:

Pos.	26	52	78	104
1	A1	A1	A1	A1
2	B1	A2	A2	A2
3	C1	B1	A3	A3
4	D1	B2	B1	A4
5	E1	C1	B2	B1
6	F1	C2	B3	B2
7	G1	D1	C1	B3
8	H1	D2	C2	B4
9	I1	E1	C3	C1
10	J1	E2	D1	C2
11	K1	F1	D2	C3
12	L1	F2	D3	C4
13	M1	G1	E1	D1
14	N1	G2	E2	D2
15	O1	H1	E3	D3
16	P1	H2	F1	D4
17	Q1	I1	F2	E1
18	R1	I2	F3	E2
19	S1	J1	G1	E3
20	T1	J2	G2	E4
21	U1	K1	G3	F1
22	V1	K2	H1	F2
23	W1	L1	H2	F3
24	X1	L2	H3	F4
25	Y1	M1	I1	G1
26	Z1	M2	I2	G2
27		N1	I3	G3
28		N2	J1	G4
29		O1	J2	H1
30		O2	J3	H2
31		P1	K1	H3
32		P2	K2	H4
33		Q1	K3	I1
34		Q2	L1	I2
35		R1	L2	I3
36		R2	L3	I4
37		S1	M1	J1
38		S2	M2	J2
39		T1	M3	J3
40		T2	N1	J4
41		U1	N2	K1
42		U2	N3	K2
43		V1	O1	K3
44		V2	O2	K4
45		W1	O3	L1
46		W2	P1	L2
47		X1	P2	L3
48		X2	P3	L4
49		Y1	Q1	M1
50		Y2	Q2	M2
51		Z1	Q3	M3
52		Z2	R1	M4
53			R2	N1
54			R3	N2
55			S1	N3
56			S2	N4
57			S3	O1
58			T1	O2
59			T2	O3
60			T3	O4
61			U1	P1
62			U2	P2
63			U3	P3
64			V1	P4
65			V2	Q1
66			V3	Q2
67			W1	Q3
68			W2	Q4
69			W3	R1
70			X1	R2
71			X2	R3
72			X3	R4
73			Y1	S1
74			Y2	S2
75			Y3	S3
76			Z1	S4
77			Z2	T1
78			Z3	T2
79				T3
80				T4
81				U1
82				U2
83				U3
84				U4
85				V1
86				V2
87				V3
88				V4
89				W1
90				W2
91				W3
92				W4
93				X1
94				X2
95				X3
96				X4
97				Y1
98				Y2
99				Y3
100				Y4
101				Z1
102				Z2
103				Z3
104				Z4

Experiments 3, 4 and 5:

	Nr. of entries		
Pos.	**2**	**4**	**8**
0	.	.	.
1	A1	A1	A1
2	B1	B1	B1
3	.	C1	C1
4		D1	D1
5		.	E1
6			F1
7			G1
8			H1
9			.

Deutsche Zusammenfassung

Einleitung

Immer mehr technische Funktionen halten Einzug in das moderne Fahrzeug, die in erster Linie dazu gedacht sind, Fahrer bei der Fahraufgabe zu unterstützen. Die Interaktion zwischen System und Mensch erfolgt in erster Linie über die visuelle Darstellung von Informationen auf einem Display, das sich in Größe, Qualität und Position im Fahrzeug unterscheiden kann. Solange die Umsetzung sprachgesteuerter Systeme (Spracheingabe und Sprachausgabe) im Auto nach wie vor schwierig ist (Umgebungsbedingungen, Wortschatz), muss auch weiterhin auf visuelle Informationsdarstellung zurückgegriffen werden (Vollrath & Totzke, 2003). Dabei sind es weniger die für die Qualität der Fahraufgabe relevanten Systeme (z.B. ESP, ACC, ALC, etc.), die den größten Teil dieser Entwicklung darstellen, sondern vielmehr die der Erhöhung des Fahrkomforts und der Unterhaltung dienenden Systeme.

Auf diese Weise hat sich das Wesen der Fahraufgabe entscheidend verändert, da die visuelle Aufmerksamkeit nicht mehr allein auf die Straße gerichtet ist, sondern zwischen Straße und Display geteilt werden muss. Die eigentliche Fahraufgabe besteht nun aber in erster Linie darin, das Fahrzeug auf Kurs zu halten, was Tätigkeiten wie Lenken, Schalten und Kontrolle der Geschwindigkeit beinhaltet. Da sich Verkehrsteilnehmer die Straße in der Regel mit anderen Verkehrsteilnehmern teilen und dabei einer sich u.U. verändernden Umwelt ausgesetzt sind (z.B. durch Wetterverhältnisse), besteht zusätzlich die Notwendigkeit der Interaktion mit der Umwelt bzw. der Reaktion auf bestimmte Ereignisse. Damit werden zusätzliche Aufgaben wie Blinken, Hupen, Licht einschalten oder den Scheibenwischer betätigen erforderlich. Die benötigten Informationen, um alle fahrrelevanten Aufgaben zu bewältigen, sind in erster Linie visueller Natur, so dass „jede Sekunde, die der Fahrer bei Tempo 100 nicht vollkommen mit dem Straßenverkehr beschäftigt ist, fast 28 Meter unkonzentrierte Fahrt bedeutet.“ (Bloch, 2005). Gute Bediensysteme sollen daher den Autofahrer so wenig wie möglich von seiner eigentlichen Aufgabe, dem Navigieren des Fahrzeugs, ablenken.

Aus diesem Grund ist es unerlässlich, herauszufinden, welche Faktoren die Fahrleistung tatsächlich beeinträchtigen und welche sie im Gegenteil unterstützen.

Die Fahrleistung hängt wie bei jeder anderen Aufgabe in erster Linie von der Aufgabenschwierigkeit und der damit verbundenen Beanspruchung ab. Diese ergibt sich wiederum aus dem Grad der Anforderungen, die eine Aufgabe auf der einen Seite an den Ausführenden stellt und den Fähigkeiten der ausführenden Person auf der anderen Seite. Faktoren, die die Komplexität der Primäraufgabe beeinflussen sind z.B. aktuelle Straßenverhältnisse, Einsehbarkeit der Strecke, Kurvenradien, Geschwindigkeit, usw. Die Schwierigkeit der Sekundäraufgabe wird zum einen von den physikalischen Eigenschaften und Interaktionsdynamiken des Displays als auch der Bedienelemente bestimmt. Zum anderen durch die Anforderungen der Inhalte selbst. Wichtige Faktoren sind hier z.B. die Lesbarkeit und Komplexität der Einträge, Tiefe und Struktur eines hierarchisch angeordneten Menüs, usw. Die Fähigkeiten des Fahrers sind sowohl angeboren (z.B. Reaktions- und Verarbeitungszeiten) und als auch erlernt (z.B. Verkehrsregeln, Maße des Autos, Antizipation von möglichen Ereignissen, motorische Fertigkeiten). Folglich wird eine Aufgabe, die nur geringe Anforderungen beinhaltet, weder geübte noch ungeübte Personen überfordern. Eine Aufgabe mit mittlerem Anforderungsniveau hingegen wird von einer geübten Person wohl weiterhin als leicht empfunden, während sie eine ungeübte Person schon eher als schwierig einstufen wird. Diese beiden Faktoren – Komplexität der Aufgabe und Fähigkeiten des Ausführenden – genügen jedoch noch nicht, um die Fahrleistung zu jedem Zeitpunkt vollständig vorhersagen zu können, da Motive und Emotionen von Situation zu Situation schwanken und damit auch die Fahrleistung in unterschiedlicher Art und Weise beeinflussen können. Während bestimmte emotionale oder motivationale Zustände die Fahrleistung verbessern können (z.B. einen guten Eindruck auf den Beifahrer machen wollen), haben andere negative Auswirkungen (z.B. Stress, Ärger, Müdigkeit). Darüber hinaus stellen grundsätzliche Einstellungen gegenüber dem Fahren einen weiteren Einflussfaktor auf die Fahrleistung dar.

Da die Fahrleistung generell am besten unter Bedingungen moderater Beanspruchung (Workload) ist (Kantowitz & Casper, 1988) und das Aufrechterhalten einer guten Fahrleistung unter sehr beanspruchenden Konditionen zum einen ermüdend ist und zum anderen von den Betreffenden als unangenehm und anstrengend empfunden wird (Hockey, 1997), sollte die mentale Beanspruchung weder eine bestimmte Grenze über- noch unterschreiten. Dies ist ein aktiver Prozess, der zum einen durch das Mobilisieren zusätzlicher Ressourcen („sich mehr anstrengen“) bewerkstelligt werden kann (Hockey, 1997), oder zum anderen, indem die Aufgabenschwierigkeit gesenkt wird. In den meisten Fällen wird dies über eine Reduktion der Geschwindigkeit erreicht (e.g., Cnossen et al., 2004; Dingus et al., 1997; Jamson & Merat, 2005; Pohlmann & Traenkle, 1994). Steigt die Beanspruchung trotzdem weiter, müssen Nebenaufgaben fallengelassen werden. Dabei ist die Fähigkeit notwendig, Aufgaben priorisieren zu können und nur die Aufgaben zu vernachlässigen, die eine geringe Priorität haben. Aber auch eine zu niedrige mentale Beanspruchung kann zu Einbußen in der Fahrleistung führen und auch hier versuchen Fahrer aktiv, sich aus dieser Zone der „Unterforderung“ heraus zu manövrieren, indem sie z.B. die Geschwindigkeit erhöhen (Brookhuis et al., 1991). Trotz der Gefahr einer Unterforderung der Fahrer sollten zusätzliche Aufgaben im Fahrbereich geringe mentale und visuelle Anforderungen stellen, um die Fahrer möglichst wenig von ihrer eigentlichen Aufgabe, dem sicheren Navigieren des Fahrzeugs, abzuhalten.

Um herauszufinden, wie sich die Fahrleistung mit der Manipulation der Erst- und Zweitaufgabenschwierigkeit verändert, wurden insgesamt ein Pilotexperiment und fünf Experimente durchgeführt. Ziel der Dissertation war herauszufinden, welche Auswirkungen Variationen der Schwierigkeit sowohl der Primäraufgabe als auch der Sekundäraufgabe auf die Fähigkeit, die Spur zu halten, Bearbeitungsdauer, Fehlerrate und subjektive Einschätzungen von Anstrengung und Ablenkung haben. Geschwindigkeit des Fahrzeugs, Kurvenradien und Biegungsrichtung der Kurve waren Faktoren, mit denen die Primäraufgabenschwierigkeit variiert wurde, während Listenlänge, Platzierung der Bedienelemente und der Abstand zwischen zwei informationspräsentierenden Monitoren die Schwierigkeit der Sekundäraufgabe beeinflusste. Insgesamt nahmen 80 Versuchspersonen (40 Männer und 40 Frauen) an den Experimenten teil. In den ersten drei Experimenten wurde die Anzahl der Einträge in der Liste variiert. Während im ersten Experiment eine Liste mit 26 Einträgen (eine Alphabetlänge) vorgegeben wurde, musste im zweiten Experiment eine Liste mit maximal 104 Einträgen bearbeitet werden.

Im dritten (vierten und fünften) Experiment bestand die Sekundäraufgabe nur noch aus maximal acht Einträgen in der Liste. Im vierten Experiment wurde dann das Bedienelement der Sekundäraufgabe dem Lenkrad angenähert und im fünften Experiment schließlich die dargestellte Information auf einem Display integriert.

Experimenteller Aufbau

Für die Simulation wurde ein stark reduzierter Aufbau gewählt, was den Vorteil hatte, dass die einzelnen experimentellen Bedingungen gut kontrolliert werden konnten. Der Nachteil besteht in einer eingeschränkten Übertragbarkeit der Ergebnisse auf reale Fahrsituationen, zumindest die absoluten Werte betreffend. Reed and Green (Reed & Green, 1995) zufolge ist es möglich – und die Ergebnisse dieser Dissertation sprechen ebenfalls dafür – dass Erkenntnisse über Unterschiede in den Ergebnissen, die durch Variationen der unabhängigen Variablen in den verschiedenen Bedingungen verursacht wurden, sehr wohl auf Situationen im realen Straßenverkehr übertragen werden können. Mit anderen Worten können mit Hilfe einer einfachen Simulation sehr wohl Aussagen wie z.B. „Häufigkeit und Ausmaß der Abweichung von der Ideallinie nehmen mit zunehmender Listenlänge zu“, getroffen werden. Darüber hinaus wird nach wie vor diskutiert, ob selbst hochwertige und teure Simulatoren ausreichen, um die Realität eins zu eins nachstellen zu können und damit eine absolute Validität zu erreichen. Schließlich wissen Probanden zu jedem Zeitpunkt, dass sie keinerlei (verkehrstechnisch bedingten) Gefährdung ausgesetzt sind und könnten sich unter diesen Umständen anders verhalten als in einer realen Fahrsituation.

Die Simulation bestand aus zwei 17 Zoll Monitoren mit einer Auflösung von je 600x800 Pixel und einer Bildschirmfrequenz von 85 Hertz. Stimuli auf dem linken Monitor bestanden aus einem roten Auto auf einer grauen Fahrbahn und wurden mit einem Lenkrad kontrolliert. Stimuli auf dem rechten Monitor bestanden aus unterschiedlich langen Listen und wurden in den ersten drei Experimenten mit einem Joystick neben dem Lenkrad und in den beiden letzten Experimenten mit Knöpfen auf dem Lenkrad kontrolliert. Monitore, Bedienelemente und Log-Dateien wurden von einem PC (Pentium 4; 1,7 GHz; 256MB Speicher) mit LINUX Betriebssystem und einer *kubuntu* Oberfläche kontrolliert.

Aufgabe der Probanden war es, das Fahrzeug auf dem linken Monitor in der Mitte der Fahrbahn zu halten, wobei sie keinen Einfluss auf die Geschwindigkeit des Autos hatten. Die Straße bestand aus 13 verschiedenen Streckenabschnitten: einer Geraden und jeweils sechs Links- und Rechtskurven, die wiederum unterschiedlich stark gekrümmt waren. Das gerade Streckenteil und die Kurven mit den drei kleinsten Radien wurden als „einfach“ kategorisiert, die drei Kurven mit den größten Radien als

„schwer“. Somit bestand die Fahrbahn aus einer Geraden, jeweils drei schweren und drei leichten Linkskurven und jeweils drei schweren und drei leichten Rechtskurven. Zu Beginn etwa jedes vierten Streckenteils – die Anzahl wurde variiert, um eine Vorhersehbarkeit der Strecke zu vermeiden – wurde der Versuchsperson eine Buchstaben-Zahlen-Kombination direkt über dem Auto angezeigt, die dann in der Liste auf dem rechten Monitor gesucht und mit einem Tastendruck auf dem Joystick oder den Knöpfen auf dem Lenkrad bestätigt werden musste.

Prozedur

Die Probanden saßen in einem Stuhl in ca. 80cm Entfernung zum linken Monitor und ca. 1m Entfernung zum rechten Monitor. Nachdem die Versuchsperson einen demographischen Fragebogen ausgefüllt hatte, erhielt sie zwei Trainingsdurchgänge, in denen die beiden Aufgaben (Fahren und Suchen in der Liste) jeweils getrennt voneinander geübt wurden. Anschließend wurden die Bedingungen in randomisierter Reihenfolge durchlaufen. Nach jeder Bedingung schätzten Probanden auf drei Skalen jeweils die subjektiv empfundene Anstrengung, Ablenkung und die vorgenommene Priorisierung der Aufgaben ein. Nachdem die Versuchsperson die Hälfte aller Bedingungen absolviert hatte, wurde die Testphase für ca. 10 min. unterbrochen, um Ermüdungseffekten vorzubeugen. Nach Abschluss der Testphase füllten die Probanden noch einen Fragebogen zum Thema Computer- und Fahrerfahrung aus und wurden bezahlt.

Datenanalyse

Alle 20msec wurden die ideale Position des Autos auf der x-Achse, die aktuelle Position des Autos auf der x-Achse, die Position des Autos auf der y-Achse, die Art des Streckenteils (Radius und Richtung der Beugung), der Neigungswinkel des Autos, der aktuell zu suchende Eintrag in der Liste (falls einer angezeigt wurde), der aktuell ausgewählte Eintrag in der Liste, falsche und korrekte Bestätigungen eines Eintrags und die aktuelle Bearbeitungsdauer der Sekundäraufgabe aufgezeichnet.

Aus diesen Log-Dateien wurden anschließend die Abweichung von der Ideallinie (Absolutwerte), der Prozentsatz an Trials die nicht korrekt vollendet werden konnten und die Bearbeitungsdauer und Fehleranzahl für korrekt vollendete Trials berechnet. Die Abweichungswerte aus der Single-Task Situation wurden als Baseline von denen aus der entsprechenden Dual-Task Situation abgezogen. Ein Trial begann mit der Anzeige des zu suchenden Listeneintrags und endete mit der richtigen Bestätigung dieses Eintrags oder der Anzeige eines neuen Listeneintrags, wenn der gesuchte Eintrag im gegebenen Zeitfenster nicht gefunden werden konnte. Da somit die Bearbeitungsdauer eines Trials u.U. stark variieren konnte (je nachdem wie schnell ein Eintrag richtig bestätigt werden konnte), wurden zur besseren Vergleichbarkeit der Ergebnisse jeweils nur die geloggten Einträge aus den ersten, mittleren und letzen 20% des Trials zur weiteren Auswertung verwendet. Diese Daten wurden dann in Tabellen zusammengefasst und Mittelwerte für die einzelnen Faktoren berechnet. Anschließend wurden mehrere Varianzanalysen (ANOVA) mit Messwiederholungen durchgeführt.

Ergebnisse

Listenlängen von zwei, vier und acht Einträgen erbrachten signifikante Unterschiede in der Fahrleistung, während die Unterschiede bei einer weiteren Erhöhung der Einträge nicht mehr signifikant wurden. Das schlechteste Ergebnis wurde mit einer Listenlänge von 26 Einträgen erzielt. Ab einer Länge von 78 Einträgen schien sich die Fahrleistung jedoch wieder zu erholen. Weiterhin wurde der Prozentsatz von nicht geschafften Trials durch Listenlängen von 26 Einträgen und höher signifikant beeinflusst. Die beiden unterschiedlichen Geschwindigkeitsstufen hatten keinen Einfluss auf die Fahrleistung, wohl aber auf die Bearbeitungsdauer (Experimente 2 und 3) und die subjektiven Einschätzungen von Anstrengung und Ablenkung (alle Experimente). Weiterhin ergaben sich die Abweichung betreffende signifikante Interaktionen zwischen Geschwindigkeit und Suchzeitpunkt (Experimente 3, 4 und 5) und Geschwindigkeit und Kurvenradius (Experiment 4). Das Ausmaß der Krümmung der Kurve hatte erwartungsgemäß einen Effekt auf die Abweichung (Experimente 1, 2 und 4), als auch auf die Fehlerrate (Experimente 2 und 3) und die Bearbeitungsdauer (Experimente 1 und 5). Unerwarteterweise hatte die Richtung der Kurve ebenfalls einen Effekt auf die Fahrleistung. So waren die Abweichungen von der Ideallinie während Rechtskurven deutlich größer als während Linkskurven (Experimente 1, 2, 4 und 5). Die Kurvenrichtung interagierte darüber hinaus signifikant mit Listenlänge in Experiment 5 und Suchzeitpunkt in den Experimenten 2, 3 und 5. Den konstantesten Einfluss auf die Fahrleistung hatte in allen Experimenten jedoch der aktuelle Suchzeitpunkt. So waren die Abweichungen von der Ideallinie in allen experimentellen Aufbauten während der ersten 20% der Suche so gut wie gar nicht von denen in der Single-Task Situation zu unterscheiden. In den Experimenten 4 und 5 war die Abweichungswerte in der Dual-Task Situation sogar geringer als in der Singel-Task Situation. Während der mittleren 20% der Suche wurden die Abweichungen dann deutlicher und erreichten ein Maximum während der letzen 20% der Suche. Darüber hinaus ergaben sich signifikante Interaktionseffekte zwischen dem Suchzeitpunkt und der Kurvenrichtung (Experimente 1, 2, 3 und 5), dem Suchzeitpunkt und der Kurvenstärke (Experimente 4 und 5), dem Suchzeitpunkt und der Geschwindigkeit (Experimente 3, 4 und 5), als auch dem Suchzeitpunkt und der Listenlänge (Experimente 2, 3, 4 und 5). Neben der Geschwindigkeit, die in allen Experimenten einen signifikanten Einfluss auf die subjektiven Einschätzungen von Anstrengung und Ablenkung durch die Sekundäraufgabe hatte, wurde in den Experimenten 3, 4 und 5 auch der Faktor Listenlänge signifikant. Bezogen auf die Einschätzungen der Aufmerksamkeitsverteilungen zwischen den beiden Aufgaben – Fahren und Suchen – wurde ebenfalls der Faktor Listenlänge in den Experimenten 2, 3, 4 und 5 signifikant.

Diskussion

Die Ergebnisse sprechen für die Annahme, dass die Teilnehmer versucht haben, die Primäraufgabe der Navigation des Fahrzeugs so gut sie konnten zu priorisieren. Erreicht wurde dieses Ergebnis durch die Anwendung verschiedener Strategien, mit dem Ziel, den Beanspruchungsgrad wenn nötig zu senken. Die naheliegendste Strategie ist wohl, sich mehr anzustrengen (was anhand der subjektiven Einschätzungen nachgewiesen werden konnte). Eine weitere Strategie zielt darauf ab, die Beanspruchung der aktuellen Aufgabenkombination zu senken, z.B. indem die Geschwindigkeit des Fahrzeugs reduziert wird. Da diese Möglichkeit den Versuchsteilnehmern nicht zur Verfügung stand, konnten sie nur die Bearbeitungsdauer der Zweitaufgabe ausdehnen, was sie auch taten. Eine dritte Möglichkeit, nämlich Nebenaufgaben gar nicht mehr auszuführen, war in den vorliegenden Experimenten schwer möglich, da dies den Instruktionen widersprochen hätte. Doch offensichtlich reichten diese Strategien nicht aus, um eine hohe Fahrleistung zu jedem Zeitpunkt aufrecht zu erhalten, da die Ergebnisse nichts desto trotz Einbußen in der Fahrleistung aufweisen, was auf mehrere Ursachen zurückgeführt werden kann. Zum einen haben sich offensichtlich die Anforderungen verschiedener Faktoren summiert, so dass zu verschiedenen Zeitpunkten das individuelle Limit eines optimalen Beanspruchungsgrades überschritten wurde, was wiederum die erfassten Verschlechterungen in der Fahrleistung bewirkt hat. Hohe Standardabweichungen während sehr beanspruchender Konditionen weisen darauf hin, das dieses individuelle Limit sehr unterschiedlich ausgeprägt ist. Zum anderen konnten durch die Strategie der zeitlichen Ausdehnung der Zweitaufgabe scheinbar nur Faktoren positiv beeinflusst werden, die nicht häufigen Änderungen unterworfen waren, wie z.B. Geschwindigkeit und Listenlänge, die sich während eines Trials nicht änderten, während auf schnell wechselnde Faktoren wie Kurvenradius und Kurvenrichtung nicht schnell genug reagiert werden konnte, wenn der visuelle Fokus zu diesem Zeitpunkt auf der Sekundäraufgabe lag. Interessanterweise ergab sich auch noch ein weiterer Faktor, nämlich die Tendenz, die Sekundäraufgabe länger auszuführen, als für die Fahrleistung optimal wäre, was durch die Unterteilung in verschiedene Suchzeitpunkte gezeigt werden konnte. Schnell wechselnde Streckenteile waren zu jedem Zeitpunkt der Doppelaufgabenbearbeitung der Fall, trotzdem konnten signifikante Unterschiede in der Primäraufgabenperformanz zwischen den ersten 20%, den mittleren 20% und den letzten 20% der Suche festgestellt werden. Dieser Effekt ist augenscheinlich darauf zurück zu führen, dass sich Versuchspersonen in dieser letzten Phase der Suche stärker auf die Sekundäraufgabe konzentrieren mussten, um den richtigen Listeneintrag identifizieren zu können. Ein Aufgabenabschnitt, der offensichtlich nicht unterbrochen werden kann, um die Aufgabe erfolgreich zu Ende führen zu können. Ein sehr dramatisches Beispiel für dieses Phänomen, dem Bereich der Flugzeugführung entliehen, ist die Kollision der Eastern Airlines L1011 mit den Everglades in den USA (NTSB, 1973), der darauf zurückgeführt wurde, dass alle vier Cockpitinsassen so damit beschäftigt waren, ein Problem der Fahrwerksklappe zu beheben, dass sie darüber hinaus vergaßen, die aktuelle Höhe des Flugzeugs zu kontrollieren.

Zusammenfassend lässt sich festhalten, dass alle Maßnahmen, die dazu beitragen, die Aufgabenschwierigkeit in moderaten Bereichen zu halten, erwünschte Maßnahmen sind, auch auf die Gefahr hin, dass geübtere Fahrer sich dann langweilen könnten. Darüber hinaus sollten weitere Untersuchungen Faktoren identifizieren, die dazu beitragen, dass die Sekundäraufgabe nicht rechtzeitig unterbrochen wird oder werden kann.

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