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The impact of in-vehicle information systems on simulated driving performance

Effects of age, timing and display characteristics

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1 Introduction

1.1 Intelligent Transportation Systems

There has been a rapid development of technology and displays that provide drivers with assistance and information: for instance, navigation systems, digital maps, adaptive cruise control and communication systems. Such systems are collectively known as Intelligent Transportation Systems. These ITS have the potential to reduce traffic congestion and increase driver comfort and safety (Barfield & Dingus,1998). However, how this new information and thus increased task complexity influences the driver and his driving behaviour is still under debate (Horberry et al., 2006). There is a concern that ITS systems could potentially overload and distract the driver, jeopardizing safety (Verwey, 2000; Pauzie, 2002; Blanco et al., 2006). The current dissertation aims to address this concern, with particular attention to elderly drivers.

When classifying ITS a distinction can be made between intelligent infrastructure systems and intelligent in-vehicle systems. Intelligent infrastructure systems are advanced traffic management systems which monitor and control the traffic on the streets and highways to reduce congestion and travel time. To manage the traffic they use video cameras, in-vehicle messaging, changeable message signs and priority control systems. Intelligent in-vehicle systems are ITS systems that support, inform or warn the driver in-car and they can be subdivided in two subclasses. First there are the Advanced Driver Assistance Systems (ADAS) which will be defined here as systems that are integrated in the vehicle and designed to directly assist the driver in controlling their vehicle particularly in potentially dangerous situations. These systems take over part of or all of the driving task. Examples of ADAS are intelligent speed adaptation, collision avoidance system and adaptive cruise control. Second, In-Vehicle Information Systems (IVIS, also called Advanced Traveler Information Systems (ATIS)) are systems that provide information to the driver and do not directly take over (part of) the driving task. They can be described as systems that provide relevant real-time in-vehicle information about components of the driving, the environment, the vehicle or the driver. Examples are navigation and route guidance systems, hazard warning and sign information systems. Nomadic devices can be seen as a special class of IVIS. These are portable systems, some of which are not especially designed for use while driving, for instance, portable navigation systems, mobile phones or Personal Digital Assistants (PDAs). These nomadic systems can be used as navigation systems, but some can at the same time be used for non-driving related activities as e-mail, web-browsing and entertainment while driving. IVIS can be grouped into several types (Barfield & Dingus, 1998). The first type are In-Vehicle Routing and Navigation Systems that provide drivers information about the route from one destination to another and can have several functional components (Figure 1.1.1):

a) Trip planning. This involves route planning for long or multiple destination journeys, and may involve identifying scenic routes, tank stations or hotels.

b) Dynamic route selection. This feature determines the route while driving taking into account updated traffic information. In addition, the driver will be alerted when making a wrong turn and a new route can be generated.

c) Route guidance, which includes turn-by-turn information either by voice command or icons indicating turn directions on a Head-up Display (HUD).

d) Route navigation. This function provides information to help the driver reach his selected destination, but does not include route guidance. It supplies information similar to a paper map of the nearby streets, direction orientation and the current location of a vehicle within the city.

The second type of IVIS consists of In-Vehicle Motorist Service Information Systems, which provide either broadcast information on services and attractions as the vehicle drives by or a directory which can be searched for the needed information about commercial services and attractions on the route. These systems can also enable the driver to communicate and make arrangements with the various destinations, for instance a hotel or restaurant reservation.

The third type of IVIS are In-Vehicle Signing Information Systems that provide non-commercial routing, warning, regulatory and advisory information. For instance they are able to give notification alerts to the driver of forthcoming sharp curves, (advisory) speed limits, stop signs and the like. These systems thus augment the information presented on existing road signs.

At the present time the In-Vehicle Routing and Navigation Systems are the most commonly implemented IVIS systems. The expected benefits of ITS are that they will reduce congestion in dense traffic areas by providing drivers with real-time traffic information and alternative routes, allowing them to avoid areas of high congestion. Less time spent in traffic jams seems likely to increase driver comfort and productivity, and avoiding congestion is expected to result in a net decrease in travel time. It has been argued that ITS has a beneficial influence on the environment because, for instance, better routing information decreases the time spent on the road, reducing pollution and fuel need. Safety benefits could include reduced accidents, injuries and property damage. Further, reducing the number of accidents would keep lanes open which would otherwise lead to congestion and situations which may contribute to further accidents. In sum, ITS potentially provide a way to help use the available road capacity more efficiently and safely. Besides these positive effects of ITS there are some negative effects which could compromise safety. What if people have an unclear idea of what the system can do in emergency situations? Since such situations are not very common it is important for the driver to know exactly what he can and cannot expect from the system. As an example, an

Adaptive Cruise Control (ACC) system is capable of maintaining a preferred constant speed just like a simple cruise control, but has the extra ability to adjust the speed of the vehicle to be able to maintain the required safety distance to the vehicle in front. However this reduction in speed is maximally 20% of the total brake force, so in case of sudden hazards the driver has to brake himself and should not rely on the systems braking. Drivers may develop an over-reliance on the system or oppositely a lack of acceptance and trust in the system. Another known problem of increased automation is that the operator is taken out of the stimulus - response loop, which could lead to a loss of skill to deal with emergencies (Wickens & Hollands, 2000). Another negative effect of ITS is behavioural adaptation. In a study of Hoedemaeker & Brookhuis(1998), results showed that when drivers used the ACC behavioural adaptation occurred: they showed more lane weaving, left lane driving and needed to brake harder in case of an emergency stop.

Figure 1.1.1: Examples of different In-Vehicle Routing and Navigation Systems and the percentage of unsafe manoeuvres compared to the baseline condition of listening to a car radio (from Janssen et al., 1999).

Another factor that has to be considered when discussing the effects of ITS is the heterogeneity of the driver population ranging from novice drivers without experience to professional drivers and from young people to drivers around the age of 80 years. Different age and experience groups can have different needs or acceptance of a system. For instance De Waard et al. (1999) studied an ITS system that enforced law abiding behaviour that was rated as useful by both young and old drivers. Whereas after using the system the older people reported the system to be satisfactory, the young people found the system frustrating, especially the verbal information concerning the maximum speed. This shows the different needs and acceptance of ITS by different driving groups.

It is necessary when evaluating the exact impact of the use of ITS on traffic safety to consider many different kinds of benefits and risks. For example, a navigation system reduces the time spent on the road and increases the comfort of the driver while reducing time spent looking for the right direction. Moreover it interferes less with the driving than looking on a paper map (Pauzie & Alauzet, 1991; Mollenhauer et al., 1997). However, a navigation system still imposes a secondary task upon the driver. This may cause IVIS to compete with the primary driving task for drivers attention and induce increased levels of distraction and workload.

1.2 Multiple task performance

It is known from accident rates that when drivers choose to perform a range of other tasks while driving there is an associated safety risk (Stevens & Minton, 2001). This could be seen as an effect of too high a workload or a failure in dividing attention between the tasks (Liu, 2001; Jamson & Merat, 2005). Guidelines and methods to assist designers to develop systems with a minimum of negative side effects have been developed e.g.: the ISO standard, the EU statement of principles (EsoP, 2000) the HMI checklist and the 15 second rule (Green, 1999). These assessment methods provide tools to identify possible design problems but are relatively unhelpful for detecting the effects on workload or attention of the driver and primary task intrusion. Multiple task performance issues exemplify the interplay of fundamental and applied research. Multiple task performance is a very common daily activity and most of the time activities overlap each other; for instance we talk while we walk or read the newspaper while listening to music. Although people are usually able to perform multiple tasks at the same time, sometimes concurrently executed tasks can interfere with each other. For some activities distraction of one of the tasks is not critical. For instance, someone distracted by the radio while concurrently reading a book can simply pause or reread some sentences if necessary. For other tasks however such a failure to engage in the two tasks concurrently can have safety-critical consequences, such as car driving. Each second that a driver fails to monitor the ongoing traffic when driving with a velocity of 120 km/hour means driving 33 meters without paying attention. If an unexpected event takes place within this time window it could take longer for the driver to detect the event and the brake reaction time will be longer (Green, 2000). The critical question is if drivers, or particular subgroups of drivers, can deal with the multiple task situation introduced by IVIS-displays. And when will multiple task performance affect driving performance or the performance on the subsidiary task? Such questions could easily be answered optimistically, if only the capacities of human perceptual processing, attentional resources and working memory were unlimited. Driving can be described as a task that is highly complex, requiring perception, motor actions and cognition (Aasman, 1995; Cnossen et al., 2000; Anstey et al., 2005) defined several subtasks within driving including speed control, lane keeping, curve negotiating, collision avoidance, motor control in handling the car (e.g. shifting gear) and visual orientation, which involves looking in the right direction at the right time. The visual orientation subtask is vital because it actualizes the overview of the traffic situation (see also situational awareness by (Endsley & Rodgers, 1998). Aasman (1995) argues that coordinating these subtasks (multi-tasking) can be seen as a task itself: doing the right thing at the right time. For example, when a driver approaches an intersection, there are many different subtasks that need to be carried out in a very short time. This involves integration and co-ordination of many discrete visual and motor actions, but also sampling and interpretation of the environment and other traffic participants' behaviour, while actions should be adapted to the environment (Cnossen, Rothengatter, & Meijman, 2000). With the introduction of driver assistance systems as a secondary task, an extra subtask is added and the already high complexity of the in-vehicle task environment is increased (Verwey, 2000; Pauzie, 2002; Blanco, Biever, Gallagher, & Dingus, 2006) Theories about this coordination and integration of multiple sub-tasks will be described here from the perspective of theories on working memory and the central executive, attention and the Supervisory Attentional System and resource theories.

1.2.1 Working Memory

Working Memory is considered one of these limiting factors for information processing. Research of information processing starting with the first measurements of mental processing speed by Wundt (around 1860) and Donders (1969), since then several lines of research have been developed that have focussed on the limitations of information processing. Humans perform much worse when they have to solve a problem that requires them to remember intermediate results, keep in mind subgoals and combine information. The limiting factor of this information processing is working memory, which is often used synonymously with the term short-term memory to refer to a memory system that holds information relevant to current goals and activities. Working memory has been defined by Baddeley (1986) as the temporary storage of information that is being processed in a broad range of cognitive tasks. Working memory has also been defined as a system comprising a "central executive", "visuospatial sketch pad" and phonological loop", each of which assigned functions involved with, respectively, attentional control, the temporary storage and manipulation of visual and spatial information and the maintenance of items in subvocal speech. (Baddeley & Della Sala, 1996; Figure 1.2.1). Thus working memory has been defined in terms of a certain way information is stored, theoretical systems in which information is temporarily stored, and systems operating on such information (cf.Gladwin, 2006).

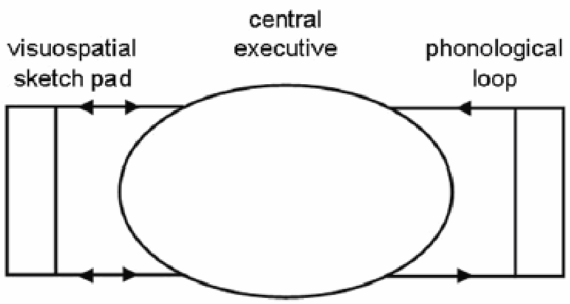

Figure 1.2.1: The working memory model (Baddeley & Della Sala, 1996).

Yet another interpretation of working memory can be given in terms of task demands, in contrast with the inferred structures and processes involved in performing those tasks. Working memory tasks typically involve a certain type of task demand: performing goal-directed mental operations on temporarily stored information (Baddeley, 1986). The storage of events makes it possible to link them together to for instance compare two tones or read multiple words. The decay of temporarily stored information may be adaptive, because in that way working memory implicitly encodes a specific kind of information, namely timing: if the information is still active, it is probably due to a recent or recently relevant event. The prefrontal cortex has been shown to play an important role in temporary storage and in goal-directed changes in how information is processed. Anderson, Reder & Lebière (1996) showed that when, in a dual task, task complexity increases (e.g. the number of digits to remember is higher), decay in working memory can account for decrements in both tasks' performance. This result shows that limitations of working memory can lead to errors and therefore is also a factor of concern in the use of IVIS while driving.

1.2.2 Attention

Another theory of a limiting information processing factor for multiple task performance is attention. While it is perhaps true that, subjectively, “everyone knows what attention is” (James, 1890), attention is not so easy to define objectively. Roughly, “attention” appears to refer to the goal-directed distribution of how much information is processed of several possible streams. Various aspects of attention have been studied (e.g. Styles, 1997; Johnson & Proctor, 2004) and can be defined in following: selective attention (when one stream is processed to the exclusion of others), divided attention (when multiple streams are being processed) and sustained attention (when a subject attempts to reduce the normal decay in effective processing over time). For driving, all these aspects of attention are relevant (Groeger, 2000). The main forms of attention that would seem to be of interest to the current thesis are selective and divided attention. Selective attention involves focussing attention on and shifting attention between stimulus locations, features or categories. It is generally evaluated by such experiments as dichotic listening, stroop task and visual search. Selective attention is needed while driving for scanning the area in front of the car to look for relevant information and cues or in case the driver needs to look at the dashboard to check the petrol. Mostly, the spot where the eyes are fixating is the focus of visual attention (but see also covert attention Posner, 1980). Visual attention serves to select some relevant sources of information in the visual field, while repressing others. Perhaps the most fundamental question about attention is the nature of this attentive selection process. In general, theories of perceptual processing propose that limitations can be classified in two classes. In the first class, it is stated that because perceptual processing is limited, it is necessary to have attention operating at an early stage to direct the perceptual processing resources toward relevant stimuli, making the processing quicker and more accurate (Treisman, 1982). The other class of theories says that the limitations lie at the post perceptual processing, and argue that attention operates at a later stage (Duncan, 1980). This is known as the early vs. late selection debate.

The issue of the locus of attentional selection has also been studied with a visual search paradigm. Two classes of Visual Search models are defined (Chelazzi, 1999): the serial model of conjunction search, based on the idea that RTs increase because individual parts or aspects must be processed in a serial manner. This serial search has been described using the metaphor of the spotlight of attention (Treisman & Gelade, 1980). The parallel model proposes parallel processing even for conjunction search: all comparison processes are simultaneously initiated. According to this model increasing RT reflects increasing competition 1) for finite computing resources in the brain as the number of distractors increase (Biased Competition Model; Duncan & Humphreys, 1989) or 2) changes in the internal-external signal-to-noise ratio (Guided Search Model; Wolfe et al., 1989). This refers to a two stage model; the first stage is usually assumed to be composed of a set of modules that process features in some sort of spatiotopic array, the general activations maps which are generated by a pre-attentive bottom-up process. The second stage is a top-down process and is the endogenous focus of attention on specific aspects of the stimuli leading to higher activation of relevant features. In the HASTE-project a visual search task was used to develop a surrogate-IVIS to manipulate the task demand of the subsidiary task. Results showed a clear influence of the difficulty of the visual search on the behavioural measures on the surrogate-IVIS. More disturbingly was an negative effect of visual search complexity on driving performance (Jamson & Merat, 2005).

Experiments of divided attention involve monitoring two or more stimulus sources for information and also include the combination of any two tasks that have to be performed simultaneously. In a typical dual task situation participants are instructed to identify two separate stimuli and make a separate response to each of the stimuli. If the two tasks involve responding to widely separated visual stimuli, dual task performance suffers because of physiological limitations- the stimuli cannot be fixated at the same time. If the two tasks have to be responded to with the same index finger, dual task performance will also suffer for simple biomechanical reasons. To avoid these effects and purely focus on effects of cognitive limitations, the two tasks are often presented in two different modalities and responses have to be made with different effectors. A robust finding is in such dual task situation is that reaction times to a second stimulus are slowed. Another effect is that the increase in RT is a decreasing function of the interval between the two stimuli. That is, when the stimulus onset asynchrony (SOA) is short, the reaction time for the second response will be slower than when the SOA between the two stimuli is long. This slowing of the second response with short SOAs has been called the psychological refractory period (PRP) effect (Telford, 1931). These tasks are typical laboratory experiments but Levy et al. (2006) recognized that this PRP-effect is also relevant for driving, and showed that a simple two choice task can increase brake time when the SOAs are short.

Whereas within the Working Memory theory the central executive is responsible for the correct organisation of handling multiple tasks, Norman and Shallice (1986) proposed an extended and more detailed variant of the central executive: the Supervisory Attentional System (SAS; Figure 1.2.2). In their model of controlled attention they define two mechanisms. The first is a basic mechanism called contention scheduling, which is an automatic process involved in both routine and non-routine schemata. Schemata are action abstractions based on experience that are triggered when the appropriate set of conditions is met. The contention scheduling mechanism sorts out conflicting schemata by interactive excitation and inhibition of schemata. Normally the most strongly activated schema will gain in control of action. In a Stroop task this would be naming the written word. However the routine operations initiated by the contention scheduling might be insufficient and Norman and Shallice (1986) propose that deliberate attentional resources are needed when tasks,

1) require planning or decision making;
2) involve trouble shooting;
3) are ill-learned or contain novel sequences of actions;
4) are judged to be dangerous or technically difficult; or
5) require overcoming a strong habitual response or resisting temptation.

Under these circumstances pre-existing schemata are either inadequate or not present and have to be suppressed or substituted by novel schemata, and then the SAS becomes active. The SAS involves consciously controlled non-routine selection of schemas. The SAS biases the selection of schemata by the application of additional excitation or inhibition to schemata, changing the probability of selection (for instance when asked to name the colour of a colour word in a Stroop task).

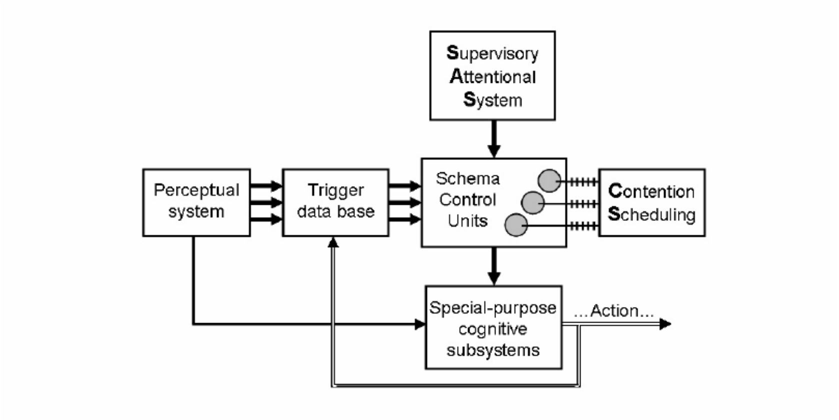

Figure 1.2.2: A simplified version of Norman & Shallice's model of attentional control (1986).

The schema selection becomes slower but is flexible as opposite to the fast and rigid selection of schemas by the contention scheduling. The SAS thus inhibits old schemas and in this way new schemas are generated and integrated in the hierarchical network of the contention scheduling schemata. The involvement or not of the SAS can also be described as whether processing is controlled or automatic (Neisser, 1976; Schneider & Shiffrin, 1977). The main critique of the SAS theory is that no explanation is offered about how the SAS knows what to do. However, models such as the SAS provide the context in which such questions are asked in the first place – the idea of the biasing of schemas is needed to ask the subsequent question of how a causal mechanism can do so in a goal-directed fashion.

1.2.3 Resources theories

The need for research on applied topics arose during the WW II when due to technological developments the nature of work had changed. Gradually the physical requirements of work were been reduced, but replaced by cognitive demands. Whereas in the Netherlands the amount of physical work an employee may be required to do is regulated (e.g. the maximum amount of weight that can be lifted without using machines) the cognitive demand placed on workers is not (yet) bound to limits. The consequences of high cognitive demand in several applied contexts have been studied, for instance the ability of air traffic controllers to divide attention between multiple aircrafts or the ability of a security guard to maintain vigilance while monitoring multiple surveillance cameras during the night. As an example, Wickens (1992) described a controversy between an airline industry and a pilot association. The airline industry claimed that a certain class of aircrafts could be flown by two crew members, while the pilot organization claimed that demands at peak times would be excessive and would require a three person complement. Such issues have raised the question of how operators cope with added multiple demands on their attention and workload and how much they can handle. In applied research this demand has been labelled mental workload and refers to the information processing required to adequately perform a given cognitive task.

Early theories formulated a single pool of attentional resources that could be allocated to different tasks; as long as the total amount of resources was not exceeded, adequate concurrent task performance would be possible (Kahneman, 1973). This pool of resources could be flexibly allocated by the operator between subtasks. However, in Kahnemans theory the total amount of attentional capacity can vary according to motivation and therefore effort. So if more effort is put into the task more attentional resources are available. The amount of effort is also related to the overall arousal state; as arousal increases or decreases, so does attentional capacity. However, there was serious criticism of this unitary-resource theory. For instance performance can also poor at low levels of task demand, and this is not explained by this theory. Further, allocating more resources to one of two tasks does not always cause performance decrement in the other one, a phenomenon known as difficulty insensitivity. This is a violation of the idea that there is a single pool of resources. It is also possible to improve performance by changing the methods while achieving the same goal (structural alteration), for instance by changing the stimulus modality of one of the tasks. Finally, researcher have found instances of perfect time sharing: two tasks can interfere separately with a third task but can nonetheless be performed together without any decrement.

Thus, this subsequent research, due primarily to Wickens (1980; 1984), revealed dual task interference that was inconsistent with these single source models, leading him to develop the multiple resource theory in which multiple resource pools were defined (Figure 1.2.3). Wickens proposed that there are separate resources available for each of the basic information processing stages of perception, central processing and responding. Also he proposed separate resources for different modalities like visual and auditory input modalities and manual and vocal responses. All these separate resources can be represented in a three-dimensional model. This model has some consistency with the proposed slave systems of working memory namely the visuospatial and phonological loop (Baddeley, 1986). However the multiple resource model does not include any organizing structure and does not offer predictions on possible interactions or conflicts between the codes and modalities. The only “organizational” aspect in the theory is that it is stated that switching attention brings a mental cost that may influence the sampling of different sources in the environment. This model therefore seems inadequate to predict possible origins of interference between tasks. Later studies commented that the multiple resource theory is untestable because it does not quantify the number of resources (Navon, 1984; Neumann, 1987). However, it can serve as a framework to guide researchers to develop task descriptions of dual task and time sharing performance: better overall performance of two tasks is expected when they use separate rather than common resources. Thus the theory predicts that when task demand increases in a secondary task (IVIS) which has different in/output modalities than the primary task it will cause less interference on the primary task (driving).

1.2.4 Summary

Described above are different theories which try to define the way people are able to perform multiple tasks. Clearly, at least in experimental settings there are several limitations to information processing and these bottlenecks cause dual task performance decrements. Systems that are proposed to coordinate this multiple task performance are the central executive in the model of Baddeley and the extended version, the SAS. So if we come back to Aasman(1995) who stated that coordinating the subtasks of driving can be seen as a task in itself we could now appoint working memory or SAS as the coordinating system of the subtasks of driving and handling a IVIS. However it is unclear what is controlling the central executive or the SAS, resulting in the homunculus problem. Neither of these theories makes clear assumptions on where decisions come from. Nevertheless, various expectations regarding using an IVIS while driving can be drawn from these well-studied theories. Combining driving with any secondary task will be more difficult when the secondary task is less automatic, when there are no existing schemas for it and when much attention and many resources need to be invested in multiple tasks. The more demanding the IVIS task is, the more working memory will be taxed and the more need there may be for dividing visual

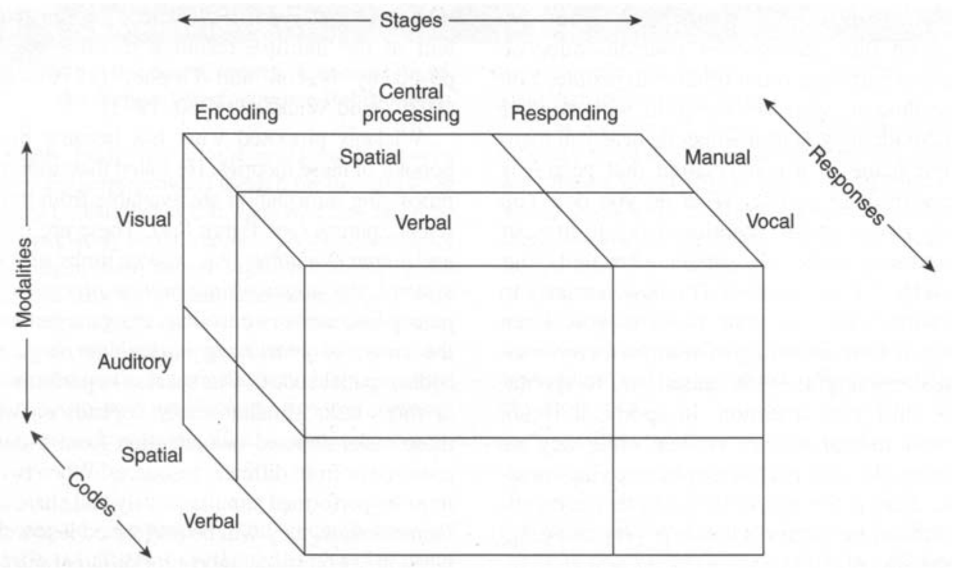

Figure 1.2.3: Wickens multiple resources theory (1984). The different modalities, processing codes and stages, and response modalities are assumed to each have a separate pool of attentional resources.

resources. Timesharing between both tasks could then become both important for the task performance and highly demanding. Due to the large numbers of factors which affect driving performance and the limited ways to standardize the tasks without losing validity, it is hard to study the limits of attention in dual tasks during driving. For instance, one has to deal with the highly uncontrollable environment when doing an on-the-road study, and the large variety of IVIS tasks. But if it were possible to make some predictions on the basis of these theories which have already proven their value as a framework for fundamental research, this would be of great value in guiding applied research. As mentioned by Groeger (2000) it would be very valuable to have a cognitive model of driving. With such a model we could predict which tasks are more or less safe to perform together with driving. With such predictions, it would save the time of trying each and every available IVIS on the market, and perhaps testing the wrong issues; and it would be possible to develop some guidelines or implementation rules for the car industry.

1.3 Cognitive driver models

As mentioned in the previous section, driving is a complex task, comprised of multiple subtasks. Attempts to model driving and predict possible errors have lead to a wide variety of driver models (Michon, 1985). Each of these models focuses on different aspects of driving. In a review article Ranney (1994) describes the lack of progress in developing a comprehensive unitary model of driving behaviour. Early models in the highway safety field have been preoccupied with accidents, ignoring the influence of driver's cognition and motivation on driving behaviour. Later motivational models arose which have the assumption that driving is self-paced and that drivers select the amount of risk they are willing to handle (Wilde, 1982; Fuller, 2005). A change in approach of driver modelling came with the implementation of theories from cognitive psychology during the 1980s. Two dominant theories arising from these changes differed from previous theories by taking into account higher order processing and decision making and driver goals. Both models are frequently referred to in ITS literature; these are the SKR-model (Skill-, Rule- and Knowledge-based) from Rasmussen (1983) and the hierarchical control model of Michon (1985). Rasmussen differentiates skill-based, rule-based and knowledge-based behaviours. Knowledge-based behaviour is invoked whenever behaviour is conscious and not automated, for instance when learning a new ability such as learning how to drive a car. Every step to reach a goal is performed consciously. Because there is no routine this is attentionally demanding and the execution of the task is slow. The rule-based level is reached when the performance of a task involves automated activation of rules by which a sequence of subroutines can be activated. Rule-based behaviour is generally based on explicit know-how and the rules can be reported by the person. Skill-based behaviour is performed without conscious attention or control, and tasks are performed smoothly and quickly. The basis for such performance is the possession of highly practised procedures, which are initiated. Behaviour at the skill-based level is triggered by sensory input.

A three-level hierarchy in driving-related cognition is also proposed by Michon (1985). The three levels include the strategic, tactical and operational level of vehicle control. On the strategic level decisions are made about trip planning in general, including planning the route, trip goals like minimize time or avoid traffic jams, and the time of departure. The tactical level involves manoeuvring to negotiate common driving situations like intersections, switching to a different gear in curves, obstacle avoidance, overtaking or entering a traffic stream. The operational level consists of decisions which are relevant for basic vehicle control activities like braking, steering and changing gear. The three levels are hierarchically dependent on each other, which means that the strategical level defines what should be done on the manoeuvring level and thus defines the goals for the operational level. The reverse can also occur: when the driver is unable to perform actions on a lower level (e.g. change lane to the right lane and take the exit) goals on the highest level may have to be revised (e.g. take another route). The three levels can be differentiated on a temporal level; the amount of time that is needed to define a goal and the time that is available to make a decision. The parts of the driving that involve the strategic level take the most time, in the order of minutes. Subtasks that have to be performed on a tactical level can have a duration of several seconds and even milliseconds at the operational level (Hommels & Hale, 1989). An interesting difference is that between the amount of time needed and the time available to come to these decisions. A discrepancy between these can cause time pressure which can lead to increased task demand and performance loss (Davidse, 2003). Time-pressure exists continuously at the operational level, when the driver has only a limited amount of time to react to visual input and to avoid safety critical situations (Brouwer et al., 1988). At the highest level time pressure is generally not that high, but if it occurs it is likely critical. For instance, due to failing to inspect the road signs a driver may need to make a last minute decision whether or not to take the upcoming exit.

These two models have been combined (Figure 1.3.1; Hale et al., 1990). For an experienced driver most driving tasks are on and under the diagonal from the upper left to the lower right of the table. The driver tasks encountered by inexperienced drivers are described by the other quadrants in upper right corner. When the driver is more experienced more tasks become automated and move to a lower level (skill). Therefore drivers operate more predictably and homogeneously at the skill- and rule-based level than at the knowledge-based level and are more likely to do so with increasing experience (Hale, Stoop, & Hommels, 1990). However, there are some (strategic) tasks that even experienced drivers have to perform at knowledge level like navigating in a unfamiliar area. It is in such situation that having a route guiding system has clear benefits.

	Planning	**Manoeuvre**	**Control**
Knowledge	Navigating in strange town	Controlling a skid on icy roads	Learner on first lesson
Rule	Choice between familiar routes	Passing other cars	Driving a unfamiliar car
Skill	Home/work travel	Negotiating familiar junctions	Roadholding round corners

Figure 1.3.1: Examples of selected driving tasks Michons control hierarchy and Ramussens skill rule knowledge framework (From A.R. Hale et al. 1990, Figure 1 p. 1383)

A recent model, the task – capability – interface (TCI) model (Fuller, 2005), places the driver in interaction with demands of the road environment; this model is a reaction to the models that try to determine driving behaviour in terms of risk, and is in line with the risk homeostasis theory of Wilde (1982). Fuller argues that risk of collision is generally not relevant for the decision making loop; instead, feedback regarding the difficulty of driving is relevant. This task difficulty is defined as the difference between the capability of the driver, and the task demands at a certain moment. When capability exceeds demand the task is easy and when demand exceeds capability the task is too difficult and the driver fails to fully control the driving, possibly leading to an accident. Thus drivers adopt a certain level of task difficulty they wish to experience when driving and try to maintain this level of task difficulty. In figure 1.3.2, a schematic overview of the TCI model is given. In this figure the factors based on driver characteristics are in the upper left corner, while factors of the environment and vehicle are in the lower right corner. The capability of the driver is limited by mental and physical characteristics, like vision, coordination and reaction time. These factors are relatively stable and can only change as a result of disorders, diseases or with age-related functional limitations. On top of these characteristics are knowledge and skills the driver has acquired through training and experience. Together these biological factors and the acquired factors determine the upper limit of competence of the driver. However this maximum level of capability is not permanently delivered due to current influences on the individual, including: motivation, effort, fatigue, emotion, drowsiness, time-of-day, drugs e.g. alcohol and stress. Each of these factors can cause the driver competence to drop temporarily and therefore decrease the level of capability (Fuller, 2005).

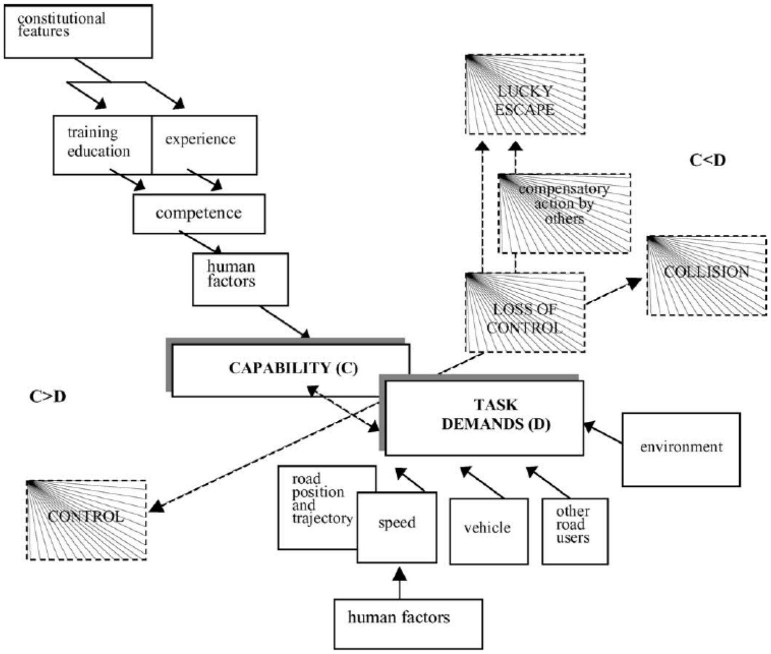

Figure 1.3.2: The task-capability-interface model from Fuller (2005).

The driving task demands in the task-capability-interface model are a large variety of interacting factors which lie outside the driver. There are environmental factors such as visibility, road marking, signals and there other road users with various properties. Also there are operational features of the vehicle being driven, such as controls, the possibility to provide roadway illumination and - importantly for this dissertation- information displays. Added to these elements are the elements over which the driver has full control, namely the speed and the vehicle's trajectory. Fuller thinks of speed as the most significant factor controllable by the driver to vary task demand. Clearly, the faster a driver travels, the less time is available to take information in, process it and respond to it. Other road users can make compensatory actions as well, such as avoiding collisions. Crashes can also be prevented by adjusting the infrastructure or the vehicle to lower task demand. For instance, intersection angles can be adjusted, which can increase the time available for the driver to perceive, to interpret, to decide, and to initiate the appropriate action. Another way to reduce task demand is (re)training the driver. The training can be aimed at removing bad driving habits, improving the useful field of view or compensating for functional limitations which increase due to ageing (Coeckelbergh, 2002). This training will improve the driver’s capabilities and help them to deal with the task demand, thus decreasing the task difficulty. We use these driver models to predict the impact of IVIS on driver performance. The SKR-model could also be valid for the learning process when dealing with an IVIS. This means that the driver will start on the knowledge level when the IVIS is introduced into the car. This beginning period would be the most demanding because each step is performed consciously, because there is no routine and the execution of the task is slow. This means that the driver will spend more time with his eyes on the systems display instead of on the road. On the basis of the TCI model, it would be expected that this novel situation is less critical for people with high capabilities in an environment with a low task demands. People with lower capabilities due to, for instance, low driving experience or due to ageing, will experience greater task difficuly. But as long as task demand does not exceed the drivers capabilities no incidents or accidents will occur. Importantly, people trying to cope with the increased task demand will try to compensate for it by, for instance, driving familiar routes to get used to the IVIS system or investing more effort. When gaining more experience with the system the drivers will deal with the IVIS system on a rule- or skill-based level which lowers the task demand because handling the IVIS becomes more automated. If the IVIS system is well designed it could assist the driver with the driving task and therefore lower the task demand. For instance, with elderly drivers IVIS systems can make the driving easier by compensating for their reduced capabilities (Davidse, 2005). However it is also known that elderly drivers have more trouble with dividing their attention with increasing age (Verhaeghen & Cerella, 2002).

There are periods that have a particularly high task demand like driving through a large city during rush hour. Further more the driver capabilities can fluctuate as well as the task demands. If the capabilities of the driver are also low during (e.g. fatigue) then it could take a long time to make a decision, and increase reaction times on the operational level (e.g. brake rection time). In this case the task demand exceeds the driver capabilities and causes an increased task difficulty. Task difficulty is thus the combined effect of the task demand (external factors like the vehicle and the environment) and the driver capabilities (human factors). The effect that the task demand has on the driver including the driver state has also been labeled as “workload” (e.g. de Waard, 1996).

1.4 What causes task difficulty?

In this section factors are described that influence task difficulty i.e. task demand and driver capability. Driving task demands are differentiated by elements outside the vehicle, like road type, weather condition and factors within the vehicle namely IVIS and telecommunication and further the characteristics of the driver to determine driver capability are discussed.

1.4.1 Characteristics of the environment

The road types can have different task demands; urban roads are mostly high on visual information caused by the presence of buildings complex and non-standardized road trajectories, visual occlusion by buildings. Urban roads have mostly speed limits between 30-

50 km/h. And in urban road areas all types of road users are present like pedestrians, cyclists and mopeds. Rural roads have partially standardised road environment. The presence of pedestrians and bicycles are few but meeting traffic is common. Also there is a large possibility to encounter slow traffic like farming vehicles. Speed limits can be 60 or 80 km/h. Motorways are highly standardised and thus predictable to the driver. Instead of the travel time in urban and rural areas which is normally short i.e. less then 1.5 hour, travel time on motor highways can be long up to several hours which can reduce vigilance due to monotony (De Waard & Brookhuis, 1991). Speed limits are 120 or 130 in Europe except for Germany where there is no speed limit but only an advisory speed of 130 km/h. One possible option to determine task demand of these different road types is to look at accident data. One could expect the distribution of road accidents to be equal between urban and rural roads and motorways taking into account the mileage and speed limits on these roads. However statistics show this is not the case. For instance, in the UK mileage is highest on the motorways which account for only 26% of the accidents while urban roads show an accident contribution of 51%. Also maximum speed limits are not linearly related to the amount of accidents. For example, in the Netherlands most accidents occur on roads outside the build-up area with a speed limit of 80 km/h instead of on the motorways where the speed limit is 120 km/h (CBS, 1999). Motorways are designed to be driven at a high speed and are therefore well standardised, predictable, and secure. On the contrary, rural roads are less standardized and sudden unexpected effects can take place like appearance of animals on the road, slow traffic or encountering oncoming traffic in the wrong lane. Junctions are usually more dangerous than the road sections i.e. links between them. On average accident rates at junctions are 2.5 times larger than at links (Kulmala, 1995). This is the case because crossing and entering intersections require the driver to perceive a lot information in a short period of time. At the same time decision are to be made together with a rather complex car handling (Hydén & Draskóczy, 1992).

Another environmental factor is weather condition, especially in northern European countries road surface condition can cause task demand to increase. For instance, braking performance of vehicles is substantially reduced in icy and snowy road surface conditions and deceleration capacity may decrease by more than 90% compared to dry conditions (Strandberg, 1998). Also visibility can be decreased due to heavy rain fall or fog. Other environmental factors can be time of day, road marking, road signs and signals. In general, night time driving is associated with a higher probability of crash involvement due to factors such as reduced visibility, fatigue, and higher incidence of alcohol use (Massie et al., 1995). The visibility of road signs also decreases significantly at night, with the problem being more pronounced for older drivers.

1.4.2 Characteristics of the IVIS

The information that the IVIS provides to the driver can be either visual, auditory or haptic. When looking at the relationship between the modalities in fundamental studies it is known that their processing is asymmetric. In most cases visual information gets the upper hand giving competing auditory or haptic information. This phenomenon is called visual dominance (Mc Gurk & Mac Donald, 1976). In case one has to turn a volume button or look at a navigation display the driver has to decide when it is safe to take the eyes of the road and for how long. It should be long enough to complete the task but short enough so the vehicle and driver will not be at risk. Although the focus of attention can be elsewhere than the eyes are directed, most of the time visual attention is linked to the point of eye fixation (Helmholtz, 1866; Eimer, 1996; Eimer & van Velzen, 2006). For a good driving performance the driver needs to attend the visual information outside the car to prevent the vehicle from going of the road or colliding with obstacles (Mourant & Rockwell, 1972). Increases in the time spent looking at in-vehicle systems will increase the chance of inadequate longitudinal and lateral tracking (e.g. Horberry, Anderson, Regan, Triggs, & Brown, 2006). When displaying visual information it is important that the time that the driver takes his eyes off the road is minimized. So the displayed message should have a low complexity, making it easy to perceive and interpret the information. Mollenhauer et al. (1997), indicated that more than four glances at a visual information display or glances longer than 2 seconds indicate dangerous allocations of visual workload to the display. The American Society of Automotive Engineers in 2000 however states that any navigation function available by the driver while in motion should have a total task time of less than 15 seconds, which is about twice the time Mollenhauer mentions. Choosing the appropriate modality to convey the information is important when designing an in-vehicle system, the combination of the modality and type of information can affect the usability and safety of the system (Noy, 1997). As most of the information needed for the driving task itself depends on vision, the auditory and haptic modality are often considered less distracting (Michael & Casali, 1995; Wickens & Seppelt, 2002). Auditory information is omni-direct making it suitable for alerting and warning messages (Sorkin, 1987). While in most cases auditory information is less interfering and preferred over visual transmission of information this does not hold for all situations. Detailed location information about a cross section can be more efficient and easier to understand shown in a picture, especially when drivers are unfamiliar with the situation (Molnar & Elby, 1996). Furthermore auditory information is discrete and system paced, requiring correct timing, while visual information is continuous and access of this information is controlled by the driver. Audio messages are discrete whereas visual displays are continuously updated. When audio messages are not correctly timed they rely on the drivers' memory to be able to recall the information at the proper time. Hence when these audio messages are too long a great demand will be put on working memory. This concern has led to research on both visual and auditory presentation of information. This research has resulted in mixed results, with some studies finding that presenting information visually resulted in a less safe condition, while other studies have found just the opposite. In one study on the effect of both visual and auditory sensory modalities in an IVIS system, Mollenhauer et al. (1997) found that although auditory presentation resulted in a greater recall of information, measures of driving performance (lane position deviations, rapid steering movements, and road-heading error) were worse under auditory presentation, indicating a less safe condition.

According to Drury and Clement (1978) and Treisman (1982), the number of elements to be searched has a dominant effect on search time. In other words, the architecture of a display influences the complexity of a system. Consequently, a display 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. Searching time is especially long in cases that the target items are not present, as is known from no-go trials in visual search tasks (Treisman & Gelade, 1980; Wolfe, Cave, & Franzel, 1989). In the letter-search task developed by Neisser (1976), participants scanned a vertical column of random three- or five-letter sequences until they detected the target letter. Within each search, the time was directly proportional to the distance of the item from the top of the menu. So from a human factors point of view it would be wise to have critical or frequently needed information in the upper left corner when designing a IVIS system in accordance with the reading direction (i.e. of western european countries).

Thus, if a display content is very complex, it may require the operator’s eyes off the road for an inordinate amount of time to extract relevant data. 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 the physical 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.

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 or even a small remote. 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).

1.4.3 Characteristics of the driver

Biological factors influence the capability of the driver (processing speed, motor coordination, reaction time etc.) and differ between drivers and within drivers. Variation within the driver is attributed to psychophysiological state like arousal and fatigue. Experience of the driver has a positive effect on task demand; more aspects of the task become automated, thus causing a lower demand on working memory. Such knowledge acquired with experience includes formal elements such as rules of the road, procedural knowledge defining what to do under what circumstances (conditional rules) and a representation of the dynamics of road and traffic scenarios which enable prediction of how those scenarios will develop, like an internalised mental video which runs on ahead of the immediately observed situation (Kaempf & Klein, 1994).

Especially vulnerable to dual task interference could be elderly drivers, who are known to have motoric, perceptual and cognitive functions decline, due to normal ageing which affects driving (Anstey, Wood, Lord, & Walker, 2005). However, reduction of the maximum level of performance with age is accompanied with a larger inter individual variability, thus making chronological age a unsuited predictor of actual driving capabilities. Older drivers can be seen as a vulnerable road user group, although there are still some common knowledge misconceptions regarding their impact on road safety. When looking at accidents rates, the number of accidents that elderly are involved in is higher than for young people (age <25 years) when looking at the total population (Merat et al., 2005). However, per driven mileage elderly drivers have an even chance of getting involved in a accident, this is called the "mileage bias". The accidents that elderly people seem to get involve in are seldom due to careless or aggressive behaviour. Elderly have a tendency to comply with the law and are less inclined to speed, dangerously overtake another vehicle or ignoring police instructions. They are underrepresented in single vehicle accidents, but have more than average multi-vehicle accidents and tend to be at fault in their collisions. The inability to handle complex traffic situations is seen as a major cause why older drivers have accidents. Accidents typically happen at cross-sections, left turns or an incorrect assessing of the gaps in traffic streams. Older drivers do have a higher chance of dying in a car accident. However, the main cause for higher dead rates among elder drivers is that if they get involved in an accident they are more likely to die due to their greater physical vulnerability ("frailty bias"). Furthermore it is known that elder people are able to compensate for part or all of their deficiencies by profiting from the experience they have gained over the years. They thus adopt a number of coping strategies. Eby et al. (2000) gives a list of typical compensation patterns:

- Reducing or even stop driving in the dark and with poor weather conditions like fog, snow and rain.
- Reducing highway driving, take more time and drive slower
- Try to avoid unfamiliar areas and routes.
- Planning routes with right turns or protected left turns.
- Driving with a co-pilot.
- And finally giving up driving voluntarily.

When using driving simulator tests to define the driving capabilities one has to be aware that this environment is artificial and can give an false impression of driving performance and can not be transferred one to one to driving on the road. For instance Schlag (1993) found when comparing driver performance of middle age (40-50) and older drivers (60-82) both in laboratory and in the field, that the performance of the elderly was worse in all laboratory experiments. However, with the road tests there was no performance difference in most of the situations. This improvement of the elderly driver performance in the field could be interpreted as an effect of experience and compensatory strategies that are used in on-the-road driving, but can not be transferred to a laboratory setting. In the study of Herriotts (2005) one in five older subjects (60-79 years; n=1013) reported that using the radio was difficult and some stated that they never used them due in part to the perceived complexity and possible distraction. Two questions arise from this result: when using a radio while driving is considered complex and interfering with the driving, how will other self reports of ITS systems be for this group of drivers? Apparently some drivers perceive the difficulties they have operating the radio resulting in giving up using the radio. Can all drivers make such estimations of how much task complexity they can handle and are they correct or do they over/underestimate themselves?

IVIS could assist drivers with part of their coping strategies, like planning a route without highway driving. Also some authors suggested that driver assistance and information systems might be able to help overcome limitations associated with ageing (Mitchell & Suen, 1997; Caird et al., 1998). This would enable older drivers to keep their drivers license longer, decreasing their accident involvement and enhancing traffic safety (Davidse, 2005). At the same time however these IVIS systems could add to task complexity and demand which could cause especially elderly drivers to driver worse. It is known that in older age deterioration of the brain begins primarily at frontal regions (Raz, 2000). These frontal brain regions play a major role in planning, decision making, conflict resolution and executive functions (Craik & Bialystok, 2006). These deteriorations could influence the capability to perform in complex multitask situation such as driving with an IVIS.

1.5 How to deal with increased task demand?

As described in the previous section, high task demand can threaten driving performance due to information processing limitations. Humans have several ways to adapt their strategies to deal with changing task demand. It is expected that drivers will adjust their strategies to reach what can be described as homeostasis or an optimum balance between effort or expected fatigue on one hand and performance or risk on the other (Wilde, 1982; Fuller, 2005; Fastenmeier & Gstalter, 2006). There are at least three ways in which a driver can adapt his behaviour to cope with higher task demand (Bainbridge, 1974; Hockey, 1993). These are investment of more effort, change of working strategy and neglecting information of secondary importance (first description by Cnossen, 2000).

1.5.1 Investment of more effort

An increase in task demands is to invest more effort into the task. Mulder (1986) distinguished between compensatory and computational effort. Computational effort applies to controlled information processing, as opposed to automatic information processing (section 1.2). Compensatory effort refers to compensation for suboptimal psychophysiological states due for example to fatigue or alcohol use. This is of course not to say that these types of task and state-related effort do not co-occur. For example, performing a complex task while being fatigued or in noisy conditions involves both types of effort. It is possible to invest both state-related effort and task-related effort at the same time. Either type of effort investment is associated with costs: fatigue, anxiety and stress. It is with this strategy that psychophysiological measurements can make a contribution by measuring extra compensatory effort - which by definition should not be directly visible in behavioural results. For instance psychophysiological measurement such as components of the electro-encephalogram (EEG) or heart rate can pick up signs of mental strain during driving even when drivers' reaction time and driving performance do not appear to be affected.

1.5.2 Change working strategy

Another way to deal with increased task demand is to change how the task is performed. There are usually multiple ways to perform a complex dynamic task (Bainbridge, 1974) and not all working methods involve equal amounts of effort. Driving speed is an important factor by which a driver can control task demand (Fuller, 2005). This is also in line with Hancock and Cairds model which predicts that task demand increases as the available time for actions decreases. Speed can be seen as an indication of the drivers tolerance for visual information rate and reaction time. By reducing the speed the driver allows himself more time to assess the situation and to react. In a study by Dingus et al. (1997), a relation was found between level of demand and driving speed. Participants were required to drive with different route guiding information systems: visual displays, traditional paper maps, or messages by voice. The authors noted the long duration of glances at the displays of the visual route guiding systems, indicating high visual demands; in general, long glances are taken as evidence that the information presented is difficult to process (Fairclough et al., 1993). The results showed that the systems with the highest visual demands were associated with lowest driving speeds.

Changing speed allows performers to use the same working strategy to achieve their goals but under less time pressure. Subjects may also change their strategies. A well known example of this comes from Air Traffic Controllers (ATCos) changing their working method to reduce the demands on their working memory. ATCos have sectors of air space in which they are responsible for all air traffic. The ATCo has multiple goals, which sometimes conflict, for example, the goal is to maximize the in and outflow of aircraft from the sector, while adhering to various strict safety criteria such as for instance a minimal separation. Task demand is relatively high because of the verbal communication, in terms of instruction and clearances given to the pilots. This vulnerable voice communication contributes to the inherent sluggishness of the system. The delay between a control issued to the aircraft to speed up, change altitude or heading, the execution of the command (including the response by the aircraft) may take several minutes to occur on the radar display. This sluggishness of the system makes prediction, anticipation and planning important aspects of the work. ATCos started using less demanding strategies by assigning standard flight routes to pilots as the number of aircraft increased (Sperandio, 1971 1978).

1.5.3 Neglecting subsidiary tasks or information

Another way to deal with high task demands is to pay less attention to secondary activities or to non-essential information. Not all subtasks are equally important in achieving the main task goal and some can therefore be skipped or be decreased in frequency (Brookhuis et al., 1991) without jeopardizing the fulfilment of the main task goal. One form of decreases in secondary task performance during high task demands is attentional narrowing, or increased selectivity. Under an increase in task demands, it has been found that peripheral information is processed less by operators, as they concentrate on information presented centrally, which they considered to be more important. And operators have even been shown to skip a subtask if that subtask is not essential for the main task (Hockey et al., 1998). They restrict their attention to a subset of information sources, ignoring other displays not directly relevant for good performance. Even people who have been told that they will be experiencing a difficult situation have been shown to restrict their attention to central cues, ignoring peripheral stimuli in a detection task (Weltman et al., 1971). Attentional narrowing can been seen in environments like aircraft cockpits where all attention is focused on one display indicating a possible problem and operators ignore other displays necessary for flight (Wickens & Hollands, 2000). This attentional narrowing by an increase of workload has also been studied with the Peripheral Detection Task (Martens & van Winsum, 2000) by measuring the detection of a stimulus in the peripheral of the functional visual field. The functional visual field decreases with increasing workload making the detection of the stimulus more difficult.

It is important to note that although the level of task performance may decrease by adopting less demanding working strategies, or by paying less attention to non-essential subtasks or information, this happens only in what the participant considers the less important parts of the task (Cnossen, Rothengatter, & Meijman, 2000). It is therefore important to know what drivers see as the main task goal at given times, under different conditions. Furthermore it should be acknowledged that drivers will not always strive for perfect task performance but will be content with a performance that is adequate. The driver will always try to protect the main task goal even when experiencing high task demands. All of the above techniques can serve to protect the main task goal. So when information or input becomes overwhelming or more motor actions have to be executed than can be performed these strategies can be put into play. It is however known that these compensatory strategies are not always sufficient to compensate for the extra demand of a IVIS while driving. In the HASTE project (Carsten & Brookhuis, 2005) a visual surrogate IVIS task consisted of a visual search task with three difficulty levels, based on Treisman's Feature Integration Theory (1988) and designed in such a way that it had high visual demand and a minimum of cognitive processing. In the baseline measurement the visual search reaction times and error rates increased with difficulty level as expected. When the secondary task was performed, while driving a driving simulator, the performance further degraded on the secondary task. Even though drivers attempted to adapt their strategy by slowing down, a reduction in secondary task performance could still be detected. More worryingly, the increase in IVIS demand was also associated with a reduction in primary task performance, most noticeable in time-to-collision (Jamson & Merat, 2005). In essence, drivers seemed incapable of fully prioritizing the primary driving task over the surrogate IVIS. And they were not able to fully compensate for the increased task demand induced by the surrogate IVIS.

1.5.4 Measuring effects of task demand using the EEG

Event Related Potentials (ERPs) are well suited for addressing the locus of selection issue and have been used to find a solution for the early vs. late selection debate. ERPs are averaged segments of the electro-encephalogram (EEG) time-locked to specific stimuli. With a sufficient number of trials any brain activity that is not time-locked to the stimulus will average out, improving the signal to noise ratio. The sequence of the components following a stimulus reflects the sequence of neural processes triggered by the stimulus, beginning with early sensory processes and proceeding through subsequent decision- and response-related processes. The amplitude and latency of the successive peaks can be used to measure the time course of cognitive processing, and the distribution of voltage over the scalp can be used to estimate the anatomical location of these processes in the brain. To asses the locus of attentional selection, researchers compare the ERP waveforms elicited by attended and unattended stimuli. In figure 1.2.2. two ERPs are shown, both elicited by a rectangle presented in the left visual field. One waveform was elicited when attention was directed to the left visual field, the other when attention was directed to the right visual field. The waveforms indicate that attention modulates the processing at 60 ms, where the waves begin to differ in latency and amplitude, providing an upper limit on when attention starts to modulate brain activity (earlier effects may exist and not be reflected in the ERP) (Luck, Woodman, & Vogel, 2000). A possible measure to define task demand or mental resources on the driver is the P300, or P3, component of the ERP. Many applied ERP studies have focused on the P300 component, because it is one of the largest components and is relatively easy to evoke using a secondary task. The P300 amplitude is assumed to reflect resource allocation to

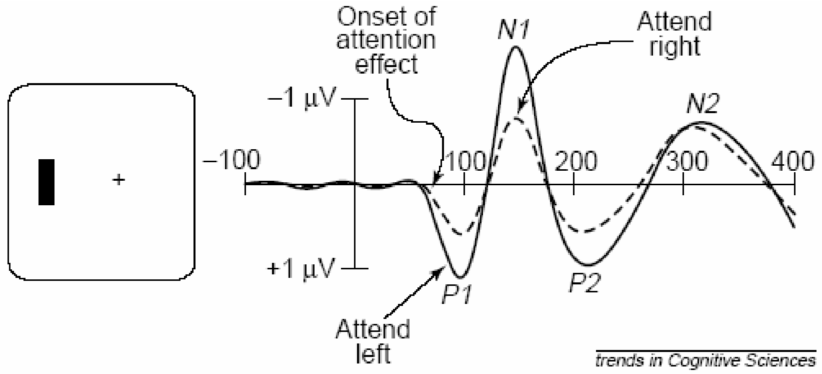

Figure 1.5.1: Paradigm for using ERPs to study attention (from Luck et al., 2000).

a task-relevant stimulus(e.g. Kok, 2001) For instance in (1985), Janssen and Gaillard studied the P300 in a secondary auditory Sternberg task when participants drove on rural, city and highway roads. They found that the P300 amplitude was decreased and latency increased as a result of task load. A recent study of Raukausas et al. (2005) studied attentional resource allocation while driving in a car simulator and performing two secondary tasks. The first task was a cell phone conversation and the second an in-vehicle task requiring visual attention and a manual output. They used an auditory novelty oddball (80% non target tones, 10% targets and 10% novel sounds) to elicit a P300. Analysis of the P300 amplitude evoked by the novel sounds showed that using a cell phone reduced the P300 amplitude and thus the resources available for attending and evaluating sudden and unexpected events. During the in-vehicle task the P3 amplitude seemed less affected than in the cellular phone condition, but was still reduced. The EEG can also be used to measure the magnitude, or power, of ongoing oscillatory activity. Of particular interest to the current study is alpha-band (8 - 12 Hz) power, as this has been shown to be sensitive to task demand (Kramer & Strayer, 1988; Sirevaag, Kramer, Coles, & Donchin, 1989; Fournier et al., 1999). Power is less sensitive to variations in the precise timing of events than ERPs, making it a useful complementary measurement. Alpha-band power has been used as a monitoring tool for drivers' state studying workload vigilance, drowsiness and attention (Schier, 2000; Brouwer et al., 2004) and alpha power increases with time-on-task and fatigue and has been used to study drowsiness while driving (e.g. Schier, 2000, Wilschut, 2005, Papadelis et al.,2007) Thus, the EEG provides multiple methods to obtain insight into cognitive processes in a non-intrusive manner. Further, effects on e.g. invested effort or attention can be detected even if behavioural effects are obscured by compensation.

1.6 Aims

As discussed above the impact of IVIS has a complex pattern of advantages and disadvantages. In the present dissertation I will focus on the effects of dual task performance while driving on drivers' attention and workload and the subsequent impact on driving performance. Such effects will be evaluated using simulated visual IVISs and simulated driving tasks. ERPs and EEG power will be used to provide more insights in effects on the cognitive state of the driver. Finally, the influence of healthy ageing on this type of dual task interference will be evaluated.

The first three experiments explore the effects of the **visual display characteristics**. An adaptation of the HASTE visual search task was used as a surrogate IVIS (Carsten & Brookhuis, 2005). In the first experiment behavioral and ERP data of the visual search task was investigated and two dimensions of the visual search task were manipulated: set size and complexity. In the second experiment the inteference of the visual search task with driving was studied using a simulated driving task. Furthermore, young and elderly participants were compared. The third experiment also investigated visual search, simulated driving and different age groups, but additionally studied the effects of attention allocation and preparation using ERPs. Finally, the advantages of using a Head-Up Display (HUD) instead of a Head-Down Display (HDD) were investigated.

The second set of experiments focussed on the **time course of interference** of an IVIS task on critical driving tasks. These experiments were inspired by the PRP effect (Telford, 1931; Welford, 1952). When the driver interacts with an IVIS while driving there is effectively a short period of dual task performance, so if IVIS information is presented in close temporal proximity with an event in traffic that requires a quick action, for instance an emergency brake, the reaction time might be affected by the processing of IVIS information. In the first experiment the effects of modality and timing on braking was investigated with a tracking task. The second experiment was executed in a driving simulator, included EEG measurements and compared young and elderly participants.

2 Experiments

2.1 Visual search performance and ERP effects: a study based on the surrogate-In-Vehicle Information System of the HASTE-project

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Abstract

Visual search experiments are concerned with the ability to detect a predefined target amongst a varying number of more or less similar non-target elements. Such research can be used to aid the design or evaluation of in-vehicle displays. In two experiments the effects of different display characteristics are evaluated, building on the search task of the previous HASTE study by separating the factors of target discriminability and set size and by studying target versus non-target responses. Target discriminability and set size showed an increase in reaction times as expected based on visual search literature. A number of ERP components were studied in experiment 2 and found to be sensitive to visual search complexity. Further, the ERP components (P3, SRN) were unaffected by set size. The stimuli coud have been interpreted as a structure, which might explain the lack of a set size effect (Schubö, 2004).

2.1.1 Introduction

Drivers continuously scan their environment for relevant visual information between a clutter of irrelevant objects, for instance when trying to find a space in a parking lot or looking for a street name. This visual processing involves sensory, perceptual and decision making components and has been studied using visual search paradigms. Visual search experiments are concerned with the ability to detect a predefined target between a varying number of more or less similar non-target elements. Such research can be used to aid the design or evaluation of in-vehicle displays. The HASTE project used a visual search task to simulate and manipulate the impact of in-vehicle information systems (IVIS) task load on driving performance and safety (Carsten & Brookhuis, 2005). The visual search task had three difficulty levels, composed by several different types of search displays (figure 2.1.1; Merat et al., 2005). The search task was displayed on a touch screen LCD mounted in the vehicle. The driver was required to make a manual response indicating whether a target arrow was present or not. Upward-pointing arrows were the targets, and were present in 50% of the displays. The visual search task had pronounced effects in terms of steering and lateral behaviour. Drivers were not always able to manage the trade-off between driving and the visual search task, leading to indications of driving performance being poorest when the demand of the visual search task was the highest. Search demands were manipulated using set size (the number of stimuli on screen) and the discriminability of the target. The search displays were described to be based on the Feature Integration Theory (FIT; Treisman & Gelade, 1980).

Visual search theories

FIT distinguishes two main different types of search processes. First, a simple and quick process that identifies stimuli that can be distinguished from distractors by a single feature (e.g. colour or form), so called *pop-out* stimuli. Such stimuli are automatically detected by parallel pre-attentive processing of elementary features. The second process is more elaborate and requires serial attentive processing. According to the FIT this is needed when a target can be detected only by a *conjunction* of several features (e.g. colour and form) in which case attention is necessary to combine information from different feature maps. Treisman and colleagues compiled a list of features based on an empirical method (Treisman & Gelade, 1980). Features defined following this method included colour, orientation, contrast, size etc. Treisman's model consists of a master map of locations and a separate feature map for each of these features. Each feature map registers activity in response to a visual feature in parallel but the individual maps give no information about location. Thus in pre-attentive pop-out search where a target has a unique feature, one has to inspect only one feature map for activity. But in case of a conjunction search, one has to move a "spotlight of attention" serially through the master map of locations looking for an object with the correct combinations of features in the feature maps. Evidence for this proposed dichotomy between parallel and serial search comes from reaction time (RT) tasks. A pop-out target is detected in the same amount of time, almost regardless of the set size; hence the set size slope (increase in RT per item) will be near zero. In contrast, serial conjunction search RT increases 10-30 ms with each additional distractor if the target is present. If the target is absent the increase in RT per additional item is around twice this rate. This is consistent with a self terminating item-by-item search in target present trials, i.e. based on chance and 50% target presentation, it is expected that on average the target will be found when half of the items in the display are inspected, and only after all items are inspected when no target is present

The dichotomy in the FIT between parallel and serial search has received a good deal of criticism (Wolfe, Cave, & Franzel, 1989; Townsend, 1990; Nakayama, 1998). For instance other findings showed that some conjunction stimuli can cause pre-attentive search or that search is asymmetric e.g. to detect a letter Q between a group of O's is quicker than to detect an O between servrel Q's. (Wolfe & Horowitz, 2004). Other theories of visual search have been suggested such as Attentional Engagement Theory (AET; Duncan & Humphreys, 1989) and Guided Search (Chelazzi, 1999). AET was developed based on the results of various experiments in which subjects had to search for a upright L between rotated T, which were either homogenous (rotated the same way) or heterogeneous (at different rotation angles). Manipulation of this heterogeneity of the distractors showed large variations in the efficiency of search that were not predicted by the FIT. The model assumes that search ability varies continuously, depending on the similarity of the elements in the search display. Search time is based on two similarities 1) the degree of similarity between the targets and non-targets. 2) the degree of similarity within the non-targets themselves. These two similarities interact, i.e. decreasing non target- non target similarity has little effect if target-non target similarity is low. In comparison to the FIT this AET theory is more concerned with the relationship between target and distractors and the way in which the information in the visual field can be segregated into perceptual groups than with spatial mapping.

In Guided Search (Wolfe, Cave, & Franzel, 1989; Wolfe et al., 1994; Wolfe, 1998) as with the FIT, early attention divides an image into individual feature maps. Within each map a feature is filtered into multiple categories, for instance the colour map is divided in blue, red and yellow. Locations with unique features receive high bottom-up activation. The model also includes top-down activation: attention under overt control of the subject can be deployed in a goal driven manner to find items with a specific property or set of properties. The bottom-up and top-down activation "mark" regions of the display; an activation map is built by combining bottom-up and top-down information, and attention is drawn to the region with highest "activation" in the location map.

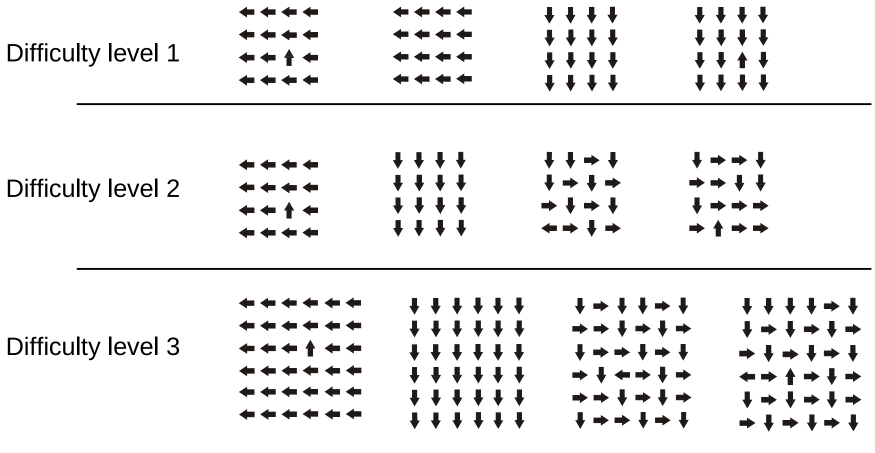


Figure 2.1.1: Example displays of the surrogate IVIS displays used in the HASTE-project (Carsten & Brookhuis, 2005). Within each difficulty level there are in fact different types of displays. For instance in difficulty level 2 half of the displays are pop-out displays (the upward pointing target arrow 'pops out' in left display). And the other half of the displays require conjunction search.

Other theories of visual search have been developed (Chelazzi, 1999) with different terminology. To have a theoretically neutral label of type of search the term *efficiency* is suggested by Wolfe (1998). For instance, *very efficient* searches are those with a target-trial search slope near zero ms/item. A search for a rotated T among rotated L’s results in an *inefficient search* with a slope of about 20 ms/item.*Visual search and ERPs*

Most empirical data for visual search theory comes from RT and accuracy data; however behavioural data can sometimes fail to differentiate between different underlying processing which can result in the same RT slopes (Townsend, 1990). A way to extract more information about processes between stimuli and responses is to use Event Related Potentials (ERPs). Luck and Hillyard (1990) studied the P3 amplitude during a visual search task and reported an increase in the P3 amplitude when set size increased. A general agreement has formed that the P3 is not a unitary brain potential, but represents a summation of overlapping components or activity from widely distributed areas in the brain (Hohnsbein et al., 1991; Falkenstein et al., 1993; Verleger et al., 2005). Luck and Hillyard (1990) interpreted the increase in amplitude as a function of set size as a possible effect of subjective target probability, because in serial search the number of negative decisions preceding the search-terminating positive decision increases as the set size increases. In contrast, other findings showed a decrease of P3 amplitude with an increase of the set size (Brookhuis et al., 1981; Kok, 2001). Luck's study differed in method because he studied the response-locked P3 instead of the stimulus-locked P3 (Brookhuis et al., 1983; Wijers et al., 1987; Zeef & Kok, 1993; Lorist et al., 1996). A possible explanation of the amplitude reduction of the stimulus locked P3 with larger set size is that the P3 overlaps with negative slow waves that occur in the same time frame as the P3 (Okita et al., 1985). These negative slow waves have been labelled the Search Related Negativity and are most pronounced at Cz. The SRN shows a systematic increase in negativity with an increase of set size or memory load of search operations (Okita, Wijers, Mulder, & Mulder, 1985) and could be interpreted as an indicator of search difficulty. The SRN can be best observed when the P3 is absent or small, preferably in target-absent trials. There are two ways to present this negativity: subtract ERPs of unattended stimuli from attended stimuli, or ERPs of low (memory) load (n=1) from ERPs obtained with a high (memory) load. Another component of interest is the Contingent Negative Variation, which is thought to reflect anticipatory and preparatory processes (CNV; Walter et al., 1964). It is a slow negative wave which develops between an event that triggers preparation and a second event that triggers a response but can also be present when no motor response is required (Brunia & van Boxtel, 2001). The CNV has been shown to correlate with performance accuracy (Hohnsbein et al., 1998) and a frontal-central increase of the CNV amplitude is found for increased effort investment (Falkenstein et al., 2003).

Aim of the study

This study focuses on the surrogate IVIS task used in the HASTE project, in which a visual search task was used to simulate displays in the car with varying human-machine interface efficiency. This approach has the advantage that it is supported by the extensive literature on visual search. In two experiments we will evaluate the effects of different displays characteristics, building on the search task of the previous HASTE study by separating the factors of target discriminability and set size and by studying target versus non-target responses, these factors were not separated previously.

2.1.2 Experiment 1

In the first experiment, the effects of the number of items that needed to be searched and of target discriminability on behavioural data were studied. It is expected that within the difficult conjunction search condition the reaction time would increase by about 10 ms or more per item with set size, whereas with the easy level the search slopes would be close to zero (Wolfe, 1998).

2.1.3 Method

Participants

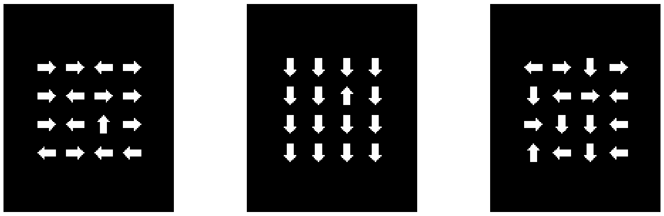
Thirty-two volunteers participated in two experiments (Experiment 1: 14 participants (7 male) aged 19-28 years, mean age 23.5). The participants had normal or corrected to normal vision. The participants had a normal night’s sleep before the test. All participants described themselves to be right-handed.

Stimuli and procedure

Each experimental trial began with the presentation of a fixation cross, which remained on screen for 1000 ms, and was followed by the presentation of a visual search display for 2000 ms (Figure 2.1.2). The display consisted of a number of arrows arranged in a square. The set size (i.e. the number of arrows) of the displays varied: nine, sixteen or twenty-five arrows. The arrows were shown for 2 seconds instead of 5 seconds in the HASTE paradigm, this was done to increase time pressure and reduce the variance in reaction time. The target stimulus was an up-facing arrow that was present in 50% of the trials. The participant had to indicate by either a left or right button press whether the target was present or not. Three target discriminability levels were used. In the easy target-discriminability condition the distractor arrows pointed to the left and right. For medium target-discriminability all distractor arrows pointed downwards and in the difficult target discriminability displays the arrows pointed to the right, left and downwards. The order of the blocks was randomized for each participant. Participants were presented with 8 blocks of different difficulty level and display size. Each block consisted of a series of 120 stimulus displays. In the training session the participant performed three blocks with different difficulty level displays and accuracy feedback was given after each trial. After training the experiment began with a duration of about 45 minutes. Subjects were seated in a dimly lit, sound-attenuated, room at 0.70 m from a 17” PC monitor. The index fingers of their hands rested on the button of a response box. Participants were asked to keep their eyes on the fixation cross and to react as quickly as possible but accurately.

Data analysis

Data were subjected to SPSS ANOVA repeated measurement analyses, with factors discriminability level (easy, medium, and difficult level), display size (load 9, 16, and 25), and target/non-target displays. In case of sphericity violation the Greenhouse-Geiser modification was used. For the different blocks averaged performance data of the RT, misses and false alarms were calculated and tested.



Easy **Medium** **Difficult**

Figure 2.1.2: Example displays with target upward pointing arrow. The visual search task with three difficulty levels ranging from easy to difficult and two display sizes i.e. 16 (shown here) or 25 arrows.

2.1.4 Results

Table 1 shows the RT, standard error, and slopes for target-present trials. The main effect of target discriminability was significant F(2,26)=87.1, p<.001), reflecting increasing RT for harder discriminability. The mean reaction time increased when set size increased (F(2,26)=121.3, p<.001) but especially for higher complexity levels (*Figure 2.1.3*). The interaction was significant showing that the reaction time increased more with set size when

Table 1: Reaction times and standard errors for target present and absent trials for each display type including the slope (ms/item).

	Target present				Target absent			
	9	16	25	slope	9	16	25	slope
Easy	590.7	590.2	611.6	1.3	659.6	700.3	771.2	6.9
	(27.0)	(25.3)	(24.2)		(27.5)	(28.4)	(38.5)	
Medium	691.0	740.7	853.9	10.2	658.2	787.3	885.1	14.2
	(35.4)	(41.3)	(44.6)		(34.0)	(42.2)	(54.9)	
Hard	713.0	852.7	902.0	11.8	988.8	1204.0	1343.5	22.2
	(37.4)	(50.8)	(44.2)		(54.0)	(69.0)	(72.8)	

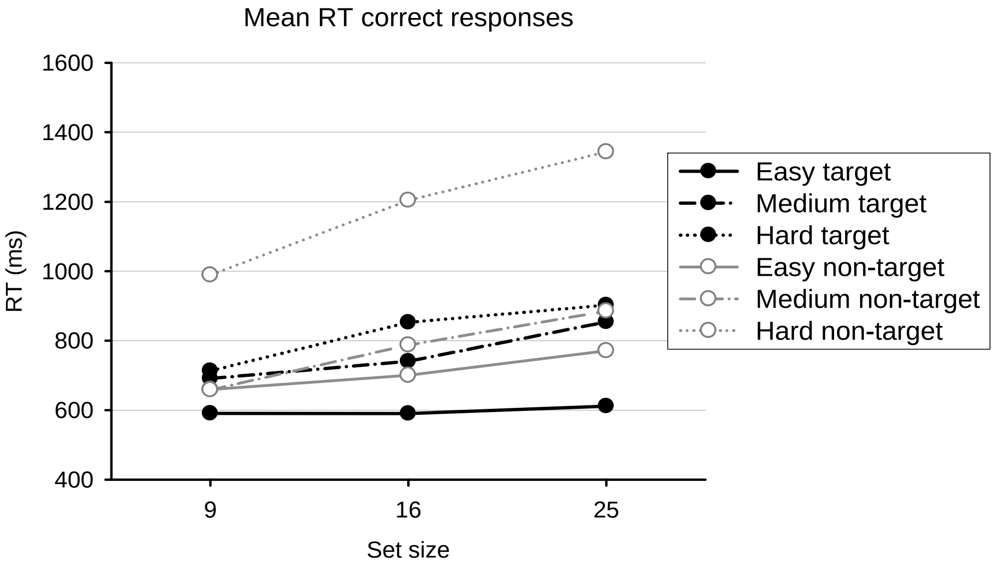


Figure 2.1.3: Mean reaction time for the target and non-target trials.

the target discriminability was low (F(4,52)=46.8, p<.001). Average RT at target present trials was 590 ms for easy discriminability displays with set size 9 and increased with set size 25 to 611 ms; this increase was significant (F(2,26)=4.4, p<.022). As expected RTs at target-absent trials were higher than on target-present trials (F(1,13)=40.5, p<.001). RTs on target-absent trials also increased with set size (F(2,26)=75.4, p<.001) and decreasing target discriminability (F(2, 26)=91.5, p<.001). Just as with the target-present trials the interaction between set size and target discriminability was significant (F(4,52)=30.2, p<.001). A post hoc paired t-test revealed that against expectations there was no significant difference in RT between target-present and target-absent trials in the medium condition.

Analysis of errors showed a greater number of errors in displays with increasing set size (F(2, 26)=48.7, p<.001) and with a decrease of discriminability (F(2,26)=32.2, p<.001); again the interaction was significant (F(4,52)= 9.7, p<.001). In the easy discriminiability conditions all errors remained under 3%, in the medium condition error percentages kept below 5% except for set size 25 (11%). With the difficult discriminability error percentages started at 9% and increased with set size 25 to 17%. Overall the error data showed the same pattern as the RT results and there was no evidence of a speed/accuracy trade-off.

2.1.5 Discussion

Arrow stimuli are a composition of an arrow head and an arrow tail, the spatial arrangement of which defines the arrow's direction. When looking closer one could say that the arrow head alone defines the direction in which the arrow points, while its visual orientation is due mostly to its tail. Orientation is a basic feature which is known to produces efficient search, whereas the feature shape seems to be less efficient in guiding attention (Wolfe & Horowitz, 2004). The easiest level of target discriminability was expected to be comparable to a pop-out search because the target arrow could be found based on orientation alone. But although the RT slope was small (from 9 –25 items:1.3 ms/item), pop-out searches are associated with a search slope near zero. The RT increase was significant thus this search can not be labelled pop-out according to the initial FIT (Treisman & Gelade, 1980). A possible explanation for this is the composition of arrow heads of lines, so that even in a display with only horizontal tails except for the target, the visual system is confronted with the smaller oblique lines of the heads. Further, non-target RTs also increased with set size.

As expected, the hard discriminability level showed a RT pattern in accordance with a conjunction search: a clear increase of RT was found when set size increased, with a slope of about 10 ms conforming to the literature (Wolfe, 1998). Non-target RTs also increased more strongly with set size than target RTs in the hard condition: the non-target RTs had a search slope which was about twice as steep. The medium discriminability level also showed a typical RT pattern and slope comparable to conjunction search. However, no difference between target and non-target RT was found in this condition. In the easy condition, non-target responses were again slower than target responses. The exception of the medium condition to the non-target – target effect hence appears to reflect a characteristic unique to displays that required targets to be detected in a field of all-vertically oriented arrows.

2.1.6 Experiment 2

In the second experiment, the components of the ERP described earlier were analyzed to evaluate attentional processes associated with target discriminability: stimulus- and response-locked P3, SRN and preparatory negativity / contingent negativities. The goal was to use

ERPs to contribute additional information next to the behavioural results, and to identify components sensitive to target discriminability and set size, and which could be applied to study the efficiency of visual information display of an IVIS in future studies.

The P3 amplitude is larger when the target trials had a low probability rate and the SRN is best observed in non-target trials on which no response was given (Donchin, 1981; Kok, 2000). Hence it was decided for experiment 2 to change the 50% targets of the first experiment into a 30% target / 70% non-target ratio and avoiding responses to non-targets. ERPs have the advantage that cognitive processes can be measured even when a response is absent, which makes it a valuable measure to evaluate target absent trials without a response. In trials without a response the SRN can be used to measure the search difficulty. In the second experiment only set sizes 16 and 25 were used; set size 9 was excluded to reduce the number of manipulations and increase the number of trials per condition.

2.1.7 Method

Subjects

18 subjects (9 male) aged 19-26 years, mean age 22,9. The participants had normal or corrected to normal vision. The participants had not taken stimulants 12 hours before and during the experiment and had a normal night's sleep before the test. All participants described themselves to be right-handed.

Stimuli and procedure

In experiment 2 the target stimulus was present in 30% of the trials, only when the target was present the participant had to respond by a right button press. The procedure was the same as in experiment one, except that only the set sizes of 16 and 25 were used.

Data recording

In experiment 2 the electroencephalogram (EEG) was recorded using 63 Ag/AgCl electrodes attached to an electrocap, from positions Fpz, Fp1, Fp2, AFz, AF7, AF3, AF4, AF8, Fz, F7, F3, F4, F8, FCz, FT9, FC5, FC3, FC1, FC2, FC4, FC6, FT10, T7, C5, C3, C1, C2, C4, C6, Cz, T8, CPz, CP5, CP3, CP1, CP2, CP4, CP6, Pz, P7, P3, P1, P2, P4, P8, POz, O9, PO7, PO3, PO4, PO8, PO10, Oz, O1, O2, I1 and I2. All electrodes were referenced to average reference and offline rereferenced to the linked-mastoids. The electro-oculogram (EOG) was recorded bipolarily from the outer canthi of both eyes and above and below the right eye, using

Ag/AgCl electrodes. Electrode impedance was kept below 5kΩ for head electrodes and 10 kΩ for the eye electrodes. EEG and EOG were sampled at 2000 Hz without filtering and offline resampled to 500 Hz.

Data analysis

Behavioural data analysis was identical to the previous experiment. The EEG data were corrected and analyzed using Brain Vision analyzer. The EOG was used to remove ocular artefacts from the EEG (Gratton & Coles, 1983). Data were analyzed with repeated measurement analyses of SPSS 13.0, except for training blocks, which were not analyzed. In case of sphericity violation the Greenhouse-Geiser modification was used. For all ERPs the baseline was the 100 ms preceding the fixation cross. The stimulus-locked P3 was measured at Pz, as the largest positive peak within 300-1000 ms in the averages, and its latency and amplitude was analyzed. For the response-locked P3, peaks were measured at Pz as the largest positive peak between –200 and +200 ms around the response. The preparatory negativity was measured at Cz and was defined as the largest negative value between -50 and 50 ms around stimulus presentation. The SRN period was measured using area averages of 100 ms periods for a time window of 250-750 ms, at electrodes Cz, Cpz and Pz.

2.1.8 Results

Behavioural data

Discriminability level affected the average reaction time (level, F(2, 34)= 264.4, p<.001;Figure 2.1.4). The reaction time increased with about 400 ms from easy to medium discriminability level and about another 150 ms from medium to difficult discriminability level. Further set size affected the reaction times significantly and reaction times were on average about 40 ms longer in the displays with 25 stimuli than 16 stimuli (size, F(1,17)=11.4, p=.004). The expected interaction between discriminability level and size was not significant (F(2,34)=.51, p=0.55). There was a significant difference in reaction time for the easy level displays (F(1,17)= 6.7, p=.019). The 16 arrow displays had an average RT of 445.3 ms (SD=8.6) and the 25 arrow displays, 462.9 ms (SD=8.1). The error percentage (figure 4) showed a significant effect of discriminability (level F(2,34)=20.0, p<.001). In the easiest discriminability condition almost no errors were made. In the medium condition the number of errors increased to 12% without any differences for display size. The error percentage increased further in the most difficult level to 15% in the small display and 20% in the large display, but the effect of display size was not significant.

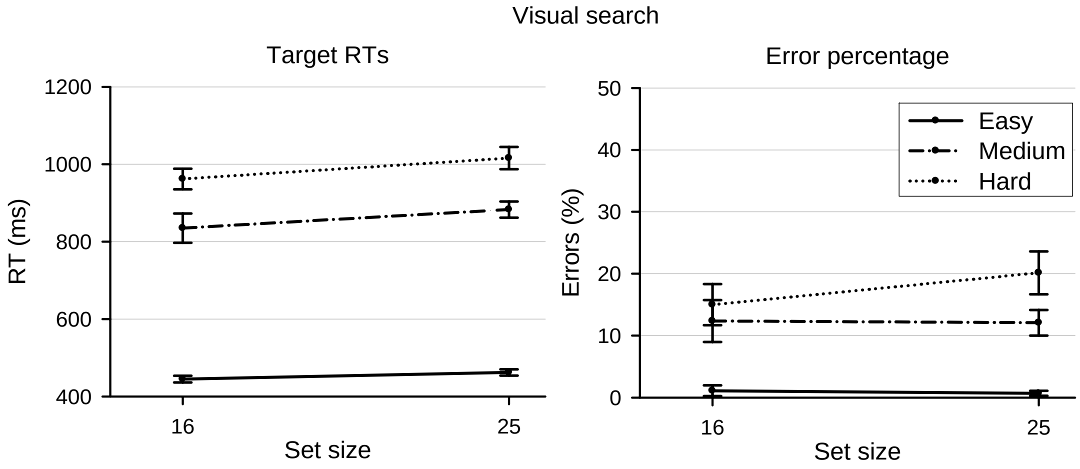
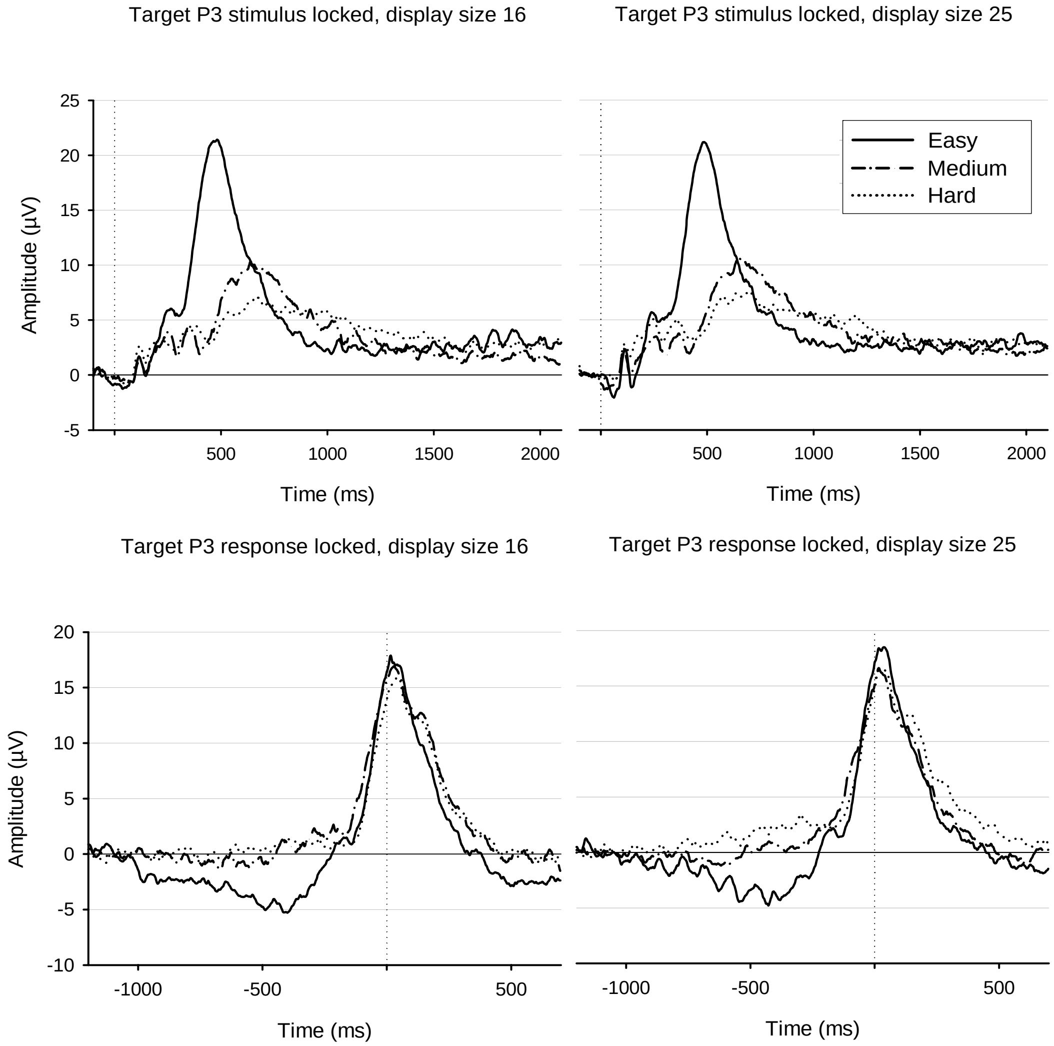


Figure 2.1.4: Mean RT and error percentage for target trials and standard error bars.

ERPs

The grand averages of the stimulus-locked target P3 are depicted in figure 2.1.5. In accordance with the literature the stimulus-locked parietal P3 (>400 ms) component's amplitudes were larger in target than in non-target averages (F(1,13)=68.3, p<.001). The P3 amplitude decreased with reduced target discriminability (F(2,26)=67.1, p<.001), showing an interaction effect, due to a larger reduction of the P3 in target than in non target trials (F(2,26)=36.7, p<.001). There was no effect of set size nor any interaction with this factor. Latency for the target P3 was longer with decreasing target discriminability (F(2,32)=9.8, p<.003) and was slightly longer for set size 25 in the easy discriminability level but this did not reach significance (p<.10). The decrement of the stimulus locked P3 amplitude in the medium and hard conditions is probably due to large latency jitters in these conditions, which after averaging reduce the P3 amplitude and causes the prolonging of the component in the averages. Therefore the P3 was inspected also in the response locked averages. The response locked ERPs showed a large positivity at about 30 ms after the response at parietal electrodes. The same baseline as the stimulus-locked P3 was used: the 100 ms preceding the fixation cross. A main effect of discriminability level was present (F(2,26)18.5, p<.001), showing that with more difficult target discriminability the response-locked P3 amplitude decreased. However, this decrease was only very small There was no effect of display size nor any interaction and no latency differences.


Target P3 stimulus locked, display size 16

Target P3 stimulus locked, display size 25

Target P3 response locked, display size 16

Target P3 response locked, display size 25

Figure 2.1.5: Grand Average stimulus locked and response locked for target trials at Pz. Six conditions with three levels ranging from easy to difficult and two display sizes 16 versus 25 arrows. P3 at time >400 ms, positive up.

The preparatory negativity was prominent at Cz starting 400 ms after the fixation until 150 ms after stimulus onset (Figure 2.1.6). After stimulus presentation there was a significant effect for level showing a decrease in negativity when task difficulty increased (F(2,26)5.8, p=.008). The negativity showed a marginal effect of display size, being more negative when display size was small (F(1,13)=4.2, p=.062).

In the non-target trials the SRN was most prominent on Cz (Figure 2.1.7) showing a decrease in the amplitude becoming more negative with lower target discriminability (F(2,26) = 13.0, p<.001 for all latency intervals between 250-650 ms). Post hoc analysis showed that only the easy level was different from the medium or hard level of target discriminability (p<.01). There was no effect of set size nor any interactions.

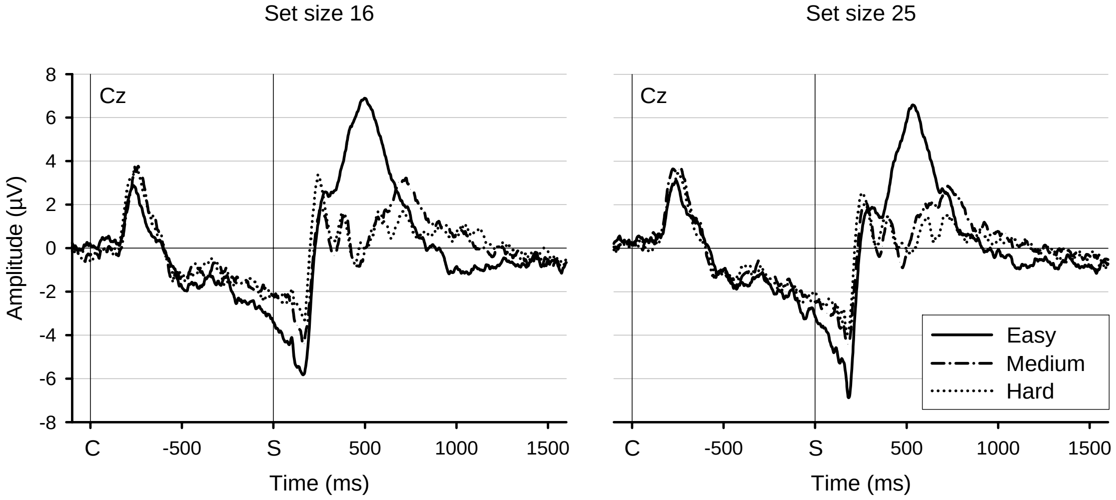


Figure 2.1.6: Grand averages locked to the fixation cross (C). The preparatory negativity was measured at Cz, defined as the largest negative value between -50 and 50 ms at stimulus presentation (S).

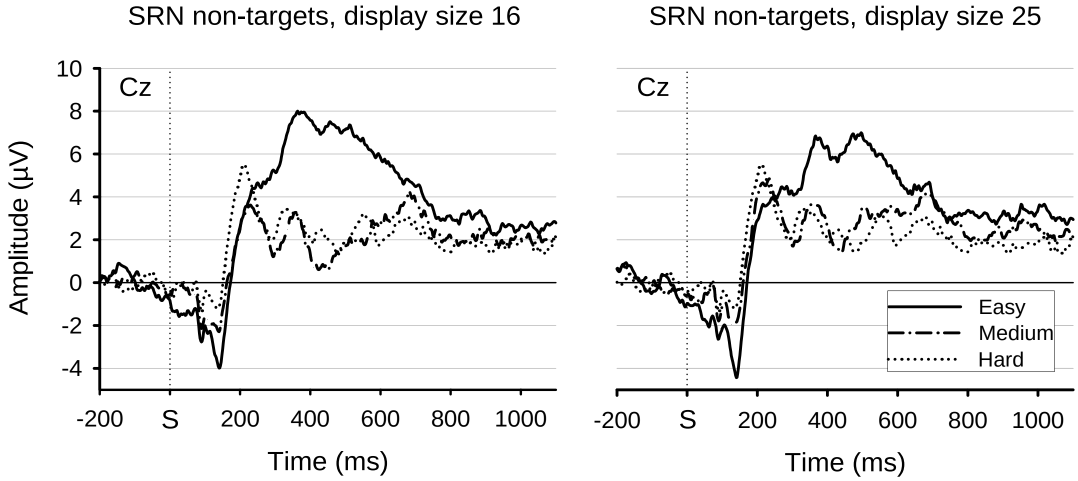


Figure 2.1.7: Grand average of the non-target trials showing the SRN. Six conditions with three levels ranging from easy to difficult and two display sizes 16 versus 25 arrows.

2.1.9 Discussion

The current experiments on visual search examined the stimuli used in the HASTE study by separating the factors of target discriminability and set size. Both factors were found to increase reaction times and reduce accuracy as expected based on visual search literature.

Besides behavioural data, a number of ERP components were studied in experiment 2 and found to be sensitive to set size and target discriminability.

Both the response- and stimulus-locked P3 showed a decrease in amplitude with decreasing target discrimination, in accordance with the literature. The stimulus-locked P3 had a smaller amplitude compared to the response locked P3. This is in contrast with the results of Verleger et al. (2005), who, in a Simon task, found equally large P3 amplitudes in response-locked as in stimulus-locked averages independent of response speed. Assuming that the response- and stimulus-locked P3 reflect the same brain activity, the data show that there is a much closer time-locking of the P3 to the response than to the stimulus. The large variation in reaction times in the medium and difficult discriminability level presumably caused the reduction of our stimulus-locked P3 amplitude compared to the response-locked P3. Moreover the profound decrease of the stimulus-locked P3 with rising task difficulty is most probably an artifact due to the larger RT variation in the more difficult compared to the easy condition. The true P3 is only slightly affected by task difficulty. Our data strongly suggest that the P3 reflects response- rather than stimulus-related processes, as claimed by many researchers (e.g. Falkenstein et al. 2 (1994). In contrast to our findings an increased response-locked P3 amplitudes for increased display size was found by Luck and Hillyard (1990). This amplitude increase was interpreted as a possible effect of subjective target probability, because the number of negative decisions preceding the search-terminating positive decision increases as the set size increases. Luck and Hillyard used the mean amplitude of the entire trial period as the baseline, in contrast to the pre-stimulus baseline used in the current study. Such baselines could have modulated the associated P3 amplitude due to differences between conditions in the baseline period. In summary the amplitude of the true P3 is hard to measure because it crucially depends on the baseline chosen. In any case, the profound decrease of the stimulus-locked P3 with rising task difficulty found in the present study and in many others is clearly due to an artifact because of the close relation of the P3 to the response and the higher RT variance in more complex tasks. P3 amplitude results should be interpreted with great caution, and response-locked averages should be evaluated in addition to stimulus-locked averages.

The SRN was more negative for the medium and hard level compared to the easy discriminability level. This effect may be similar to the negative shift found by Okita et al. (1985) associated with increased display load and suggests the presence of a negativity, the SRN, in the search (medium, hard) vs. the nonsearch (easy) conditions. However, the pattern of data could also be at least partly explained by an overlapping fronto-central positivity, the so-called no-go P3 (e.g. Verleger et al., 2006). The no-go-P3 may have been enhanced in the easy task compared to the medium/hard ones despite the lowered ratio of targets to non-targets intended to make this less likely to occur (Kok, 2001). Hence the lack of a reliable baseline condition and no RT for non-targets makes it hard to interpret the SRN and therefore the non-target results. The pre-stimulus negativity showed no effects. However, post-stimulus it became largerfor the easy than for the other tasks, which may reflect an enhanced motor preparation (‘readiness potential’) evoked by efforts to respond quickly to pop-out stimuli.

Summarizing, behavioural data clearly showed an effect of target discriminability and set size in both experiments. Of the ERP components the P3, CNV and the SRN were more negative with complex tasks, i.e. with lower target discriminability. A severe problem with interpreting the effects is the possibility of different RT variance across the complexity conditions, which might affect averages differently (e.g. the P300). Hence, the ERP results should be interpreted with caution. Future studies could address this issues e.g. by constructing a pop-out condition without no-go stimuli, and by ensuring eye fixation in the conjunction conditions. Further, the ERP components (P3, SRN) were unaffected by set size. The difference in set size may have been insufficient to find these effects. Alternatively, characteristics of the display may have rendered set size irrelevant to certain processes, despite expectations based on FIT and visual search ERP literature. In the orginal FIT experiments the elements were scattered randomly, but here the grid of the elements in the display. The stimuli could have been interpreted as a structure, which might explain the lack of a set size effect (Schubö, 2004).

The strategy of using well-defined visual search paradigms to simulate IVIS, used in the HASTE study, allow the controlled study of task demand effects of IVIS on driving. The taxation of processes associated with discriminating targets and searching through more stimuli can be studied behaviourally and using ERPs, to disentangle effects of separable factors. In our study, discriminability affected various ERP components that were indifferent to set size. This suggests that the factors may differ in their impact on drivers. Future research is needed to link the cognitive processes underlying those components to driving performance.

2.2 Elderly drivers' performance in a lane-change task is vulnerable to increased secondary task complexity

E.S. Wilschut, G. Rinkenauer, M. Falkenstein, K.A. Brookhuis

Abstract

There is an ongoing debate whether the secondary tasks introduced by driver assistance systems affect driving performance and if they cause safety risks to the driver and road traffic. Especially vulnerable could be elderly drivers, who are known to have decreased perceptual, motor and cognitive functioning due to normal ageing. In this study we evaluate the effect of secondary task complexity on driving performance using different complexity manipulations of a visual search task. The lane-change task (Mattes, 2003) was used as the primary task to simulate driving. Results showed that participants (n=24) were unable to maintain their driving performance at baseline level when the secondary task had to be attended and reacted to by button presses. The performance of elderly participants (50-70 years) was slower overall and showed severe and stronger dual task decrements with increasing visual search complexity.

2.2.1 Introduction

A safety-critical question in contemporary driving research concerns the influence of in-vehicle devices on drivers’ performance and traffic safety (Hancock et al., 2003). Modern cars are often outfitted with in-vehicle information systems (IVIS) such as the In-Vehicle Routing and Navigation Systems (IRANS) that provide drivers information about the route from one destination to another (Hulse et al., 1998). Accurate and timely traffic information and routing information can decrease travel times and costs, but there are possible negative side effects. One of these expected negative effects is that the extra information source in the car may lead to increased task demand and capacity overload in the driver (Pauzie & Alauzet, 1991; Verwey, 2000; Blanco, Biever, Gallagher, & Dingus, 2006; Levy et al., 2006), which could become dangerous in critical driving situations. IRANS should thus be designed in such a way that their task demands are reduced as best as possible. Janssen et al. (1999; see also Lenior et al., 2006) compared the impact of four different designs of IRANS. The number of unsafe manoeuvres was compared to the well accepted condition of listening to a car radio. Results showed that two of the four systems were not necessarily less safe than the baseline condition, however the other two systems caused a far higher percentage of safety critical situations.

This was attributed to a failure to implement elementary ergonomic principles regarding display and handling characteristics. Choosing the appropriate modality to convey the in-vehicle information is important and the combination of the modality and type of information can affect the usability and safety of the system (Noy, 1997). As most of the information needed for the driving task itself is dependent on vision (Mourant & Rockwell, 1972; Hills, 1980), the auditory and haptic modality are considered less distracting. (Micheal & Casali, 1995; Liu, 2001; Wickens & Seppelt, 2002). Auditory information can be perceived regardless of e.g. gaze direction, making it suitable for alerting and warning messages (Sorkin, 1987). But while in most cases auditory information is less interfering and preferred over visual transmission of information this does not hold for all situations. Detailed location information about a cross section can be more efficient and easier to understand shown in a picture, especially when drivers are unfamiliar with the situation (Molnar & Elby, 1996). Furthermore auditory information is discrete and system paced, requiring correct timing, while visual information is continuous and access of this information is controlled by the driver. Looking at an onscreen map requires selecting the most relevant information, and if the system is well-designed this search for relevant information is efficient, requiring the driver to take the eyes of the road for a minimum amount of time. Complex colouring, signs, and long text messages in displays make the search for information inefficient, imposes the requirement of multiple glances, and in general results in a high attentional demand. Factors that influence the search time of a display have been studied intensively with the visual search paradigm. Visual search requires rapid change of visual attention to select some relevant aspects of information in the visual field, while repressing others. The fundamental nature behind this attentive selection process is still under debate (Duncan, 1980; Treisman, 1982; Madden et al., 2007). Visual search is easier when the target can be defined by one feature such as colour, e.g. the target colour (blue) is different from its distractors (red). Within the Feature Integration Theory (Treisman & Gelade, 1980; Treisman, 1982) this type of feature search is called pop-out. When a target is defined by a conjunction of two or more features, for instance the target is a blue letter ’A’ between distractors consisting of blue ‘T’s and red ‘A’s, search for a target is more difficult and thus slower. A typical finding of Treisman was that the time needed to search for a conjunction target becomes slower as a function of the set size (the number of elements in a search display) while search for a pop-out target will be relatively independent of set size. Theories on attention try to explain this difference in reaction times between searching for conjunction versus pop-out targets. Because there is no clear dichotomy between pop-out and conjunction search it was suggested to use the term “efficiency” to describe the continuum of search complexity Wolfe (1998). The efficiency of visual search depends for instance on the number of distractors and on the number of features in the display (e.g. form and colour). A typical finding is that more distractors and more equality between distractors and targets makes the visual search less efficient, slower and less accurate (Treisman, 1982; Wolfe, 1998). The aim of this experiment is to separate the effects of pop-out (efficient) vs. conjunction (inefficient) search on a simulated driving task. Research has been conducted in the HASTE project (Carsten & Brookhuis, 2005) in which a visual search task was used as a surrogate IVIS (Figure 2.1.1.). The visual search task was performed both in isolation and concurrently with a laboratory driving task, in a simulator and during on-the-road driving. The visual surrogate IVIS task in the HASTE project consisted of a choice-reaction task with three difficulty levels as shown in figure 2.1.1. Each display contained a mixture of pop-out and conjunction displays i.e. of the different classes of search requirements. The current experiment looks directly at the effects of pop-out versus conjunction displays and the effect of set size; these factors of complexity are blocked. Results of the HASTE studies showed that the difficulty of the visual task had a pronounced effect on steering and lateral positioning. Moreover the increased secondary task load led to speed reduction and increase in time headway. In a study of Dingus et al. (1997) IRANS with the highest visual demand were also associated with the lowest driving speed. Thus drivers adapted their working strategies and made the driving task less demanding by lowering their speed (e.g. Fuller, 2005). It is expected that drivers will adjust their strategies to deal with this additional task demand and reach what can be described as homeostasis or an optimum level of accepted risk or task difficulty (Wilde, 1982; Fuller, 2005; Fastenmeier & Gstalter, 2006). For instance, Pohlmann and Traenkle (1994) also found speed reductions and deterioration in lateral control with high visual demand of IRANS. They found this effect particularly near intersections. Drivers reduce speed to allow time to drive safely and were highly motivated to check the IRAN system, even in difficult traffic situations. Unfortunately, it is especially near intersections which are complex traffic situations that the need for route information is high (Cnossen et al., 2004). So this could be a situation where task demands are higher than normal and possibly cause dual task decrement. As long as the driving task is self-paced and compensating strategies can be executed the interference of secondary tasks will be limited. However, driving can also be paced by the environment. In that case compensating by considerably reducing speed would hardly be possible. So there are situations in which compensating strategies are not sufficient or can not be executed, and when this is the case and task demand is high, driving performance is likely to suffer.

Especially vulnerable to dual task interference could be elderly drivers, who are known to show declines in motor perceptual and cognitive functions, due to normal ageing which affects driving (Anstey et al. , 2005). However elderly people may be able to maintain their driving performance at an adequate level by compensating for part or all of their deficiencies by profiting from the experience they have gained over the years. Thus they may adopt a number of coping strategies. Eby et al. (2000) give a list of typical compensation patterns, e.g., reducing or even stop driving in the dark and with poor weather conditions like fog, reducing highway driving, trying to avoid unfamiliar areas, and routes and planning routes with right turns or protected left turns. IRANS could assist drivers with part of these coping strategies, by for instance planning a route without highway driving. Also some authors suggested that driver assistance and information systems might be able to help overcome limitations associated with ageing (Mitchell & Suen, 1997). This should enable older drivers to keeping their drivers license longer, decreasing their accident involvement and enhancing traffic safety (Davidse, 2005). At the same time however these IVIS systems could add to task complexity and demand which could cause especially elderly drivers to drive worse. It is known that age deterioration of the brain begins primarily at frontal regions (e.g. Raz, 2000). These frontal brain regions play a major role in planning, decision making, conflict resolution and executive functions (Craik & Bialystok, 2006). These deteriorations could influence the capability to perform in complex multitask situations such as driving with an IVIS. In a study in which the visual search task was performed by elderly drivers (60-70 years), especially in the task with the highest visual demand a significantly higher degree of speed variation and more incidences of markedly reduced speed, compared to that of average drivers was present (Merat et al., 2005). Also, all levels of task difficulty were shown to cause marked variation in lane position for the older drivers, as well as an increase in the number of steering corrections.

Aim of the study

In the present study the effect of secondary, visual search complexity on driving performance is evaluated, using a visual search task as a surrogate IVIS and the lane-change task as the primary task to simulate driving (Mattes, 2003). The lane-change task was used because of the relative low-cost equipment and to prevent a high number of drop-outs due to simulator sickness. The aim of the present study is to extend the previous research by focusing on the effect of search difficulty (pop-out versus conjunction) and the effect of set size. Another factor that differentiates the present study from the previous HASTE studies is that driving speed was fixed at 60 km/hour. Thus participants were unable to compensate for the task demand by decreasing their speed. Both tasks were performed separately to acquire the baseline values of each participant, and are then compared to the performance of the two tasks in a dual task situation. In this dual task situation the lane-change task was defined as the primary task which was instructed to be given the highest priority. It was expected that in the dual task situation the performance of the visual search task would decrease and that the secondary task may have a possible negative effect on the simulated driving task if the participants are unable to fully prioritise the driving task or compensate for the dual task demand. We expect this effect to be larger with increasing set size and with conjunction search displays. We expect the elderly drivers to have slower reaction times in the baseline visual search task compared to the younger drivers (Hommel et al., 2004), and that their performance will deteriorate more strongly under dual task conditions, in terms of lane positioning and variance of steering wheel angle.

2.2.2 Method

Participants

Twelve young participants with age between 20 and 22 years (M=20.3(0.6)) and twelve older participants between 50 and 70 years (M= 58.7 (6.0)) were tested. All participants had their driver's license for at least 2 years (young participants: M=2.8(0.8); old participants: M=35.6(6.1)). Participants had normal or corrected to normal vision.

Procedure

The experimental procedure consisted of three different parts. The first part was a simulated driving task called the Lane Change Task (Mattes, 2003). The second part was a visual search task. The sequence of these two parts was counterbalanced across participants. The final part of the experiment combined the simulated driving and the visual search task. Each part started with a training block. In total participants received about half an hour of training. The training of the visual search task continued until the participants reached a minimum of 80% correct trials. Each part was followed by a short brake.

Primary task: simulated driving

The simulated track consisted of a straight three-lane road. With the gas pedal pressed maximally the participant drove a distance of 3 km at a constant velocity of 60 km/h. This resulted in a total driving time per track of about 3 minutes. There were 18 signs along each track indicating the lane the participant had to change to as soon as the sign was identified. Signs were present with a mean distance of 150 m (min. 140 and max. 188 metres). Each of the 6 possible lane changes occurred three times during one track. The performance on six different tracks was measured of which the first two were considered training. Data were

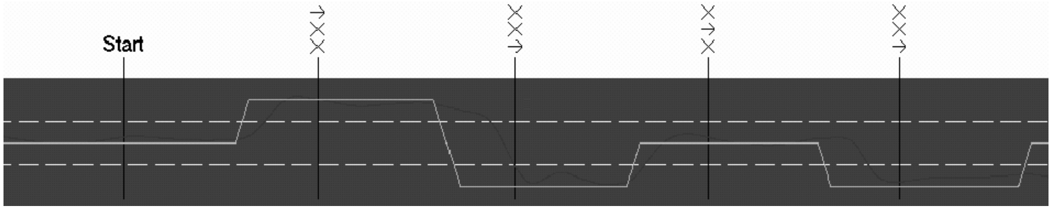


Figure 2.2.1: Measurement of driving performance as the deviation between a normative model and the participants' actual course on the track. Aside the road there are traffic signs that indicated the lane change with symbols, the arrow indicates the required lane. The traffic signs are white until the car has a distance of -40 meter to the signs location, than the symbols appear.

continually sampled with a sample rate of 130 Hz, namely the lateral and longitudinal position, speed and steering angle. As a measure of driving performance the deviation between a normative model and the participants' actual course on the track was calculated (Mattes, 2003; Figure 2.2.1).

Secondary task: Visual search

In the visual search task each experimental trial began with the presentation of a fixation cross, which remained on screen for 1000ms. The fixation cross was followed by the presentation of a visual search display for 3000ms (figure 2.2.2). The display types consisted of a complexity manipulation (pop-out/conjunction) and a set size manipulation (4 vs. 9 items). The four types of display were blocked. Participants were presented with 8 blocks, each consisting of 40 trials, the order of the blocks was randomized. The target stimulus was an upward-pointing green arrow or a right-pointing red arrow, only one target was present per trial with a 50% probability. The target appeared at a random location. The non-targets were all other combinations of green or red arrows with orientation to the left, to the right, up or down. The participant had to indicate by a button press whether the target was present or not. They were instructed to react as quickly and accurately as possible. In the pop-out displays the target was distinguishable from the non-target either by colour or orientation. Thus there were two situations possible, distractor arrows all pointed in the vertical direction when the target was a red right-pointing arrow or when the target was a green upwards arrow, and all distractors were red. In conjunction displays the non-targets pointed in all directions and distractors were red and green arrows (see caption figure 2.2.2).

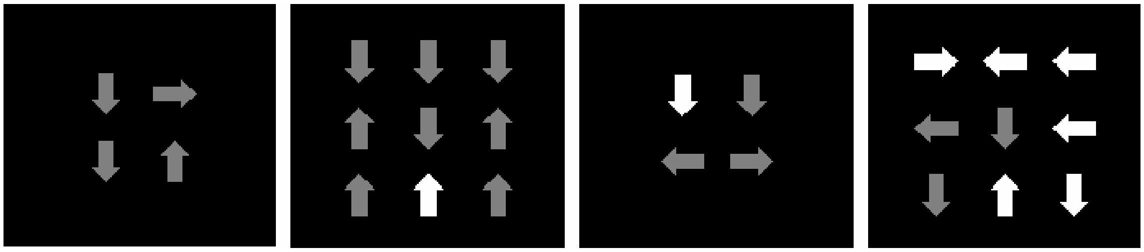


Figure 2.2.2: Four example displays with the two different target arrows: a green (=white) upward pointing arrow or a red(=grey) arrow pointing to the right. The two left displays are the pop-out search displays; participants can discriminate target arrows from distractor arrows by looking at direction or colour. The displays on the right side are the conjunction search displays, where both features colour and direction have to be determined to find the target. Set size was either four or nine items.

Dual task

In the dual task the instructions and conditions for driving as well as for the visual search task were kept identical and the participant was instructed to give first priority to the driving task. The constant required driving speed of 60 km/h made it impossible to compensate for secondary task difficulty by reducing speed. In each of the eight blocks one of the four visual search conditions was presented. Each condition was thus presented twice and the order of the blocks was randomized. Each block of 40 trials started at the beginning of a track and took the same amount of time as reaching the end of the track when driving 60 km/h. After each block self-reports of invested effort were rated with a German version of the Rating Scale of Mental Effort (RSME (Zijlstra, 1993)). Ratings had a range of 0-150, zero meaning ‘absolutely no effort’ and a rating of 110 or higher indicating ‘extreme effort’. The semantic terms mentioned in the result section are those closest in distance to the mean ratings.

Equipment

The simulated driving task was presented on a 67 inch CRT screen (Barco® simulation products: Baron). For tracking a Logitech® gaming steering wheel was used with gas and brake pedals. The visual search task was displayed on a 15 inch LCD screen which had a distance of 1.45 m with a visual angle of 18°. This LCD screen stood in front of the CRT screen(distance 1.96 m, visual angle 38° x 29°) without blocking the sight on the road. For stimulus presentation of the search task E-prime® was used (Psychology Software Tools, Inc., Pittsburgh, USA). The small set size was visible within 1° the large set size within 1.6° visual angle. Two of the original response buttons behind the steering wheel were adapted to make accurate RT acquisition possible using the printer port.

Analysis

Data were subjected to ANOVA repeated measurement analyses of SPSS 13.0, except for training blocks. The between-subjects factor was group (Old/Young). Within-subjects factors were complexity (pop-out/conjunction), set size (4/9 items) and single / dual task performance. For the behavioural results of the visual search task target and non-target responses are combined in the analysis.

2.2.3 Results

Primary task performance

Generally older drivers showed less accurate tracking, having an overall larger mean deviation (1.58 m) than the young drivers (1.28 m) (F(1,22)=10.1, p=.004; Figure 2.2.3). When both tasks were performed simultaneously the lane change task performance of both young and old drivers became worse (1.43 m) compared to the baseline level (1.23 m) (F(1,22)=18.6, p<.001). There was a main effect of complexity (F(1,22)=30.8, p<.001) and a main effect of set size (F(1,22)=7.2, p=.013), both effects going in the expected direction (Figure 2.2.3). The interaction between complexity and set size failed to reach significance (p=.12). There was an interaction with age group and complexity (F=1,22)=4.4, p=.049). There was no three way interaction between set size, complexitz and age group.

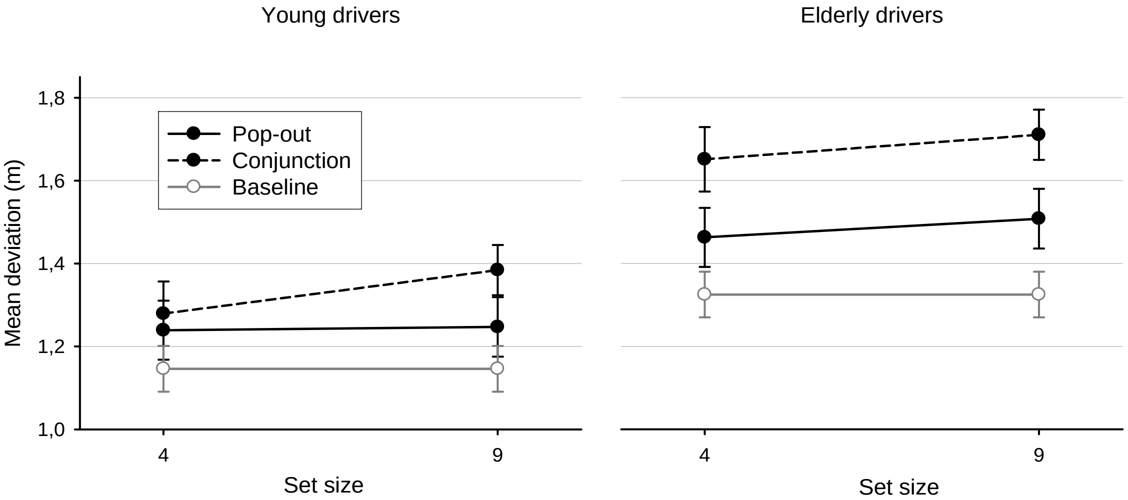


Figure 2.2.3: Mean deviation from the normative model for single task baseline driving and driving with a secondary task, i.e. visual search with varying set size and display complexity.

Subjective rating of effort

The self-reports of invested effort showed no difference between the two age groups (p=.38). There was a main effect for search complexity and set size (F(1,22)=73.7, p<.001; F(1,22)=44.7, p<.001). Also the interaction between complexity and set size was significant (F(1,22)=24.3, p<.001). This reflects an increase in self reported effort for the conjunction search when display size was enlarged (small display m=53.2 'rather much effort'; large display m=75.4 'considerable effort') while for the pop-out search the change of set size did not affect the subjective rating of effort (m=35.7 'some effort').

Secondary task performance

The analysis of the reaction time showed that participants took on average 92 ms longer to react in the dual task situation(F(1,22)=8.8, p<.007;) compared to single task performance. Reaction times were about 1000 ms slower when complex displays had to be evaluated compared to simple displays (F(1,22)=956.4, p<.001). Also with larger set size the reaction time increased with 244 ms (collapsed over both levels of complexity F(1,22)=279.0, p<.001) The expected interaction between set size and the complexity of search was replicated, i.e. reaction time increases more with conjunction search with increasing set size (F(1,22)=251.6, p<.001). There was a main effect of age on average older subjects showed an increased of reaction time by 249 ms relative to younger subjects (F(1,22)=16.7, p<.001; Table 1). Significant effects of age were revealed for single versus dual task showing an increase in reaction time for display difficulty (F(1,22)=6.0, p<.023).

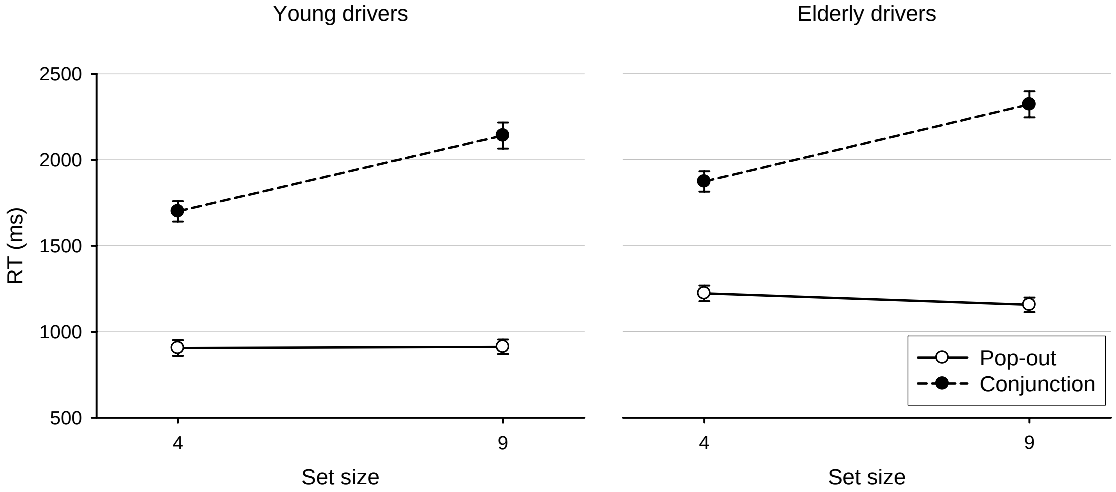


Figure 2.2.4: Reaction times of the visual search task in the dual task condition (averaged over target and non-target displays) for the conditions set size and complexity.

In the dual task performance participants made significantly more errors (8.8 vs. 14.9% (F(1,22)=17.3, p<.001; Figure 2.2.5) compared to single task performance. The amount of errors in simple displays was 2.3% compared to 21.6% with complex displays (F(1,22)=134.9, p<.001). Also with larger set sizes the amount of errors increased (F(1,22)=64.5, p<.001). The interaction between set size and the complexity of search was significant; showing a larger increase in errors for complex versus simple displays with a larger set size. Older subjects showed a 5.2% higher error rate (F(1,22)=6.3, p<.02). Significant interaction effect of age was revealed, showing a larger increase for elderly when comparing single versus dual task error rates (F(1,22)=10.8, p<.003). Also there were interactions where elder people showed an increase in errors when the task got more demanding in the dual task condition: with large display size (F(1,22)=8.0, p<.009), increased complexity (F(1,22)=7.9, p<.01) and a four-way-interaction (age x task x complexity x set size) with large complex displays (see figure 2.2.5.; F(1,22)=9.7, p<.005).

In the dual task situation, there is no significant difference in the number of false alarms between the age groups (p<.44). The number of misses however is larger for elderly then for younger drivers (F(1,22)=8.8, p<.007). The two main effects for complexity and display size were found as well as the interaction between the two (F(1,22)=35.5, p<.001; F(1,22)=44.0, p<.001; F(1,22)=34.5, p<.001). Age interacted with complexity and set size and the interaction between the two ((F(1,22)=8.2, p<.009; F(1,22)=6.8, p<.016; F(1,22)5.4, p<.029) In sum, elderly drivers had more misses than young drivers for more complex and larger displays during dual task performance.

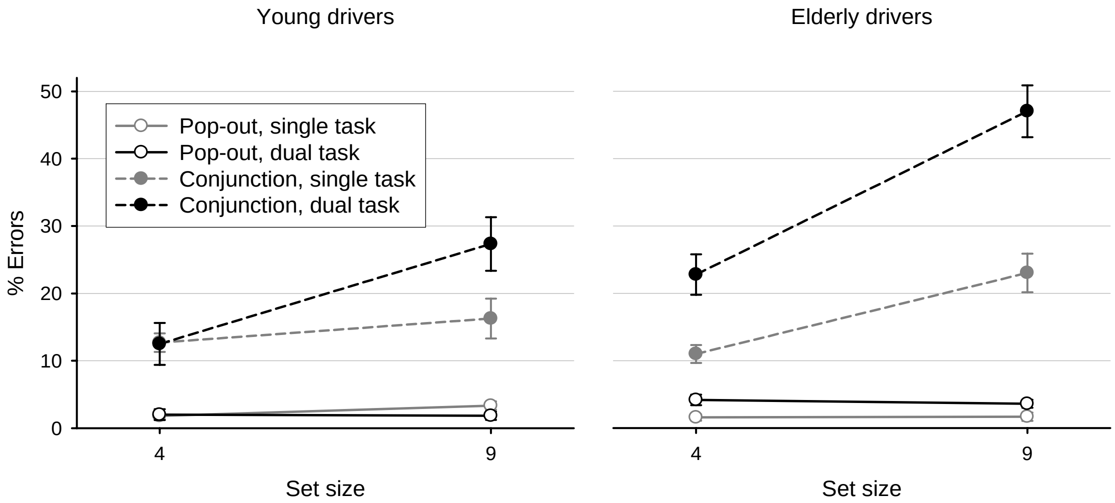


Figure 2.2.5: Errors in percentage of the visual search task in single and dual task condition (averaged over number of false alarms and misses).

Tabel 1. Performance measures on dual task Visual Search task

	Dual task performance			Dual-Single task difference			
	Young	Old	p-value	Young	p-value	Old	p-value
RT	1359 (39.3)	1625 (47.3)	<.001	85.9 (37.0)	.021	114.0 (50.5)	.023
Error (%)	10.6 (1.1)	19.8 (2.5)	.005	2.3 (0.8)	.010	10.1 (1.7)	<.001
Misses	13.4 (2.7)	39.1 (8.5)	.011	9.1 (2.1)	<.001	28.9 (6.1)	<.001
False	20.4 (3.4)	23.4 (1.7)	n.s.	-1.3 (2.6)	n.s.	4.3 (2.6)	n.s.

The table shows the mean and standard error, also T-test with corrected p values in case of variance inequality. Mean performance measures on dual task minus single task are given and the paired t-test of this dual vs. single task difference for both the young and older group.

2.2.4 Discussion

People are fairly good at performing multiple tasks at the same time when one of the tasks is automated or highly trained or when coping mechanisms can be applied when task performance is threatened. One of the common adaptations seen while driving is to reduce the speed to allow more time for decision making (Pohlmann & Traenkle, 1994; Fuller, 2005). Because the speed in the current experiment was fixed there was no possibility to compensate for high task demand by reducing the speed. The results of this experiment showed that both age groups were unable to continue performing the driving task adequately at baseline level in the dual task condition. Apparently they could not or at least did not sufficiently prioritise the lane change task. In general elderly participants were more affected by dual task performance; they showed a larger deviation and worse performance on the visual search task in comparison to the younger drivers. Results showed that even the young drivers were unable to continue performing the driving task at baseline level resulting in a larger mean deviation index. Moreover this was even the case for the pop-out search displays containing only four elements with a target with a salient feature (colour or orientation). As in the HASTE studies (Merat et al., 2005) where higher complexity of the visual search task resulted in a large deviation of the lateral positioning on the road, the performance on the lane change task decreased, as was shown in the mean deviation index. The findings of the visual search task performance were in accordance with the literature (Treisman & Gelade, 1980; Treisman, 1982; Wolfe, Cave, & Franzel, 1989; Chelazzi, 1999), i.e. almost no increase in RT or errors for pop-out displays when set size increases, but a large increase of RT and errors with set size for conjunction displays. The visual search task also modulated the mean deviation of the driving task. Participants were unable to perform the secondary, visual search task at baseline level. Both reaction time and percentage of errors increased in the dual task condition. The performance decrease of the elderly drivers with the most difficult display was alarming, because RTs were >2 seconds and the number of errors rose to 47%. Thus they were hardly performing better than chance level. This severe increase in errors could be attributed to an increase of the number of misses. A likely explanation is that elderly need more time to inspect the visual head-down display for the target. It could also be interpreted that the elder drivers have partly given up the secondary task and focus on the driving task. This would explain the lack of increase in deviation of ideal driving performance with set size when confronted with the most difficult search display. Although it is not verifiable given the current data, it could be that the larger mean deviation from the reference track could be a result solely of the fact that elder people spend a larger amount of their time looking at the visual search display or take a long time switching between the two task or are not able to switch in a efficient manner between the two tasks.

The results found in the current experiment could be attributed to the amount of time that people spend looking at the Head-Down Display. To minimize the physical switching distances between two spatial locations of visual attention, head-up displays (HUDs) have been introduced into the modern automobile. The benefit of this technology is that it decreases eyes-off-the-road and accommodation time (Liu & Wen, 2004), although there are also some concerns about the cluttering of information (Wickens, 1992). A follow-up of the present experiment will focus on the use of a HUD to verify if the performance decrease in the driving task can be attributed to the time that the participants spend looking on the head-down display. Although elderly drivers' performance was worse than the young drivers the measure of self report of mental effort did not show any effects for age group. This could mean that they invested the same amount of mental effort as the young drivers did but failed to compensate for the effects of healthy cognitive aging (i.e. slowing of reaction times), whose effects became more prevalent with increased task complexity. However, other explanations are also possible, for instance, that they have invested more mental effort but have related that with their own standard effort investment which is generally higher than that of young people. However as critics of self report measures stated it is hard for participants to introspectively diagnose mental effort, the measure could also be referring to physical load of the task rather than mental effort (see e.g., O'Donnell & Eggemeier, 1986).

When using a laboratory driving task to measure driving performance it should be considered that this environment is artificial and can give a false impression of driving performance and can not be transferred directly to driving on the road. For instance Schlag (1993) found when comparing driver performance of middle age (40-50) and older drivers (60-82) both in laboratory and in the field, that the performance of the elderly was worse in all laboratory experiments. However, in the road tests there was no performance difference in most situations. This lack of effects of healthy cognitive ageing on driving performance in the field could be interpreted as an effect of experience and compensatory strategies that are used in on-the-road driving, but which maybe could not be applied to simulated driving. From this experiment it can be concluded that when participants can not adapt their speed, dual task performance decreases when displays require conjunction search and a large number of elements are displayed. Displays with conjunction features forcing inefficient search should be avoided, because reaction time increases and in the dual task situation the amount of errors increases drastically especially with elderly drivers, and at least simulated driving performance is worsened.

2.3 Comparison of a Head-Down Display (HDD) versus a Head-Up Display (HUD) in a lane-change task: effects of ageing and display complexity

E.S. Wilschut, G. Rinkenauer, A.A. Wijers, K.A. Brookhuis, M. Falkenstein

Abstract

In a previous experiment (section 2.2) questions were raised about the role of shifting gaze between the driving display and a surrogate-IVIS. In the current study, a HUD was introduced to evaluate potential benefits of reducing required eye movements, and to investigate whether effects were similar in different age-groups. The results showed that displaying the visual search task on a HUD had a positive impact on performance. Young subjects improved their driving and visual search performance in terms of rection time and accuracy while older subjects only improved their search performance by making fewer errors. The decrease in performance with the secondary task presentation on the HUD compared to HDD was strongest for conjunction search displays. In the single visual task the elderly subjects appeared to prepare more intensively for the upcoming visual search task than did younger participants. ERPs appear to indicate a failure of the elderly subjects to invest in effortful preparation in the dual task situation, particularly in the most difficult HDD condition; this may be a factor in the performance decrease.

2.3.1 Introduction

The results of section 2.2 could be attributed to the amount of time that people spend looking at the external display (Head-Down Display or HDD). Results showed that both young and elderly drivers were unable to keep their driving task performance at a baseline level when they had to perform a secondary visual search task. Especially with increasing set size for conjunction search RT increased and the accuracy dropped to chance level for the elderly drivers. It was hypothesized that the elderly drivers spent more time looking for the target within the visual search display and therefore show a larger mean deviation from the ideal driving line than did younger people. Studies have shown that driving performance at least in a driving simulator is affected by IVIS-display location. It is assumed that the closer to the point of fixation the less looking at the display interferes with driving. For example Wittmann (2006) systematically varied the position of the display and found that the positions that had the smallest spatial distance to the outside road scene interfered the least with driving in a simple driving simulator. The most favourable display locations were those above the usual speedometer and above the middle console. These finding speak in favour of a head-up display (HUD). A HUD is a display in which the displays' elements are largely transparent, meaning the information is superimposed on the user's normal environment. It allows complex information to be presented to the driver without diverting their eyes from the road to look at a HDD. HUDs were originally developed for the aviation domain. HUDs have been introduced into the car for their perceived benefit regarding the location of information, thus decreasing eyes-off-the-road (e.g. Gish & Staplin, 1995). This experiment will be a replication of the section 2.2 experiment, but will make use of a HUD to minimize the physical switching distances between the driving and the visual search task. Again the effect of secondary, visual search complexity on driving performance is evaluated, using a visual search task (pop-out versus conjunction) as a surrogate IVIS and the lane-change task as the primary task to simulate driving (Mattes, 2003).

A number of studies have demonstrated the benefits of HUDs while driving as compared to the similar information displayed on a HDD. These benefits were expressed in tracking performance in the primary task, responses to events outside the car and responses to display information (Sojourner & Antin, 1990; Horrey & Wickens, 2004; Liu & Wen, 2004). However, some critics are concerned that overlapping information will cause cluttering of the visual field (Horrey & Wickens, 2004). There may still be costs associated with switching between even visually overlapping information sources, and possibly irrelevant information is harder to ignore when it is projected on the field of view, a phenomenon called cognitive tunnelling (Gish & Staplin, 1995; Ververs & Wickens, 1998). Other research has shown that the benefits of HUD may be reduced or reversed in response to unexpected events (Wolffsohn (Wolffsohn et al., 1998; Fadden et al., 2001) and in conditions of high workload (Wolffsohn, McBrien, Edgar, & Stout, 1998; Edgar, 2007) and can cause inappropriate accommodation of the eyes (Edgar, 2007). The age of the drivers covers a far wider range than the military pilots for whom the HUDs were initially developed. Few studies have been done on healthy cognitive ageing comparing the benefits of HUD versus HDD use. Kiefer (1991) found no significant differences between age groups when a speedometer was presented on a HUD compared to the usual speedometer for speed and scanning behaviour. Another study also found an overall decreased performance for elderly drivers but no interaction with display location and age. Thus the elderly showed the same improvement when the information was presented on a HUD as young drivers (Gish & Staplin, 1995). With both of these studies the workload was relatively low, and reading of the speedometer in the windscreen is highly practised and involves standardized information.

Also, as an addition to the experiment in section 2.2, the electroencephalogram (EEG) will be measured. The EEG will be used to measure the amplitude of different components before and after the onset of the search array. We were especially interested in the amplitude of the P3b that has been shown to be sensitive to resource allocation in a dual task paradigm. For example when the priority was manipulated higher priorities were associated with larger P3b amplitudes (Hoffman et al., 1985). The P3b amplitude of the primary task increases with increased primary task difficulty (Wickens et al., 1983; Sirevaag et al., 1989) while the P3b on secondary tasks decrease with increases in the primary task difficulty (Isreal et al., 1980; Kramer et al., 1983). Thus the P3b amplitude seems to be sensitive to resource allocation and reciprocal effects of primary and secondary task difficulty. In visual search tasks, the P3 amplitude of target trials are less enhanced for old than for young participants (Lorist et al., 1995). In contrast to the P3b, the P3a component has a more frontocentral maximum and an earlier latency. The P3a is associated with novel stimuli or unexpectedness and attentional requirements (i.e. difficulty of stimulus discrimination or presence of distractors). The P3a has been linked to orienting of attention, or processing biasing, towards a potentially significant stimulus (Rugg & Coles, 1995).

Further, an electrophysiological correlate of invested effort will be studied. A decline in cognitive abilities with age is not necessarily linked to performance deterioration. There are indications that compensation could be achieved by the use of additional brain regions as shown in a PET study (Reuter-Lorenz et al., 2001). It has been shown that slow negative potentials that precede task-relevant stimuli can indicate voluntary mobilization of extra effort. Falkenstein et al. (2003) found a larger fronto-central contingent negative variation (CNV) for effort trials , in which participants were instructed to invest extra effort, than for standard trials. Also Wild-Wall et al. (2007) found an increased frontal CNV amplitude for a conjunction search task for old compared to young participants. The latter results suggest that old participants were trying to compensate problems with conjunction search by effortful task preparation. These studies give an indication that slow negative potentials may be useful to measure effort investment objectively.

The electro-oculogram will be used to correct ocular artefacts in the EEG but also to measure the time that participants look at the HDD to get an indication of the time-sharing between the HDD and the lane change task. Expectations are that conjunction search will cause the mean glance time to increase and the glance frequency to drop (Victor et al., 2005). We will focus on differences in glance behaviour due to age that could explain part of the performance differences.

In this experiment the performance using the HUD will be compared with the usage of the HDD as was used in the previous experiment. We expect that both age groups will improve their driving performance and visual task performance in the HUD condition (Liu & Wen, 2004). We are in particular interested in the elderly drivers, because their RTs on the visual search task are slower and with the HUD they no longer have to divert their eyes from the lane change task; hence time sharing between the two tasks should become less demanding. The research described above suggests that there will be no interaction between age group and display type. However, previous studies had a relatively low workload and our results may yet reveal such an interaction.

2.3.2 Method

Participants

Twenty young participants aged between 20 and 29 years (M=23.3(2.5)) and twenty older people between 50 and 70 years (M= 60.2 (5.0)) were tested. All participants had had their driver's license for at least 2 years (young participants: M=5.3(2.3); old participants: M=39.9(9.9)). Participants had normal or corrected to normal vision. In each group half of the participants were female. In both age groups two of the participants described themselves to be left-handed.

Primary simulated driving task

The driving task was identical to the driving task used in the lane change task described in section 2.2. The simulated track consisted of a straight three-lane road. With the gas pedal pressed maximally the participant drove a distance of 3 km at a constant velocity of 60 km/h. This resulted in a total driving time per track of about 3 minutes. There were 18 signs along each track indicating the lane the participant had to change to as soon as the sign was identified.

Secondary visual search task

The visual search task stimuli were identical to the ones used in LCT1 but only the displays with a set size of nine arrows were used. Pop-out and conjunction displays were blocked (see caption of figure 2.3.1). The visual search task was presented on a head-up display (HUD) or a head-down display (HDD; see Procedure for details). The timing of the task was slightly adjusted: to allow more time for the response the duration of the fixation cross was decreased to 500 ms instead of 1000 ms and the visual search stimuli remained on the screen for 3500 ms instead of 3000 as in the previous experiment. Participants were presented with 8 blocks, each consisting of 40 trials, each block consited of trials of the following conditions: display type (HUD/HDD) complexity (pop-out/conjunction) and a repetition of all conditions. The target stimuli were an upward-pointing green arrow and a right-pointing red arrow; only one target or no target was present per trial. The probability of a target stimulus being present was 50%. The target appeared at a random location. The participant had to indicate by a button press whether the target was present or not. They were instructed to press the right button if a target was present, and the left button if no target was present. Further they were asked to react as quickly and accurately as possible.

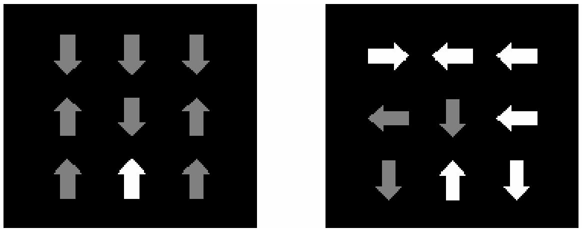


Figure 2.3.1: Two example displays with as target arrow, a green upward pointing arrow. The left display is the pop-out search display; participants can discriminate target arrows from red distractor arrows by looking at colour. The displays on the right side are the conjunction search displays, where both features colour and direction have to be determined to find the target.

Dual task

In the dual task blocks the instructions and conditions for driving as well as for the visual search task were kept equal and the participant was instructed to give first priority to the driving task. With each driving track a block of visual search stimuli was presented, either only conjunction trials or only pop-out trials. In contrast to the first experiment, the visual search task was time locked to the driving task. The first visual search stimulus appeared at the exact time that a lane change symbol was given in the lane-change task. The second stimulus appeared four seconds after the lane change symbol, in between two lane change symbols. Then the next stimulus appeared again at the exact time of a lane change symbol.

Procedure

The experimental procedure consisted of five different parts. The first part was the simulated driving task called the Lane Change Task to obtain a baseline for driving performance. The second part was the visual search task, which could either be displayed on the HDD used in the previous experiment or on a HUD, described below in the equipment section. This was done to obtain the baseline visual search performance. The third part combined the driving task together with the visual search task on the display used in the previous part. In part four and five the baseline search task and the driving task together with the visual search task were performed again but on the other display type (HUD / HDD). The sequence of the display types was counterbalanced across participants. Each part started with a training block. In total participants received about 30-45 minutes of training. The training of the visual search task continued until the participants reached a minimum of 80% correct trials. Each part was followed by a short brake. After each block self-reports of invested effort were rated with a German version of the RSME (Rating Scale of Mental Effort; (Zijlstra, 1993). Ratings had a range of 0-150, zero meaning ‘absolutely no effort’ and a rating of 110 or higher indicating ‘extreme effort’. The semantic terms mentioned in the result section are those closest in distance to the mean ratings.

Equipment

The simulated driving task was presented on a 67-inch CRT screen (Barco simulation products: Baron). For tracking a simple Logitech gaming steering wheel was used with gas and brake pedals. For the HDD the visual search task was displayed on a 16-inch LCD screen that had a distance of 1.45 m with a visual angle of 18°. This LCD screen stood in front of the CRT screen (distance 1.96 m, visual angle 38° x 29°) without blocking the view on the road. This equipment was identical to the equipment in the first experiment. Additionally, a head-up display was created by using a half transparent mirror, which stood in front of the participant with an angle of 45°. During the whole experiment the participant looked through the mirror, but only in the HUD condition a semi-transparent image of the visual search task was visible for the participant at the horizon of the driving task. On a 16 inch LCD screen behind the participant perpendicular to the mirror the visual search task was displayed (mirrored and size adjusted for equal stimuli size as the HDD). Seat height was adjusted individually to keep the angle of the eyes equal between participants.

Data recording

The recording of the behavioural data was the same as in the previous experiment. Additionally the electroencephalogram (EEG) was recorded using 11 Ag/AgCl electrodes attached to an electrocap, from positions: Fz, FC3, FCz, FC4, C3, Cz, C4, Pz, Oz, O1 and O2. All electrodes were referenced to common reference and offline rereferenced to the mastoids. The electro-oculogram (EOG) was recorded bipolarily from the outer canthi of both eyes and above and below the right eye, using Ag/AgCl electrodes. Electrode impedance was kept below 5kΩ for head electrodes and 10 kΩ for the eye electrodes. EEG and EOG were sampled at 500 Hz without filtering.

Analysis

The same analyses were done as in the LCT1 experiment: data were subjected to ANOVA repeated measurement analyses of SPSS 13.0, except for training blocks. The between-subjects factor was group (Elderly / Young). Within-subjects factors were display location (HUD / HDD), search type (pop-out / conjunction), and single vs. dual task performance. The EEG data were corrected and analysed using Brain Vision analyzer. For stimulus-locked ERPs the baseline was the 100 ms preceding the fixation cross. The P3-like component after the fixation cross was measured as the maximum value of the peak at FCz within 150 and 300 ms after the fixation cross. The preparatory negativity was measured at FCz, defined as the largest negative value between 100 and 150 ms after stimulus presentation. The stimulus-locked P3 was measured at Pz, as the largest positive peak within 500-700 ms in the averages. For the response-locked P3, peaks were measured at Pz as the maximum value between –75 and +50 ms around the response. The EOG was used to remove ocular artefacts from the EEG (Gratton & Coles, 1983). The EOG channels were used to measure the glance length and frequencies when participants drove with a HDD. Markers were set in the vertical EOG to determine the vertical saccade from and to the HDD (Figure *2.3.2*). Glance duration was defined as the time between an upward and downward marker to determine the duration of looking towards the road, and visa versa for time looking towards the HDD. Glance frequencies were defined as the number of eye movements towards the driving task (which equalled the total of eye movements minus those downwards to the HDD). To obtain an insight in the number of glances and their durations a frequency distribution was constructed. The number of glances of given durations were counted. Duration bins were used of 100 ms (i.e. 0-100 ms, 101-200 ms etc, until 2901-3000 ms). Frequency distributions were made separately for the glances to the driving task and to the HDD, and for pop-out versus conjunction.

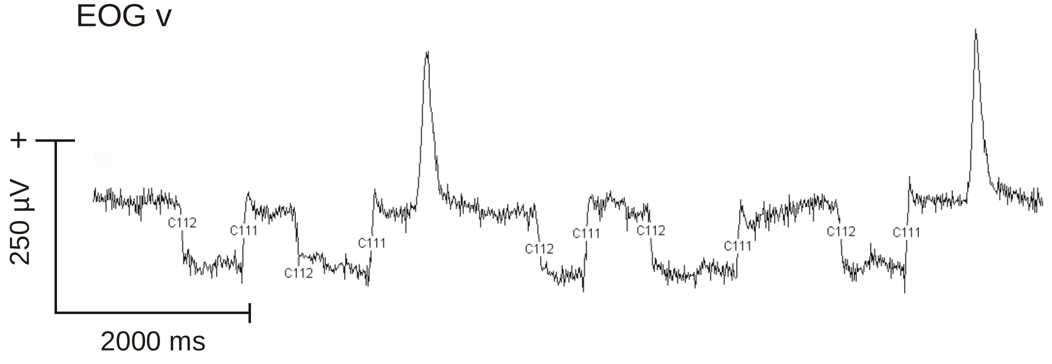


Figure 2.3.2: Example of the vertical EOG signal with saccades towards the road (more positive) or towards the HDD (more negative) and two eye blinks (sharp positive peak). Glance duration was defined as the time between an upward and downward marker for the time looked with eyes on the road, or visa versa for the HDD.

Post-hoc it was decided to statistically analyse the distribution according to glances with a duration <1000 ms and glances with duration >1000 ms, because short glance durations formed a clear peak around 600 ms versus the long tail. Statistics should be carefully interpreted because measures are not completely independent, for instance when the mean glance duration is higher, the frequency of looking between the two locations also drops.

2.3.3 Results

Primary driving task

When performing the visual search task as a secondary task to the driving task, both age groups performed worse in the driving task than when driving with no secondary task (F(1,38)=14.1, p<.001; Figure 2.3.3). The tracking performance for the elderly drivers grew worse when the visual search display required conjunction search (F(1,38)=6.5, p<.015). There was a three-way interaction showing that Elderly drivers had no differences in driving performance between HUD and HDD display for either type of search task. For pop-out search, younger drivers also showed no effects of HUD or HDD display in their driving performance. For conjunction search however driving performance was better when the visual search task was presented on the HUD. Surprisingly the improvement of driving performance with a HUD for conjunction search was so large that the driving performance of young subjects appeared to be better than the performance during pop-out search (F(1,38)=4.5, p<.041).

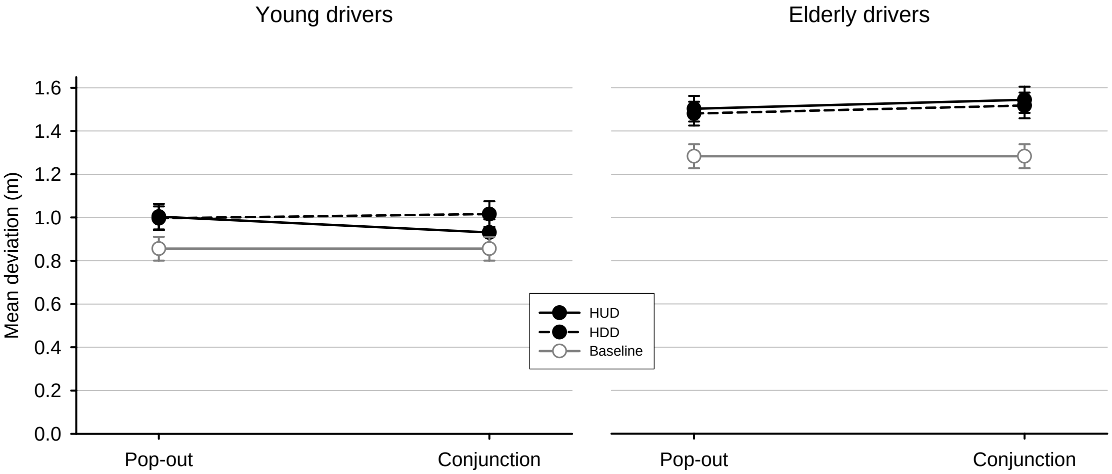


Figure 2.3.3: Mean deviation from the normative model for single task baseline driving and driving with different visual search conditions.

Rating Scale of Mental effort

When the visual search task was performed as a single task the mean rating was 25.8, which corresponds to “a little effort”. The effort rating increased when the visual search task was performed as a secondary task while the participants were driving to a mean rating of 40.0 with the label ‘some effort’ (F(1, 38)=55.4, p<.001). When the visual search task was presented on the HDD effort was rated higher than when the HUD was used to present the stimuli (F(1, 38)=10.7, p<.002). Also pop-out search received lower ratings of effort (27.0) than conjunction search (38.9; F(1,38)=62.2, p<.001). There was an interaction between single / dual task and type of display. Effort ratings were equal for single task performance independent of display type. However, in the dual task situation participants rated more effort when they had to use the HDD instead of the HUD (F(1,38)=8.2, p<.007). There was no effect of display type for pop-out search, but when participants were confronted with conjunction search tasks they rated more effort when using a HDD than with a HUD (F(1,38)=4.1, p<.048). There were no effects of age group.

Secondary visual search task

The reaction times of correct trials on the visual search task showed that participants were more than 1.2 seconds faster when responding to pop-out search (M= 931 ms) than to conjunction search (M= 2133 ms; F(1,38)=1671.1, p<.001; Figure 2.3.4). When the visual search task is performed while simultaneously performing the driving task reaction times increase by 133 ms (F(1,38)=29.0, p<.001). In the single task performance there is no difference in reaction time when the stimuli are presented on the HDD or HUD (M=1465 ms, SD= 35). However in the dual task performance reaction times are higher when the stimuli are presented on the HDD (M=1639 ms, SD=33), than when presented on the HUD (M= 1557 ms, SD=32; F(1,38)=11.8, p<.001). Young drivers showed an effect of display location and were responding quicker to conjunction search when it was presented on a HUD (F(1,38)=4.5, p<.041). Although there was a main effect showing elderly drivers were significantly slower overall (M=1656 ms, SD=39) than younger drivers (M=1407.4 ms, SD=38) there were no further effects of age group. There was no three-way interaction of single/dual task x display type x complexity.

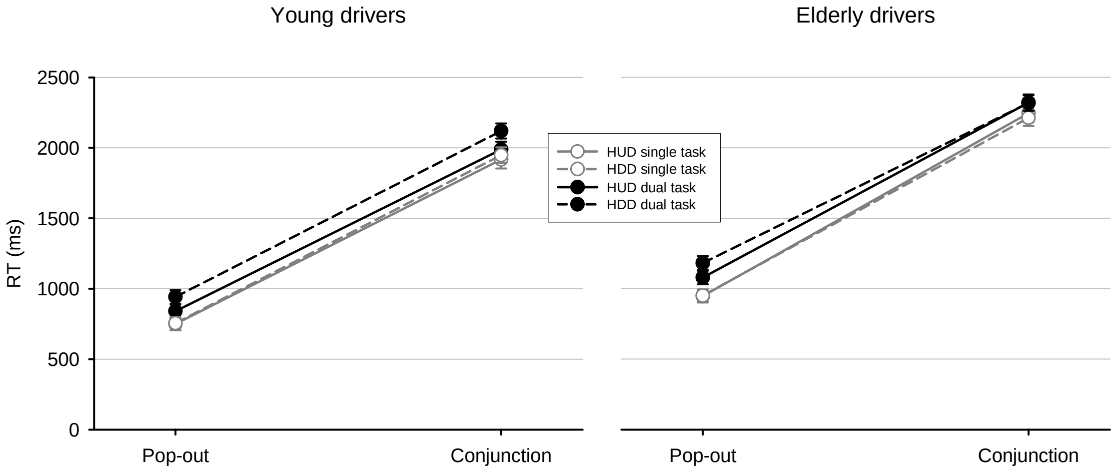


Figure 2.3.4: Reaction times of the visual search task in the single/dual task condition (averaged over target and non-target displays) for the visual search types both on HUD and HDD.

Error percentages increased from 8.1 to 13.4 % when the visual search task was performed as a secondary task (figure 2.3.5; F(1,38)=68.8, p<.001). There was an interaction with age showing that this increase of errors in a dual task situation is stronger for the elderly drivers (F(1,38)=8.8, p<.005). There was a large difference in error percentages for pop-out versus conjunction search showing that with pop-out search participants made about 1.6% errors while in the more complex conjunction search participants made on average 20% errors (F(1,38))=190.3, p<.001). There was also an interaction with age group showing that there was no difference in errors for age groups when pop-out search was required, but with conjunction search elderly participants made more errors than young participants (F(1,38)=11.9, p<.001). Also there was a dual task interaction effect showing that when pop-out search was required simultaneously with the driving task error percentages hardly increased with 0.8 %. For conjunction search the error percentages for dual vs. single task performance increased drastically with 9.7% (F(1,38)=55.5, p<.001). The display location also had an effect on the errors showing that fewer errors were made with the HUD (10%) than with the HDD where the eyes had to be diverted from the road (12.1%; F(1,38)=20.2, p<.001).

As with the reaction times, there was no difference in error percentages for HDD or HUD when the visual search was performed without the driving task (Figure 2.3.5). However with dual task performance errors increased and were 5.3% higher when a HDD was used (F(1,38)=44.2, p<.001). This increase in errors for the HDD with dual task was stronger for the elderly participants (F(1,38)=6.7, p<.014). The type of search interacted with the display location: for pop-out there was no difference, but for conjunction the amount of errors increased and increased more for HDD to 22.5% than for the HUD (17,5 %; F(1,38)=28.3,

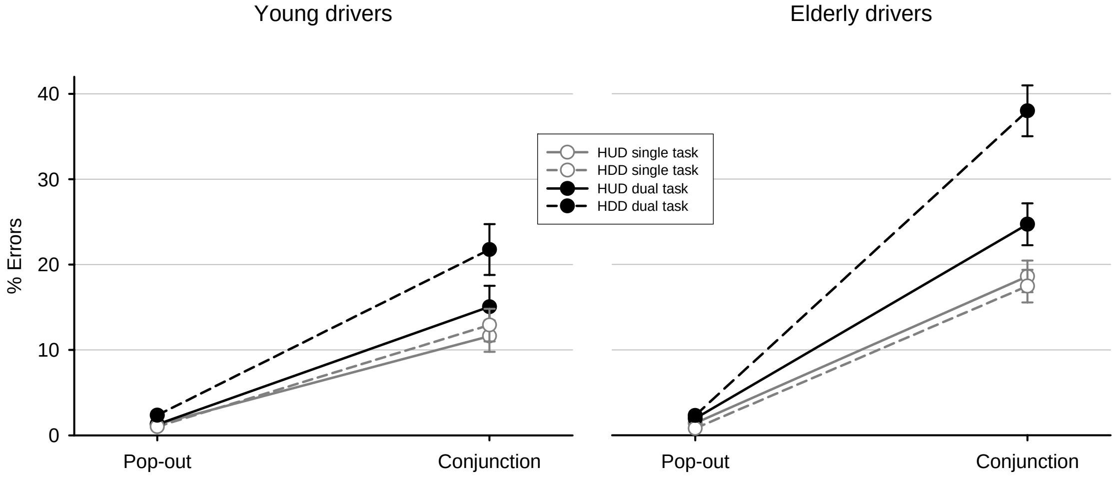


Figure 2.3.5: Errors in percentage of the visual search task in single and dual task condition for the visual search types both on HUD and HDD.

p<.001). Display location showed an interaction with type of search and single / dual task: for pop-out search all error percentages remained below 2.5% but for conjunction search error rates increased especially in the dual task condition, when the visual search task was performed with the driving task. Error percentages were highest in dual task performance for conjunction search stimuli presented on a HDD (F(1,38)=21.6, p<.001). This effect was also affected by age group showing that in the most difficult condition with conjunction search and with a HDD for the dual task performance, error percentage increased even more for the elderly participants than for younger ones (F(1,38)=6.2, p<.017). In this most difficult condition the error percentage of the old participants was 38% compared to 21.8% for the young drivers. In comparison, the error rate of the elderly for conjunction search was much lower in the HUD than in the HDD condition.

Eye movement

Eye movement data was analysed only for the condition in which the HDD was used for presentation of the visual search task while participants were simultaneously performing the driving task. This condition required of the participant to make vertical eye movements to perceive visual information to be able to perform the driving and the visual search task correctly. For three young participants it was not possible to analyse the EOG data due to artefacts, and they were excluded from this analysis. With pop-out search the mean glance duration towards the road was about 2.5 sec whereas the mean glance duration at the HDD was 0.8 s, this difference was significant (F(1,35)=49.2, p<.001; Figure 2.3.6). With conjunction displays there is a decrease in the mean glance duration at the road and an increase in the glance duration at the HDD, resulting in a (non-significant) difference of the mean glance duration at both locations. The main effect of complexity was only showed a trend (F(1,35)=3.7, p=.062). The interaction between the focus of the eyes (road/HDD) and complexity was significant (F(1,35)=18.6, p<.001)The mean glance duration showed no effects of age groups.

Glance frequency was higher for pop-out (58.6) than for conjunction search (51.4), when the HDD display had to be inspected (F(1,35)=26.3, p<.001; Figure 2.3.6), there was a group by search type interaction (F(1,35)=5.8, p<.021). Glance frequencies were equal for the age groups when performing the driving task together with a pop-out search (Mean=58.5, SD=3.1). However, conjunction search caused a reduction of the glance frequency. This reduction was especially strong for elderly drivers; they made about 10 fewer glances compared to driving with the pop-out search displays. Increased complexity of the visual search resulted in fewer alternations between the HDD and the driving task, because the eyes were fixated on the HDD for a longer period of time.

The distribution of the glance durations was further explored using two glance duration periods: short glance duration (<1000 ms), and long glance duration (>1000 ms; Figure 2.3.7). Especially with the short glances there were differences visible between conditions and age groups. The results of this analysis of the frequency distribution overlapped with the previously reported mean glance frequency showing the same results, thus only the effects that showed an interaction with glance duration period are reported here. For pop-out search there was a larger number of short glances than with conjunction search where there were

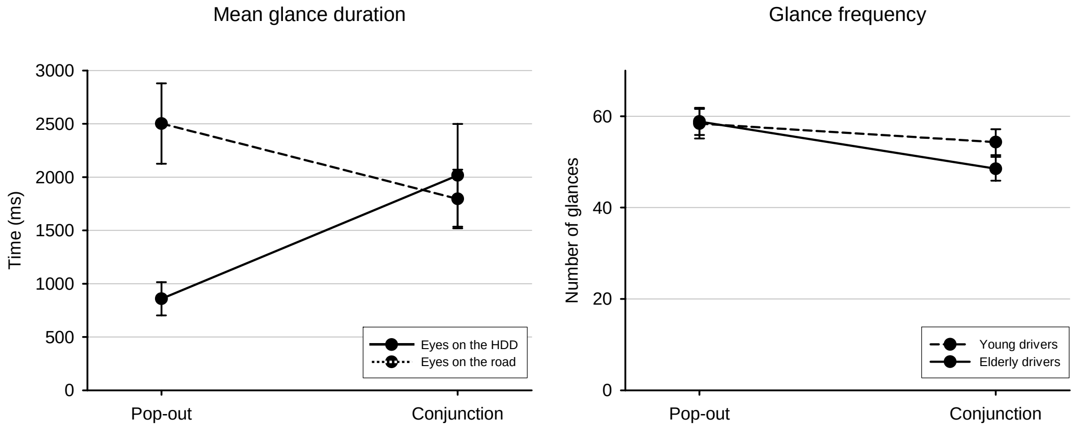


Figure 2.3.6: Mean glance time and glance frequencies for the visual search types are derived from the vertical EOG, but only for the condition that visual search task is displayed on the HDD and is performed as a secondary task to the driving. They give an indication of the number of times that the eyes change locations and the mean glance duration to this location.

many long glances (F(1,35)= 133.0, p<.001). More short glances were directed to the HDD than to the road (F(1,35)126.8, p<.001). There is an interaction with age-group showing that the elderly drivers made fewer short eye glances compared to young drivers for conjunction search (F(1,35)=5.2, p<.023). There was tendency showing an interaction of complexity with age group, namely that elderly drivers made fewer short glances to the road with conjunction displays than younger participants (F(1,35)=4.0, p<.055).

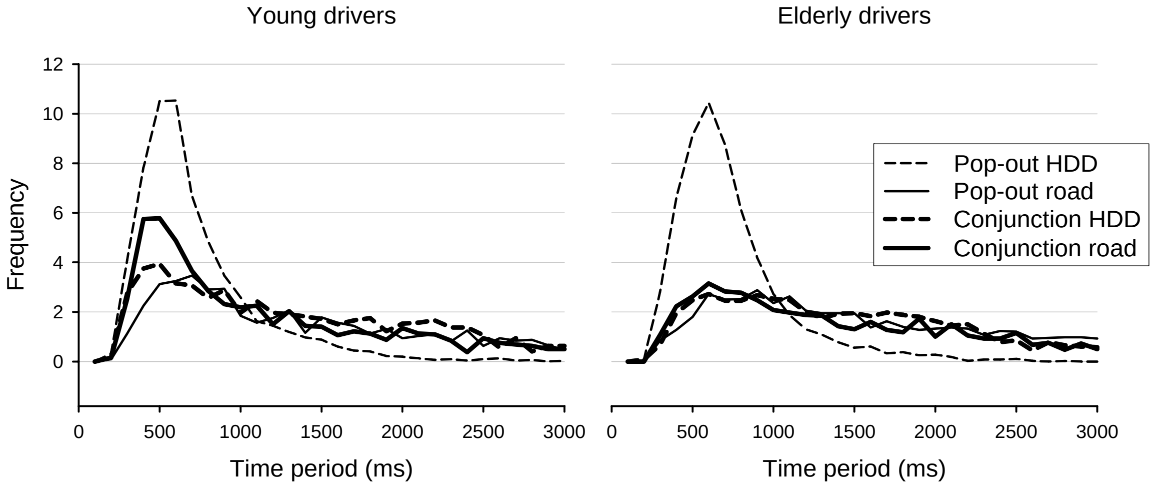


Figure 2.3.7: Glance duration distributions for each time period of 100 ms the number of glances with that duration are counted. Glance duration distributions are made for the driving task with HDD display .

ERPs

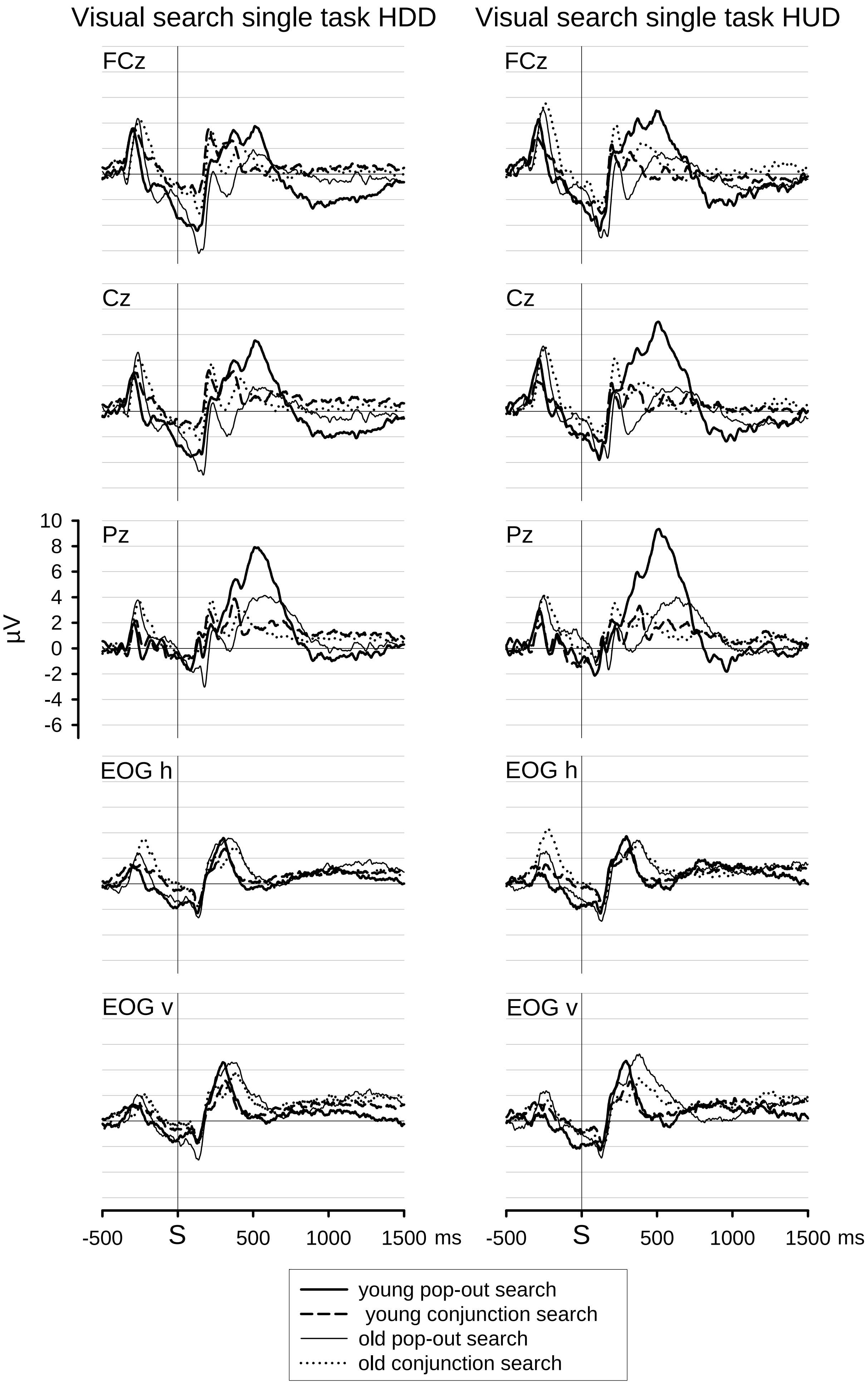
The stimulus-locked ERPs showed a sharp positive peak after the fixation cross that was most prevalent at FCz, called P3a (Figure 2.3.8). When the stimuli were presented on the HUD the P3a was more positive than when presented on the HDD (F(1,38)=9.3, p<.004). However, there was an interaction with age group showing that for young participants there is no effect of display location while for elderly participants the presentation on the HUD caused the component to increase from 4.5 µV to 5.5 µV (F(1,38)=4.8, p<.034). There was a trend towards an interaction between type of visual search and age on P3a amplitude (F(1,38)=3.1, p<.08): in the elderly participants the amplitude was larger in conjunction search than in pop-out search. For young participants the reverse was true for single task performance with the HUD, the amplitude of the P3a decreased with conjunction search. The P3a was generally larger when stimuli were presented via HUD than via HDD.

After the P3a component a negativity developed until after the visual search stimulus. This negative shift was most prevalent at FCz. This negative component became less negative when participants had to drive and perform the visual search as a secondary task than when participants prepared for the single task (F(1,38)=28.4, p<.001). This reduction of the negative shift amplitude with dual task was especially prevalent for the elderly drivers (F(1,38)=7.1, p<.011). There was an effect of search type: with pop-out displays the negative shift's amplitude was more negative (-3.2 µV) than with conjunction search (-1.6 µV; F(1,38)=99.3, p<.001). In the single task this search type effect on the negative shift was stronger than in the dual task (F(1,38)=10.1, p<.003). There was also an interaction of search type with display location: for pop-out search the negative shift was more negative when presented on the HDD than on the HUD (F(1,38)=18.1, p<.001) while for conjunction search there was no significant effect of display location. In the single task situation the negative shift was more negative for the elderly than for the young participants mainly for HDD(F(1,38)=9.1, p<.005). In contrast, in the dual task situation the young participants showed a more negative CNV when stimuli were presented on the HDD vs. the HUD while for elderly participants the CNV almost disappeared and did not show any differences between HDD and HUD presentation.

After the onset of the visual search stimuli an early positive component, the P2 showed which was followed by a positive complex consisting of an earlier positivity peaking at about 400 ms and an immediately following large positivity with Pz maximum, the P3b, with a latency of about 500 ms. For the dual task situation the early subcomponent appeared almost absent in the HDD conditions, while it appeared large and very early in the HUD condition, here overlapping with the P2. Within the scope of this work only the P3b is evaluated statistically because of too strong component overlap in the earlier time window. There was a significant difference in P3b amplitude between pop-out and conjunction search (F(1,38)=99.6, p<.001): the amplitude of the P3b was strongly reduced with conjunction search There was an interaction of age group and search (F(1,38)=24.6, p<.001):for pop-out search the P3b was larger for young than for old participants (F(1,38)=15.4, p<.001), while there was no age difference for conjunction search. For conjunction displays the P3b is reduced so strongly that almost no positivity can be seen, therefore ERPs with conjunction search are excluded from further P3b-analysis. For pop-out search the P3b amplitude was smaller with dual task performance than with single task performance (F(1,38)=15.3, p<.001). A group by task interaction (F(1,38)=5.8, p<.021) showed that this decrease with dual task performance was substantial (from 7.9 µV to 5.6 µV) and was significant for the younger participants while for the elderly the P3b decrease was not significant. The amplitude of the P3b was smaller with HDD than with HUD presentation (F(1,38)=16.4, p<.001), but this P3 reduction for the HDD only showed up in the dual task (F(1,38)=12.6, p<.001).

ERPs were also calculated locked to the response (Figure 2.3.9). A positive peak with Pz maximum shortly after the response time was identified as the response-locked P3. Like the stimulus-locked P3 (P3b) the response-locked P3 had a parietal maximum and a larger amplitude for young than for elderly participants (F(1,38)=12.1 p<.001). There was an effect of search type showing that the amplitude of the response-locked P3 was higher for conjunction (6.1 µV) than for pop-out search (5.1µV; F(1,38)=7.8, p<.008). For the HDD the response-locked P3 amplitude was larger in dual than in single task performance (F(1,38)=20.8, p<.001). Although not significant there is a weak trend that mainly elderly participants contribute to this effect (F(1,38)=2.0, p<.15).

Figure 2.3.8 on the next pages: Stimulus-locked ERPs on correct target trials, showing for both age groups (young / old) the ERPs related to pop-out and conjunction search. Single task ERPs for HDD / HUD and finally dual task ERPs.


Visual search single task HDD
Visual search single task HUD
FCz
Cz
Pz
EOG h
EOG v
µV
10
8
6
4
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-2
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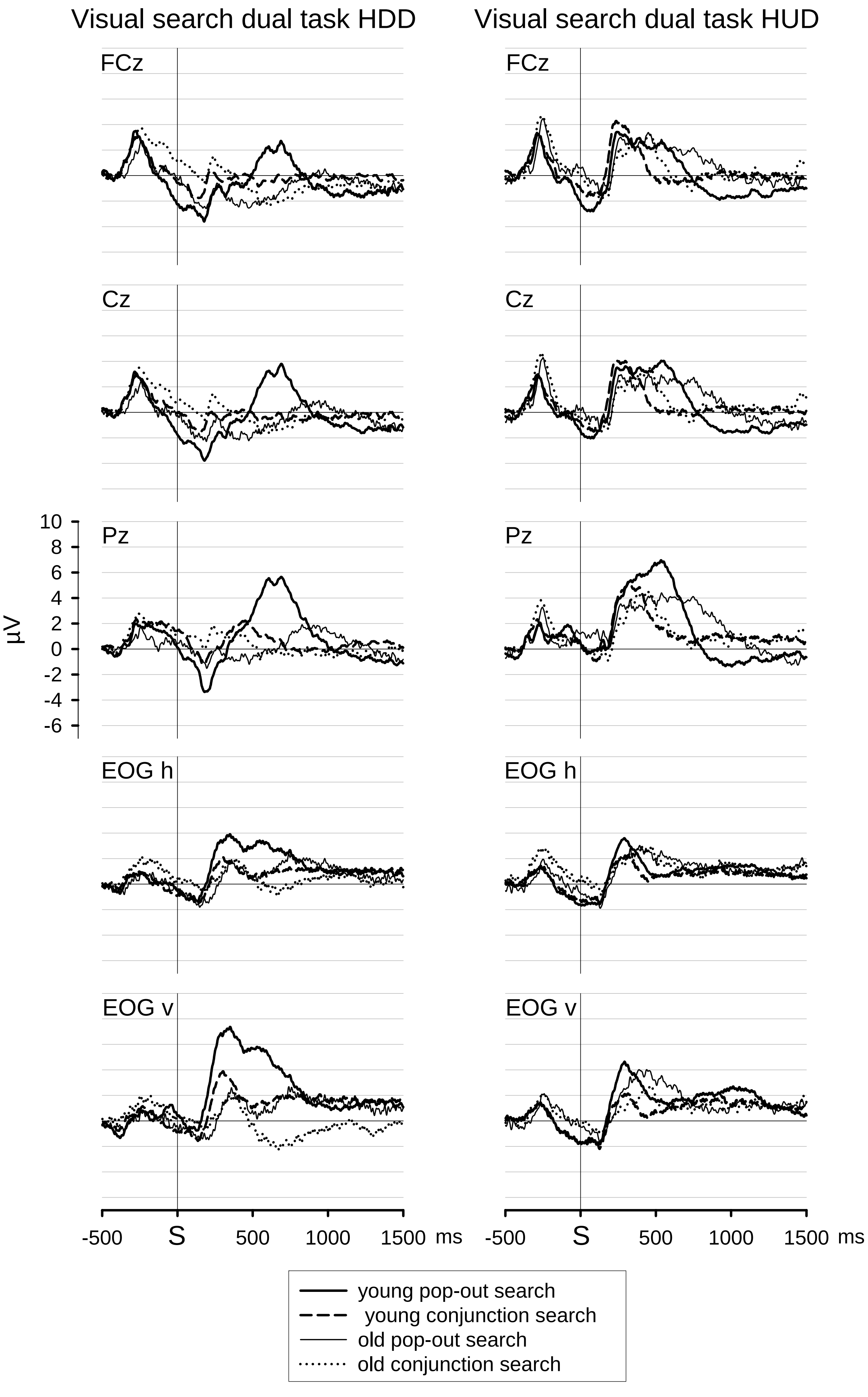
-500
S
500
1000
1500 ms
young pop-out search
young conjunction search
old pop-out search
old conjunction search


Visual search dual task HDD
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FCz
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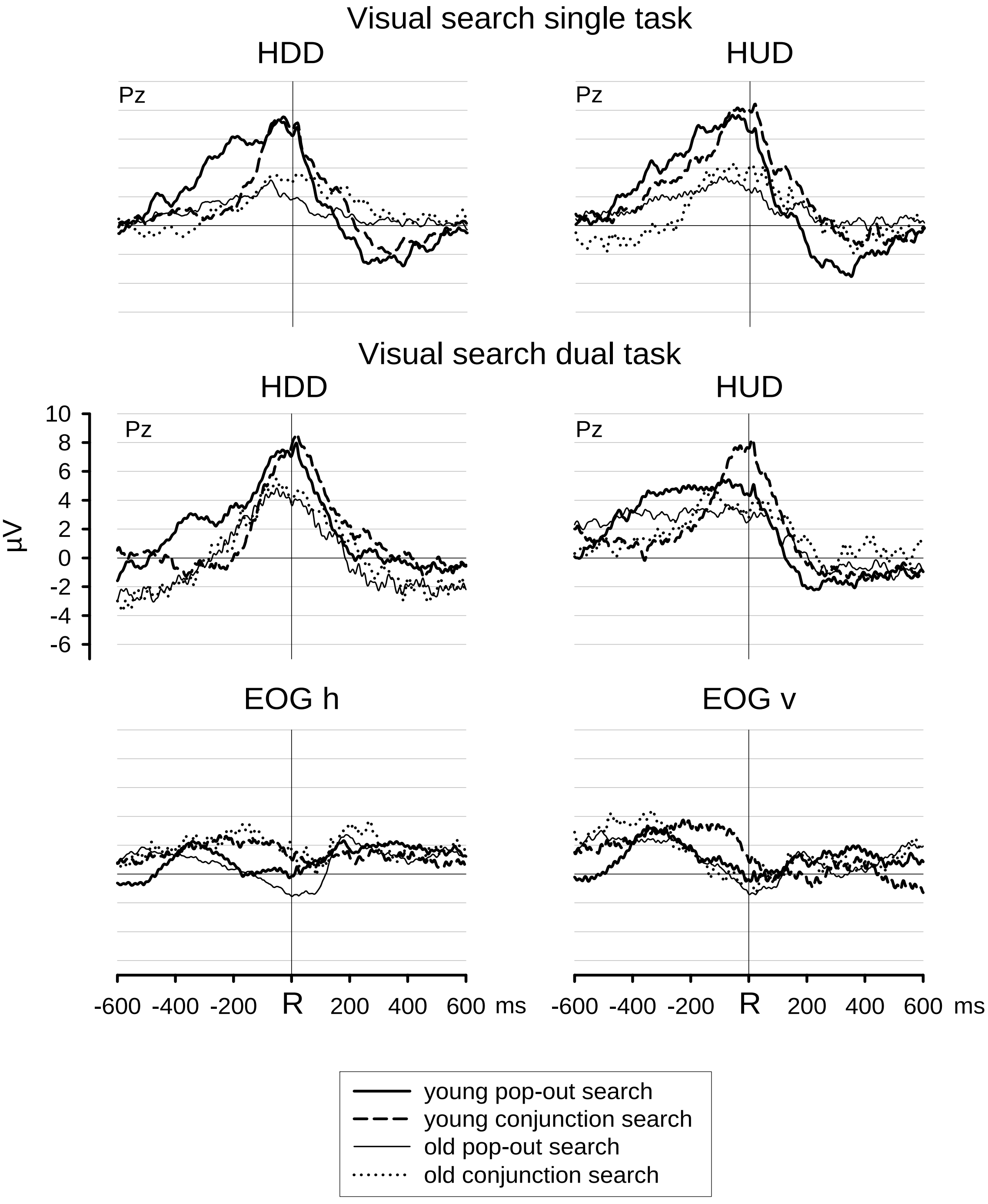

Figure 2.3.9: Reponse-locked ERPs on correct trials, showing for both age groups (young / old) the ERPs related to pop-out and conjunction search.

2.3.4 Discussion

In this experiment the effects of display location HDD / HUD and visual search complexity on a driving task was investigated for young and elderly drivers. The baseline driving data showed that elderly drivers performed the driving task less accurately than younger drivers did. When the surrogate IVIS task was introduced as a secondary task to the driving both young and elderly drivers were unable to keep their driving accuracy at a baseline level. Performance on the driving task worsened when the visual search task required conjunction search. Similar results were found in the HASTE studies (Merat et al., 2005) in a driving simulator study: when the complexity of the visual secondary task increased elderly drivers showed worse lane keeping behaviour and a greater reduction of speed than young drivers.

Elderly drivers did not improve their driving performance when the visual search task was presented on the HUD, but for young drivers driving performance improved for conjunction search when the stimuli were presented on the HUD compared to HDD. Participants rated less effort when the visual search display search was presented on the HUD, but only for conjunction search. There were no effects of age group on effort ratings. Performance on the secondary visual search task showed that RTs increased by about 130 ms compared to single task performance. As was expected, participants needed significantly longer to respond to conjunction search trials than to pop-out search trials. Whereas in the single task condition there was no difference between the presentation of the stimuli on the HUD or HDD, RTs were slower when the stimuli were presented on the HDD when subjects had to perform the driving task as well. Elderly participants were slower overall but no interactions with other conditions were present which is also in accordance with the findings of Merat et al. (2005).

The error percentage increased drastically when the driving task was combined with the visual search task, but only for the conjunction displays. Especially elderly participants made a large amount of errors (38%) in the dual task performance with conjunction search displayed on the HDD. Error percentages were still high but improved when the visual search task was presented on the HUD rather than the HDD, for both young and elderly participants. Here both age groups seem to benefit from the presentation on the HUD showing a better performance in terms of errors when the visual search task is presented at the same location as the central area of the driving task.

Analysis of the eye glances showed that with pop-out search it was sufficient for the participants to direct their eyes towards the HDD for a short time and kept their eyes on the road for the majority of the time. With conjunction search displays participants spent an equal amount of time looking at the road and the HDD, and elderly participants made fewer eye movements between the road and the HDD. Thus the mean glance duration towards the HDD increased with the visual search complexity affecting the frequency of making transitions between the two locations. A similar result was found in a driving simulator study where the visual task difficulty resulted in more glances towards the display. An increased gaze concentration to the road centre area was present when the eyes returned to the road (Victor et al., 2005). For young participants there seemed to be an indication that they make short glances towards the road even when they are occupied with finding the target in the conjunction search display, which could explain why their driving behaviour is less affected by the visual search task. The eye movement data in this experiment could only distinguish between eyes positioned on the road versus the HDD. It was not accurate enough to detect the number of eye fixations that were needed to find the target, or if eye fixation were directed at the road centre, as can be done with an eye tracker (Victor, et al., 2005). The results therefore cannot indicate if elderly drivers require more eye fixations within the visual search display to find the target. Other studies have found that older participants have larger deficits in their useful field of view, i.e. the region of the visual field from which an observer can extract visual information without moving the eyes (Ball et al., 1988). These changes in the useful field of view can be especially relevant for finding relevant information or changes in a cluttered real-world driving scene overlaid with a HUD and require older drivers to make more eye movements (Owsley et al., 1991).

Another factor concerning the transfer of the current results to real driving is that in the current experiment static visual search displays were used, however real IVIS and HUD are dynamic, and update the information continuously. Research of Kramer & Atchley (2000 (2000; Becic et al., 2007) showed that older participants can successfully restrict search to newly added objects to speed search in a static visual search experiment. However, in a replication of this study with a dynamic display by Watson & Maylor (2002), when the target and non-target items were moving across the background, results showed that older participants were not able to selectively prioritise the new objects in a display. This could be relevant for certain type of IVIS were the road environment is displayed and continuously updated from the current car position. This could be a disadvantage for elderly drivers and increase the search time of the displays, if they can not selectively prioritise new information.

The ERP results can only be interpreted with reservations, because of the large number of (eye) artefacts and due to the apparent jitter in the ERP components reducing the amplitudes in e.g. the conjunction search stimulus locked ERPs. In that case effects cannot be directly attributed to changes in cognitive processing. The P3-like component after the fixation cross probably reflects the so-called P3a, which has been linked to the allocation of attention or more specifically the change of the attentional focus to a new task (e.g. Barceló et al. 2002; Kopp et al., 2006). It had a larger amplitude for elderly participants, especially when they performed conjunction search presented via HUD. Similar results were found by Falkenstein et al. (2003): in a cue - stimulus CNV paradigm they could observe an enhancement of a fronto-central positive component after the cue in effort compared to standard trials. In a visual search experiment of Wild-Wall et al. (2007) responses were followed by a 700 ms preparation interval, and at 250 ms a positive peak named the P3-like component deflection was followed by a CNV. This P3-like component was larger for older participants (54-64 years) than for young participants (18-25 years). The interpretation of the effect was that older participants paid more attention to the indication of the upcoming stimulus and that the effect was especially enhanced in the difficult search task. In our experiments the increased P3-like component for the older participants could reflect an increased allocation of attention to the fixation cross in order to prepare for the upcoming visual search and that this effect is stronger for conjunction search. In other words, given that the P3a reflects (re)allocation of attention its enhancement would indicate an attempt of the elderly to compensate for problems with the search task by attending the upcoming array as well as possible.

After the P3a a negative shift developed which most likely reflects a CNV (Falkenstein et al. 2003). Although the experiment was not developed to measure a classical CNV component (Walter, Cooper, Aldridge, McCallum, & Winter, 1964; Brunia & van Boxtel, 2001), we try to show that the component shows some resemblance with components described in the CNV literature and to be an indicator of task preparation. In single task visual search, elderly drivers showed a more pronounced negative shift at least when using the HDD, and a visible trend for the HUD. These results are in line with the study of Wild-Wall et al. (2007) where an increased CNV was found for the elderly participants, which is interpreted as more intense preparation on the upcoming visual search. We could therefore conclude that older participant built up a stronger preparation before the onset of the visual search stimuli. The CNV was more pronounced in pop-out than conjunction search for both age groups which shows a reduced preparation for conjunction search. This effect might be explained by the RTs because there might be more to gain by effortful preparation before the pop-out trials because participants are able to respond shortly after the stimulus presentation. In the dual task condition the negative shift was reduced for all participants but mainly so for the older subjects. This indicates less preparation in the elderly, and particularly so in the conjunction search, where there is hardly any CNV left in the elderly. This failure to prepare might be due to the reduction of glances to the array, rather than to a deficit in preparatory ability. Differences between HUD / HDD were difficult to interpret because of the eye movements that were required in the HDD condition. For instance, participants may sometimes have been involved in the driving task and missed a part of the visual search stimulus on the HDD.

With conjunction search the stimulus-locked P3 (P3b) was reduced and hardly showed any positivity. This could be explained by the large variation of the responses in the conjunction condition since there is evidence that the P3 seems to serve as a mediator between the stimulus and response and is hence more locked to the response than to the stimulus (Falkenstein, Hohnsbein, & Hoormann, 1993; Verleger, Jaskowski, & Wascher, 2005), as also found in experiment 1 of the present study Pop-out search did produce a clear peak in the single task condition; this peak was reduced for the elderly participants. However, even this could be due to a larger RT variance between trials in the elderly than in the young. In the dual task condition the pop-out P3 disappeared for the elderly when they had to perform with a HDD but was again present using the HUD. For the young participants the P3b amplitude was reduced but remained present. It should be noted that this effect cannot be attributed solely to cognitive functioning but again could be due to the eye-movement that had to be made towards the HDD. The fact that the averaged stimulus-locked P3b is most probably differentially influenced by different RT variance made it more reasonable to measure the P3b in the response-locked averages. The response-locked P3 was still smaller for the elderly participants. However, in contrast to the stimulus-locked P3, the amplitude of the response-locked P3 was more positive for conjunction search than for pop-out search. Even with dual task performance on the HDD this peak was clearly visible and had a larger amplitude than in single task. Thus the response-locked P3 seemed to be a measure of the visual search task difficulty showing a larger amplitude for conjunction and dual-task with a HDD. The interesting variations of the early subcomponent of the positive complex are hard to verify statistically because not only the P3b but also the P2 overlaps with the early P3. The impression when looking at the data is that in the HUD condition the early P3 subcomponent is strongly enhanced and speeded up compared to the HDD condition. Assuming that the early subcomponent is identical with the P3a and hence attention allocation the data would suggest that compared to the single task condition attention allocation to the array in the dual task condition is impaired for the HDD projection and strongly accelerated and intensified in the HUD projection. In a planned deeper evaluation of the present data set the subcomponents will be separated and measured independently.

Conclusion

Effects of age were visible in the single task condition, elderly drivers having a worse driving performance, increased RTs and higher error percentages compared to younger drivers. When participants had to perform the driving task together with the visual search task on the HDD the driving performance was affected as well as the performance on the dual task for both age groups. These effects were stronger for the elderly drivers, especially for conjunction search displays: their driving performance decreased and they made a large amount of errors in the visual search task. These results replicated the results of section 2.2; this will be further discussed in the overall discusison (Section 3). The ERPs of the elderly drivers may indicate an increase in the preparatory allocation of attention to the visual display in order to prepare for the upcoming visual search, which was supported by the negative shift but only in single task. In general and in single task conditions elderly prepare more intensely for the upcoming visual search task than younger participants. The dual task ERPs appear to indicate a failure of elderly subjects to invest in effortful preparation particularly in the most difficult HDD condition, and this might be one reason for the deterioration of performance. The ERP results further show, as in experiment 1, that the usual P3-analysis for assessing resource allocation in the stimulus-locked data is most likely misleading, while the assessment of the P3b in the response-locked data appears more promising. In fact the response-locked P3b was larger with higher task difficulty, which is in line with the assumption that the P3b – if properly measured – reflects the investment of processing resources to a task.

The HUD had a positive effect on performance in the dual task condition and this improvement was most pronounced for conjunction displays. However, only young participants improved their driving performance and reaction time on the visual search task compared to driving with the HDD. Elderly drivers showed also an improvement with HUD but this was only visible in a reduction of the error percentages, in which younger participants showed improvement as well. It could be the case that, despite instructions that the driving task should be prioritised, elderly drivers focused more on the secondary visual search task.

The data seem to suggest that for a carefully designed display with pop-out features the presentation on a HUD hardly improves performance, but for a display with conjunction features a HUD is beneficial for performance. Driver age is an important factor to be considered when designing the display of information, because elderly drivers' performance is slower and more inaccurate. Elderly drivers did not benefit as much as younger drivers with presentation on a HUD, but the presentation on the HUD did clearly increase their accuracy. It should be considered that even though information presentation on a HUD is more advantageous, it still causes dual task decrements, at least in this simulated driving task.

2.4 Slowing of brake reaction time after a visual or auditory task: an effect of the Psychological Refractory Period

E.S. Wilschut, M. Falkenstein, K.A. Brookhuis

Abstract

When two stimuli are presented in quick succession, the reaction time to the second stimulus is increased. As information systems are being introduced into the car at an increasing pace lately, it is becoming more likely for drivers to have to deal with two or more events around the same time. If one of the events is crucial for driving (such as a brakelights) its processing can be impaired by the other event and hence cause a risky situation or even a crash. The present experiment was conducted to investigate whether the psychological refractory period (PRP) effect influences brake response time when the stimulus onset asynchrony (SOA) between either an auditory or a visual task-related stimulus and a stimulus requiring a brake response is short. As expected, reaction times on the brake lights showed an increase when the SOA was short especially on trials involving a lane change, but also on no-go trials. Thus, cognitive research concerning the PRP may have important applications to driving safety.

2.4.1 Introduction

A large number of studies have shown that performing dual tasks while driving decreases driving performance both in driving simulators and on the road (Brookhuis, deVries, & deWaard, 1991; Brookhuis et al., 2003; Santos et al., 2005). However, not much focus has been on the time course of this dual task interference. From laboratory research it is known that the quality of information processing of two stimuli is decreased when the time window between the two is short (Telford, 1931; Welford, 1952; De Jong, 1993) Logan & Gordon, 2001). This effect is exhibited in the Psychological Refractory Period (PRP) paradigm in which two (simple) stimuli are presented in close succession; this increases the reaction time (RT) of the second response by up to several hundred milliseconds (Figure 2.4.1). Another robust effect of the PRP-paradigm is that the increase in RT is a decreasing function of the interval (in the range of about 0-800 ms) between the two stimuli. That is, when the stimulus onset asynchrony (SOA) is short, i.e. <150 ms, the reaction time for the second response will be considerably slower. It is obvious that if two tasks have to be responded to with the same index finger or if two visual stimuli have a wide visual angle, dual task performance will also suffer because of simple physiological or biomechanical limitations. To avoid these effects and purely focus on effects of information processing limitations the two tasks are often presented in two different modalities (visual and auditory) and responses have to be made with different effectors (vocal, manual). Even when modalities are separated, PRP-effects remain significantly prevalent which suggests a “central bottleneck” of information processing. This effect is called central because a long line of evidence seems to indicate that the bottleneck occurs at the stage of response selection (for a review see Pashler, 1994)) after “early” perceptual processing and before “late” response production.

Several theories have been developed that describe the cause of this bottleneck. The different models of PRP can be categorized along two dimensions. The first dimension concerns the extent to which the performance cost is described as the result of sharing a limited capacity resource as opposed to a bottleneck because of the serial nature of information processing. The second dimension considers the extent to which the cost is a result of structural inability to concurrently select two responses versus a result of cognitive strategic processes of an executive system (Marois & Ivanoff, 2005). The cognitive strategy hypothesis has drawn support from findings that PRP effects can be significantly reduced when subjects are highly trained, provided that the two tasks are equally important (for the conditions under which perfect time sharing is predicted see Kieras & Meyer, 2001). Nevertheless, it has been shown

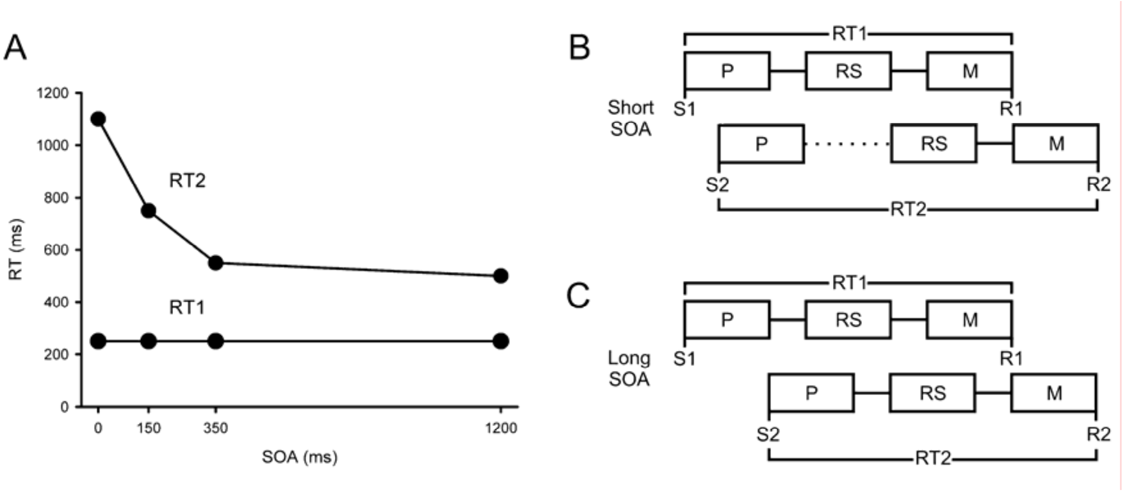

Figure 2.4.1: A) typical reaction time pattern for a PRP-paradigm. SOA: stimulus onset asynchrony. RT1 is the reaction time on the first task, RT2 on the second task, the second task onset is delayed from the first task with a certain SOA . B) Schematic overview of the information processing stages and the bottleneck dashed line) at a trial with short SOA, P= perception, RS= response selection, M= motor execution. The RS phase following S2 is delayed until the RS of S1 is completed. C) Same as B but with a long SOA between task 1 and 2. Note the reduced delay between the perception stage and the response selection following S2.

that with extensive practice the PRP effect does not completely disappear (36 sessions Ruthruff et al., 2001; 3408 trials of which 852 dual task; Tombu & Jolicoeur, 2004)

It is unclear, however, whether PRP effects are relevant in real-life situations because these laboratory studies usually involve simple and artificial tasks. Also PRP-effects in real life settings could be diminished because of the high level of practice experience people generally have with the task, e.g. braking in a car. From an applied perspective the possible reaction time increase by PRP effects on braking is interesting because several hundred milliseconds delay of brake onset could mean the difference between having an accident or not. The only experiment thus far concerning the question whether the PRP effect generalizes to real-life activity of driving was conducted by Levy et al. (2006) in a driving simulator. In that experiment the participants performed two tasks concurrently. First, a choice task where the participants responded either manually or vocally to the number of times a visual or auditory stimulus occurred (1 or 2 times). Second, a braking task in which the participants had to press the brake pedal as soon as they detected the lead car's brake lights. The time between the onset of the lead vehicle's brake lights and the subject's braking response is referred to as the "brake RT". The SOA between the stimuli in the two tasks was varied: 0,150, 350, 1200 ms. Results showed that at the SOA of 0 ms, the brake RT was slowest and the RT decreased over the next two SOA levels to the level of the braking task without a secondary task. Results showed no significant brake RT differences between vocal or manual responses. However, brake RT's were slightly faster following auditory than visual stimuli. The authors argued that this could be attributed to a conflict in visual perceptual processing between the two visual stimuli or simply that visual perceptual processing took longer than auditory because RTs were also longer for visual stimuli in the single task condition. This experiment showed that a highly practised real life task (braking) can be slowed up to 175 ms by a previous event due to the PRP-effect/ the central bottleneck.

In the Levy et al. (2006) study the choice task was very simple and irrelevant to the driving task. In the present experiment PRP-effects are investigated on brake RT when the secondary task is relevant to the driving task as well. In this experiment we wanted to investigate whether the slowing of the brake RT depends on the relevance of the choice reaction task for the driving/tracking. Therefore, a visual or an auditory stimulus was used to indicate on which of two lanes the participant had to perform a tracking task. Participants had to identify which lane was indicated, decide whether it was necessary to change to a different lane and, if so, to execute the required movement to arrive in the middle of the other lane. In a third of the trials a neutral stimulus was given which was clearly distinguishable from the lane-indicating stimuli, and did not represent a required lane. After a neutral stimulus the brakelights would appear with different SOAs. In the condition in which a lane change response has to be executed, the brake RT should be delayed when the SOA between the “lane-stimulus” and braking light of the leading car was short. In the condition in which the participant has to decide that it was not necessary to change lane short SOAs are expected to slow the brake RT as well, because the correct response – do not change lanes – still had to be selected. Because no motor response was required and it is shown that the PRP effect is reduced in size but still present when the first task does not require a response (De Jong, 1993) a diminished but still present effect in this condition was expected. For the neutral stimuli we expect that brake RT after would hardly show an influence of SOA. Finally, in accordance with the results of Levy et al. (2006) brake RT should be slower when visual stimuli were used rather than auditory stimuli. Tracking difficulty was manipulated by either right or left hand tracking.

2.4.2 Method

Fourteen students (Mean age = 20.5 (0.7) years) participated in a 90 minute session in exchange for a partial course credit. All participants were right handed and had had their driver's license for at least 2 years. They had normal or corrected to normal vision.

Driving was simulated by a tracking task. Participants had to maintain their car in the centre of one lane at a two lane road (Figure 2.4.2). This was done with a regular mouse and the tracking task had to be performed either with the left or the right hand. The primary task was a *lane change task*; the lane on which the participant had to ‘drive’ was indicated by either visual or by auditory stimuli. Visual stimuli appeared on the number plate of the car (X=’drive at the left lane’ or O=’drive at the right lane’ for 200 ms), and auditory stimuli were either a high or a low tone (1250 Hz=’drive at the left lane’ and 750 Hz’drive at the right lane’ , 200 ms, 60 dB). The participant could either already be driving on the lane that was indicated and thus not need to change position (‘*keep lane’* in 33% of the trials) or had to change to the other lane (‘*change lane’* in 33% of the trials). On one third of the trials a neutral visual or auditory cue was presented instead of a stimulus which indicated the left or right lane. For the neutral visual cue the number plate changed colour from grey to white and the neutral auditory cue was a burst of white noise (200 ms, 60 dB). For the secondary task, called the *brake task*, the participants pushed a button with the index finger of the other hand as soon as the brake lights of the car turned red. The time between the stimuli indicating the lane positioning and the brake task was varied (SOA= 0, 100, 300, 800, 1200, 1600 ms). Total trial duration was 3 seconds. Participants were asked to give priority to the lane change task and to perform both tasks as quickly and accurately as possible. After being instructed, participants performed two training blocks, one visual one auditory, with a total of 180 trials. The experiment consisted of 6 blocks of 180 trials. Half of the blocks were with visual stimuli, the other half with auditory. After each block self-reports of invested effort were rated with a

German version of the Rating Scale of Mental Effort (RSME; (Zijlstra, 1993)). Between blocks participants were allowed to rest. Halfway through the experiment the participants had to switch the hands to perform the tracking and the brake task.

The experiment was programmed using E-prime (Psychology Software Tools, Inc., Pittsburgh, USA), which ran on a regular PC and a 19 inch CRT-monitor was situated on a table about 80 cm in front of the participant. Brake lights and number plate were within 1° visual angle. The loudspeaker was situated on the table next to the monitor. The data were subjected to ANOVA repeated measurement analyses (SPSS 13.0). Post hoc tests were performed on the SOA levels using Bonferroni's method to adjust the significance level for multiple comparisons. In case of sphericity violation the Greenhouse-Geiser modification was used. The data of the lane change task were used to define if participants drove on the correct lane. Brake RTs were only analysed if the lane positioning was correct.

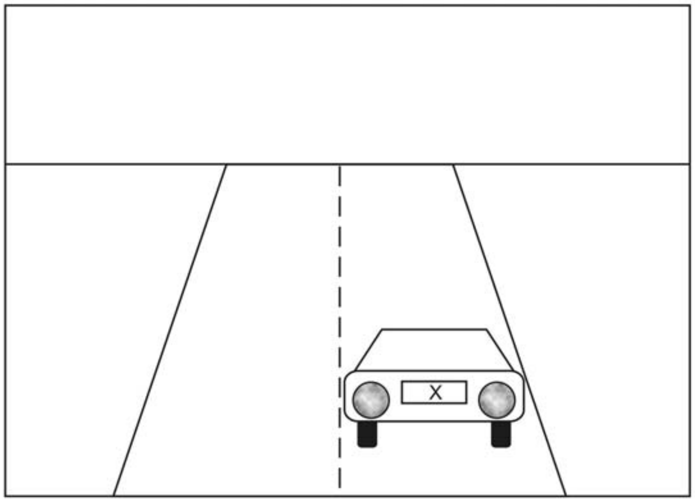

Figure 2.4.2: Participants had to maintain their car in the centre of one lane at a two lane road. The primary task was a lane change task. The lane on which the participant had to 'drive' was indicated by either visual or auditory stimuli. Visual stimuli appeared on the number plate of the car (in this case "X"). For the second task, called the brake task, the participants pushed a button as soon as the brake lights of the car turned red.

2.4.3 Results

The results for the brake RT as a function of SOA are shown in figure 2.4.3. The effect of SOA was significant (F(5,65)=32.6, p<.001). High brake RTs were present in accordance to the PRP effect for the short SOA and RTs decreased for longer SOAs (all p-values <.01; except for SOA 1200 vs. 1600). Collapsed across all conditions RT was highest at SOA 0

(695 ms, S.E.=28) and decreased to 532 ms (S.E.=12) at SOA 1600. The effect of stimulus type (change lane, keep lane, neutral) on brake RT was significant (F(2,26)=33.9, p<.001). The change lane condition produced the highest brake RTs, followed by the neutral stimuli and the keep lane conditions which was equal to neutral stimuli for the three shortest SOAs and after that RTs were shorter for keep lane trials (all p-values <.03). Also the interaction between SOA and lane change condition reached significance (F(10,130)=28.1, p<.001). Brake RTs at the change lane condition were only significantly higher for the shortest four SOAs than those at the keep lane condition. Brake RTs for the change lane condition started at 794 ms for SOA 0 and with prolonging of the SOA the RTs became smaller at each increase except for SOA 100 versus SOA 300, until they reached 510 ms at SOA 1600. For the keep lane condition brake RTs were lower than for the change lane conditions at SOA 0 (660 ms). The pattern followed the PRP effect and brake RT significantly decreased with increasing SOA (521 ms at SOA 1600). At SOA 1200 reaction times became equal for the keep and change lane conditions and remained so at SOA 1600. Brake RTs after the neutral

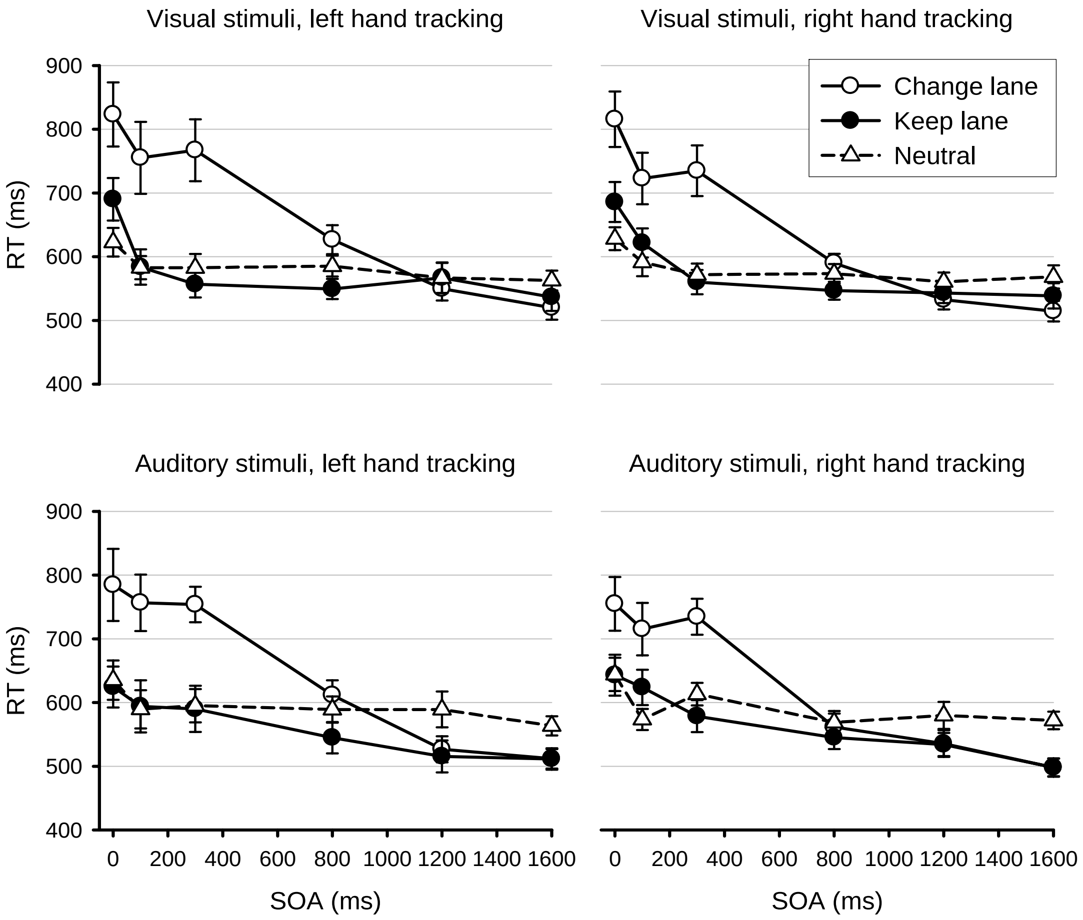

Figure 2.4.3: Reaction times on the brake light (brake RT) as a function of SOA for right / left hand tracking and the visual /auditory conditions: change lane, keep lane and neutral cue.

stimuli showed a larger RT for SOA 0 than for the longer SOAs, for which the brake RT did not show a significant decline (p<.05; tested to the previous SOA-level).

There was a significant effect on brake RT for left versus right hand tracking but only in the lane change condition (F(2,26)=6.5, p<.006).For the ‘change lane’ condition the brake RT was prolonged for 23 ms when tracking was performed with the left hand and braking with the right hand than when reversed. Although for every condition brake RTs were slower after visual stimuli than for auditory stimuli, except for the neutral stimuli, this effect did not reach significance. Tracking data showed that left hand tracking caused a larger deviation from the ideal lane tracking than right hand tracking (F(2,26)=21.3, p<.001). In the lane change trials with right hand tracking, the movement started at 493 ms after the visual or auditory stimuli. With left hand tracking the start of the movement was delayed to 606 ms. With both hands the lane change movement was completely finished at about 1100 ms. There was no effect of SOA on quality of tracking.

The number of errors (see table 1; mean total errors =5.2%) showed a significant main effect of SOA (F(5,65)=16.5, p<.001) and lane change condition (F(12, 26)=7.5, p<.003). And the interaction between SOA and lane positioning stimuli was also significant (F(10, 130)=12.8, p<.001) For the first three SOAs error rates were equal among lane position stimuli but they increased significantly for the keep lane and change lane for SOA 800, 1200 and 1600. About half of the errors were made because people pressed too early i.e. before the brake lights appeared at the long SOAs. Error rates for neutral stimuli were independent of SOA and showed no significant effect. The self report of effort showed no significant difference between blocks with auditory or visual stimuli. Surprisingly also no significant difference was found for subjective effort between right and left hand tracking. Overall participants gave an average rating of 58 which is labelled on the scale as ‘rather much effort’.

Table 1: Percentage of errors for each condition as function of SOA

	SOA (ms)					
Condition	0	100	300	800	1200	1600
Change lane	2.9	2.8	2.0	5.6	7.9	10.0
Keep lane	2.3	2.6	2.5	8.6	9.6	14.2
Neutral	4.2	4.4	4.1	3.8	3.3	2.6

2.4.4 Discussion

The results showed that the brake RT was significantly longer at shorter SOAs, especially in the change lane condition. This is in accordance with a classical PRP effect. The effect of

SOA on brake RTs (difference between SOA 0 and SOA 1600) was about 280 ms in the change lane condition. In real traffic this would mean continuing almost 8 meters before stopping when driving at a speed of 100 km/hour.

Interestingly, the brake RTs for left hand tracking were higher than with right hand tracking but only in the change lane condition. It seems that the difficulty of the tracking task influences the brake RT. Secondly, the data seem to show that SOA 300 is special in the change lane condition because RTs remain as high as SOA 100 although they should become quicker. It could be so that participants are slower because they focus on performing the lane change in a correct manner. However, a PRP effect, although smaller, was also found in the keep lane condition, so that executing the lane change movement was not the sole cause of the effect of SOA. The decreased effect was expected because no-go trials are known to produce a smaller PRP effect (De Jong, 1993). In the neutral condition, however, the PRP-effect was only weakly present, showing that a PRP effect was only strong for stimuli that in some cases had to be followed by a response. However, even in the neutral condition there was a significant PRP effect for SOA zero, which shows the distracting effect of any irrelevant stimuli for driving performance.

The number of errors increased with long SOA because participants reacted too soon. They may have adopted a strategy to prepare for early brake light. In contrast to the findings of Levy et al. (2006) we did not find a clear effect of modality although visual stimuli tend to give higher brake RTs. Visual and auditory stimuli both elicited the same brake RT patterns. The small visual angle between the two visual stimuli locations could explain this result; also this experiment had less visual distracting information than usually present in a driving simulator environment. The results imply that even when the information given by a driver assistance system does not require a response and is irrelevant the stimulus could still disturb driving performance.

In conclusion, timing is an essential factor determining the impact of interfering stimuli. After all, display characteristics can be controlled by a designer, but external events such as a sudden brake of another driver are unpredictable. However care must be taken to ensure that experimental designs include relevant timing relationships. If for instance IVIS events and driving events were always separated by relatively long periods of time, the potential interference could be underestimated.

2.5 The effect of visual search complexity and stimulus onset asynchrony on brake reaction time in a driving simulator

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Abstract

The time course of surrogate-IVIS interference on brake reaction time (RT) was shown in the current driving simulator. Brake RT was increased when the SOA between the surrogate-IVIS display and the onset of the brake lights was short. This effect was stronger for elderly drivers. The target in the surrogate-IVIS display required either pop-out or conjunction search for both young and elderly drivers. At short SOAs, the brake RT was higher after the presentation of a conjunction than a pop-out search display. After conjunction displays, drivers reduced driving speed more strongly than for pop-out displays. The ERPs showed age effects for the P3 locked to the IVIS stimuli: the frontal P3 was larger in elderly than in young drivers. Trials with a conjunction search display caused the alpha power at parietal electrodes to decrease both for young and elderly drivers.

2.5.1 Introduction

Performing two tasks at once generally decreases the performance of one or both of them and performing additional tasks while driving can deteriorate driving performance (e.g. Brouwer 1991; Brookhuis et al., 1991; Janssen et al., 1999; Santos et al., 2005). Such performance reductions are called dual task costs. Not only is there the potential for interference and a greater draw on resources, subjects have to additionally deal with coordinating the two tasks. Introducing an in-vehicle information system (IVIS) into the car creates a dual task situation. This could be highly relevant for elderly drivers, as ageing has been reported to lead to impaired performance in dual task situations (Verhaeghen et al., 2003). These drivers could have more difficulty achieving adequate time sharing or using compensation strategies to cope with the dual task situation of driving and dealing with an IVIS. It has been suggested (Craik & Salthouse, 2000) that an increase in dual task costs with ageing is a result of general slowing of information processing combined with impaired coordination between to tasks required for time sharing. However, there are studies that have found no age-differences in dual task performance (Baddeley, 1996; Baddeley, 2002). Results of a meta-analysis (Verhaegen, 2003) showed that both young and older adults show dual-task costs, i.e. performing the dual task requires an extra processing stage over those needed for single task completion. These extra costs were larger for older adults and were larger than would be expected from general slowing. Another meta-analysis (Riby et al., 2004) found similar age effects on dual task costs, which were more pronounced for tasks that required controlled processing or had a difficult motor component.

The psychological refractory period (PRP) may play a role in dual task costs. In the PRP-paradigm, two choice tasks are presented to the participant with a short time interval between the two tasks. The time interval is called the stimulus asynchrony onset (SOA). Interference in the PRP-paradigm is revealed by an increase of RTs for the responses to the second task, the effect increasing as the SOA decreases (Telford, 1931; Welford, 1952; De Jong, 1993; Logan & Gordon, 2001). The most common interpretation is that this reflects a bottleneck of central stage processing associated with the selection of the one of the possible responses (e.g. Pashler, 2004). That is, there is a certain period following one stimulus in which the response to a second cannot be selected. A larger PRP effect has been found with higher age (Göthe et al., 2007), suggesting that the PRP may be an important factor in the use of IVIS by elderly drivers.

In a review on brake RT by Green (2000) it was concluded that brake RT studies have produced mixed results regarding ageing. Older drivers responded more slowly in some cases (Broen, 1996; Lings, 1991, Nilsson, 1991; Summala, 1990 in Green, 2000) However in other studies no slowing of the brake RT was found with age (Korteling, 1990; Olson, 1986). Green argues that this finding is caused by a bias; older people who are in better health are more likely to drive and participate in experiments. Moreover ageing tends to make the older driver population heterogeneous and their data more variable, which makes it harder to find significant differences. Olson & Sivak (1986) suggest that older drivers have more experience and that their experience compensates for any slowing of movement or perception. It would be highly interesting to examine the mechanism for compensation, e.g. with neurophysiological methods such as ERPs. Comparing the results of the meta-analysis Green (2000) suggests that age effects occur in driving simulator studies but tend to disappear in on-road studies. Hence an effect of age on brake RT is likely to be found in a driving simulator study, especially together with increased task complexity and information processing demand (Summala, 2000).

Measures derived from the electro-encephalogram (EEG) may help assess the dual task demands induced by the IVIS and reveal processes underlying effects of search complexity and ageing. These include the P3a and P3b event-related potential (ERP) components, and alpha power (8-12 Hz). As mentioned above, the parietal P3b amplitude has been shown to be sensitive to resource allocation in a dual task paradigm. For example when priority is manipulated higher priorities are associated with larger P3b amplitudes (Hoffman et al., 1985). The P3b amplitude of the primary task increases with increased primary task difficulty (Wickens, Kramer, Vanasse, & Donchin, 1983; Sire vaag, Kramer, Coles, & Donchin, 1989) while the P3b on secondary tasks decrease with increases in the primary task difficulty (Isreal, Chesney, Wickens, & Donchin, 1980; Kramer, Wickens, & Donchin, 1983). Thus, P3b amplitude seems to be sensitive to resource allocation. In visual search tasks, the P3b amplitude of target trials is less enhanced for old than for young participants (Lorist, Snel, Mulder, & Kok, 1995). Compared with the P3b, the P3a component has a more frontocentral maximum and an earlier latency. The P3a is associated with novel stimuli or unexpectedness and attentional requirements (i.e. difficulty of stimulus discrimination or presence of distractors). The P3a has been linked to the orienting of attention, or processing biasing, towards a potentially significant stimulus (Rugg & Coles, 1995). Finally, alpha-band power has been used as a monitoring tool for drivers' state studying workload vigilance, drowsiness and attention (Schier, 2000; Brouwer et al., 2004). Alpha power tends to increase with time-on-task and fatigue (e.g. Schier, 2000, Wilschut, 2005, Papadelis et al.,2007) and decrease as a function of increased task demand (Kramer & Strayer, 1988; Sirevaag, Kramer, Coles, & Donchin, 1989; Fournier et al., 1999).

Aim of the study

When the driver interacts with an IVIS while driving, a dual task situation occurs. The reaction time to an event in traffic, for instance an emergency brake, might be affected by the IVIS information processing depending on the timing of the traffic event relative to IVIS-related events. This could result from a gaze direction away from the road, visual load, cognitive load or possibly the PRP-effect. Braking however is a highly practiced motor response and a go/no-go type of response instead of a choice reaction as usually used in the PRP paradigm. However, in section 2.4 we showed that simple reactions can elicit a PRP effect and Levy and Pashler (2006) found that this PRP effect appears with short SOAs when a secondary visual or auditory task was followed by a brake response when driving in a simulator. To extend these studies, we varied the IVIS complexity using pop-out and conjunction displays (Treisman & Gelade, 1980). In section 2.2 & 2.3 we showed that elderly people need more time to process a visual search display. Therefore we expect their reaction to a lead car's brake lights to be more affected by the IVIS, especially when the surrogate IVIS display requires conjunction search. To investigate the time course of this dual task interference in this experiment the stimulus onset asynchrony between the presentation of an IVIS display and the brake lights of a lead car was varied. We expect that if the IVIS display is more complex, drivers will need more time to evaluate the display. Because the processing of the IVIS-display takes longer, we expect the brake RT to be more strongly affected at short SOAs.

2.5.2 Method

Participants

Twenty-nine volunteers participated in the experiments: 16 young participants (7 male), aged 21-28 years mean age 23.9 (SD=2.3) and 13 older participants (6 male), aged 50-64 years mean age 58,8 (SD=4.9) The participants had normal or corrected to normal vision. The participants had not taken stimulants during the 12 hours before the experiment and had had a normal sleep in the night before the test. All participants described themselves to be right-handed. All participants had their driver's license for at least 2 years and had an annual mileage of at least 10.000 km per year. With five initially recruited elderly drivers the experiment had to be aborted in the training phase due to simulator sickness. Two more old participants were excluded from analysis based on their large amount of errors in the driving task.

Stimuli and procedure

The primary task was a car-following task in which a participant followed two cars on a two lane road. Participants were instructed to keep a normal distance to the cars in front. When they were at a speed of 80 km/h a secondary task was presented directly in front of the participant without blocking the view on the lead cars brake lights. The secondary task was a visual search task that was used as a surrogate IVIS, with a duration of 2 seconds. Participants had to find either a green "**X**" or a red "**O**" presented between 4 distractors which could either be green "**O**"s and/or red "**X**"s. The visual search could either be pop-out (**XXXOX**) in 50% of the trials or conjunction (**XOXOO**) in the other half of the trials. The target letter indicated the lane that the participant should drive in. Two conditions were distinguished: either the participant was driving on the lane that was indicated and thus did not need to change position (*'keep lane'* in 50% of the trials), or he did have to change to the other lane (*'change lane'* in 50% of the trials). When the car needed to change lane participants were required to wait for an auditory stimulus (a 2000 Hz tone) until 3 seconds after the visual search task to perform the required manoeuvres to change lane (Figure 2.5.1). This was done to separate the lane change manoeuvre from the dual task situation, which hence only consisted of (probable) braking and deciding whether to change lanes or not. After each visual search stimulus the lead cars could brake in 80% of the time, with a SOA of 500, 600, 700 or 800 ms. Participants were instructed to brake as quickly as possible when the cars in front braked, even when they would not have braked in a normal driving situation. Brake RT was measured as the time between the onset of the brake lights and pushing the brake pedal of the simulator.

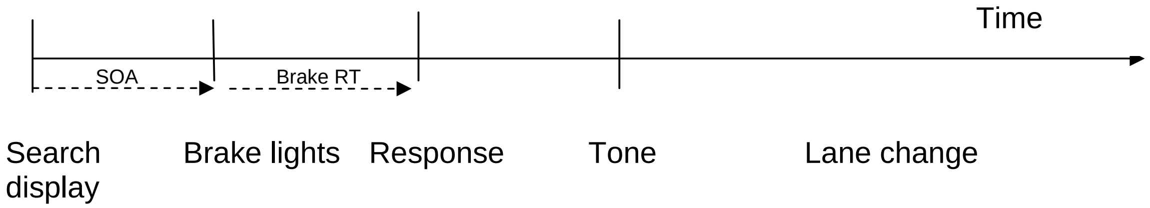

Figure 2.5.1: Schematic presentation of a trial which starts with a pop-out or conjunction search display where the target defines the right lane to drive at. After a SOA (500, 600, 700, 800 ms) the brake lights of the two lead cars could light in 80% of the time in which case the participant had to brake as well (brake RT). The tone indicated when to change lanes, as was required in 50% of the trials.

At the start of the session participants completed the Trail Making Test, part B. This paper and pencil test is used to measure mental flexibility, visual search and motor function. The participant is required to connect 25 numbers and letters in their natural order, but alternating between letter and number (A-1-B-2-C-…). The total time to complete the task is the score on the test. The time to complete the Trail Making B increases with age and can predict driving performance (Stutts,1998).

After participants performed a training block to get used to the driving simulator EMG, EOG and EEG electrodes were applied. In total six experimental blocks were performed with 100 trials each. Between blocks the participants were allowed to take a short rest.

Data recording

The driving simulator included a fixed-base mock driving set-up with a car seat, steering wheel, pedals, clutch and indicators (Volkswagen style). The projection of the virtual world consisted of three channels each displayed on frontal 32 inch screens, which gave the participant a 210° view. The screens had a frame rate of 60 Hz and driving performance data was measured at 10 Hz. The driving simulation software was developed by ST Software©, and is capable of simulating highly interactive traffic. For the experiment a two-lane road was constructed with a simple rural environment. Two lead cars drove at a speed of 80 km/hour in front of the participant, but speed was adjusted when participant used the brakes, so that the cars were always within 50 metres distance. Velocity, lateral positioning, time headway and brake RT were measured. Brake RT was defined as the point when brake force was higher than 5% of the maximum brake force. The electroencephalogram (EEG) was recorded using 20 Ag/AgCl electrodes attached to an electrocap, from positions: AFz, Fz, F3, F4, FCz, FC3, FC4, Cz, C3, C1, C2, C4, CPz, Pz, P3, P4, POz, PO3, PO4 and Oz. All electrodes were referenced to linked ear electrodes. The electro-oculogram (EOG) was recorded from the outer canthi of both eyes and above and below the right eye, using Ag/AgCl electrodes. The electromyogram (EMG) was measured at the calf of the right leg to record the muscle activity of the movement of the foot releasing the gas pedal and applying the brake pedal. Electrode impedance was kept below 5kΩ for head electrodes,10 kΩ for EOG electrodes and below 20 kΩ for EMG electrodes. EEG, EOG and EMG were sampled at 200 Hz.

Data analysis

All data were analyzed using the GLM repeated measurements test of SPSS 14.0; in the case of sphericity violation the Greenhouse-Geiser modification was used. The behavioural measures of brake RT, accuracy and velocity were analysed using custom Matlab programs.
The EEG data were corrected and analyzed using Brain Vision analyzer. The EOG was used to remove ocular artefacts from the EEG (Gratton & Coles, 1983). For ERPs the baseline was 100 ms preceding the visual search stimuli. ERPs were locked to visual search stimuli, and the P3a was analyzed at Fz and the P3b amplitude at Pz both measured as maximum positive peak between 250 and 500 ms. The EMG was used as an extra measure for brake RT. Effects of age (young / old), visual search type (pop-out / conjunction), SOA (500, 600, 700 and 800 ms between visual search task and the onset of the brake lights) and lane change (keep lane / change lane) were analysed. For the EEG spectral analysis segments of 6 seconds were created and segments with artefacts were discarded. A Fast Fourier Transform was calculated and averaged over segments. Power was exported of the Alpha I (8-10 Hz) for each condition.

2.5.3 Results

Elderly drivers had much longer brake RTs (mean=1213 ms) than younger drivers (mean= 848 ms; F(1,25)=13.0, p<.001; Figure 2.5.2). Brake RT was higher when the SOA was short and decreased for each longer SOA (F(3,75)=7.4, p<.001). Bonferroni post hoc comparison showed that this decrease in brake RT was significant for each prolonging of SOA (p<.03), except for SOA 700 and 800. There was an interaction of SOA with age (F(3,75)=7.4, p<.008) showing that short SOAs increased brake RT more for elderly than for young drivers. If the conjunction search display required a change of lane, brake RTs of the elderly participants were quicker than when they had to stay in the same lane (F(1,25)=3.9, p<.048) while for young drivers this effect was absent. Further, for elderly drivers brake RT was 170 ms longer when a conjunction display was presented before the brake light than a pop out display. The interaction age by display type was significant, i.e. for younger drivers the type of display had a smaller effect of 64 ms (F(1,25)= 8.1, p<.009).

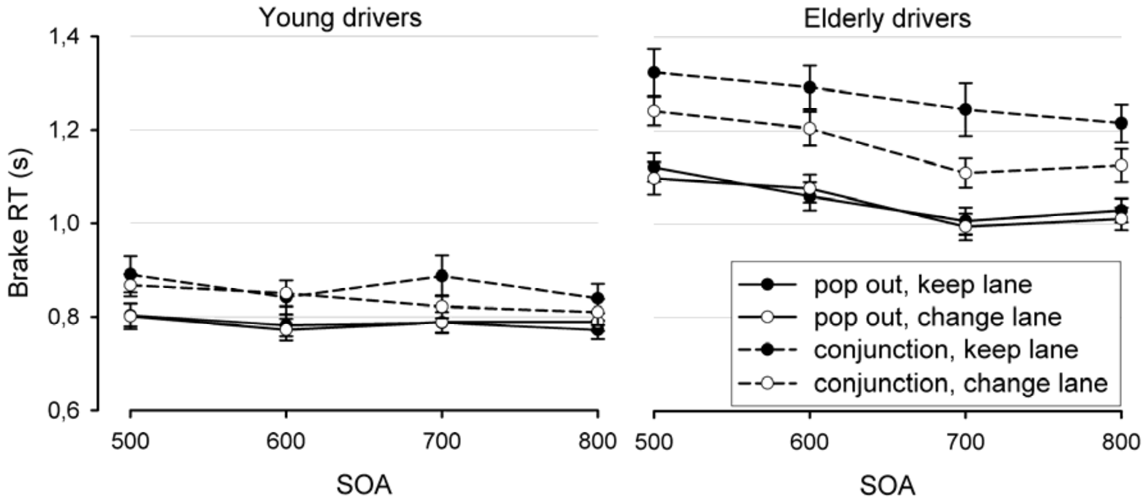

Figure 2.5.2: Brake RT for young and elderly drivers, showing the reaction times on the lead car's brake light in seconds. Reaction times are displayed for the different the different SOA of the brake lights, visual search type (pop-out/conjunction) and for trials in which the visual search display indicated a change of lane or keep in the same lane.

Error percentages showed that elderly drivers had more difficulty performing the brake task correctly and the lane-change manoeuvre and failed to do so in 31 % of the trials, whereas younger participants had an error percentage of 19% (F1,25)=4.9, p<.036). More errors were made in trials with conjunction search displays than with the pop-out stimuli (F(1,25)=13.7, p<.001); this effect was not influenced by age. There was an effect of SOA showing that participants made more errors for the shortest SOA compared to the later SOA (F(3,75)=5.7, p<.001) and there was an interaction between age and SOA; this was due to a more pronounced effect of age at shorter SOAs. The age difference in error rate was largest for the shortest SOA (SOA 500=11%) and was reduced when SOA interval became longer (SOA 800= 4.3%).

The Trail Making Test B showed a significant effect of age (F (1, 25) =9.8, p<.004): younger participants needed 41 seconds (SD=15.1) to complete the test whereas elderly participants needed 92 seconds (SD=45.8). This result correlated moderately with age and had a Pearson correlation of r^2=.40 (p<.001). Completion time also showed a weak although significant positive correlation with brake RT (r^2=.25, p<.003) and error percentage (r^2=.19, p<.009).

The relative velocity per condition shows how strongly participants reduced their speed by braking after the lead cars braked (Figure 2.5.3). When braking after pop-out displays, speed was reduced down to 12% of the original baseline speed; with conjunction displays participants reduced their speed to 10.6% (F(1,25)=23.3, p<.001). When the target of the

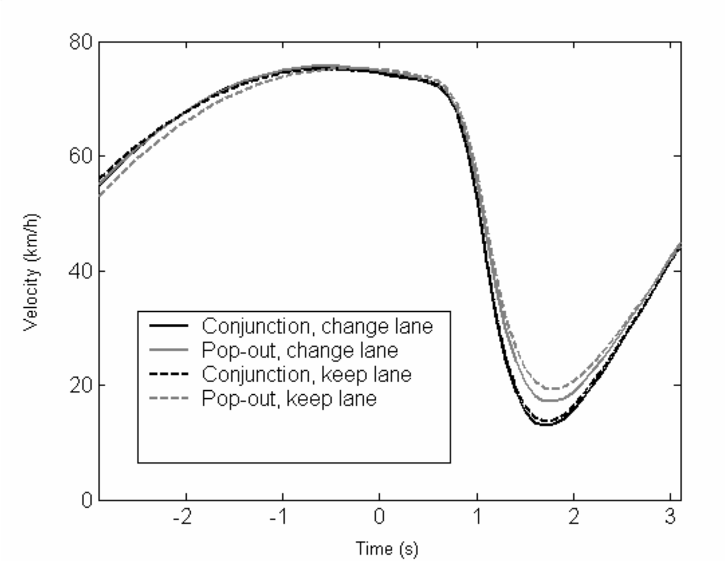

Figure 2.5.3: Velocity in km/h locked on brake-light onset (time= 0). For visual search type (pop-out/conjunction) and for trials in which the visual search display indicated a change of lane or keep in the same lane.

search display had indicated the need to change lane participants reduced their speed more (11.3%) than when no lane change was required (10.5%; F(1,25)=17.5, p<.001). An analysis of the absolute speed showed the same pattern of results. There was no interaction and no effects of age were found.

The variance of the lateral positioning showed no effects in the first second after presentation of the search display. The absolute values of the lateral position showed an effect for display type at the moment of lane change, showing that the lane change after conjunction displays was initiated later (F(1,25)=12.3, p<.003).

The alpha power (8-10 Hz) per trial showed a significant alpha decrease at parietal electrodes with conjunction displays compared to pop-out displays (F(1,25)=45.9, p<.001; Figure 2.5.4). There was an effect of age showing that elderly drivers had lower alpha power overall (F(1,25)=11.4, p<.001). The young drivers showed a larger decrease in alpha power for the conjunction search (F(1,25)=6.6, p<.011).

The ERP locked to the visual search display showed a large positive peak after 300 ms (Figure 2.5.5). The P3 at Fz had a significantly larger amplitude for elderly than for younger drivers (F(1,25)=4.1, p<.045), but could be contaminated by horizontal EOG. At parietal electrodes the P3 had a larger amplitude in younger than older drivers (F(1,25)=4.0, p<.046).

Latencies of the P3 were significantly longer for elderly drivers (F(3,75)=10.4, p<.001). There were no effects of visual search type.

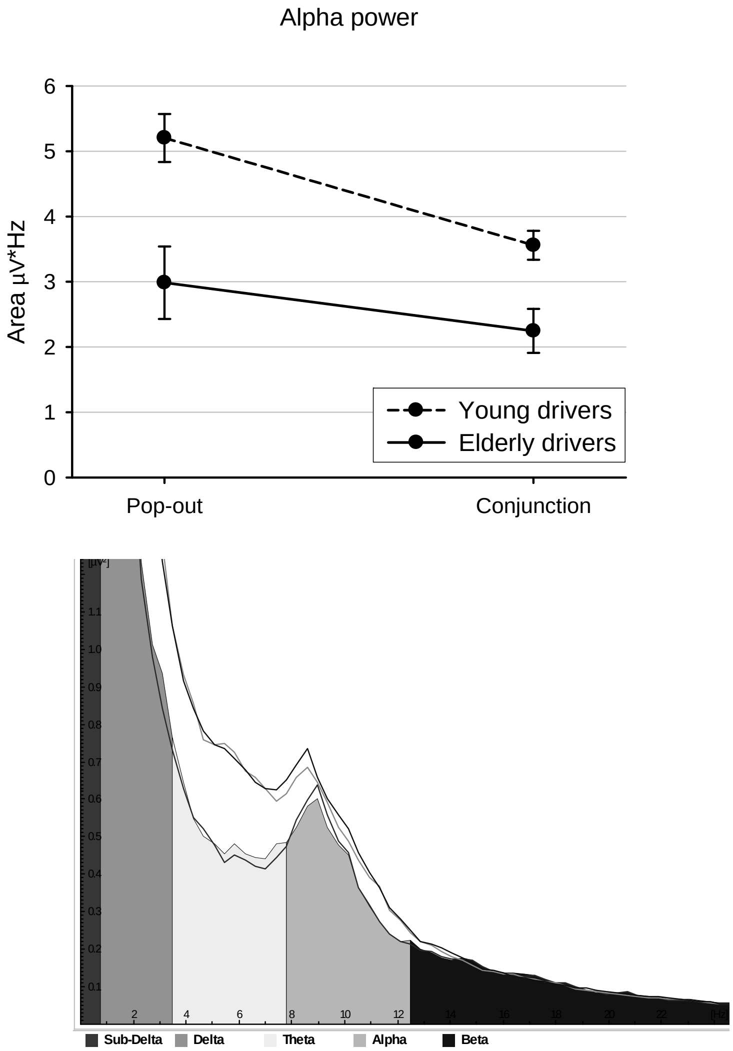

Figure 2.5.4: Alpha power (8-10 Hz) averaged over trials for pop-out / conjunction search and for young (higher curves) and elderly drivers (lower curves).

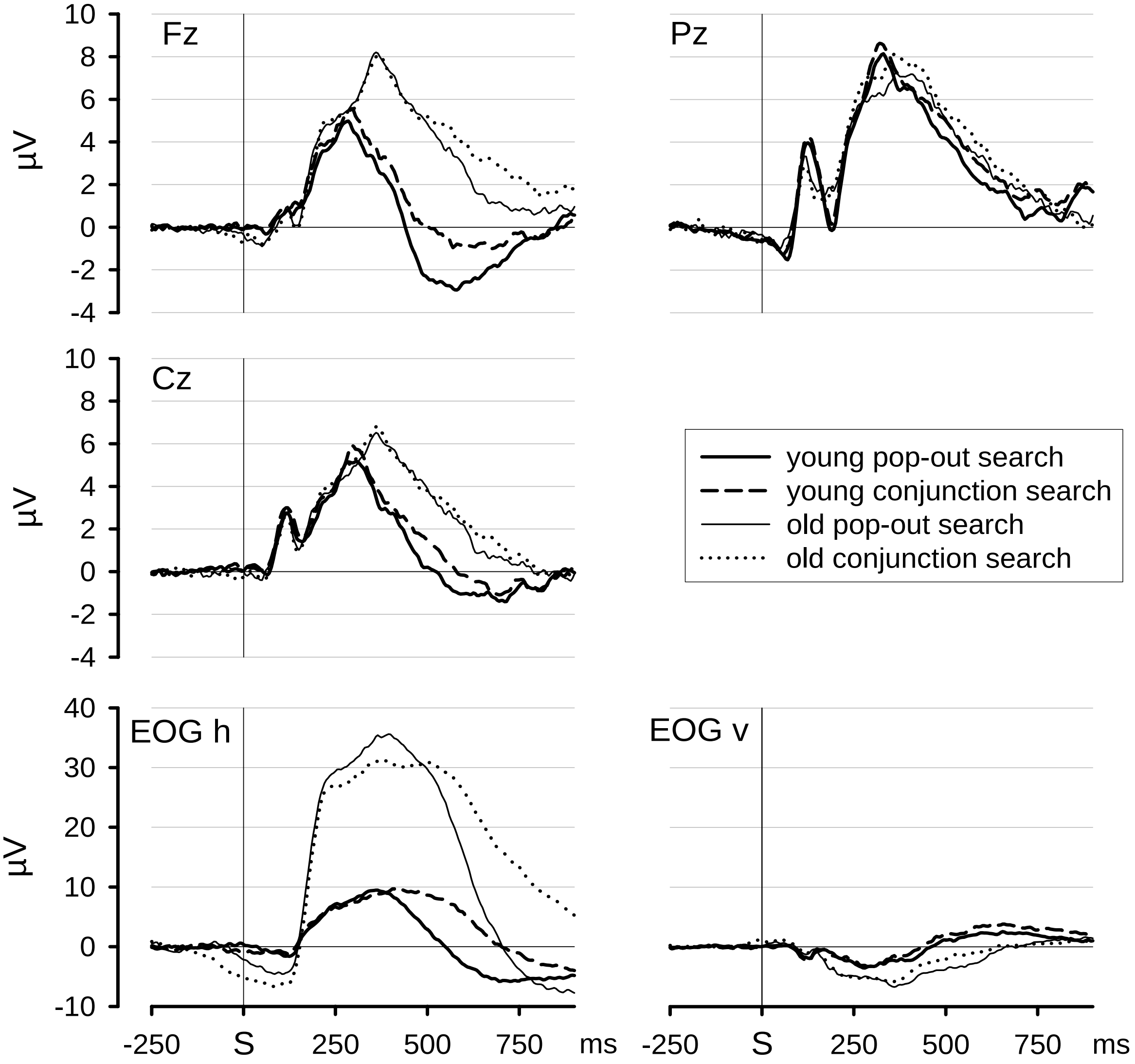

Figure 2.5.5: Grand-average ERPs time-locked to the visual search stimuli for both age-groups and pop-out vs. conjunction search for Fz, Cz and Pz and the uncorrected EOG channels. Note that the EEG channels have a different scaling than the EOG channels.

2.5.4 Discussion

As expected, the results showed dual-task interference that depended on the stimulus-onset asynchrony (SOA) between an IVIS task and a driving task. Elderly drivers suffered more from short SOAs, suggesting that timing may be an important factor to consider in designs aimed at evaluating effects of IVIS on driving. As in other experiments, we found evidence for an effect of search complexity on driving performance, indicated by slower or missed braking following a conjunction search display. These effects were more pronounced for older participants. This may be due to a reduction in cognitive flexibility; as suggested by the Trail Making Test B results, which showed longer completion times for older participants and that we interpret here as reflecting primarily cognitive processes (Stutts,1998). An interesting effect was that of improved brake times in older drivers following conjunction search when they had to change lanes compared to the keep lane condition. This could be explained as a need to have shorter brake RTs to be able to prepare for the upcoming lane change. This would suggest the possibility of elderly to exert a certain degree of control over brake RT even in case of dual-task situations.

Further, indices of heightened attention and effort were found in the EEG: the P3 was much larger at Fz for old than young drivers, which may reflect an enhanced P3a, which is thought to be linked to orientation of attention (Friedman et al., 2008). There are indications that altered executive processing in older adults results in the recruitement of prefrontal cortex at a lower task demand and with more types of attentional realocation than in younger participants, and that is reflected in the P3a amplitude (Friedman et al., 2008). For the current study this suggests that the elderly drivers were allocating more prefrontal resources to the display than the young drivers. However, the P3a results may have been influenced by differences in reaction time variation across conditions and subjects, and eye movements which were different for age-groups. Especially the horizontal EOG may potentially have caused artifacts. However the age differences in the ERPs do not seem like to be purely EEG artefacts; until 250 ms the ERPs at Fz hardly differ in amplitude between the age groups whereas the EOGh already shows a clear difference. Hence it appears that the P3 effect is a genuine one. This result is nicely in line with the finding of enhanced P3a to cues in the preceding experiments and shows enhanced orienting of elderly to relevant stimuli. Alpha power also showed effects of age, suggesting that elderly drivers show less variation in invested effort over conditions, perhaps because they were continuously taxed to a greater extent. Alpha power provides a complementary index to ERPs due to its insensitivity to precise event timing. Further, power measures could even be used in the absence of stimuli, which may provide the opportunity to probe fluctuations in attention without having to use driving-unrelated stimuli.

The current study involved a simulation, and so the question of generalization to real life must be raised. An effect of age on brake RT in a driving simulator study has also been obtained in a previous study (Summala, 2000), but an absence of an age effect has been reported in real traffic by Green (2000). On the other hand, the effect found here could be more severe in real traffic, because drivers have to consider alternative options. Instead of an emergency brake they might consider avoiding the car in front by steering, in that way it would no longer be a simple reaction but a choice reaction that could lead to higher brake RT. Moreover in real traffic the emergency braking could be far less expected by the driver than in our study , therefore the dual-task costs should be even higher in real traffic situations. Unexpected brake responses are associated with a brake RT which is about twice as long as brake RTs to an expected event (Green, 2000). Also more complex driving choices would likely to exacerbate the “PRP-like” effects we found. However, it must also be noted that in real driving, many compensating factors may be relevant. Subjects may for instance choose to ignore the IVIS until the road is safe. Such strategic compensation may be especially important for the generally more experienced older drivers. In conclusion, future studies could be aimed at minimizing PRP effects of IVIS stimuli. This could be possible because IVIS systems may in the future be able to intelligently sense and timely predict environmental events such that information is not presented at the wrong time or inteferring with other messages. The current study suggests that investing in such environmental awareness is worthwhile.

3 Summary and discussion

3.1 Summary of results

The overall aim of the studies described in this dissertation was to examine the effects of visual IVIS on simulated driving. In the first three experiments the focus was on effects of display complexity. An adaptation of the HASTE visual search task was used as a surrogate IVIS (Carsten & Brookhuis, 2005). Previous research was extended by independently manipulating set size and distinguishing between displays with pop-out or conjunction features, based on feature integration theory (Treisman & Gelade, 1980; Wooldridge, Bauer, Green, & Fitzpatrick). Potential effects of search type and display size on driving were studied using a simulated driving task and a driving simulator. In two of the experiments effects of attention allocation and preparation were studied using ERPs, and in one experiment the use of Head-Up and Head-Down Displays was compared. The second set of experiments focussed on the time course of interference of an IVIS task on critical driving tasks. These experiments were inspired by the PRP effect (Telford, 1931; Welford, 1952). We hypothesized that when the driver interacts with an IVIS while driving there is effectively a short period of dual task performance, so if IVIS information is presented in close temporal proximity with an event in traffic that requires a quick action, for instance an emergency brake, the reaction time might be affected by the processing of IVIS information. A second overall focus was on ageing. In healthy cognitive ageing there is a decline in executive functions (Raz, 2000) which are needed e.g. for integrating information and planning actions. This could effectively put more time-pressure on decision making and increase dual task costs, and hence exacerbate effects of additional information processing load due to IVIS.

3.1.1 Visual search experiments

In the first visual search experiment (section 2.1), we replicated the behavioural results of the visual search task; reaction time increased for more difficult target discriminability and the expected interaction between search difficulty and set size was found. Search time increased especially for displays with difficult target discriminability as the number of stimuli in displays increased. The second experiment (section 2.2) replicated these behavioural results. Further, effects on ERP components were found. The SRN and CNV, which are indicators of search difficulty (Okita et al., 1985) and preparation (Wild-Wall 2007, Falkenstein, 2003), respectively, both showed an effect of more preparation and less negativity related to search load for the easy displays, but not for medium and hard displays. No effects of set size were found. Only the response- and stimulus-locked P3 showed a clear effect of the three target discriminability levels; for the stimulus-locked P3 effects were most likely caused by variations in the latency of the P3 affecting the amplitude. The response-locked P3 is less sensitive to the sources of jitter that can attenuate stimulus-locked P3s. The response-locked P3 showed the same target discriminability effects, but no effects of set size.

In section 2.2 the visual search task of section 2.1 was slightly adapted and used as a surrogate IVIS in combination with a driving task. In this experiment we showed that the complexity of the surrogate IVIS display affects tracking performance. Dual task costs were found even for the easiest search display and increased with search difficulty. Elderly participants showed slower and less accurate performance on single task driving and visual search. Their performance in both driving and visual search task performance worsened most when they had to perform conjunction search with a large set size in addition to the driving task. This effect was mainly visible in the errors elderly committed in the visual search task (48% errors; hence their performance reached chance level). We suggested that the main cause of driving performance decrease with increasing visual search task complexity could be the time that was needed to search the display. Since the IVIS was a head-down display, eyes were off the road during the search for the target. Elderly participants needed more time to perform the visual search task and thus the driving performance decrease could have been directly affected by eyes-off-the-road time. Alternatively, they could have had more difficulty switching between the two locations of interest.

Section 2.3 described a follow-up experiment aimed at further studying the effect of display position. A Head-Up Display (HUD) was introduced to evaluate potential benefits of reducing required eye movements and the possible different effects for different age-groups. Further, we wanted to determine whether the performance decrease described in section 2.2 could be attributed to the time that the participants spend looking towards the head-down display. The results showed that displaying the visual search task on a HUD had a positive impact on performance. Young subjects improved their driving performance while older subjects improved their search performance (error rate). The improvements were mainly visible for conjunction search displays.

3.1.2 Onset asynchrony experiments

Section 2.4 describes a dual-task experiment that studied the time course of interference of a secondary task stimulus on a driving-relevant response. Between 0 and 1600 ms after an IVIS event indicating a possible lane change, subjects had to brake in response to a leading car. Interference was greatest at short SOAs. In the condition in which a lane change response had to be executed, the brake RT was delayed when the SOA between the “lane-stimulus” and braking light of the leading car was short. In the condition in which the participant has to decide that it was not necessary to change lane short SOAs also slowed the brake RT but to a lesser extent. In our interpretation, this was because the correct response – do not change lanes – still had to be selected, but because no subsequent motor response was required the PRP effect was reduced in size.

In section 2.5 a similar time course of interference was shown in a driving simulator. Further, elderly and young participants were compared and the EEG was measured. Again, brake RT was affected by the information processing required by the surrogate-IVIS. Further, brake RT was increased when the SOA between the surrogate-IVIS display and the onset of the brake lights was short, and this effect was stronger for elderly drivers. The target in the surrogate-IVIS display required either pop-out or conjunction search for both young and elderly drivers. At short SOAs, the brake RT was higher after the presentation of a conjunction search display. A rather paradoxical result was found for the elderly drivers that had a shorter brake RT in the lane change condition than in in the keep lane condition. After conjunction displays, drivers reduced driving speed more strongly than for pop-out displays. A stronger reduction of velocity was also found when the surrogate-IVIS indicated a lane change. The ERPs showed age effects for the P3 locked to the IVIS stimuli: the frontal P3 was more enhanced for elderly than young drivers. The amplitudes of the frontal and parietal P3 were not dependent on the surrogate-IVIS task complexity. Trials with a conjunction search display caused the alpha power to decrease for both young and elderly drivers. This reduction was stronger for younger drivers; however, they had higher baseline alpha power than the old drivers.

3.2 Conclusion

The results of the experiments showed how inefficient design of IVIS displays can negatively impact driving performance. While the experiments only used simulated driving, it is likely that the results will hold for driving on the road (Carsten & Brookhuis, 2005). Displays that require attentive conjunction search should be avoided, especially when the number of different objects which need to be inspected is high. Conjunction search increases the search time and thus, especially with a HDD, increases the eyes-off-the road time. The experiment in section 2.3 showed that using a HUD improves driving performance, especially for the young drivers, although there were still dual task costs. In older drivers HUDs showed a smaller advantage, but still reduced the error rate in the conjunction search task. Remaining dual task effects in the HUD presentation could come from the fact that drivers still have to focus their attention on the IVIS ("mind-off-the-road"). This is comparable to research on the use of mobile phones while driving, which showed effects of cognitive distraction and that having a hands free conversation can be as much interfering with driving as with a hand held mobile phone (Haigney & Westerman, 2001).

In all the experiments in which healthy elderly drivers participated (sections 2.2, 2.3, 2.5), detrimental effects of ageing were found. Effects of ageing were found for both the driving performance and the visual search task performance. In the first lane-change task experiment (2.2) the performance on all single tasks was worse for elderly than younger drivers. In the dual task situation in which they performed the lane-change task together with the visual search task elderly drivers showed larger dual task costs on driving performance than young drivers, especially in the error rates of the visual search task. Elderly subjects did not, however, indicate more effort on the subjective rating scale. Elderly subjects showed an increased effect of conjunction search on brake RT and error rates, as well as an increased effect of short SOAs when IVIS events interfered with braking. Especially strong effects of visual search complexity were found in the error rates of the visual search task. ERP data indicated that this was due to elderly subjects investing more effort in preparation for the irrelevant information. Thus elderly drivers are likely to be strongly affected by inefficient design of IVIS displays which require conjunction search and involve large set sizes. This can result in a reduction in driving performance (brake RT) and in the extreme case a breakdown in secondary task performance. If the secondary task is essential, e.g. the driver needs the IVIS to determine where to go, this breakdown will cause subsequent stress as the driver attempts to compensate. Design and evaluation of the quality of IVIS should therefore pay particular attention to this group of drivers.

The use of HUDs is a promising approach to improving IVIS. Dual-task costs, both in terms of driving and secondary task performance, were lowered in young participants when secondary information was presented on a HUD. Elderly drivers showed an improvement with HUD but this was only visible in a reduction of the error percentages. That is, many costs remained, in contrast to other studies on ageing and the usage of HUDs (Gish & Staplin, 1995; Kiefer, 1991). This effect could be caused by the high visual complexity of stimuli, which made the task more demanding compared to previously used tasks. Evidence for such an influence of visual complexity has been found in a driving simulator study (Merat, Anttila, & Luoma, 2005): a systematic increase of the visual complexity of a secondary task caused worse lane keeping behaviour and a greater reduction of speed for elderly drivers than for young drivers. Thus driver age remains an important factor to be considered when designing the display of information on a HUD. It should be considered that even though information presentation on a HUD is more advantageous, it still caused dual task decrements both for young and elderly drivers in this simulated driving task.

The ERP results showed attentional and preparatory effects which were generally more pronounced in elderly drivers; this finding is in line with other studies which also showed an enhancement of cue-locked P3 and CNV in healthy elderly subjects (Falkenstein, Hoormann, Hohnsbein, & Kleinsorge, 2003; Wild-Wall, Hohnsbein, & Falkenstein, 2007). It is also in line with the idea that cognitive ageing seems to be compensated for e.g. by using additional brain regions (Reuter-Lorenz et al., 2001) or a stronger activation of processes also used by young subjects. The pattern of cue-locked P3 and CNV enhancement suggests that elderly drivers increase their orienting to the fixation cross in order to prepare for the upcoming visual search, but only in dual tasks presented via HUD. In single task conditions elderly subjects prepared more intensely for the upcoming visual search task than younger participants. However, the ERPs in the dual task situation indicate a failure of elderly to prepare particularly in the most difficult condition (conjunction search, HDD), and this might be one reason for their performance decrease in particularly that condition.

The stimulus- and response-locked ERP results showed that the usual P3b-analysis for assessing resource allocation in the stimulus-locked data can be misleading. In conjunction search the amplitude of the stimulus-locked P3b was reduced but this was most likely an effect of latency jitter. This could be explained by the large variation of the reaction times in the conjunction condition, since there is evidence that the P3b seems to serve as a mediator between the stimulus and response and is hence more locked to the response than to the stimulus. Indeed, the P3b was clearly visible in the response-locked ERPs under conditions when it was lost using stimulus-locked averaging. Thus the response-locked P3b amplitude may provide a promising alternative measure for resource allocation. A further promising measure for future evaluation of IVIS design is the alpha power, which has the advantage compared to the ERPs that it is less influenced by precise time-locking to an event. Alpha power has already been shown to fluctuate with task demand in applied domains (Schier, 2000; Brouwer et al., 2004; Wilschut et al., 2005). Alpha power was shown to reflect search-related processes, as it differed between pop-out and conjunction search trials. In general, the EEG makes it possible to derive additional information about attention allocation, preparation and task demand without the need for additional probe stimuli.

An important question in simulation studies is always: how do the present results transfer to driving on the road? Concerns have been raised about the reliability and validity of data gathered from laboratory driving tasks and driving simulators (De Waard et al 1991). Several experiments have shown age effects in simulator studies which seemed to disappear in road driving (Schlag, 1993). In the review of Green (2000) differences in brake RTs seemed to increase with ageing, but these results are mainly found for simulator studies and seem to disappear in real road studies. It seems likely that many additional factors come into play in the real world that can compensate for cognitive effects of ageing. However, there are certain advantages of simulated driving research over the real world. First, there is a much higher control over the events and the environment that the drivers encounter. Second, some traffic research might be impossible to perform on the road because it causes too much risk for the participants. Third, it can investigate scenarios and traffic events which are uncommon or traffic scenarios that are based on expectations of real-traffic in the future). As an argument for the transfer of the present results to on the road driving is the controlled study in the HASTE-project (Santos et al., 2005). In this study the effects of visual surrogate-IVIS on performance was evaluated using a laboratory task, a driving simulator and an instrumented vehicle in real traffic. Here, more subtle differences of visual task demand were only found in the driving simulator and in the field, but also in the laboratory task effects of visual demand affected performance, mainly the lateral positioning on the road. Strikingly, in all three settings participants adapted their behaviour when the visual demand of the secondary task affected driving performance (Santos, 2005). Another factor concerning the transfer of the current results to real driving is that in the current experiments static visual search displays were used, whereas real IVIS and HUD are dynamic, updating the information continuously. Research of Kramer & Atchley (2000; in Becic, Kramer, & Boot, 2007) showed that older participants can successfully restrict search to newly added objects to speed search in a static visual search experiment. However, in a replication of this study with a dynamic display by Watson & Maylor (2002), when the target and non-target items were moving across the background, results showed that older participants were not able to selectively prioritise the new objects in a display. This could be relevant for certain types of IVIS were the road environment is displayed and continuously updated from the current car position. This could be a disadvantage for elderly drivers and increase the search time of the displays, if they can not selectively prioritise new information. Further research should use dynamic surrogate IVIS stimuli in addition to driving.

In the introduction of this dissertation, three different strategies were described with which a driver can adapt his behaviour to cope with higher task demand (Bainbridge, 1974; Hockey, 1993). These are investment of more effort, change of working strategy and neglecting information of secondary importance. All these strategies are relevant to the patterns of results found in the experiments. ERP results indicated that older drivers invest more effort when performing the visual search task together with the simulated driving compared to younger drivers. A change in working strategy is often reflected in slower speed, which is an important factor by which a driver can control task demand (Fuller, 2005). However, in the present experiments drivers were instructed to remain at constant speed. It could therefore be that the dual task costs found in the present study were more pronounced than they would be found in real driving where the task demand can sometimes be influenced by lowering speed. However, lowering of speed is not always possible, e.g. in highway situations with heavy two-lane traffic drivers might hesitate to reduce speed. Finally, elderly drivers made many errors in the visual search task in section 2.2 & 2.3. It could be that this was a strategy to cope with the high task demand simply by pressing a button at chance level to be able to attend to the driving task and in that way neglecting a task which has only secondary importance. When difficult conditions of the secondary task are facilitated, such as with HUDs that reduce gaze shifts, secondary task performance in elderly can be improved, but will still interfere with the driving to some extent. Therefore further research is necessary to optimize the IVIS' HMI design as well as to develop validated tests that can define which visual displays are acceptable and which are critical for optimal driving performance.

As was stated in the introduction, the total impact of IVIS on driving is a multi-faceted problem. Besides the dual costs that were found in these studies, which were more pronounced for elderly drivers, IVIS could also have advantages and assist elderly drivers with their coping strategies (Mitchell and Suen; 1997 Davidse, 2005). Future research is needed to focus on the strategies and compensatory mechanisms that drivers adopt to deal with IVIS task demand, especially those strategies adopted by elderly drivers. In particular, effects of dynamic IVIS displays should be explored in dual task paradigms. Also, the relative timing of critical primary driving situations and IVIS stimuli should be systematically varied, as effects are highly dependent on the timing of events.

In conclusion, the dual-task costs of IVIS must be taken seriously, especially in older drivers. These costs can be reduced by taking display characteristics into account, or by using alternative display methods such as HUDs. However, elderly drivers seem likely to remain vulnerable to interference of secondary tasks, such as dealing with IVIS information, on driving. Therefore future studies on in-car HMI must take special account on this group. As shown in the current experiment, EEG may provide useful measures in such studies.

4 Nederlandse samenvatting (Dutch summary)

Er is een ontwikkeling gaande in de automobiel industrie die er op gericht is het rijden veiliger en comfortabeler te maken door middel van additionele apparatuur die in een voertuig geplaatst kan worden om de bestuurder te informeren en te ondersteunen tijdens het rijden, bijv. de cruise control of het navigatiesysteem. Deze systemen die informatie geven aan de bestuurder worden In-Vehicle Information Systems genoemd (IVIS). IVIS worden door de automobiel industrie op de markt gebracht, maar er is op dit moment nog onvoldoende regelgeving van uit de Europese unie en de regering ten aanzien van de specificaties van deze systemen. Tevens is er behoefte aan onderzoek van het effect van IVIS op het rijgedrag en het verkennen van mogelijke interferentie van IVIS op het rijgedrag. In dit proefschrift wordt onderzoek naar de invloed van IVIS op het rijden beschreven, en hoe dit samenhangt met (1) eigenschappen van de display, (2) de timing van IVIS gebeurtenissen en (3) cognitieve effecten van ouderdom. (1) Dit onderzoek bouwt voort op onderzoek van het HASTE-project (Carsten & Brookhuis, 2005), waarbij de IVIS display werd gesimuleerd door een visuele zoektaak. De visuele zoektaak komt voort uit de Feature Integration Theory van Treisman (1980) waarbij een target element gezocht moet worden tussen een aantal irrelevante elementen. Wanneer de target duidelijk van de irrelevante elementen te scheiden is door één afwijkend kenmerk, bijv. kleur of vorm, springt de target in het oog en is snel in het display te herkennen. Dit wordt het “pop-out” effect genoemd. Uitgaand van deze theorie zou als de informatie van een IVIS op deze manier aan de bestuurder gepresenteerd worden, het relatief weinig tijd kosten om op het display te kijken. Hoe minder tijd de ogen afgewend zijn van de weg hoe beter voor de kwaliteit van het rijgedrag. Indien het ontwerp van het IVIS display inefficient is zorgt dit voor een langere reactietijd. Dit is het geval bij “conjunctie” zoek taken waarbij het target element alleen door een combinatie van meerdere kenmerken van de irrelevante elementen te onderscheiden is, bijv. het zoeken van een groene appel (target) tussen groene peren en rode appels. In het geval van een conjunctie zoektaak neemt de reactietijd toe naarmate het aantal elementen toeneemt, terwijl bij pop-out het nauwelijks verschil maakt voor de reactietijd hoeveel irrelevante elementen aanwezig zijn. Naast de karakteristieken van het IVIS display speelt ook de timing een rol in de mogelijke interferentie van IVIS op het rijgedrag. Wanneer nieuwe informatie van de IVIS wordt aangeboden en tegelijkertijd een kritische situatie in het verkeer optreedt kan de aanbieding zorgen voor interferentie. (2) Een kleiner afstand in tijd tussen een boodschap van het IVIS display en het remmen van een voor op rijdende auto, zorgt er voor dat de bestuurder een vertraagde remreactie heeft. Het tijdsverloop van dit effect is onderzocht in twee in dit proefschrift beschreven experimenten. (3) Bestuurders van voertuigen verschillen in de snelheid en accuratesse van hun informatieverwerking. Omdat mensen met het ouder worden over het algemeen langzamer worden en in hun reacties is het vooral van belang te kijken naar de effecten van IVIS op rijgedrag bij deze gebruikersgroep. De verwachting bij ons onderzoek hiernaar was dat vooral ouderen een grotere interferentie ondervinden van IVIS op rijgedrag en een grotere prestatie vermindering zouden laten zien wanneer een display inefficiënt (dus conjunctie) ontworpen is. Tenslotte werd in een aantal van de experimenten hersenactiviteit gemeten met behulp van het elektro-encefalogram (EEG). Het EEG maakt het mogelijk te kijken naar effecten van taakbelasting, voorbereiding en verdeelde aandacht op processen in de hersenen. De invloed van IVIS op rijgedrag is in vijf experimenten onderzocht.

Experiment 1: In dit experiment werden verschillende zoektaak displays gebruikt die verschilden in complexiteit en in het aantal elementen. Het EEG werd gemeten en het bleek dat componenten van het EEG gevoelig waren voor verschillende gradaties van complexiteit van de displays en minder gevoelig voor het aantal elementen. Zoals verwacht was de pop-out zoektaak nauwelijks afhankelijk van het aantal irrelevante elementen in het display, terwijl bij de conjunctie zoektaak de reactietijd sterk toenam evenals het aantal fouten.

Experiment 2: Voortbouwend op het eerste experiment werd de zoektaak gecombineerd met een gesimuleerde rijtaak en werden zowel jonge (20-25 jaar) als oudere (50-70 jaar) proefpersonen getest. Bij beide groepen zorgde het toevoegen van de zoektaak voor een verslechtering van het rijgedrag in vergelijking tot het rijden zonder de zoektaak. Dit effect was het grootst voor de moeilijkste conditie van de zoektaak met conjunctie kenmerken en veel elementen. De oudere proefpersonen waren over het algemeen langzamer en presteerden op de zoektaak tijdens de moeilijkste conditie bijna op een niveau dat op basis van kans te verwachten was.

Experiment 3: In het tweede experiment werd de zoektaak aangeboden op een scherm dat de proefpersoon dwong de ogen af te wenden van de rijtaak: een Head Down Display (HDD). In het derde experiment is onderzocht of een scherm dat het mogelijk maakt tegelijkertijd de weg en de zoektaak te zien een verbetering van de prestatie veroorzaakt. Dit is een semi-transparant scherm: een Head-Up Display (HUD). De HUD zorgde ervoor dat de prestatie van zowel jongeren als ouderen proefpersonen verbeterde. Bij de jongeren zorgde de HUD er voor dat zij hun rijprestatie en de reactie tijd en accuratesse op de zoektaak verbeterde. Voor de ouderen groep was er ook een grote verbetering zichtbaar het aantal fouten dat gemaakt werd op de zoektaak werd met een derde gereduceerd. Tevens werd het EEG gemeten en dat liet zien dat ouderen meer frontale hersenprocessen aanspreken en ook irrelevante informatie slechter kunnen onderdrukken.

Experiment 4: Om het tijdsverloop van interferentie tussen IVIS en het rijden te onderzoeken werden visuele en auditieve IVIS stimuli aangeboden en na verschillende tijdsintervallen (0-1600 ms) moest er gereageerd worden op de remlichten van een auto. Als rijtaak werd er een continue volgtaak gebruikt. De reactietijden op de remlichten waren langer wanneer de tijdsafstand kort was, maar er was geen verschil tussen visuele of auditieve stimuli. De resultaten ondersteunden een hypothetische effect van IVISs op het rijden, dat te maken heeft met interferentie tussen cognitieve processen.

Experiment 5: In een rijsimulator experiment werd ook het tijdsverloop onderzocht tussen de presentatie van de IVIS en het oplichten van de remlichten van de voorganger, waarna zo snel mogelijk geremd moest worden. De oudere proefpersonen waren daarbij langzamer en vooral wanneer de IVIS een conjunctie zoektaak was reageerden de ouderen veel langzamer op de remlichten. Het kort na elkaar aanbieden van de IVIS en de remlichten had dus een vertragende werking op de remreactie. Het EEG liet een verlaging van de alpha activiteit (8-10 Hz) zien voor conjunctie zoektaken. Deze activiteit is gekoppeld aan aandacht, en zou dus een maat kunnen bieden voor hoeveel moeite mensen hebben met het rijden en verwerken van IVIS informatie.

De resultaten laten zien dat aandacht voor cognitieve eigenschappen van de mens belangrijk is bij de vormgeving van IVIS schermen. De meest relevante informatie zou het beste pop-out kenmerken kunnen hebben. In geval van conjunctie kenmerken zouden het aantal elementen op het scherm zo klein mogelijk moeten zijn. Het onderzochte tijdsverloop laat zien dat de grootste interferentie tussen de IVIS en de rijtaak optreedt wanneer de gebeurtenissen kort op elkaar plaats vinden, wat de remreactietijd kan vertragen. Oudere bestuurders zijn langzamer en ondervinden meer interferentie van IVIS bij het rijden, en dus zouden ontwerpers van IVIS interfaces extra rekening moeten houden met deze groeiende groep van bestuurders. De EEG resultaten benadrukten dat deze maat van hersenactiviteit gebruikt kan worden om de taakbelasting en verdeelde aandacht tijdens het rijden met een IVIS te onderzoeken.

5 References

Aasman, J. (1995). *Modelling driver behaviour in SOAR.* University of Groningen, the Netherlands.

Anderson, J. R., Reder, L. M., & Lebiere, C. (1996). Working memory: activation limitations on retrieval. *Cognit Psychol, 30*(3), 221-256.

Anstey, K. J., Wood, J., Lord, S., & Walker, J. G. (2005). Cognitive, sensory and physical factors enabling driving safety in older adults. *Clin Psychol Rev, 25*(1), 45-65.

Baddeley, A. (1996). The fractionation of working memory. *Proc Natl Acad Sci U S A, 93*(24), 13468-13472.

Baddeley, A., & Della Sala, S. (1996). Working memory and executive control. *Philos Trans R Soc Lond B Biol Sci, 351*(1346), 1397-1403; discussion 1403-1394.

Baddeley, A. D. (1986). *Working memory*. Oxford: Oxford University Press.

Baddeley, A. D. (2002). Is working memory still working? *European Psychologist, 7*(2), 85-97.

Bainbridge, L. (1974). Problems in the assessment of mental load. *Le Travail Human, 37*, 279-302.

Ball, K. K., Beard, B. L., Roenker, D. L., Miller, R. L., & Griggs, D. S. (1988). Age and visual search: expanding the useful field of view. *J Opt Soc Am A, 5*(12), 2210-2219.

Barcelo, F., Periáñez, J. A., & Knight, R. T. (2002). Think differently: A brain orienting response to task novelty. *NeuroReport*, 13, 1887-1892.

Barfield, W., & Dingus, T. A. (1998). *Human Factors in Intelligent Transportation Systems.* . Mahwah, New Jersey: Lawrence Erlbaum Associates.

Becic, E., Kramer, A. F., & Boot, W. R. (2007). Age-related differences in visual search in dynamic displays. *Psychol Aging, 22*(1), 67-74.

Blanco, M., Biever, W. J., Gallagher, J. P., & Dingus, T. A. (2006). The impact of secondary task cognitive processing demand on driving performance. *Accident Analysis & Prevention, 38*(5), 895-906.

Brookhuis, K. A., De Waard, D., & Fairclough, S. H. (2003). Criteria for driver impairment. *Ergonomics, 46*(5), 433-445.

Brookhuis, K. A., deVries, G., & deWaard, D. (1991). The effects of mobile telephoning on driving performance. *Accid Anal Prev., 23*(4), 309-316.

Brookhuis, K. A., Mulder, G., Mulder, L. J., & Gloerich, A. B. (1983). The P3 complex as an index of information processing: the effects of response probability. *Biol Psychol, 17*(4), 277-296.

Brookhuis, K. A., Mulder, G., Mulder, L. J., Gloerich, A. B., van Dellen, H. J., van der Meere, J. J., et al. (1981). Late positive components and stimulus evaluation time. *Biol Psychol, 13*, 107-123.

Brouwer, W. H., Duistermaat, M., Hogema, J. H., Brookhuis, K. A., de Waard, D., & Wilschut, E. S. (2004). Detecting drowsiness under different highway scenarios using a simple hypovigilance diagnosis system. *TNO Human Factors*.

Brouwer, W. H., Rothengatter, J. A., & Wolffelaar, P. C. v. (1988). Compensatory potential in elderly drivers.

Brunia, C. H., & van Boxtel, G. J. (2001). Wait and see. *Int J Psychophysiol, 43*(1), 59-75.

Caird, J. K., Chugh, J. S., Wilcox, S., & Dewar, R. E. (1998). *A design guideline and evaluation framework to determine the relative safety of in-vehicle intelligent transportation systems for older drivers*. Retrieved. from.

Carsten, O., & Brookhuis, K. (2005). Issues arising from the HASTE experiments. *Transportation Research Part, 8*, 191-196.

Chelazzi, L. (1999). Serial attention mechanisms in visual search: a critical look at the evidence. *Psychol Res, 62*(2-3), 195-219.

Cnossen, F. (2000) Adaptive strategies and goal management in car drivers, PhD thesis, Rijksuniversiteit Groningen, Groningen

Cnossen, F., Meijman, T., & Rothengatter, T. (2004). Adaptive strategy changes as a function of task demands: a study of car drivers. *Ergonomics, 47*(2), 218-236.

Cnossen, F., Rothengatter, T., & Meijman, T. (2000). Strategic changes in task performance in simulated car driving as an adaptive response to task demands. *Transportation Research Part F, 3*, 123-140.

Coeckelbergh, T. R. M. (2002). *Effect of compensatory viewing strategies on practical fitness to drive in subjects with visual field defects caused by ocular pathology*. University of Groningen, Groningen.

Craik, F. M., & Bialystok, E. (2006). Cognition through the lifespan: mechanism of change. *TICS, 10*(3), 131-138.

Craik, F. I. M., & Salthouse, T. A. (Eds.). (2000). *The handbook of aging and cognition.* 2nd ed., Mahwah, NJ: Erlbaum

Davidse, R.J. (2003). *Ouderen en ITS: samen sterk(er)?* R-2003-30. Stichting Wetenschappelijk Onderzoek Verkeersveiligheid SWOV, Leidschendam.

Davidse, R. J. (2005). Older Drivers and ADAS - Which systems improve Road Safety? *Mobility for the Elderly*, 6-20.

De Jong, R. (1993). Multiple bottlenecks in overlapping-task performance. *Journal of Experimental Psychology: Human Perception and Performance, 19*, 965-980.

De Waard, D. (1996). *The measurement of drivers mental workload.* Rijksuniversiteit Groningen, Groningen.

De Waard, D., & Brookhuis, K. A. (1991). Assessing driver status: a demonstration experiment on the road. *Accident Analysis & Prevention, 23*, 297-307.

De Waard, D., van der Hulst, M., & Brookhuis, K. A. (1999). Elderly and young drivers' reaction to an in-car enforcement and tutoring system. *Applied Ergonomics, 30*(2), 147-157.

Dingus, T., Hulse, M., Mollenhauer, M. A., Fleishman, R. N., McGehee, D. V., & Manakkal, N. (1997). Effects of age, system experience, and navigation technique on driving with an advanced traveler information system. *Human Factors, 39*(2), 177-199.

Donchin, E. (1981). Surprise!...Surprise? *Psychophysiology, 18*, 493-513.

Donders, F. C. (1969). On the speed of mental processes. *Acta Psychologica (Amst), 30*, 412-431.

Drury, C. G., & Clement, M. R. (1978). The effect of area, density, and number of background characters on visual search. *Human Factors, 20*, 597-602.

Duncan, J. (1980). The locus of interference in the perception of simultaneous stimuli. *Psychological Review, 87*, 272-300.

Duncan, J., & Humphreys, G. W. (1989). Visual search and stimulus similarity. *Psychol Rev, 96*(3), 433-458.

Eby, D., Shope, J. T., Molnar, L. J., Vivoda, J. M., & Fordyce, T. A. (2000). *Improvement of older driver safety through self evaluation: The development of a self-evaluation instrument*. Michigan.

Edgar, G. K. (2007). Accommodation, cognition, and virtual image displays: A review of the literature *Displays, 28*(2), 45-59.

Eimer, M. (1996). The N2pc component as an indicator of attentional selectivity. *Electroencephalography and Clinical Neurophysiology, 99*(3), 225-234.

Eimer, M., & van Velzen, J. (2006). Covert manual response preparation triggers attentional modulations of visual but not auditory processing. *Clinical Neurophysiology, 177*(5), 1063-1074.

Endsley, M. R., & Rodgers, M. D. (1998). Distribution of attention, situation awareness and workload in a passive air traffic control task: Implications for operational errors and automati. *Air Traffic Control Quarterly, 6*(1), 21-44.

ESoP (2006). *European Commission Recommendation on safe and efficient in-vehicle information and communication systems: Update of the European Statement of Principles on human machine interface.* Brussels.

Fadden, S., Wickens, C. D., & Ververs, P. (2001). *Costs and benefits of head up displays: An attention perspective and a meta analysis.* Paper presented at the Proceedings of the 2000 World Aviation Congress, Warrendale, PA.

Fairclough, S. H., Ashby, M. C., & Parkes, A. M. (1993). In-vehicle displays, visual workload and usability evaluation. In A. G. Gale, I. D. Brown, C. M. Haslegrave, H. W. Kruysse & S. P. Taylor (Eds.), *Vision in Vehicles IV* (pp. 245-254). Amsterdam: Elsevier.

Falkenstein, M., Hohnsbein, J., & Hoormann, J. (1993). Late visual and auditory ERP components and choice reaction time. *Biol Psychol. , 35*(3), 201-224.

Falkenstein, M., Hoormann, J., Hohnsbein, J., & Kleinsorge, T. (2003). Short-term mobilization of processing resources is revealed in the event-related potential. *Psychophysiology, 40*(6), 914-923.

Fastenmeier, W., & Gstalter, H. (2006). Driving task analysis as a tool in traffic safety research and practice. *Safety Science, In Press, Corrected Proof.*

Friedman D, Nessler D, Johnson R, et al. (2008). Age-related changes in executive function: An event-related potential (ERP) investigation of task-switching. *Aging Neuropsychology and Cognition*, 15(1), 95-128.

Fournier, L. R., Wilson, G. F., & Swain, C. R. (1999). Electrophysiological, behavioral, and subjective indexes of workload when performing multiple tasks: manipulations of task difficulty and training. *Int J Psychophysiol, 31*(2), 129-145.

Fuller, R. (2005). Towards a general theory of driver behaviour. *Accident Analysis & Prevention, 37*(3), 461-472.

Gish, K. W., & Staplin, L. (1995). *Human Factors Aspects of Using Head Up Displays in Automobiles: A Review of the Literature, DOT HS 808 320* Retrieved. from.

Gladwin, T. E. (2006). *Time-frequency domain EEG activity during the preparation of task sets and movements.* University of Groningen.

Göthe, K., Oberauer, K. & Kliegl, R. (2007). Age differences in dual-task performance after practice. *Psychology Aging*, 22, 596-606.

Gratton, G., & Coles, M. G. H. (1983). A new method for off-line removal of ocular artifact. *Electroencephalography and clinical neurophysiology, 55*, 468-484.

Green, M. (2000). "How long does it take to stop?" Methodological analysis of driver perception-brake times. *Transportation Human Factors, 2*, 195-216.

Green, P. (1999). The 15-Second Rule for Driver Information Systems. *ITS America Ninth Annual Meeting Conference Proceedings, Washington, D.C.: Intelligent Transportation Society of America, CD-ROM.*

Groeger, J. A. (2000). *Understanding Driving. Applying cognitive psychology to a complex everyday task.* Hove: Psychology Press Ltd.

Haigney, D., & Westerman, S. J. (2001). Mobile (cellular) phone use and driving: a critical review of research methodology. *Ergonomics, 44*(2), 132-143.

Hale, A. R., Stoop, J., & Hommels, J. (1990). Human error models as predictors of accident scenarios for designers in road transport systems. *Ergonomics, 33*, 1377-1387.

Hancock, P. A., Lesch, M., & Simmons, L. (2003). The distraction effects of phone use during a crucial driving maneuver. *Accident Analysis & Prevention, 35*(4), 501-514.

Helmholtz, H. (1866). *Handbuch der Physiologischen Optik* (Vol. 3). Hamburg: Voss.

Herriotts, P. (2005). Identification of vehicle design requirements for older drivers. *Applied Ergonomics, 36*(3), 255-262.

Hills, B. L. (1980). Vision, visibility and perception in driving. *Perception, 10*, 183–216.

Hockey, G. R. J. (1993). Cognitive-energetical control mechanisms in the management of work demands and psychological health. In A. Baddeley & L. Weiskrantz (Eds.), *Attention: selection, awareness, and control* (pp. 328-345). Oxford: Oxford University Press.

Hockey, G. R. J., Wastell, D. G., & Sauer, J. (1998). Effects of sleep deprivation and user interface on complex performance: a multilevel analysis of compensatory control. *Human Factors, 40*(2), 233-253.

Hoedemaeker, M., & Brookhuis, K. A. (1998). Behavioural adaptation to driving with an adaptive cruise control (ACC). *Transportation Research Part F: Traffic Psychology and Behaviour, 1*(2), 95-106.

Hoffman, J. E., Houck, M. R., III, M., Frank, W., Simons, R. F., & Oatman, L. C. (1985). Event-related potentials elicited by automatic targets: A dual-task analysis. . *Journal of Experimental Psychology: Human Perception and Performance., 11*(1), 50-61.

Hohnsbein, J., Falkenstein, M., & Hoormann, J. (1998). Performance differences in reaction tasks are reflected in event-related brain potentials(ERPs). *Ergonomics, 41*(5), 622-633.

Hohnsbein, J., Falkenstein, M., Hoormann, J., & Blanke, L. (1991). Effects of crossmodal divided attention on late ERP components. I. Simple and choice reaction tasks. *Electroencephalogr Clin Neurophysiol, 78*(6), 438-446.

Hommel, B., Li, K. Z., & Li, S. C. (2004). Visual search across the life span. *Dev Psychol, 40*(4), 545-558.

Hommels, J. G. M., & Hale, A. R. (1989). *Modellen voor het voorspellen en beheersen van verkeersgedrag.* Technische universiteit Delft, Delft, the Netherlands.

Horberry, T., Anderson, J., Regan, M. A., Triggs, T. J., & Brown, J. (2006). Driver distraction: The effects of concurrent in-vehicle tasks, road environment complexity and age on driving performance. *Accident Analysis & Prevention, 38*(1), 185-191.

Horrey, W. J., & Wickens, C. D. (2004). Driving and side task performance: the effects of display clutter, separation, and modality. *Hum Factors, 46*(4), 611-624.

Huey, B. M., & Wickens, C. D. (1993). *Workload Transition: Implications for Individual and Team Performance*. Washington, DC: National Acadamy Press.

Hulse, M. C., Dingus, T. A., & Barfield, W. (1998). *Description and applications of advanced traveller information systems.* Mahwah, NJ: Laurence Erlbaum Associates.

Hydén, C., & Draskóczy, M. (1992). *Safety objectives for RTI application*. Retrieved. from.

Isreal, J. B., Chesney, G. L., Wickens, C. D., & Donchin, E. (1980). P300 and tracking difficulty: evidence for multiple resources in dual-task performance. *Psychophysiology, 17*(3), 259-273.

James, W. (1890). *The principles of psychology*. New York: Dover Publications.

Jamson, A. H., & Merat, N. (2005). Surrogate in-vehicle information systems and driver behaviour: Effects of visual and cognitive load in simulated rural driving. *Transportation Research Part F: Traffic Psychology and Behaviour, 8*(2), 79-96.

Janssen, W. H., & Gaillard, A. W. K. (1985). Proceedings of the workshop Electroencephalography in transport operations.

Janssen, W. H., Kaptein, N., & Claessens, M. (1999). *Behavior and safety when driving with in-vehicle devices that provide real-time traffic information*. Toronto.

Johnson, A., & Proctor, R. W. (2004). *Attention : Theory And Practice*. Thousand Oaks, USA: Sage Publications.

Kaempf, G. L., & Klein, G. (1994). Aeronautical decision making: the next generation. In N. Mc Donald, N. Johnston & R. Fuller (Eds.), *Aviation Psychology in Practice* (pp. 223-254). Aldershot: Avebury Technical.

Kahneman, D. (1973). *Attention and effort*. New Jersey: Prentice Hall.

Kiefer, R. (1991). *Effect of a head-up versus head-down digital speedometer on visual sampling behavior and speed control performance during daytime automobile driving.* Paper presented at the Society of Automotive Engineers, New York.

Kieras, D. E., & Meyer, D. E. (2001). Virtually perfect time sharing in dual-task performance: Uncorking the central cognitive bottleneck. *Psychological Science*, 12, 101-108.

Kok, A. (2000). Age-related changes in involuntary and voluntary attention as reflected in components of the event-related potential (ERP). *Biol Psychol, 54*(1-3), 107-143.

Kok, A. (2001). On the utility of P3 amplitude as a measure of processing capacity. *Psychophysiology, 38*(3), 557-577.

Kopp, B., Rist, F., & Mattler, U. (1996). N200 in the flanker task as a neurobehavioral tool for investigating executive control. *Psychophysiology*, 33, 282–294.

Korteling, J.E. (1994). *Multiple-Task Performance and Aging.* Ph.D.Thesis, TNO Human Factors, Soesterberg & University of Groningen, The Netherlands.

Korteling, J.E. (1990). Perception-response speed and driving capabilities of brain-damaged and older drivers. *Human Factors*. 32(1), 95-108.

Kramer, A. F., & Atchley, P. (2000). Age-related effects in the marking of old objects in visual search. *Psychol Aging, 15*(2), 286-296.

Kramer, A. F., & Strayer, D. L. (1988). Assessing the development of automatic processing: an application of dual-task and event-related brain potential methodologies. *Biol Psychol, 26*(1-3), 231-267.

Kramer, A. F., Wickens, C. D., & Donchin, E. (1983). An analysis of the processing requirements of a complex perceptual-motor task. *Hum Factors, 25*(6), 597-621.

Kulmala, R. (1995). *Safety at rural three- and four-arm junctions. Development and application of accident prediction models.* VTT Publications 233, Espoo, Finland.

Lenior, D., Janssen, W., Neerincx, M., & Schreibers, K. (2006). Human-factors engineering for smart transport: Decision support for car drivers and train traffic controllers. *Applied Ergonomics, 37*(4), 479-490.

Levy, J., Pashler, H., & Boer, E. (2006). Central Interference in Driving. Is There Any Stopping the Psychological Refractory Period? *Psychological Science, 17*(3), 228-235.

Liu, Y., & Wen, M. (2004). Comparison of head-up display (HUD) vs. head-down display (HDD): driving performance of commercial vehicle operators in Taiwan *International Journal of Human-Computer Studies, 61*(5), 679-697.

Liu, Y. C. (2001). Comparative study of the effects of auditory, visual and multimodality displays on drivers' performance in advanced traveller information systems. *Ergonomics, 44*(4), 425-442.

Logan, G. D., & Gordon, R. D. (2001). Executive control of visual attention in dual-task situations. *Psychological Review*, 108, 393-434.

Lorist, M. M., Snel, J., Kok, A., & Mulder, G. (1996). Acute effects of caffeine on selective attention and visual search processes. *Psychophysiology, 33*(4), 354-361.

Lorist, M. M., Snel, J., Mulder, G., & Kok, A. (1995). Aging, caffeine, and information processing: an event-related potential analysis. *Electroencephalography and clinical neurophysiology, 96*(5), 453-467.

Luck, S. J., & Hillyard, S. A. (1990). Electrophysiological evidence for parallel and serial processing during visual search. *Percept Psychophys, 48*(6), 603-617.

Luck, S. J., Woodman, G. F., & Vogel, E. K. (2000). Event-related potential studies of attention. *Trends Cogn Sci, 4*(11), 432-440.

Madden, D. J., Spaniol, J., Bucur, B., & Whiting, W. L. (2007). Age-related increase in top-down activation of visual features. *Q J Exp Psychol (Colchester), 60*(5), 644-651.

Marois, R., & Ivanoff, J. (2005). Capacity limits of information processing in the brain. *Trends Cogn Sci, 9*(6), 296-305.

Martens, M.H. & W. van Winsum (2000). Measuring distraction: the Peripheral Detection Task. Proceedings NHTSA Internet Forum on the safety impact of driver distraction when using in-vehicles technology. Washington, D.C.: NHTSA.

Massie, D. L., Campbell, K. L., & Williams, A. F. (1995). Traffic accident involvement rates by driver age and gender. *Accident Analysis and Prevention, 27*(1), 73-87.

Mattes, S. (2003). *The Lane-Change_Task as a tool for Driver Distraction Evaluation*. Stuttgart: Ergonomia Verlag.

McGurk, H., & MacDonald, J. (1976). Hearing lips and seeing voices. *Nature, 264*(5588), 746-748.

Merat, N., Anttila, V., & Luoma, J. (2005). Comparing the driving perfomance of average and older drivers: The effect of surrogate in-vehicle information systems. *Transportation Research Part, F 8*, 147-166.

Merat, N., Anttila, V., & Luoma, J. (2005). Comparing the driving performance of average and older drivers: The effect of surrogate in-vehicle information systems. *Transportation Research Part F: Traffic Psychology and Behaviour, 8*(2), 147-166.

Michael, S. G., & Casali, J. G. (1995). *Auditory prompts: Effects on visual acquisition time and accuracy in a dashboard-mounted navigational display task.* Paper presented at the Proceedings of the 3rd annual Mid-Atlantic Human Factors conference, Blacksburg, Virginia.

Micheal, S. G., & Casali, J. G. (1995). *Auditory prompts: Effects on visual acquisition time and accuracy in a dashboard-mounted navigational display task.*

Michon, J. A. (1985). A critical view of driver behavior models: what do we know, what should we do? In L. Evans & R. C. Schwing (Eds.), *Human behavior and traffic safety* (pp. 485-524). New York: Plenum Press.

Mitchell, C. G. B., & Suen, S. L. (1997). *ITS impact on elderly drivers*. Toronto.

Mollenhauer, M. A., Hulse, M. C., Dingus, T. A., Kahns, S. K., & Carney, C. (1997). Design decision aids and human factors guidelines for ATIS displays. In Y. J. Noy (Ed.), *Ergonomics and safety of intelligent driver interfaces* (pp. 23-61). Mahwah, NJ: Erlbaum.

Molnar, L. J., & Elby, D. W. (1996). *Preliminary guidelines for development of advanced traveler information systems for the driving tourist: route guidance features*. Croydon: Automotive Automation Ltd.

Mourant, R. R., & Rockwell, T. H. (1972). Strategies of visual search by novice and experienced drivers. *Hum Factors, 14*(4), 325-335.

Mulder, G. (1986). The concept and measurement of mental effort. In G. R. J. Hockey, A. W. K. Gaillard & M. G. H. Coles (Eds.), *Energetics and human information processing*. Dordrecht: Martinus Nijhoff.

Nakayama, K. J., J. S. . (1998). *The Attentive Brain* Cambridge: MIT Press.

Navon, D. (1984). Resources - a theoretical soup stone? *Psychological Review, 91*, 216-234.

Neisser, U. (1976). *Cognition and reality: Principles and implications of cognitive psychology*. San Francisco: Freeman.

Neumann, O. (1987). Beyond capacity: A functional view of attention. In H. Heuer & A. F. Sanders (Eds.), *Perspectives on perception and action* (pp. 361-394). Hillsdale, NJ: Lawrence Erlbaum.

Norman, D., & Shallice, T. (1986). *Attention to action: Willed and automatic control of behavior*. New York Plenum Press.

Noy, Y. I. (1997). Human factors in modern traffic systems. *Ergonomics, 40*(10), 1016-1024.

O'Donnell, R. D. & Eggemeier, F. T. (1986). *Workload assessment methodology. In K. R. Boff & J. P. Thomas (Eds.), Handbook of perception and human performance*. Volume II cognitive processes and (pp. 42-1-42/49). New York: Wiley.

Okita, T., Wijers, A. A., Mulder, G., & Mulder, L. J. (1985). Memory search and visual spatial attention: an event-related brain potential analysis. *Acta Psychol (Amst), 60*(2-3), 263-292.

Olson, P. L. & Sivak, M. (1986). Perception-response time to unexpected roadway hazards. *Human Factors*, 28(1), 91-96.

Owsley, C., Ball, K., Sloane, M. E., Roenker, D. L., & Bruni, J. R. (1991). Visual/cognitive correlates of vehicle accidents in older drivers. *Psychol Aging, 6*(3), 403-415.

Papadelis, C., Chen, Z., Kourtidou-Papadeli, C., Bamidis, P.B., Chouvarda, I., Bekiaris E. & Maglaveras N. (2007). Monitoring sleepiness with on-board electrophysiological recordings for preventing sleep-deprived traffic accidents. *Clinical Neurophysiology*, 118 (9), 1906-1922.

Pashler, H. (1994). Dual-task interference in simple tasks: Data and theory. *Psychological Bulletin, 116*, 220-244.

Pauzie, A. (2002). In-vehicle communication systems: the safety aspect. *Inj Prev, 8 Suppl 4*, IV26-29.

Pauzie, A., & Alauzet, A. (1991). *Specificity of elderly drivers and road safety, in "Designing For Everyone"*. Paris: Taylor & Francis.

Pohlmann, S., & Traenkle, U. (1994). Orientation in road traffic. Age-related differences using an in-vehicle navigation system and a conventional map. *Accident Analysis & Prevention, 26*(6), 689-702.

Posner, M. I. (1980). Orienting of attention. *Quarterly journal of experimental psychology, 32*, 9-25.

Rakauskas, M. E., Ward, N. J., Bernat, E. M., Cadwallader, M., Patrick, C. J., & de Waard, D. (2005). Psycholphysiological measures of driver distraction and workload while intoxicated. *Symposium:Human Factors in Driver Assessment, Training and Vehicle Design*.

Ranney, T. A. (1994). Models of driving behaviour: a research of their evolution. *Accident analysis & prevention, 26*(6), 733-750.

Rasmussen, J. (1983). Skills, Rules, and Knowledge; Signals, Signs, and Symbols, and Other Distinctions in Human Performance Models. *IEEE Transactions on Systems, Man, and Cybernetics, 13*(3), 257-266.

Raz, N. (2000). Aging of the brain and its impact on cognitive performance: Integration of structural and functional findings. *The Handbook of Aging and Cognition*, 1-90.

Reuter-Lorenz, P., Marshuetz, C., Jonides, J., Smith, E. E., Hartley, A., & Koeppe, R. (2001). Neurocognitive ageing of storage and executive processes. *The European Journal of Cognitive Psychology, 13*(1-2), 257-278(222).

Riby, L. M., Perfect, T. J., & Stollery, B. T. (2004). The effects of age and task domain on dual task performance: A meta-analysis. *European Journal of Cognitive Psychology*, 16, 863–891.

Rugg, M. D., & Coles, M. G. H. (1995). Event-related brain potentials: An introduction. *electrophysiology of mind*.

Ruthruff, E., Johnston, J. C., & Van Selst, M. (2001). Why practice reduces dual-task interference. *Journal of Experimental Psychology: Human Perception and Performance, 27*, 3-21.

Santos, J., Merat, N., Mouta, S., Brookhuis, K., & de Waard, D. (2005). The interaction between driving an in-vehicle information systems: Comparison of results from laboratory, simulator and real-world studies. *Transportation Research Part, F 8*, 135-146.

Schier, M. A. (2000). Changes in EEG alpha power during simulated driving a demontration. *International Journal of Psychophysiology, 37*, 155-162.

Schlag, B. (1993). Elderly drivers in Germany -- Fitness and driving behavior. *Accident Analysis & Prevention, 25*(1), 47-55.

Schneider, W., & Shiffrin, R. M. (1977). Controlled and automatic human information processing: I. Detection, search, and attention. *Psychological Review, 84*(1), 1-66.

Sirevaag, E. J., Kramer, A. F., Coles, M. G., & Donchin, E. (1989). Resource reciprocity: an event-related brain potentials analysis. *Acta Psychol (Amst), 70*(1), 77-97.

Schubö A., Schröger, E., Meinecke, C. (2004). Texture segmentation and visual search for pop-out targets.: An ERP study. *Cognitive Brain Research*, 21(3), 317-334.

Sojourner, R. J., & Antin, J. F. (1990). The effects of a simulated head-up display speedometer on perceptual task performance. *Hum Factors, 32*(3), 329-339.

Sorkin, R. D. (1987). *Design of Auditory and Tactile Displays*. New York: NY: Wiley.

Sperandio, J. C. (1971). Variation of operators strategies and regulating effects of workload. *Ergonomics, 14*(5), 571-577.

Stevens, A., & Minton, R. (2001). In-vehicle distraction and fatal accidents in England and Wales. *Accid Anal Prev, 33*(4), 539-545.

Strandberg, L. (1998). *Winter braking tests with 66 drivers, different tires and disconnectable ABS.* Paper presented at the International Workshop on Traffic Accident Reconstruction, Tokyo.

Stutts, J.C., 1998. Do older drivers with visual and cognitive impairments drive less? *J. Am. Geriatr. Soc*. 46, 854–86.

Styles, E. A. (1997). *The psychology of attention*. Hove, UK: Psychology Press.

Summala, H. & Hyvén, A. (1990). Measuring (safety-related) driver skills in the laboratory: towards a new test for the driver examination (Report No. 21). Helsinki: Traffic Research Unit, University of Helsinki.

Taatgen, N. A. (1999). *Learning without limits : from problem solving towards a unified theory of learning.* University of Groningen.

Telford, C. W. (1931). The refractory phase of voluntary and associative responses. . *Journal of experimental Psychology, 14*, 1-36.

Tombu, M., & Jolicoeur, P. (2004). Virtually no evidence for virtually perfect time-sharing. *Journal of Experimental Psychology: Human Perception and Performance, 30*, 795-810.

Townsend, J. T. (1990). Serial vs. parallel processing: Sometimes they look like Tweedledum and Tweedledee but they can (and should) be distinguished. *Psychological Science, 1*, 46-54.

Treisman, A. (1982). Perceptual grouping and attention in visual search for features and for objects. *Journal of Experimental Psychology: Human Perception and Performance, 8*(2), 194-214.

Treisman, A. (1988). Features and objects: the fourteenth Bartlett memorial lecture. *Q J Exp Psychol A, 40*(2), 201-237.

Treisman, A. M., & Gelade, G. (1980). A feature-integration theory of attention. *Cognitive Psychology, 12*, 97-136.

Verhaeghen, P., & Cerella, J. (2002). Aging, executive control, and attention: a review of meta-analyses. *Neuroscience & Biobehavioral Reviews, 26*(7), 849-857.

Verhaeghen, P., Steitz, D. W., Sliwinski, M. J., & Cerella, J. (2003). Aging and Dual-Task Performance: A Meta-Analysis. *Psychology and Aging, 18*(3), 443-460.

Verleger, R., Jaskowski, P., & Wascher, E. (2005). Evidence for an Integrative Role of P3b in Linking Reaction to Perception. *Journal of Psychophysiology, 19*(3), 165-181.

Verleger, R., Paehge, T., Kolev, V., Yordanova, J., & Jaskowski, P. (2006). On the relation of movement-related potentials to the go/no-go effect on P3. *Biological Psychology, 73*(3), 298-313.

Ververs, P. M., & Wickens, C. D. (1998). Conformal Flight Path Symbology for Head-Up Displays: Defining the Distribution of Visual Attention in Three-Dimensional Space. *ARL-98-5/NASA-98-1*.

Verwey, W. B. (2000). On-line driver workload estimation. Effects of road situation and age on secondary task measures. *Ergonomics, 43*(2), 187-209.

Victor, T. W., Harbluk, J. L., & Engstrom, J. A. (2005). Sensitivity of eye-movement measures to in-vehicle task difficulty. *Transportation Research Part F: Traffic Psychology and Behaviour, 8*(2), 167-190.

Victor, T. W., Harbluk, J. L., & Engström, J. A. (2005). Sensivitiy of eye-movement measures to in-vehicle task difficulty. *Transportation Research Part, F 8*, 167-190.

Walter, W. G., Cooper, R., Aldridge, V. J., McCallum, W. C., & Winter, A. L. (1964). Contingent Negative Variation: an Electric Sign of Sensorimotor Association and Expectancy in the Human Brain. *Nature, 203*, 380-384.

Watson, D. G., & Maylor, E. A. (2002). Aging and visual marking: selective deficits for moving stimuli. *Psychol Aging, 17*(2), 321-339.

Welford, A. T. (1952). The ‘‘psychological refractory period’’and the timing of high-speed performance–A review and a theory. *British Journal of Psychology, 434*, 2-19.

Weltman, G., Smith, J. E., & Egstrom, G. H. (1971). Perceptual narrowing during simulated pressure-chamber exposure. *Human Factors, 12*, 99-107.

Wickens, C., Kramer, A., Vanasse, L., & Donchin, E. (1983). Performance of concurrent tasks: a psychophysiological analysis of the reciprocity of information-processing resources. *Science, 221*(4615), 1080-1082.

Wickens, C. D. (1980). The structure of attentional resources. In R. Nickerson (Ed.), *Attention and Performance VIII* (pp. 239-257). Hillsdale, NJ: Lawrence Erlbaum.

Wickens, C. D. (1984). Processing resources in attention, dual task performance, and work load assessment. In R. Parasuraman & D. R. Davies (Eds.), *Varieties of Attention*. New York: Academic Press.

Wickens, C. D. (1992). *Engineering Psychology and Human Performance*. New York: Harper-Collins Publishers, Inc.

Wickens, C. D., & Hollands, J. G. (2000). *Engineering Psychology and Human Performance*. New Jersey: Prentice Hall.

Wickens, C. D., & Seppelt, B. (2002). Interference with driving or in-vehicle task information: The effects of auditory versus visual delivery. *Technical report AHFD/GM*.

Wijers, A. A., Okita, T., Mulder, G., Mulder, L. J., Lorist, M. M., Poiesz, R., et al. (1987). Visual search and spatial attention: ERPs in focussed and divided attention conditions. *Biol Psychol, 25*(1), 33-60.

Wild-Wall, N., Hohnsbein, J., & Falkenstein, M. (2007). Effects of ageing on cognitive task preparation as reflected by event-related potentials. *Clinical Neurophysiology, 118*(3), 558-569.

Wilde, G. J. S. (1982). The theory of risk homeostasis: implications for safety and health. *Risk Anal, 2*, 209-225.

Wittmann, M., Kiss, M., Gugg, P., Steffen, A., Fink, M., Poppel, E., et al. (2006). Effects of display position of a visual in-vehicle task on simulated driving. *Appl Ergon, 37*(2), 187-199.

Wolfe, J. M. (1998). Visual search. In H. E. Pashler (Ed.), *Attention* (pp. 13-59). Hove, East Sussex: Psychology Press.

Wolfe, J. M., Cave, K. R., & Franzel, S. L. (1989). Guided search: an alternative to the feature integration model for visual search. *J Exp Psychol Hum Percept Perform, 15*(3), 419-433.

Wolfe, J. M., Friedman-Hill, S. R., & Bilsky, A. B. (1994). Parallel processing of part-whole information in visual search tasks. *Percept Psychophys, 55*(5), 537-550.

Wolfe, J. M., & Horowitz, T. S. (2004). What attributes guide the deployment of visual attention and how do they do it? *Nat Rev Neurosci, 5*(6), 495-501.

Wolffsohn, J. S., McBrien, N. A., Edgar, G. K., & Stout, T. (1998). The influence of cognition and age on accommodation, detection rate and response times when using a car head-up display (HUD). *Ophthalmic Physiol Opt, 18*(3), 243-253.

Zeef, E. J., & Kok, A. (1993). Age-related differences in the timing of stimulus and response processes during visual selective attention: performance and psychophysiological analyses. *Psychophysiology, 30*(2), 138-151.

Zijlstra, F. R. H. (1993). *Efficiency in work behavior. A design approach for modern tools*. Delft: Delft University Press.

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