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Divided attention and driving. The effects of aging and brain injury

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Summary

In this thesis, divided attention was investigated in four groups of subjects: closed head injury (CHI) patients, young control and healthy older subjects, and older subjects with cognitive impairments. It was studied how diffuse brain injury and normal and abnormal aging affect cognitive processes involved in divided attention tasks. Furthermore, it was investigated how deficits in divided attention relate to performance of instrumental activities of daily living (IADL), with an emphasis on car driving.

Divided attention is defined in this thesis as the capacity to perform multiple tasks concurrently and is conceived of as the resultant of a diversity of contributing cognitive processes. Divided attention deficits can be the result of impairments in each of the contributing basic processes, as well as in control processes involved in task coordination and integration (executive functions).

In chapter 1, an overview is provided of several theories of attention. The chapter starts with the well-known distinction between automatic and controlled information processing and describes the two-process model, proposed by Shiffrin and Schneider. This is followed by a description of the model developed by Norman and Shallice. They distinguish a mechanism responsible for automatic processing, contention scheduling, and a system for controlled processing, supervisory attentional control. Evidence from neuro-imaging studies is presented, linking control aspects of attention to frontal parts of the brain. Finally, the model of Brouwer and Fasotti is described. This model describes the interaction between basic cognitive and higher order control processes and offers explanations for deficits in complex task performance.

Emphasis is placed on methodological concerns and theoretical notions especially relevant for divided attention studies, such as disentangling the influence of basic cognitive and higher order control processes, resources and skill. Visual attention received special consideration due to its major relevance for perceptual-motor skills necessary in car driving. Spotlight metaphors are described along with the influential visual attention theories developed by Mesulam and Posner. Two theories of visual attention relevant for perception in car driving, namely the Useful Field of View model,

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and the Ecological Approach are also described.

Chapters 2 and 3 are review studies, describing the impact of diffuse brain injury in CHI patients and cognitive impairments in older drivers on car driving. Chapter 2 deals with the issue of fitness to drive in patients suffering from traumatic brain injury (TBI), the most frequent cause being CHI. Guidelines for assessment are proposed and three types of studies are reviewed: studies of impairments of attention and information processing, studies of driving competence, and driver selection studies applying and evaluating procedures for assessing fitness to drive. From these reviews a relicensing rate emerges of about 50% for very severe TBI patients. Unsuccessful relicensing particularly occurs in patients with a very long duration of post-traumatic amnesia (exceeding one month) and with severe impairments of perception and judgement.

Furthermore, a review of studies describing training of driving competence in traumatically brain-injured patients is presented. It is argued that graded procedures for (re)training should be developed and that assessment should extend to training advice and prediction of training success. Evaluation procedures should not only focus on operational capacities, but should include measures of executive functions and learning potential as well.

Chapter 3 is a review on assessment of fitness to drive in older drivers with cognitive impairments. Early studies on dementia and driving generally failed to distinguish between safe and unsafe drivers on the basis of cognitive test performance. Predictive studies demonstrated that cognitively impaired subjects as a group, perform significantly worse than controls on both neuropsychological and driving measures. A high prevalence of cognitive impairment is found in groups of older drivers involved in traffic accidents and crashes. Meanwhile, a large range in neuropsychological test scores is found. Low to moderate correlations have been reported between neuropsychological test results and on-road driving performance. Thus, it remains difficult to discriminate between cognitively impaired subjects who are fit or unfit to drive. The review concludes with a discussion of methodological difficulties in the field of dementia and driving, including subject selection, the choice of neuropsychological tests, and the operationalization of driving performance.

Chapters 4 through 6 describe assessment methods of driving performance, including a driving simulator test ride (chapter 4), selection methods (chapter 5),

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neuropsychological tests and on-road tests (chapter 6). Chapter 4 focuses on driving simulator assessment. In an attempt to combine the merits of neuropsychological assessment (standardization, reliability) and an on-road test (ecologically valid measures, behavioral observations), a virtual test ride was developed in the driving simulator of the Centre for Environmental and Traffic Research (University of Groningen). The implementation of intelligent traffic participants provided a convincing driving environment, in which interaction with other cars was studied and behavioral observations were scored. Results of a pilot study with eight subjects are presented. The sample included five (mildly) demented patients, one patient with Parkinson's disease and two TBI patients. The most significant problem that arose in the pilot study was the increased susceptibility for simulator-sickness in this group.

The test ride was subsequently validated in a group of 29 healthy older subjects. They were experienced drivers and their operational and tactical driving performance in the driving simulator was scored as sufficient to good. The subjects rated the resemblance of the virtual simulator world with the actual traffic environment as satisfactory. In particular, the intelligent interactive robot cars were perceived as "real" road users. Most subjects needed time to get used to the simulator car but they rated the test ride as easy to perform. Five subjects became sick and aborted the test ride. Two additional subjects suffered from serious nausea. Subjects also complained about dizziness, and an uncomfortable feeling of tension. Eight subjects (28%) were completely free of complaints related to simulator sickness. Due to the high incidence of simulator sickness, even in healthy subjects, the driving simulator was not routinely used for clinical assessments, despite the initially high expectations of its usefulness.

Chapters 5 and 6 describe parts of a driver evaluation study to investigate fitness to drive in cognitively impaired older drivers. The study consisted of three assessments: a medical screening (for all subjects), and a supplementary neuropsychological evaluation and an on-road driving test (for subjects with cognitive impairment). The study was implemented in the official, obligatory relicensing procedure for older drivers in the Netherlands.

Chapter 5 describes the medical screening and the selection procedure, and provides an estimation of the prevalence of cognitive impairments and an overview of relicensing rates in older drivers. For the medical screening a behavioral rating scale for cognitive

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impairments was developed. This instrument (the OPS) covered the domains of Orientation and memory, Praxis and attention, and Social functioning. Almost three-thousand subjects ($n = 2992$) who applied for license renewal were included in the study. The mean age of the group was 74 years, ranging from 65 to 94 years. Only 111 subjects (4%) demonstrated signs of cognitive impairment as observed during the medical screening. Of these persons, 45 subjects (39%) could renew their driving license for the full period of five years. Thirty-two candidates (29%) voluntarily stopped the relicensing procedure, and 21 subjects (19%) failed the on-road test, with the consequence that their license was not renewed. An additional 10 subjects (12%) needed restricted licenses. The 45 subjects with renewed full licenses were significantly younger and scored significantly better on a diversity of neuropsychological measures than the others.

Of the initial 111 subjects selected from the 2992 older drivers described in chapter 5, 80 subjects completed both the neuropsychological assessment and the on-road driving test. The neuropsychological test results and driving performance data of these 80 subjects are described in chapter 6. The average age of the subjects was 78 years, with a standard deviation of $sd = 5.8$. The neuropsychological evaluation covered four domains for predicting driving performance, namely perceptual-motor speed, visual attention, divided attention and executive functions, and practical task performance. Driving performance was evaluated by means of an observation method, the TRIP (Test Ride to Investigate Practical fitness to drive). The group as a whole demonstrated impaired driving skills. The neuropsychological evaluation revealed severely impaired scores on a diversity of tests. Impaired scores were also obtained on the Mini Mental State Examination (mean MMSE score was 23 with a standard deviation of 4.5). Thirty-two subjects scored below 24 on the MMSE, reflecting mild (30%) to moderate (10%) cognitive decline. All cognitive domains were significantly correlated with driving performance, the correlation coefficients varying between $r = 0.40$ and $r = 0.50$. In a stepwise multiple regression analysis, the domains of visual attention and practical task performance (operationalized as drawing from memory and copying from example, reflecting overlearned skills) emerged as the strongest combination of predictors, explaining one third of the shared variance with driving performance (adjusted $R^2 = 0.32$). A logistic regression analysis resulted in 76% correct test-score-based predictions

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in terms of passing or failing the on-road test.

Chapters 7 and 8 are concerned with the nature of deficits in divided attention in terms of speed and control. The study described in chapter 7 evaluated the contribution of speed and control processes to divided attention tasks in a group of 26 (very) severe CHI patients and 25 orthopedic controls. All subjects were evaluated three months post-injury. Single and dual task paradigms were administered to assess stimulus driven flexibility (four-choice visual and auditory reaction time task), memory driven flexibility (Trail Making test), and strategy driven flexibility (continuous tracking task and arrow identification). Secondly, the relationship between divided attention measures and subjective impairments in IADL was investigated. Reduced speed of information processing following CHI proved to be largely responsible for difficulties in dual task performance, but dual task measures resulted in higher correlations with self-reported IADL than single task measures.

Chapter 8 compares the deficits in divided attention of CHI patients and healthy older subjects. The test scores on the divided attention tasks of the 26 subacute CHI patients were compared with data from 54 healthy older subjects (mean age 65 years with a standard deviation of 7.6). It was hypothesized that aging, like CHI, would lead to a reduction in processing speed. Impairments in control processes, emerging in dual task performance after (statistically or experimentally) controlling for single task performance, were supposed to exist for healthy older subjects, but less so for CHI patients. A general reduction in the speed of information processing in healthy older subjects was demonstrated in most single task conditions. These effects were comparable with the reduction in speed of information processing observed in CHI patients. Healthy older subjects demonstrated some impairments in control processes but these were less extensive than reported in earlier studies. In fact, the results of the CHI patients and the healthy older subjects were fairly convergent. In both groups, impairments in control processes emerged in the most complex tasks in which active strategies to divide, allocate and shift attention were required.

The final chapter contains the discussion. The main theoretical themes of the thesis are recapitulated, along with some clinical and practical implications and methodological concerns. Three topics are considered. The first topic is concerned with the contribution of speed and control processes in complex task performance in CHI

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patients and healthy older subjects. The second topic addresses the role of deficits in divided attention in driving and other IADL activities. The last topic is concerned with clinical and practical implications.

The rationale behind the single/dual task paradigms used in this thesis is discussed. The single task variants were regarded as baseline measures reflecting the effectiveness of all basic cognitive processes, as expressed in terms of speed, needed to perform the specific single task. The dual task is the experimental condition reflecting the total contribution of both basic cognitive processes and of processes involved in task coordination and integration. When the influence of basic cognitive impairments is statistically or experimentally controlled, additional dual task effects can be interpreted as impairments in task coordination and integration (control processes).

Visual attention was given special consideration. It is argued how control processes may be involved in a mainly perceptual task and how attention may be distributed across the functional field of view.

In both CHI patients and healthy older subjects, it was concluded that impairments in control processes emerged in the most complex tasks in which active strategies to divide, allocate and shift attention were required. It should be realized, however, that the deficits in control were mostly small and could not be demonstrated in all tasks. Speed, therefore, remains a major factor in understanding the nature of deficits in divided attention in these groups.

Significant correlations between neuropsychological measures and an on-road driving test in older drivers with cognitive impairments were established. From a theoretical point of view these correlations are promising, but for individual assessment of fitness to drive, predictions of success still lead to high numbers of misses and false alarms. Therefore, actual observation and driving measures remain warranted.

Despite its experimental and methodological advantages, the driving simulator proved not to be feasible for routine assessments due to the high incidence of simulator sickness. On-road tests have not been evaluated yet for their psychometric properties. Thus, up to date, no information on validity and reliability is sufficiently available. Validation research in this field is therefore very important.

With regard to relicensing, a three-stage model is proposed: a medical screening for all older drivers, and a neuropsychological evaluation and an on-road test for drivers

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with observed cognitive impairments. The debate of relicensing in older drivers is, however, a controversial issue. Organizations that promote the rights and interests of older individuals claim that a special relicensing procedure for older people is a form of discrimination. In justifying relicensing procedures, licensing authorities claim that the prevalence of impaired fitness to drive is increased in older people compared to middle-aged subjects due to aging-related functional impairments and/or diseases.

The studies described in this thesis enhance our knowledge to some degree about the relationships between cognitive impairments and complex task performance, but also point out the limitations encountered in this field of research. Future research should not be directed in the first place at finding new neuropsychological tests or experimental tasks being used in prediction of driving performance. A more fruitful approach would be to develop observation instruments that meet certain psychometric quality characteristics of neuropsychological tests and tasks. Observation instruments or methods should combine the ecological validity of current driving tests with the psychometric qualities of neuropsychological tests.

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