Critical factors for safe driving after an acquired brain injury

Per-Ola Rike

Sunnaas Rehabilitation Hospital
Department of Research

and

Faculty of Medicine

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Gjettum, 21st June 2016

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This thesis is based on the following papers which are referred to in the text by their numbers I-III.

**Paper I**

**Paper II**

**Paper III**
**Abbreviations**

<table>
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<th>Abbreviation</th>
<th>Description</th>
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<tbody>
<tr>
<td>ADHD</td>
<td>Attention Deficit Hyperactivity Disorder</td>
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<td>ADSES</td>
<td>Adelaide Driving Self-Efficacy Scale</td>
</tr>
<tr>
<td>AQ</td>
<td>Awareness Questionnaire</td>
</tr>
<tr>
<td>BRIEF-A</td>
<td>Behavior Rating Inventory of Executive Function - Adult version</td>
</tr>
<tr>
<td>CWIT</td>
<td>Colour-Word Interference Test</td>
</tr>
<tr>
<td>D-KEFS</td>
<td>Delis-Kaplan Executive Function System</td>
</tr>
<tr>
<td>DBQ</td>
<td>Driver Behaviour Questionnaire</td>
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<tr>
<td>DHQ</td>
<td>Driving Habits Questionnaire</td>
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<tr>
<td>MDA</td>
<td>Multidisciplinary Driving Assessment</td>
</tr>
<tr>
<td>PASAT</td>
<td>Paced Auditory Serial Addition Test</td>
</tr>
<tr>
<td>PCRS</td>
<td>Patient Competency Rating Scale</td>
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<tr>
<td>SDMT</td>
<td>Symbol Digit Modalities Test</td>
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<tr>
<td>SDPQ</td>
<td>Sunnaas Driving Pattern Questionnaire</td>
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<tr>
<td>TBI</td>
<td>Traumatic Brain Injury</td>
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<tr>
<td>TMT</td>
<td>Trail Making Test</td>
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<tr>
<td>UPPS</td>
<td>UPPS Impulsive Behaviour Scale</td>
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<td>WAIS-III</td>
<td>Wechsler Adult Intelligence Scale - Third Edition</td>
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1. Introduction

1.1 Background

Road traffic accidents are a major public health problem. The estimated number of people killed worldwide in road traffic crashes each year is approximately 1.2 million, whereas the number of people injured could be as high as 50 million. Human factors are a sole or contributing factor to the majority of crashes and include cognitive failure, fatigue, use of alcohol and drugs, risky driver behaviour and demographical factors such as age and gender. In addition, various diseases also compromise driving safety. The influence of cognitive deficits on driving fitness has been extensively studied, especially in older drivers and those with dementia of Alzheimer type, stroke and TBI. While some survivors of stroke and TBI are completely unable to drive again, approximately 40-80% resume driving.

In Norway, medical doctors, psychologists and opticians have a mandatory duty to report to the authorities when a patient’s health condition is contrary to drive as specified in Norwegian statutory guidelines and laws (The Health Personnel Act §34). The Norwegian law that specifies the health requirements for driving (Førerkortforskriften, Vedlegg 1), includes descriptions of medical conditions that may affect driving fitness, such as neurological disorders, cardiovascular disorders, diabetes mellitus, visual disorders, psychiatric disorders and drug or alcohol misuse or dependence. The vast majority of driving assessments is carried out by general practitioners (GPs) and involves a broad spectrum of illnesses and diagnoses that may affect driving capacity. GPs often apply screening methods. In cases where hospitalization or rehabilitation is required after a brain injury or in other complex medical and psychiatric conditions, patients can be referred to a multidisciplinary driving assessment (MDA), which is the topic of this thesis.

While the health requirements for driving are specific and often clear-cut with regard to many medical conditions, cognitive functions and higher-level cognitive and mental functions in particular (e.g., executive functions, awareness of deficits and self-regulation) are challenging to assess and properly interpret in terms of predictive value regarding driving safety. Studies examining driving capacity after brain injuries have largely focused on performance-based measures such as neuropsychological examination and on-road driving tests because they measure critical functions for safe driving, such as sensory, motor and
basic cognitive functions like processing speed, visual attention and visuospatial abilities \(^{11}\). However, performance-based tests may systematically fail to identify higher-level cognitive and regulatory deficits with relevance for driving capacity \(^{12,13}\). Studies of healthy drivers have shown that a their \textit{perceptions} of their own functional abilities have a profound influence on driving behaviour \(^{14-16}\). The common denominator of these higher-level self-perceptions is the awareness of own abilities that may influence how drivers cope with the ever-changing demands in traffic \(^{17}\).

The main objective of this thesis is to explore how higher-level mental functions were associated with post-injury driving behaviour outcomes in a sample of survivors of stroke and TBI, supplementary to a standardized multidisciplinary driving assessment (MDA) including neuropsychological assessment and an on-road driving test. The thesis combines performance-based and self-rating measures, which is lacking in the stroke and TBI literature where the focus has tended to be on neuropsychological testing of underlying component of cognition in predicting driving outcome.

### 1.2 Higher-level mental functions and driving

The ability to flexibly adapt driver behaviour to the changing demands of the environment involves adequate higher-level and top-down mental processes essential for the compensatory aspects of driving \(^{18}\). Good compensatory decisions rely on higher-level reasoning skills and include being able to take a meta-perspective of own driving capacity \(^{19,20}\). Research on higher-level functions has been undertaken in various fields such as neuropsychology, social and personality psychology, neuroscience, rehabilitation and education \(^{21}\), and include constructs such as executive functions, metacognition, self-awareness and self-regulation \(^{22-26}\). Unfortunately, findings have not been combined across fields resulting in variability in definitions of the constructs \(^{27}\). One of the objectives of this thesis was to explore relationships between executive functions, self-regulation and self-awareness, and to understand how these inter-relationships affect driver behaviour in adults with acquired brain injury.

#### 1.2.1 Self-regulation and executive functions

According to Hoffman and colleagues \(^{27}\), the capacity for self-regulation is a core aspect of human behaviour that for years have been studied largely in parallel in the field of social and
personality psychology and cognitive psychology. Self-regulation has been defined as the process of adjusting performance as an individual works toward identified behavioural goals within a specific context. In clinical neuropsychology, self-regulation is regarded as an active, overarching process that utilize executive functions, and involves planning, self-observation, self-reflection and performance adaptations that occur automatically or at a conscious level. Like self-regulation, executive functioning has also been described as an overarching process, but more specifically a cognitive process, mediated by attention, that integrates and coordinates multiple subordinate cognitive skills to enable goal-directed behaviour. Executive functions include higher-order, goal-directed cognitive processes, including those related to problem solving, planning, initiation, inhibition, cognitive flexibility and deficit awareness.

Self-regulation and executive functions are largely associated with activity in the prefrontal cortex. The prefrontal cortex shares connections with a wide range of systems that generate and modulate behaviour and emotions. According to Stuss, studies from the field of neuroscience have included four functional domains that involve executive functions and self-regulatory processes that also have been associated with specific brain areas, namely 1) executive cognitive functions (lateral prefrontal cortex), 2) behavioural-emotional self-regulatory functions (ventromedial prefrontal cortex), 3) energization regulating functions (medial frontal) and 4) metacognitive processes (polar region). Self-regulatory deficits after a brain injury may also manifest themselves as personality changes, such as reduced emotional control and increased impulsivity. These personality changes are often related to deficits in executive cognitive processes.

However, in traffic psychology from the literature on older drivers, self-regulation applies to how drivers evaluate their own functional abilities and adjust their driving behaviour accordingly. Compensatory driving strategies are regarded as a result of self-regulatory actions of the driver, not only within a minimal temporal perspective as described in the neuropsychological literature, but also strategic regulatory decisions regarding when and where to drive. Further, in the field of social and personality psychology, self-regulation have been defined as a behavioural and emotional response to internal and external phenomena. Because driving research is conducted in all these fields, it has been challenging to specifically formulate and operationalize executive functions and self-regulation in order to communicate with all research fields in a thesis mainly originated from the field of rehabilitation and neuropsychology. This is reflected in the current thesis’s
papers: In Paper I and Paper III we labeled executive functions and impulsive personality traits as self-regulatory mechanisms as described by Hoffman and colleagues. However, self-regulatory mechanisms were not applied as an overarching construct in Paper II after discussions with the reviewers during the publishing process. In this thesis, self-regulation is regarded as a behavioural and emotional response influenced by cognitive capacities (i.e., lower level cognitive and executive functions), personality dispositions (i.e., impulsive personality traits), situational factors (e.g., driving context) and awareness and attribution processes (e.g., driving self-efficacy), which corresponds to the descriptive framework outlined by Hofmann and colleagues.

**Self-regulation, executive functions and driving**

Several authors have proposed that accident risk is moderated by self-regulatory capacities and executive functioning. Stroke and TBI studies that have explored executive functions as predictors of driving behaviour have mainly included performance-based tests that measure the three aspects of executive cognitive functions as described by Miyake et al., namely 1) Inhibition (e.g., Stroop tests), 2) Updating (e.g., Letter/Number sequencing tests and PASAT) and 3) Shifting (e.g., TMT B and WCST). The association between performance-based executive tests and driving performance have yielded mixed results, and most of the studies have used on-road driving tests as an outcome measure. In a comprehensive TBI driving study by Coleman and colleagues that included multiple medico-psychological predictors and multilevel outcome measures (driving cessation, self-reported driver behaviour and incidents), a composite score consisting of 4 neuropsychological tests measuring working memory, reasoning, psychomotor speed and mental flexibility (Letter/Number Sequencing and Matrix Reasoning (WAIS-III) and Coloured Trails 1+2) combined with number of years post-injury and disability at discharge from a rehabilitation hospital, predicted post-injury accidents and violations. In a stroke and TBI study by Lundqvist and colleagues, a comprehensive neuropsychological test battery were used as predictors of driving performance (simulator and on-road driving test), including executive tests like TMT B, PASAT, WCST and Listening Span. A factor analysis grouped the tests into four factors, 1) executive, 2) cognitive, 3) automatic attentional capacity and 4) simple perceptual-motor capacity. The most potent subtest was the executive cognitive test TMT B. Another study reported that TMT B was associated with failure on an on-road driving test.
Even though there are some indices that single neuropsychological tests, or composite scores of multiple tests may predict post-injury driving fitness, it is recommended that higher-level mental functions such as level of awareness of deficits also need to be taken into consideration in driving assessments and research 5-7.

1.2.2 Self-awareness and self-efficacy

Self-awareness is viewed as the highest form of brain activity that interacts with other brain processes that include the interaction between both neuropsychological and psychological processes and capacities 22,46. Because of the variability in the clinical representation of awareness deficits, it is unlikely that a single theory may explain the mechanisms underlying self-awareness 22. According to Hunt and colleagues 21, self-regulation involves self-observation and self-reflection. This corresponds to Prigatano’s understanding of self-awareness as “the capacity to perceive the ‘self’ in relatively ‘objective’ terms while maintaining a sense of subjectivity” 46. In addition, Ylvisaker 47 posited self-awareness as one of many aspects of executive functions. Building upon Crosson’s hierarchical Pyramid Model of self-awareness 48, Toglia and Kirk 49 describe self-awareness as a dynamic process between intellectual and online awareness. Intellectual awareness refers to the cognitive capacity to understand and acknowledge the implications of a particular cognitive deficit on functional performance (e.g., driving). Online awareness refers to the ability to recognize a problem when it is occurring and to anticipate whether a cognitive deficit may be experienced during future tasks.

Accurate self-awareness is critical to driver behaviour because knowledge of their strengths and weaknesses can help drivers take efficient compensatory action to moderate risk and to ensure safety in hazardous environments 50. Some researchers regard self-awareness as related to the broad concept of metacognition in cognitive psychology and to executive functions within neuropsychology 25,49,51. Following acquired brain injuries, there is a close connection between the level of executive deficit and the patient’s capacity to make realistic appraisals of the level of cognitive functioning 52. Similarly, there is an overlap between self-awareness and the concept of self-efficacy from social-cognitive psychology 53. Self-efficacy refers to beliefs about one’s effectiveness and capabilities to successfully execute tasks and achieve goals in different contexts, including driving 54. Self-efficacy beliefs are regarded by some authors as a sub-process of self-regulation, and this relationship is reciprocal in that manipulating self-regulation processes can produce changes in one’s self-perceptions 55.
Perceived self-efficacy and personal risk judgment have been reported to affect self-reported driving behaviours\(^\text{15}\), and drivers who display greater overconfidence in their own driving ability are significantly more likely to report a crash\(^\text{56}\).

The observation of drivers’ self-perceptions following stroke and TBI has a direct bearing on risk and fitness to drive because persons who acknowledge having e.g. cognitive deficits must also accurately assess their severity in order to invoke compensatory behaviours that are proportionate to the need. Lundqvist and Alinder\(^\text{17}\) reported that participants with acquired brain injuries that failed the on-road driving tests significantly overestimated their driving performance. By contrast, those who passed the driving test had self-rating in concordance with the result of the driving test. The authors concluded that persons that passed the driving test were more aware of their cognitive functioning and also due to this had better abilities to adjust driving behaviour to cognitive capacity than those with awareness deficits. Rapport et al.\(^\text{8}\) reported that TBI survivors with cognitive deficits (as measured with neuropsychological tests) and whom still rated their abilities as unchanged and high (indicative of unawareness), drove more and were also involved in a higher number of driving incidents. As noted by Lundqvist and Alinder\(^\text{17}\), individuals with brain injury whom recognize their limitations may to a lesser extent engage in driving situations that are beyond their capabilities, lowering their risk of accidents. Griffen et al.\(^\text{6}\) reported that awareness has a mediating role between neuropsychological performance and driving performance (on-road driving test). Adequate awareness of deficits after a stroke and TBI influences the self-regulatory skills in ways that most likely enhance driving safety in these groups.

1.2.3 **Premorbid risk factors and post-injury driving behaviour**

Studies have shown that premorbid risk factors such as impulsive personality traits, inadequate self-control and risky driving style continue to influence driver behaviour even after a brain injury\(^\text{57}\). Some authors have ultimately hypothesized that the interaction of premorbid profiles and post-injury self-regulatory and cognitive executive deficits (i.e., impaired inhibitory control, switching, top-down control of attention and regulation of affect), may increase accident risk in some post-TBI drivers\(^\text{58-61}\), but this has not been tested directly. In terms of self-regulation, people high in impulsivity and impaired response inhibition are likely to struggle to stay on track in the pursuit of important goals or outcomes
Thus, impulsive personality traits may be regarded as dispositions that influence self-regulatory processes \(^{27}\).

TBI survivors that initially got their TBI due to some sort of risky behaviour (e.g., driving under influence of drugs/alcohol or due to excessive speeding/overtaking), may require additional attention during driving assessments. TBI typically involves diffuse axonal injuries \(^{63}\) along with multifocal contusions often involving temporal and frontal areas, which results in a prototype pattern of impaired attention, memory and executive deficit. This might exacerbate premorbid risky behaviour traits \(^{57,60,64}\).

Although studies have reported that stroke and TBI survivors with cognitive impairments seem to increase their use of compensatory driving strategies (e.g., avoiding rush hour and night driving) \(^{60,65-67}\), one follow-up study indicated that some TBI drivers reported driving as they had prior to the TBI despite acknowledging cognitive impairments that reduced their driving abilities \(^{60}\). This TBI sample also exhibited increased accident rates compared to normative data, but the sample size was small \((n = 28)\). A similar pattern was reported in another TBI study where drivers with poorer neuropsychological functioning at the time of rehabilitation discharge drove less frequently and shorter distances, but did not avoid challenging driving situations \(^{68}\). This cognitive-behavioural paradox supports the notion that driving behaviour to some individuals seems resistant to change, even after a TBI \(^{69}\).

However, few stroke and TBI studies have implemented personality traits as predictors of driving behaviour \(^{11}\). Pietrapiana et al. \(^{57}\) reported that premorbid personality and driving behaviours accounted for 72.5% of post-TBI accidents and violations. Another study with stroke and TBI participants that included a comprehensive cognitive test battery, reported that cognition and personality traits (e.g., sensation-seeking, social responsibility, self-control, and emotional stability) significantly predicted the outcome of an on-road driving test \(^{70}\).

In essence, survivors of stroke and TBI with mild to moderate sensorimotor, cognitive and self-regulatory deficits may be at low risk for accidents if they acknowledge their deficits and act accordingly during driving. By contrast, unawareness or under-appreciation of even mild deficits may increase accident risk substantially. Safe operation of a motor vehicle requires a complex interaction of motor, cognitive and perceptual skills. Higher-level functions such as self-awareness and self-regulation hold a key status in the models of driving behaviour because drivers who recognize their skill limitations often are able to adapt their driving behaviour accordingly \(^{19,20}\).
1.3 Models of driver behaviour

Several conceptual models have been proposed to describe the complex skills and abilities necessary for safe driving behaviour and low accident risk, including models targeted at brain-injured drivers. The models proposed by Michon, Hatakka et al. and Sümer are hierarchical in structure and describe the interplay between lower functions such as vehicle handling and higher-level functions such as self-evaluation and awareness of impulse control, planning skills, hazard perception and the strengths and weaknesses of one’s own driving skills.

Michon described the following three levels of driving behaviour: operational (e.g., largely automatized driving skills, such as basic vehicle handling), tactical (e.g., anticipation and interaction with traffic) and strategic (e.g., navigation and route planning). Some authors pose that basal cognitive functions such as processing speed, attention and visuospatial abilities correspond primarily with the operational level and, to a lesser extent, with the tactical level, whereas executive functions and impulsive personality traits, are highly influential on tactical and strategic aspects of driving behaviour. Executive processes are integral to higher-level brain functions particularly in the areas of goal formation, planning, goal-directed action, self-monitoring, attention, response inhibition and coordination of complex cognition for effective performance. Executive functions, including self-control and awareness of cognitive capacity, are regarded as moderators between neuropsychological functioning and driving performance. Executive control is a key aspect of emotional regulation, judgement and decision making in daily life and required skill for adequate decision-making under time pressure in traffic. Cognitive and executive deficits may distort the decision-making process at the tactical and strategic levels of control, given that adequate reasoning depends on cognitive capacity. Some authors hypothesize that executive function deficits decrease the ability to acknowledge when to compensate on tactical and strategic levels in traffic, which may ultimately increase accident risk. Michon’s hierarchical model works well as a descriptive/qualitative concept, yet there is no empirical support for it in the literature.

Hatakka et al. specifically address higher-level functions such as self-evaluation and awareness of impulse control, self-critical thinking, planning skills, hazard perception, and the strengths and weaknesses of one’s own driving skills as the higher levels in the hierarchy of driver behaviour. These higher-level self-regulating skills and the individuals’ awareness
of own skill limitations may moderate the relationship between cognitive functions and driver behaviour to affect post-injury driving fitness. Sümer’s contextual mediated model considers cognition, personality characteristics and socio-demographic variables factors in a distal context that indirectly influence accident proneness mediated through driver behaviour in daily life (e.g., aberrant driving behaviour, violations, errors, speeding), which is considered as a proximal context more closely related to accident tendencies. Driving under influence of drugs and alcohol are specific proximal risk factors. The proximal context is considered to be directly related to accident risk. Sümer argues that the relationship between the distal context (e.g., cognition and personality) and accidents is weaker than the association between the distal and the proximal driver context. Thus, the distal factors create a generalized tendency in drivers to have high levels of risky driving behaviours (i.e., proximal factors), and that these behaviours in turn influence accident rates. Sümer’s model may explain why neuropsychological tests (distal context) have shown mixed results when predicting accident rates in stroke and TBI studies, because surprisingly few stroke and TBI driving studies have incorporated the proximal context in the study designs.

The scope of this thesis is to examine the associations between the subjective and objective parameters in the distal and proximal context and accidents.

1.4 Driving after stroke and TBI – a risk assessment

A stroke or TBI survivor may experience various functional impairments with relevance for safe driving such as sensory and motor functioning, processing speed, attention, visuospatial abilities, memory, problem solving, executive functions and self-awareness. When assessing fitness to drive after stroke and TBI, clinicians consider a number of factors and their risk potential magnitude when estimating the likelihood that unsafe driving behaviour will occur in the future due to health related deficits. The theoretical models of driving...
behaviour serve as frameworks that specify what functional areas (i.e., risk factors) that require attention in driving assessments and research.

Focal deficits that are often seen after uni-lateral strokes such as neglect, apraxia and visuospatial deficits, are often concrete and directly observable as impaired performance on neuropsychological tests. Multifocal brain injuries or subarachnoidal haemorrhages may produce executive deficits (e.g., poor self-monitoring, planning and decision-making) that are more difficult to quantitatively assess than focal cognitive deficits. Stroke and TBI survivors with higher-level deficits may perform adequately on many neuropsychological tests, and may pass a driving assessment despite having poor judgement and self-regulatory impairments in everyday living that may impair risk perception and driving fitness. Thus, some authors have suggested that accidents risk is moderated by higher-level functions such as executive functions and self-awareness. These overarching executive, regulating and metacognitive functions affect the capacity and integrity of other sensory, motor and cognitive abilities and are often affected after stroke or TBI.

The higher-level functions described in the field of neuropsychology have many equivalents in the models of driving behaviour. Hattaka et al. describe the importance of realistic self-evaluation and awareness of the strengths and weaknesses of one’s own driving skills for driving safety. In addition, Hattaka et al. stress the importance of cognitive and personality factors that may influence driving behaviour, such as self-control, impulse control, sensation seeking and planning abilities. These factors from the field of traffic psychology correspond to the higher-level functions in neuropsychology, namely self-regulation, executive functions and awareness of deficits. Of critical importance for driving safety is how the post-stroke or TBI driver adapts his abilities (sensory, motor, perceptual and cognitive) to cope with the demands of the given driving scenario. This adaptation process requires self-regulating essential to tactical and strategic driving decision making processes, namely self-evaluations and self-control.

Risk assessment

A key feature of a multidisciplinary driving assessment is to estimate probabilities of potential post-injury risky driving behaviours based on the individual’s sensory and motor functions, cognitive and perceptual factors as well as higher-level functions. In the brain injury literature, no evidence-based or theoretically derived algorithms specify how to combine and weigh multilevel risk parameters in relation to specific driving outcomes. This is in part due to a lack of follow-up studies that include multilevel predictors and outcome
measures. In addition, few studies have applied the same methods, making comparisons across studies challenging. Thus, in a clinical driving assessment, clinicians need to estimate the probability of whether e.g. a young male TBI survivor with injury related impulsivity and reduced emotional control are able to cope with these deficits and still be a safe driver. Because the existing stroke and TBI driving literature rarely have explored to what degree such post-injury deficits affect daily life aberrant driver behaviour and accident rates compared to the healthy population, driving assessments are reliant on the clinicians experience and subjective decisions. Because patients with moderate to severe cognitive deficits rarely are included in driving studies due to health requirements that prevents them from driving, little is known whether they still can be safe drivers if they have adequate awareness of deficits and apply effective compensatory actions during driving. Thus, the literature have not explored whether drivers with minor cognitive deficits that do not apply adequate compensatory actions during driving are more unsafe in traffic than drivers with more severe cognitive impairments that compensate for this during driving.

In addition to the injury-related deficits that may impair driving, clinicians also need to consider premorbid risk factors that may influence driving fitness, e.g. personality traits and driving style/behaviour. Even though studies have shown that the impact of premorbid risk factors on post-injury driving may be substantial, such parameters have only been included in a few stroke and TBI driving studies. Schanke et al. (2008) reported that many post-TBI drivers “continued to drive as before” indicating that a subgroup of potential drivers do not compensate for deficits even they do acknowledge that these cognitive deficits impair driving capacity. Therefore, awareness of deficits does not necessary lead to compensatory actions, and in such cases, the influence of premorbid factors (e.g., sensation-seeking personality traits, increased accident involvement, aberrant driver behaviour and history of driving under influence of drugs) upon post-injury driving behaviour seems substantial. Thus, the interactions between premorbid risk factors and post-injury cognitive and self-regulatory deficits may produce a sub-group of high-risk drivers that require a multifaceted driving assessment that extends beyond performance-based methodology such as neuropsychological testing and on-road driving tests.
1.5 Performance-based and rating measures

The procedures used to assess driving capacity in clinical settings and research employ performance-based and rating measures, and they differ in terms of how they are administered and scored. Performance-based methods have been the method of choice when assessing driving capacity, because they involve standardized procedures requiring accuracy and timed performance. Rating measures involve self or informant reporting on difficulties with carrying out everyday tasks. Rating scales of basic cognitive and executive functions were developed to provide ecological valid indicators of abilities not necessarily measured with performance-based tests, such as anticipation and deployment of attention, impulse control, utilization of feedback, planning ability and organization and initiation of activity. This is exemplified with research that has shown a lack of association between performance and ratings of executive functions. Toplak and colleagues argue, as with the construct of intelligence, that executive functions have been defined broadly, but measured narrowly (by means of performance-based tests). This analogy may as well be suitable for the construct of driving behavior that also has been broadly elaborated in theoretical models, but is mostly measured with performance-based measures such as driving tests and cognitive performance measures. This is unfortunate because some of the higher-levels functions that are included in the theoretical models of driving, e.g. driving self-efficacy and awareness of cognitive capacities, have no specific equivalents in performance-based methods, but they are assessable with rating measures. Because it currently remains unclear to what extent performance-based and ratings of e.g. executive function assess the same underlying construct, studies that seek convergence between these methodological approaches are needed. The narrow scope of cognitive executive function measurement in driving studies may explain why the predictive value of executive tests of post-injury driver behaviour are poorer than would be desired for valid decision-making when determining post-stroke and TBI driving fitness. Even though rating measures is a popular method to assess a variety of psychological functions in many research areas, clinical driving research has rarely have incorporated rating measures in the studies. This is probably due to the susceptibility of underreporting of symptoms that may arise during driving assessments, but also because post-injury cognitive deficits may distort the capability of rating one’s own functions in a valid manner. Thus, little is known whether it is the post-stroke and TBI driver own perceptions of own driving capability that influence daily life driver behaviour, or the results from performance-based tests.
Self-rating of cognitive and higher-level functions and driving

Rating scales of cognitive and executive function were developed to provide ecologically valid indicators of competence in daily life situations. A variety of rating measures are available to specifically assess cognitive functions (Cognitive Failures Questionnaire (CFQ)), executive functions (Behaviour Rating of Executive Functions (BRIEF-A)), functional abilities/self-awareness (Awareness Questionnaire (AQ)) and driving self-efficacy (Adelaide Driving Self-Efficacy Scale (ADSES)). The few studies that have utilised self-rating of executive functions report that attention regulation and driver errors measured with Driver Behaviour Questionnaire (DBQ) and high symptom reports on the BRIEF-A are associated with increased number of aberrant driver behaviours. Lapses during driving are reportedly correlated with self-reported cognitive failures (CFQ) and reduced attention vigilance during computerised tasks. Rating of daily life aberrant driver behaviours have in many studies shown associations with road traffic accidents and impulsive personality traits in healthy populations.

Significant others’ rating

Coleman and colleagues concluded that caregivers’ ratings on the Patient Competency Rating Scale were stronger determinants of driving status and number of miles driven than the patients’ ratings. Another study utilized discrepancy scores on patient and informant ratings on the AQ to establish measures of awareness levels. Level of awareness was strongly associated with driving performance (on-road driving test), as awareness increased, driving performance improved. The authors concluded that the relationship between neuropsychological performance and on-road driving test outcome depended on levels of awareness.

Self-perceptions, awareness and behaviour

Self-rating requires stroke and TBI survivors to accurately estimate the deficits they may have, a process that depends on adequate awareness. Even though few stroke and TBI driving studies have explored to which extent self-perceptions of functional abilities (e.g., cognitive capacity and driving skills) actually direct behaviour, beliefs about one’s own confidence have been proposed as one of the most important predictors of performance and behaviour. Thus, overestimation of own skills may engage people in activities that are too difficult, such as driving. One study concluded that over-positive appraisal was higher
among drivers with higher error/violation score and with the ones that were evaluated by the expert as unsafe 50.

Summarized, self-rating of own functional abilities after stroke and TBI (i.e., sensory and motor functions, basal cognitive functions, executive functions and behavioural/affective and self-regulatory processes), may provide unique insight into a person’s awareness levels that ultimately may predict daily life driver behaviour and accidents.

1.6 Driving outcome measures

Driving outcome measures are those parameters used to assess the actual driving fitness after stroke or TBI to distinguish the safe from unsafe driver. They are indexes thought to reflect daily life driving behaviour on a temporary and longitudinal basis. Three main outcome measures have been used in stroke and TBI driving research, namely 1) accident rates 2) driving tests (on-road driving tests and driving simulators) and 3) self-ratings of daily life driver behaviour. Driving tests and accidents rates includes directly observable and objective data, whereas daily life driver behaviors are accessible through rating measures. Compared to driving tests and accident rates, ratings of daily life driver behavior have largely been neglected in stroke and TBI driving studies 9,11,96.

Accident rates

In a public health perspective, the ultimate gold standard outcome measure of driving fitness is whether the stroke or TBI driver have increased accident rates compared to the healthy population or not. Some studies report a higher accident risk after stroke and TBI 58-60,64 while other studies do not report higher accident risk post-stroke 60,65,67,97,98. A number of authors have proposed that one risk group consists of TBI-survivors who exhibit premorbid risky personality and driving behaviours, given the interaction of these behaviours with executive deficits due to frontal or multifocal brain injuries 57,60. Specifically, some argue that post-TBI drivers might represent a higher risk in traffic due to younger age and the predominance of males compared to post-stroke drivers 60,64. In the healthy Norwegian population, younger males have higher accident rates compared to other drivers 99. In order to collect all accident data with relevance for the brain-injured driver, some authors recommend the use of self-rating of minor accidents in addition to official accident registers that mainly contain severe accidents reported to police or insurance companies 65,100. It is likely that minor accidents may be related to cognitive deficits, as shown in a study by
Rapport et al. (2008)\(^8\), where among post-TBI drivers, lower cognitive functioning and unawareness of deficits (high estimates of driving ability) were associated with increased accident risk.

**On-road driving tests and driving simulators**

In driving assessment after stroke and TBI on-road testing have been considered a criterion standard in driving evaluations\(^6,7,44,81,101\). On-road driver assessment is regarded as the more accurate means of assessing driving fitness by assessing the effects of sensory and motor, visual and cognitive impairments on driving capacity\(^81\). Studies have demonstrated that on-road driving tests in many cases can distinguish the performance of persons with cognitive impairments from healthy controls\(^7,44,102,103\). Driving simulators are also available in the assessment of post-injury driving fitness without the obvious safety risks of on-road testing\(^104-106\). Despite being an ecologically valid measure of driving capacity\(^107\), the on-road driving test may in some cases fail to adequately measure the higher-levels of driver behaviour such as risk acceptance, self-awareness, planning abilities, impulsivity, strategic thinking and decision-making processes that influence daily life driver behaviour specified in the models of driving behaviour. Some drivers may adjust their risky driving behaviours (e.g., avoid speeding, tailgating and overtaking) in order to pass the driving test. Some argue that the on-road driving test over-dependent on subjective observation and often lack standardization\(^108\). In contrast, driving simulators may offer standardized routes and challenging assessment to establish the individual’s capacity limits that also may include participants with severe cognitive deficits. The most challenging part of driving simulation is the phenomenon of simulator sickness that causes dropout especially among older drivers\(^109\).

**Daily life driver behaviour**

Stroke and TBI studies have mainly explored relationships between measurements collected during a driving assessment (i.e., neuropsychological and on-road driving test performance) and follow-up studies have mostly included accident parameters to compare with baseline data from a driving assessment. Between these two points of measurement (driving assessment and follow-up), numerous daily life driving behaviours are available for study, such as driving mileage/frequency, driving style and compensatory driving strategies. According to Sümer\(^72\), such daily life driving behaviors are proximal factors more closely related to both accidents and the distal demographic and medico-psychological characteristics than the association between distal factors and accidents. Thus, daily life
driving behaviours have a mediating role between distal factors and accident involvement, which have largely been neglected in stroke and TBI driving research. Studies have shown that stroke survivors strategically limit their driving exposure and avoid challenging environments (night driving, heavy traffic and inclement weather) compared to pre-injury. Unfortunately, follow-up studies have rarely included ratings of daily life driver behaviour, and even fewer studies have compared such ratings with a comprehensive set of baseline predictors and outcome measures including multilevel medico-psychological parameters. As of today, there is a knowledge gap regarding whether e.g. observed self-regulatory deficits (not necessarily detected with performance-based methods), may impact the degree of post-injury compensatory driving strategies, aberrant driving behaviour or accident involvement compared to the non-impulsive stroke and TBI driver. Therefore, self-rating measures of driver behaviour, such as the Manchester Driver Behaviour Questionnaire (DBQ)\textsuperscript{112} and the Driving Habit Questionnaire (DHQ)\textsuperscript{113} have the advantage of being measure of daily life driving parameters that are suitable for use in the study of stroke and TBI drivers. In addition, rating measures of driving behaviour usually have a larger variance in the responses than the rare evented and Poisson distributed accident parameter. The specific subscales of the DBQ (Violations, Inattention and Mistakes) are relevant to the post-injury driver because the items reflect behaviours that are related to self-regulatory mechanisms such as executive control (i.e., the violations subscale) and the cognitive aspects of driving (i.e., the error and mistakes subscales)\textsuperscript{88}. In order to assess the complexity of post-driving behaviour, a combination of rating and performance-based measures that also include daily life driving parameters is needed.
2. Aims of the present study

The main aim of this thesis was to investigate the impact of higher-level mental functions such as self-regulation, executive functions, impulsive personality traits, driving self-efficacy and perceived functional abilities on driving behaviour concurrently during a driving assessment (baseline) and longitudinally (follow-up) with the cohort who passed the driving assessment. The thesis further sought to elaborate whether self-report measurements would add significant to the understanding of post-injury driver behaviour supplementary to performance-based methods such as neuropsychological tests.

The specific research questions addressed in the three papers included in the thesis were:

Paper I

- Did the participants who passed the MDA rate themselves different than those who failed the MDA on measures of executive functions in daily living (BRIEF-A) and impulsive personality traits (UPPS Impulsive behaviour scale)?
- Was baseline rating of executive functions and impulsive personality traits associated with premorbid driving behaviours?
- Were baseline measurements of executive functions, impulsive personality traits and neuropsychological tests associated with follow-up driving behaviours after approximately twelve months, namely driving mileage, compensatory driving strategies and accident rates?
- Did the post-injury drivers show changes of driving mileage, compensatory driving strategies and accident rates compared to pre-injury levels?

Paper II

- Did ratings of driving self-efficacy (ADSES) and perceived functional abilities (Awareness Questionnaire) and number of compensatory driving strategies (SDPQ) change from baseline to follow-up?
- What baseline factors (neuropsychological tests and ratings of executive functions and impulsive personality traits) showed the strongest associations with driving self-
efficacy (ADSES) and perceived functional abilities (Awareness Questionnaire) at follow-up?

- To what extent were follow-up ratings of driving self-efficacy (ADSES) and perceived functional abilities (AQ) associated with driver behaviour (DBQ), driving mileage and compensatory driving strategies?

**Paper III**

- Did ratings of driver behaviour (DBQ) change from pre-injury (rated retrospectively during a multidisciplinary driving assessment (MDA)) to follow-up (after one year of post-injury driving)?
- To which extent were age, a comprehensive baseline neuropsychological test battery and self-regulatory rating measurements (BRIEF-A & UPPS) associated with baseline and follow-up ratings of daily life driver behaviour (DBQ)?
3. Methods

3.1 Design

The present study is a consecutive case series follow-up study of stroke and TBI survivors who were referred to a multidisciplinary driving assessment, which was conducted in a clinical setting at Sunnaas Rehabilitation Hospital, Norway.

3.2 Procedures

This consecutive follow-up study was conducted in two phases, baseline (MDA) and follow-up after twelve months. At baseline one of the researchers obtained written informed consent and executed all of the neuropsychological assessments. The MDA outcomes (Pass/Fail) were based on the following three multidisciplinary assessments: 1) Medical examination, 2) Neuropsychological assessment and 3) On-road driving test. These MDA procedures were previously described in detail. Individuals who passed the medical and neuropsychological examinations or who had results that yielded doubt regarding their driving safety after the neuropsychological testing were referred to complete an on-road driving test. A multidisciplinary team composed of a physician and a neuropsychologist determined who satisfied the Norwegian health requirements for driving fitness (i.e., MDA Pass/Fail). When necessary, participants completed supplementary neuropsychological tests in addition to the standard test battery. When participants displayed executive, emotional or behavioural dysfunctions that could affect driving fitness, this was taken into consideration regarding their MDA outcomes. In some cases, this dysfunction was quantified with measures such as the Awareness Questionnaire. Independent of the driving assessment conclusion, participants completed rating measures of executive functions in daily living (BRIEF-A), impulsive personality traits (UPPS Impulsive Behaviour Scale), perceived functional abilities (Awareness Questionnaire, AQ), driving self-efficacy (Adelaide Driving Self-Efficacy Scale, ADSES), driving behaviours (Driver Behaviour Questionnaire, DBQ) and questionnaire measuring their pre-injury driving characteristics (Sunnaas Driving Pattern Questionnaire, SDPQ). To minimise underreporting, all participants were explicitly instructed that the questionnaires were not part of the driving assessment conclusion. At
follow-up, approximately one year after the MDA baseline, those who passed the MDA received questionnaires that measured post-injury driver behaviour (DBQ and SDPQ) and perceived functional abilities and driving self-efficacy (AQ and ADSES).

3.3 Participants

All stroke and TBI patients who participated in this study were referred to the multidisciplinary driving assessment (MDA) at least 3 months post-injury. Participants who were eligible to drive after a MDA at the hospital typically had well-preserved daily life functions. Inclusion criteria were stroke or TBI that was confirmed by Computerised Tomography (CT) or Magnetic Resonance Imaging (MRI). Moreover, proficiency in the Norwegian language and having acquired a pre-injury driver’s license were required for inclusion in this study. None of the participants held a valid driver’s license at the MDA due to stroke or TBI. Exclusion criteria were severe psychiatric illness, dementia or other somatic/neurological illnesses causing cognitive deficits. A total of 113 patients were eligible for participation. Three patients failed to meet the inclusion criteria due to severe psychiatric, neurological and somatic disorders. One stroke patient opted not to participate. A total of 109 patients between the ages of 19 and 80 years satisfied the inclusion criteria and were willing to participate, of which 77 had experienced a stroke and 32 had experienced a TBI. The follow-up cohort \( (n = 34) \) which included the participants that passed the MDA, were 24 with stroke and 10 with TBI.

3.4 Neuropsychological tests

All patients were administered a standardised neuropsychological test battery that was selected specifically for driving \(^7,114\). Visual field deficits: Friedmann Visual Field Analyser MK2 (number of misses: max. 60). Visual attention: Sunnaas Tachistoscope Test \(^{114}\). This is a computerised test of visual attention and neglect. Symbols are briefly presented in both hemifields across 18 trials, which are 300 milliseconds during the Simple subtest (only one type of symbol is presented) and 500 milliseconds during the Complex subtest (three different types of symbols are presented, and participants are instructed to count the total number of only one type). The maximum total number of hits in the Simple and Complex subtests is 54. Visuomotor reaction time: React \(^{115}\) is a test in which participants are
instructed to press the spacebar when numbers randomly appear on the computer screen. The total score is calculated by summing the three default output mean scores (i.e., the mean reaction times in seconds to the left, right and middle visual fields), which is then divided by three. *Psychomotor speed and mental effectiveness*: Grooved Pegboard Test, Trail Making Test A \(^{116}\), Symbol Digit Modalities Test (SDMT) \(^{117}\), and D-KEFS Colour Word Interference Test parts 1 & 2 \(^{118}\). *Visuospatial*: Copy a 3-D cross (max. score of 10 points) \(^{119}\) and Block Design (WAIS-III) \(^{120}\). *Verbal abstraction*: Similarities (WAIS-III) \(^{120}\). *Visual reasoning*: Picture Completion (WAIS-III) \(^{120}\). *Executive cognitive functions*: D-KEFS Colour Word Interference Test parts 3 & 4 \(^{118}\), Digit Span (WAIS-III) \(^{120}\) and Trail Making Test B \(^{116}\). All D-KEFS and WAIS-III scores were adjusted for age. The Halstead-Reitan scores were adjusted for age, gender and education.

3.5 Rating measurements

3.5.1 Executive functions

An authorised Norwegian translation of the Behaviour Rating Inventory of Executive Function–Adult Version (BRIEF-A) \(^{82}\), which measures everyday executive functioning, was administered to the participants. The 75 items had response options of 1 (*never a problem*), 2 (*sometimes a problem*) or 3 (*often a problem*). The clinical subscales of Inhibit, Shift, Emotional Control and Self-Monitor form the broader Behaviour Regulation Index (BRI). The subscales of Initiate, Working Memory, Plan/Organise, Task Monitor and Organisation of Materials form the Metacognition index (MCI). The overall summary score consists of the Global Executive Component (GEC). The subscales and indices form normalised T-scores based on US-normed data. A T-score of 65 represents 1.5 standard deviations above the mean and is interpreted as abnormally elevated \(^{82}\).

3.5.2 Impulsive personality traits

An authorised Norwegian translation of the UPPS Impulsive Behaviour Scale was administered \(^{121}\). The UPPS is a 45-item Likert-rated (1 = “I agree strongly”, 2 = “I agree somewhat”, 3 = “I disagree somewhat” and 4 = “I disagree strongly”) questionnaire that measures the following four facets of impulsivity: Urgency, (lack of) Premeditation, (lack of) Perseverance, and Sensation-seeking. The range for each subscales’ mean score is from 1
(minimum) to 4 (maximum), with high scores implying impulsive behaviour. The UPPS is a factor-analytically derived measure with items that are compiled from well-known impulsivity scales, including the Barratt Impulsiveness Scale-11 (BIS-11)\textsuperscript{122}, the Sensation-Seeking Scales\textsuperscript{123} and the Five Factor Model of Personality (NEO-PI-R)\textsuperscript{124}. A short version of the UPPS has been used with brain-injured populations\textsuperscript{36}, and two studies have found that high scores on the UPPS are associated with executive dysfunctions\textsuperscript{38,125}. The \textit{UPPS Total} score was calculated by summing the mean raw scores for each subscale and then dividing by four to create a total mean across the subscales.

### 3.5.3 Driving Behaviour

The current study administered an authorised Norwegian direct translation of the Swedish DBQ\textsuperscript{89}, which is based on the Manchester Driver Behaviour Questionnaire (DBQ)\textsuperscript{112}. The DBQ has been widely used as a measure of aberrant driver behaviour\textsuperscript{3,90,126}. The Manchester DBQ was originally intended to provide self-report data on driver behaviour in daily life (violations, errors, and lapses) that are too private to measure by direct observation, such as during on-road driving tests\textsuperscript{112}. The DBQ has shown multiple associations with accidents, demographics, cognition, executive functions and impulsive personality traits\textsuperscript{90,127-130}. The 32 items of the Swedish DBQ form four subscales: driving violations, inattention, inexperience, and mistakes. Each item is scored from 0 (never) to 5 (very often). The mean subscale score range is 0 (minimum) to 5 (maximum), the total range of all items is 0 to 160 points. Higher scores imply aberrant driver behaviour. In this study, two of the four Swedish DBQ factors correspond to the two factors that were presented by Reason et al. (1990), violations and dangerous errors (mistakes). The third factor, harmless lapses, was divided into inattention errors and inexperience errors. The DBQ exists in many different versions with unique combinations of number and type of items\textsuperscript{131}. Thus, mean scores on the factors from the healthy population are difficult to interpret and compare between studies. In a sample of healthy drivers with a mean age of 42 years (range 20-70 years), the participants had higher means on the Swedish DBQ violations items (range 1.54-3.30 points) than the other three factors where most of the mean scores were below 1 point\textsuperscript{89}. No total mean score for each subscale was reported.
3.5.4 Pre- and post-injury driving characteristics

Sunnaas Driving Pattern Questionnaire (SDPQ) described by Schanke et al. ⁶⁰, which is a modified version of Schultheis et al.’s questionnaire ⁶⁵, provided data regarding participants’ pre- and post-injury driving characteristics. SDPQ measures parameters such as the number of years participants had a driver’s license, the number of kilometres they drove per week, their use of compensatory driving strategies, the number of traffic violations they had received (e.g., speeding tickets) and the number of at fault reported (to police or insurance companies) and unreported accidents they had experienced over the last 5 five years prior to their injury. Three parameters were selected for the current study: Kilometers driven per week, total number of compensatory driving strategies and accident rates. The eight items that measured compensation were the following: “Do you limit your driver behavior after your brain injury? (Yes/No): 1) Drive more slowly 2) Drive mostly together with others 3) Avoid cities 4) Avoid unknown places 5) Drive only when feeling well 6) Only during daytime 7) Avoid highways 8) Avoid rush-hour. The total score was the summation of number of Yes responses (minimum = 0 points, maximum = 8 points). The frequencies for the at fault reported/unreported accident rates were calculated per million driven kilometres, as described by Schanke et al. ⁶⁰.

To provide data of post-injury driving characteristics, the participants that succeeded the MDA were mailed the SDPQ and rated their post-injury driving behaviours. Three parameters were selected for the current study: 1) Kilometers driven per week, 2) total number of compensatory driving strategies and 3) accident rates.

3.5.5 Perceived functional abilities

A Norwegian authorized translation of the Awareness Questionnaire (AQ) ⁸⁴ was administered to the participants. The AQ measures three subtypes of current functional abilities, motor/sensory, cognitive and behavioural/affective, that form the AQ Total score. The patient rate their current functions compared to pre-injury across 17 questions on a 1-5 point scale, ranging from much worse than before, a little worse than before, like before, better than before and much better than before. A score of 51 points indicates overall functioning like before. Lower total score is indicative of perceived post-injury impairments.
3.5.6 Driving self-efficacy

A Norwegian authorized translation of the ADSES was administered to the participants. The ADSES is a 12-item self-report scale asking participants to rate their confidence levels from 0 (no confidence) to 10 (full confidence) about driving situations, including roundabouts, driving in high-speed areas and to a new destination. Minimum score is 0, maximum score is 120 points. ADSES is a reliable and valid measure of driving self-efficacy that has shown to predict performance of on-road driving tests.

Table 1. Measurements completed at baseline and follow-up

<table>
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<th>Domain</th>
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<th>Baseline</th>
<th>Follow-up</th>
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<td>Impulsive personality traits</td>
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<td>Driving self-efficacy</td>
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3.6 On-road driving test

In Paper I, a total of 65 (60.0%) of the 109 participants were referred to the on-road driving test following medical and neuropsychological assessments, of which 41 participants had experienced a stroke and 24 had experienced a TBI. Forty-two of the participants (38.5%) did not drive due to neuropsychological deficits, of which 36 had experienced a stroke and 6 had experienced a TBI. Additionally, two TBI participants did not drive due to other reasons. The on-road driving assessment was completed with an experienced occupational therapist and a professional driving instructor in mostly rural and suburban areas with varied traffic density and complexity and lasted approximately 45 minutes. Most participants drove identical routes with three possible outcomes, which were rated according to the driving instructor’s checklist (Acceptable, Doubtful or Not Acceptable). In total, 53 of the 65 participants that completed the driving test (81.5%) were rated as acceptable, eight (12.3%) were rated as doubtful, and four (6.2%) were rated as not acceptable.
3.7 Statistics

The statistical analyses were performed using SPSS PASW (version 21.0). Prior to analysis, data were screened for violations of assumptions for parametric tests. For measures that markedly violated the assumptions for parametric statistics due to non-normal distributions, data analysis was conducted with non-parametric tests. Missing neuropsychological data were mostly due to aphasia and hemiparesis and more frequently observed in the stroke sample. Missing data on the rating measures were mainly due to aphasia.

Paper I

To compare the MDA Pass and Fail groups, t-tests were used for normally distributed data, whereas Mann–Whitney U tests were used for non-normally distributed data. Series of Ancovas were carried out to control for age between the two diagnostic groups. To compare premorbid driving behaviour (Swedish DBQ) with the ratings of executive functions (BRIEF-A) and impulsive personality traits (UPPS), bivariate Spearman Rank Order Correlations (rho) were calculated. To compare baseline measures with follow-up driving characteristics (SDPQ), bivariate Spearman Rank Order Correlations (rho), partial correlations controlling for age and Wilcoxon Signed Ranks Test were calculated. The raw scores from the rating measures and neuropsychological tests were used in the analyses.

Paper II

For measures that markedly violated the assumptions for parametric statistics due to non-normal distributions (ADSES, AQ, Swedish DBQ, SDPQ and BRIEF-A), data analysis was conducted with non-parametric tests. To compare the change of ADSES and AQ scores from baseline to follow-up, Wilcoxon Signed Rank tests were conducted. To compare post-injury driving self-efficacy (ADSES) and perceived functional abilities (AQ) with age, BRIEF-A, UPPS, and Swedish DBQ, bivariate Spearman Rank Order Correlations (rho) were calculated. To compare post-injury ratings of driving behaviours (Swedish DBQ and SDPQ compensatory driving strategies) and accident rates, bivariate Spearman Rank Order Correlations (rho) were calculated. Mann-Whitney U tests were used to compare involvement in reported and unreported accidents (Yes/No) with the scores on the baseline ratings of the BRIEF-A, UPPS, ADSES, AQ and Swedish DBQ, and follow-up ratings of the ADSES, AQ and the Swedish DBQ. Raw scores were used in the analysis. Partial correlations controlling for age were conducted with transformed raw scores. To compare
the stroke and TBI groups, t-tests were used for normally distributed data whereas Mann–Whitney U tests were used on non-normally distributed data.

**Paper III**

To compare the stroke and TBI groups, t-tests were used for normally distributed data whereas Mann–Whitney U tests were used on non-normally distributed data. Series of ANCOVAs were carried out to control for age between the two diagnostic groups. To compare the Swedish DBQ scores at baseline and follow-up, Wilcoxon Signed Rank tests were conducted. To compare post-injury driver behaviour (Swedish DBQ) with neuropsychological tests and ratings of executive functioning in everyday living (BRIEF-A) and impulsive personality traits (UPPS), bivariate Spearman Rank Order Correlations (rho) and partial correlations controlling for age were calculated. Raw scores were used in the analysis.

3.8 **Ethics**

Recruiting participants for a study conducted during a clinical driving assessment may have made it difficult for participants to decline to participate, as they may have been afraid that declining would negatively influence their assessment outcomes. It was explicitly stated that declining would not have any negative consequences. The researcher conducted the neuropsychological testing but did not make decisions regarding driving fitness.

Written and signed informed consent was obtained from all participants. The study was approved by the Regional Committees for Medical Research Ethics, South-East, Norway.
4. Summary of papers

Paper I: Behavioural ratings of self-regulatory mechanisms and driving behaviour after an acquired brain injury

Purpose: To explore whether measurements of self-regulatory mechanisms and cognition were associated with driving behaviour after an acquired brain injury (ABI).

Methods: At baseline participants included 77 persons with stroke and 32 persons with a traumatic brain injury (TBI), all of whom completed a multidisciplinary driving assessment (MDA). The MDA included a medical examination, neuropsychological testing and an on-road driving test, was considered in the decision for or against granting a driver’s license. Self-regulatory mechanisms (executive functions and impulsive personality traits) and driving behaviour were examined for research purposes only. A follow-up cohort of 34 persons that succeeded the MDA was included.

Results: At baseline, self-regulatory mechanisms were significantly associated to aberrant driving behaviour, but not with neuropsychological data or with the outcome of the on-road driving test. Aspects of self-regulation were associated to driving behaviour at follow-up.

Conclusions: It is recommended that self-regulatory measurements in should regularly be considered in the driving assessments after ABI.

Paper II: Exploring associations between self-reported executive functions, impulsive personality traits, driving self-efficacy, and functional abilities in driver behaviour after brain injury

Purpose: The assessment of self-awareness and self-efficacy as they relate to driving after stroke and TBI is lacking in the literature where the focus has tended to be on neuropsychological testing of underlying component of cognition in predicting driving outcome. Therefore, this study aims to investigate the associations between self-rating of higher-level functions and post-injury driving behaviour.

Methods: The present one-year follow-up study included twenty-four adults with stroke and ten adults with traumatic brain injury (TBI) deemed suitable for driving after a comprehensive driving evaluation according to Norwegian regulations. In addition, but not part of the decision making, baseline measurements included self-rating of executive
functions (Behaviour Rating of Executive Function (BRIEF-A)), impulsive personality traits (UPPS Impulsive Behaviour Scale), driving self-efficacy (Adelaide Driving Self-Efficacy Scale (ADSES)), and functional abilities (Awareness Questionnaire (AQ)). Follow-up measurements twelve months after baseline were collected, the ADSES, AQ, SDPQ and Swedish Driver Behaviour Questionnaire (Swedish DBQ).

Results: Driving self-efficacy and perceived functional abilities did not change from baseline to follow-up. Baseline perceived executive functions and impulsive personality traits were significantly associated with driving self-efficacy at follow-up. Lower self-efficacy and functional abilities were associated with lower driving mileage and increased use of compensatory driving strategies, whereas lower self-efficacy beliefs were associated with driver mistakes and inattention. Driver violations and inattention were associated with minor accidents.

Conclusions: The present study demonstrates that higher-level functions such as executive functions, impulsive personality traits, driving self-efficacy and perceived functional abilities, influence post-injury accident involvement mediated through proximal driving factors such as driver inattention. Further evidence is warranted to explore self-rating measures compared to performance-based methods as predictors of risky driver behaviour, crashes, and near misses.

Paper III: Exploring associations between self-regulatory mechanisms and neuropsychological functioning and driver behaviour after brain injury

Purpose: The objective was to explore the associations between self-regulatory mechanisms and neuropsychological tests and ratings of pre- and post-injury driver behaviour.

Methods: This was a prospective one-year follow-up study. The subjects were a cohort with stroke and traumatic brain injury (TBI) that were previously found fit to drive after a multidisciplinary driver assessment. Baseline measures included neuropsychological tests and behavioural rating of self-regulatory mechanisms (Behaviour Rating of Executive Function (BRIEF-A) and UPPS Impulsive Behaviour Scale), and pre- and post-injury driver behaviour (Swedish Driver Behaviour Questionnaire (Swedish DBQ)).

Results: Better performances on neuropsychological tests were significantly associated with more post-injury DBQ Violations. The BRIEF-A main indexes were significantly associated with baseline and follow-up ratings of DBQ Mistakes and follow-up DBQ Inattention. UPPS
(lack of) Perseverance was significantly associated with baseline DBQ Inattention, while UPPS Urgency was significantly associated with baseline DBQ Inexperience and post-injury DBQ Mistakes. There were no significant changes in DBQ ratings from baseline (pre-injury) to follow-up (post-injury).

Conclusions: Neuropsychological functioning and self-regulatory mechanisms are related to driver behaviour. Some aspects of driver behaviour do not necessary change after brain injury, which reflects the influence of premorbid driving behaviour or impaired awareness of deficits upon post-injury driving behaviour. Further evidence is needed to predict the role of self-regulatory mechanisms on driver behaviour and crashes or near misses.
5. General discussion

5.1 Summary of the main findings

The thesis concurrently explored aspects of driving after stroke and TBI during a driving assessment (baseline) and longitudinally (follow-up) with the cohort who passed the driving assessment, with a particular focus on the associations between self-perceived abilities (executive functions, impulsive personality traits and driving self-efficacy) and daily life driver behaviour. The thesis further sought to elaborate whether self-rating measurements of such abilities would add significant to the understanding of post-injury driver behaviour supplementary to performance-based methods such as neuropsychological tests. In paper I this was investigated in the whole clinical sample that was referred, while paper II and III included the cohort found suited for driving after MDA. While Paper I and III included baseline ratings of everyday executive functioning and impulsive personality traits, Paper II expanded the rating measurements from paper I and III by including measures of functional abilities and driving self-efficacy measures at baseline and follow-up. The main findings were threefold:

1. Baseline measures and follow-up driver behaviour: Ratings of everyday executive functioning and impulsive personality traits were associated with self-reported post-injury driver inattention and mistakes, while better performance on neuropsychological subtests measuring processing speed were associated with higher numbers of post-injury driving violations. Post-injury accident involvement was unrelated to performance on neuropsychological tests, but higher accident rates were associated with baseline ratings of impulsive personality traits (i.e., sensation seeking) and driving violations.

2. Changes of driver behaviour from baseline to follow-up: The participants did not report an increase in their use of compensatory driving strategies after one year of post-injury driving or elevated accident involvement compared to pre-injury estimates. No specific changes of daily life driving behaviour were observed compared to pre-injury levels (i.e., driving violations, mistakes, inattentive errors or inexperience errors). The participants did not display higher accident rates compared with pre-injury levels or than the comparable healthy population.
3. **Relationships between driving self-efficacy, self-regulatory mechanisms and driving behaviour:** Increased reporting of executive deficits in daily living (BRIEF-A) and higher levels of impulsive personality traits (UPPS) at baseline were associated with lower post-injury driving self-efficacy (ADSES). Lower ratings of post-injury driving self-efficacy was related to post-injury driving mistakes and inattention (DBQ), increased use of compensatory driving strategies and shorter driving distances.

5.2 **Discussion of the main findings**

5.2.1 **Baseline measures and follow-up driver behaviour**

**Associations between baseline measures and post-injury DBQ ratings**

Paper III investigated the relationships between a comprehensive neuropsychological test battery, ratings of everyday executive functioning and impulsive personality traits and daily life driver behaviour (DBQ). As in Sümer’s contextual mediated model [78,132], significant relationships between the distal (i.e., neuropsychological functioning and rating of self-regulatory mechanisms in everyday living) and proximal (i.e., driver behaviour) driving contexts were found. Better performance on neuropsychological tests was positively correlated with increased post-injury driving violations, specifically three tests of processing speed (TMT A, Grooved Pegboard and the oral subtest of the SDMT). It is likely that drivers with better performance on such cognitive tests may feel safer during overtaking and speeding (driving violations) than those with slower processing speed. Because parameters such as driving violations usually decrease with age in the general population [89,112], the potential confounding factor of age was analyzed, but found to be trivial. The associations between aberrant driver behaviours and cognitive, perceptual, and psychomotor abilities have rarely been studied, but a study of healthy drivers reported that better selective attention predicted driving violations [132]. These findings suggest that preserved basic cognitive abilities such as psychomotor speed and mental efficiency (as measured by neuropsychological tests) may create a proclivity for unsafe driving by means of increased driving violations. Furthermore, studies of healthy drivers have reported associations between increased driving violations and accidents [86,90]. This was also shown in Paper I where the baseline DBQ Violations subscale was significantly correlated with follow-up at-fault minor accident rates (accidents not reported to police and/or insurance companies).
Conversely, the positive correlation between cognitive performance and driving violations may also imply that those with awareness of their cognitive deficits drive more carefully in terms of fewer driving violations. Thus, preserved cognition may simultaneously be a facilitator of accident risk to those individuals who report increased post-injury driving violations and a moderator of accident risk because driving fitness depends on adequate cognitive functions. No studies have demonstrated what driving violation amplitudes increase accident risk to such an extent that it would have clinical implications. It seems plausible that extreme DBQ violation scores in combination with some cognitive and perceived self-regulatory deficits in everyday living may negatively affect driving fitness.

In Paper III, with reference to everyday executive functioning (BRIEF-A), the strongest associations were observed with pre- and post-injury ratings of DBQ Mistakes and Inattention subscales, not with DBQ Violations. This observation confirms previous studies that have reported a positive correlation between the BRIEF-A and the DBQ total score and research where cognitive failure has been associated with DBQ errors (Mistakes) and lapses (Inattention). Thus, executive deficits in everyday living, as measured by the BRIEF-A, which according to Sümer’s contextual mediated model may be considered as falling within the distal driving context, are associated with aspects of post-injury daily life driver behaviour (i.e., mistakes and inattention) (proximal driving context) that have been associated with accidents.

In contrast to BRIEF-A, the neuropsychological tests were not associated with DBQ Mistakes or Inattention. This result may be interpreted as indicating that BRIEF-A, in this sample of drivers that passed MDA, is more closely related to driver behaviour that requires cognitive resources (i.e., driving inattention and mistakes). This interpretation is supported by literature reporting that the BRIEF-A measures executive deficits in everyday living that performance-based neuropsychological tests (including executive tests) may fail to identify. In contrast to the self-rating of executive functions in everyday living (i.e., BRIEF-A), the neuropsychological executive tests (WAIS-III Digit Span, D-KEFS Colour Word Interference Tests and Trail Making Test Part B) included in the MDA were not significantly related to any of the DBQ subscales. However, due to lack of research, it is difficult to interpret BRIEF-A scores by means of cut-off values to driving outcomes. Furthermore, we observed that the subscales of the UPPS, which is based on the five-factor model of personality, in contrast to the symptom-based BRIEF-A, were also related to different aspects of post-injury driver behaviour. UPPS Urgency, the tendency to frequently
experience strong reactions under conditions of negative affect, was associated with DBQ mistakes and inattention.

**Baseline measures versus post-injury driving mileage and compensatory driving strategies**

Paper I explored to which extent baseline measurements were associated to specific follow-up driving behaviours, namely driving mileage and compensatory driving strategies. Compared to pre-injury, the participants had reduced their weekly driving mileage significantly at follow-up, most likely because a high proportion of the participants were still on a sick leave or received medical rehabilitation. Of all the baseline measures, including rating measurements and neuropsychological tests, only lower levels on the UPPS (lack of) Perseverance subscale was associated with higher driving mileage at follow-up.

None of the baseline measures were associated with number of post-injury driving compensatory strategies. The lack of association between cognitive function and compensatory driving strategies found in this thesis could suggest that the need of adjusting driving behaviour due to cognitive deficits among the participants in this thesis were lower than reported in other studies. This may indicate that stroke and TBI survivors who have passed a comprehensive driving assessment are not in need of increased compensatory actions, reflecting a conservative clinical practice. Therefore, in such a cohort of drivers with presumable good cognitive functioning, the impact of premorbid factors on post-injury driver behaviour seems substantial as previously reported by Pietrapiana and colleagues. The potential influence of premorbid functions upon post-injury driving were seen in a stroke and TBI study where the TBI participants did not report an increase in compensatory driving strategies compared to pre-injury, despite simultaneously reporting worsened driving skills. The authors hypothesized that this was because of premorbid risk factors (impulsive personality traits and risky driver behaviour) and injury-related deficits in executive functioning within the TBI group that exerted a stronger influence on post-injury driver behaviour than cognitive deficits, which may also be the case for some of the participants in this thesis. Thus, awareness of one’s own cognitive and self-regulatory deficits in everyday living is not a prerequisite for engaging in post-injury compensatory strategies.

**Baseline measures versus post-injury accident rates**

Paper I and II explored if baseline and follow-up rating measures (executive functions, impulsive personality, driving self-efficacy and perceived functional abilities) and post-injury ratings of aberrant driver behaviour and compensatory driving strategies (DBQ and
SDPQ) were associated to post-injury accident involvement. Summarized, none of the rating measures or neuropsychological tests was associated with major accidents (reported to police and/or insurance companies). However, baseline and follow-up ratings of the DBQ violations subscale were associated to unreported accident rates (minor accidents) (Paper I and II). Further, minor accident rates were also associated with baseline ratings on the UPPS sensation seeking subscale (Paper I) and follow-up ratings on the DBQ inattention subscale (Paper II). Some authors have argued that unreported accidents may provide sensitive information of unsafe driving behaviours that may be overlooked if one solely include accident parameters from motor vehicle records (major accidents reported to police/insurance companies). Further analyses’ showed that the only significant difference between the colliders and non-colliders was that those who had been involved in minor accidents, displayed higher ratings of driving violations and inattention (Paper II). The findings may reflect that this sample of post-injury drivers have not been involved in a higher proportion of major accident compared with pre-injury estimates or a comparable healthy population. Driving violations did not change in compared to pre-injury estimates in this cohort of drivers. Thus, it is plausible to assume that premorbid impulsivity and driving style (i.e., violations such as speeding, overtaking and tailgating) to some extent may influence post-injury minor accident involvement. But due to the Poisson distribution of all the accident data, these associations need to be interpreted with caution. On the other hand, the association between driving inattention and minor accidents may be due to cognitive and injury-related factors among one group of drivers, while the association between accidents and driving violations may be influenced by premorbid driving style and impulsive personality traits to others. A third group that would require special attention during a MDA, are patients with both injury-related cognitive deficits and premorbid risky driving style and impulsive personality traits that hypothetically may be associated with post-injury driving violations and inattention.

5.2.2 Changes of driving behaviour from baseline to follow-up

Studies have shown that brain-injured drivers adjust and cope in traffic compared with pre-injury estimates, and the parameters of study have mainly included parameters such as compensatory driving strategies and accident involvement. What is lacking is studies that explore whether observed changes (or lack of changes) of driving behaviour after a brain injury are associated with specific cognitive functions. In this thesis, three
specific driving outcomes parameters were subject to study: 1) Aberrant daily life driver behaviour (DBQ), 2) Compensatory driving strategies (SDPQ) and 3) Accident rates. All parameters were assessed during baseline and compared with follow-up ratings.

**Changes of DBQ ratings**

Some authors have reported that despite brain injury, many aspects of driver behaviour is resistant to change. Paper III investigated whether the participants reported changes in daily life driver behaviour (DBQ) from pre-injury to follow-up. As a group, the participants did not report changes of such driving behaviours despite that some of the participants had injury-related sensory-motor and cognitive deficits. This is somewhat surprising because some of the participants had mild/moderate cognitive impairments that have been associated with inattentive driving errors and mistakes in the healthy population. Although the participants in the study did not display unawareness of deficits to such an extent that they were regarded as unfit to drive during the MDA, the lack of self-reported driving behaviour changes may be related to unawareness of deficits for some of the participants, which is a common sequelae after a brain injury. On the other hand, no reported changes of driver behaviour, especially for the DBQ driving violations subscale, may as well reflect that many of the participants were not in need of compensatory actions due to well-preserved cognitive functions. Because baseline ratings of BRIEF-A and UPPS show associations with both baseline and follow-up ratings on the DBQ, it seems plausible that the variance in these measurements also represents the participants’ premorbid self-regulatory levels.

The degree of unawareness, indicated by means of contrasting the participants’ scores on, e.g., the self-rating questionnaires with proxy measures (e.g., significant others’ ratings), was not explored in this study but should be subject to future research.

**Changes of compensatory strategies**

As shown in Paper I, the participants did not report a significant increase of compensatory driving strategies from pre-injury to post-injury. This is somewhat unexpected compared to previous studies that have shown that post-injury drivers limit their driving behaviours. When analyzing those who actually did increase use of compensation compared to those who did not compared to pre-injury estimates, the results indicate that increased compensation are related to fewer impulsive personality traits (UPPS lack of perseverance and premeditation) and self-monitoring symptoms (BRIEF-A Self-Monitoring subscale) and higher scores on a verbal abstraction test (WAIS-III) similarities. This may fit the notion
that self-regulatory deficits and inaccurate self-assessments may preclude the use of adaptive strategies and overestimation of driving capacity and may engage the driver in more risky driving behaviors post-injury. In the current study pre-injury estimates of daily life driving behaviour (DBQ) was unrelated to use of post-injury compensatory driving strategies. By contrast, the DBQ was significantly related to some aspects of self-regulatory mechanisms that in turn were associated to compensatory driving strategies. This illustrates the complexity of inter-related factors that may comprise driving behaviour, but also that drivers that have succeeded a MDA, do not necessary need to increase compensation compared to pre-injury.

**Accident involvement**

To establish the validity of driving assessments after brain injuries and rehabilitation programmes, long-term information regarding accident rates and traffic infringements are needed. Methods used to explore accident rates in among post-stroke and TBI drivers include self-report or official records. Car crashes are rare events with little statistical power, thus, in stroke and TBI studies where the samples sizes are usually are small, accident data need to be interpreted with caution. The participants in Papers I-III did not report any increased accident involvement compared to pre-injury estimates or comparable healthy drivers as shown in other studies. As previously mentioned, the only baseline parameters to show significant associations to accidents of minor types (unreported to police/insurance companies), were ratings of the UPPS Sensation-seeking subscale and DBQ Violations (Paper I). These are known risk factors of accident involvement among healthy drivers, and the results reflect how premorbid personality traits and driving style may continue to influence post-injury driving behaviour.

Compared with minor accidents, none of the baseline measures were associated with major accidents (reported to the police/insurance companies), but the frequency of such accidents were lower than minor accidents among the participants. But due to the Poisson distribution of all of the accident parameters, low sample size and short follow-up time, these numbers must be interpreted within those limitations.

**5.2.3 The mediating role of driving self-efficacy**

Perceived self-efficacy is considered to be an important predictor of behaviour, and this perception affects not only whether an individual chooses preventive behaviours, but can
also be involved in risk-taking. Post-stroke and TBI drivers who have a realistic perception (awareness) of their own capabilities may be better able to adjust their behaviour and respond to driver rehabilitation than those with impaired awareness of illness. Self-perceived driving capacity, driving self-efficacy, may serve as a mediator between driving capacity and driving behaviour. Post-injury driving experiences may also provide feedback that influences intellectual and online awareness of which functional deficits may impair driving abilities to increase driving safety.

*Changes of driving self-efficacy and awareness processes*

Paper II explored whether the first year of driving after a brain injury would change perceived driving self-efficacy (ADSES). No such changes from baseline to follow-up were found. This finding is in concordance with previous studies of brain-injured drivers in which driving self-efficacy has remained stable. This observation may reflect the fact that participants deemed fit to drive after an MDA most likely have well-preserved functional abilities (including driving ability) such that post-injury driving experiences do not substantially alter their driving self-efficacy.

All participants had previously completed a comprehensive MDA, which makes it likely that most of them had intact awareness of cognitive deficits that enabled them to apply appropriate compensatory driving strategies when needed. For some of the participants, it is likely that driving self-efficacy beliefs remained high despite potential cognitive deficits due to adequate compensation. However, the lack of changes in driving self-efficacy among some of the stroke and TBI participants may be interpreted as impaired awareness and overestimation of driving ability especially for the participants with cognitive deficits that reported no changes of driving self-efficacy from baseline to follow-up. Over-estimation of driving ability has previously been reported in studies of brain-injured drivers that may put these drivers at a higher risk in traffic than those with realistic views of their own capabilities. In addition, despite being aware of impaired driving abilities after a brain injury, all drivers do not necessary compensate for this. These findings may altogether reflect that among stroke and TBI drivers who have completed an MDA, a critical factor in the prediction of post-injury driving behaviour is how the drivers perceive their capabilities. Thus, self-perceived abilities (assessed through rating measures or interview), might be equally important to assess as capacity testing by means of performance on e.g. neuropsychological and on-road driving tests. In some cases, driving self-efficacy may serve as a mediator between distal factors (i.e., basal cognition, executive cognitive functions, self-
awareness and personality traits) and proximal driving factors (i.e., compensatory driving strategies) to influence post-injury driver behaviour.

**Relationships between baseline measures and post-injury driving self-efficacy**

Paper II further explored how baseline self-regulatory measurements and neuropsychological tests were associated with follow-up ratings of driving self-efficacy (ADSES) and a non-driving functional ability measure (AQ). It was demonstrated that the baseline ratings of executive functions (BRIEF-A) and impulsive personality traits (UPPS) were only significantly associated with the driving self-efficacy measure. An interpretation of this observation is that in a sample of drivers that have succeeded a MDA, ratings of everyday executive deficits (e.g., self-monitoring, shift of attention, planning, organizing, and working memory) may moderate driving self-efficacy beliefs.

**Driving self-efficacy and daily life driving behaviour**

Inaccurate self-assessments may preclude the use of adaptive strategies and over-estimation of driving capacity (high self-efficacy) and may engage the driver in more risky driving behaviours post-injury \(^{15,16}\). Thus, Paper II examined whether perceived driving self-efficacy and functional abilities were associated with daily life driver behaviour (DBQ) at follow-up. First, the results showed that lower driving self-efficacy beliefs were associated with driver inattention and mistakes. Second, it was observed that higher driving self-efficacy and perceived functional abilities were related to an increase in driving mileage and fewer compensatory driving strategies. This finding supports previous literature in which lower driving self-efficacy has been associated with lower driving mileage and an increase in driver mistakes and inattention \(^{14}\). With reference to the findings presented in this thesis, perceived driving abilities influence specific driving behaviours in daily life and are associated with perceived self-regulatory abilities (i.e., ratings on the BRIEF-A and UPPS), but not with performance on neuropsychological tests. These findings underline the importance of including rating measures in the study of the higher-level processes that influence post-injury driver behaviour. By contrast, better perceived functional deficits (physical, cognitive, and behavioural/affective as measured with AQ) were not associated with daily life driver behaviour (violations, mistakes, inattention, or inexperience) but with increased driving mileage and fewer compensatory driving strategies (Paper II).
This observation may prove that in this sample, higher-level functions such as driving self-efficacy, executive functions and impulsive personality traits are associated with many aspects of daily life driver behaviour after an acquired brain injury.

5.3 Methodological issues

There are some strengths and limitations that already have been discussed, the main topics will however, be emphasized in the following.

5.3.1 Representativity and generalizability

The participants in this thesis were recruited from a large specialized rehabilitation hospital during a multidisciplinary driving assessment. Thus, the generalizability of our findings must be interpreted within the context of these sampling limitations. Specifically, these stroke participants were younger than the general stroke population, and the TBI participants were older than the general TBI population and were predominantly males. The age-difference between the stroke and TBI sample (approximately 6 years mean difference), was not significant ($F(1, 33) = 1.362, p = 0.252$). Thus, the confounding effect of age in the study when comparing the diagnoses was expected to be small. The median age of the participants in the follow-up cohort was 49.7 years, approximately 20 years older than TBI the median age of TBI survivors from the same geographic area (29 years $^{136}$). Further, the mean stroke-debut age in Norway are 77.7 years for women and 75.3 years for men $^{137}$, which is considerably older than our current sample (53.8 years). The stroke sample had a larger proportion of hemiparesis and aphasia in the samples at baseline and follow-up, which in most cases accounted for the missing data. The follow-up cohort in Paper I-III included a small sample ($n = 34$) and had a relatively short follow-up timeframe (twelve months), which limits the generalization of the results. Bonferroni correction was used to counteract the problem of multiple comparisons and is a conservative method to control the family-wise error rate. Due to these strict criteria, many associations between driver behaviour and the self-regulatory measurements failed to reach statistical significance.
5.3.2 Measurements

Neuropsychological tests

In this thesis a comprehensive neuropsychological test-battery were used in the MDA decision. The test battery includes tests from different standardized test batteries (i.e., WAIS-III, D-KEFS and Halstead-Reitan Test Battery). A methodological concern regarding the use of an eclectic test-battery from different providers is that the norm sets differ. The WAIS-III and D-KEFS norm sets include age adjusted scaled scores (range 1-19), while the Halstead-Reitan Tests Battery norms include age, gender, education and ethnicity adjusted T-scores (range 0-100). Ultimately, identical performance on a neuropsychological test (raw scores) may produce small differences in the adjusted scores due to demographic differences (e.g., higher versus lower education levels) that may influence the Pass/Fail decision in the MDA. Specifically, participants with lower education levels get a higher adjusted score on the TMT A and B with identical raw scores compared with participants with higher education levels. Further, there is an ongoing debate whether to use raw scores or adjusted scores in the neuropsychological driving assessment decision (see Barrash et al. \textsuperscript{138} for further details). To minimize such norm-sampling issues, only raw scores were used in the analyses in Papers I-III.

Neuropsychological assessment of executive function is highly challenging, and this thesis included a limited number of executive cognitive subtests (D-KEFS CWIT 3+4 and TMT B) suitable for the time-limited clinical MDA. To further enhance the assessments of executive functions, Iowa Gambling Task \textsuperscript{139} and the Behavioural Assessment of the Dysexecutive Syndrome (BADS) \textsuperscript{140} represents interesting paths to capture executive functions in a broader sense.

On-road driving test

The majority of the participants in Papers I-III that were referred to an on-road driving test passed the driving test. Thus, the results from the on-road driving test (Pass/Fail) were of limited statistical use in comparison with the other baseline and follow-up measures. In retrospect, the on-road driving test would have benefited from a systematic rating of performance with validated and standardized instruments with two independent raters. This might have yielded data with a variance suitable for analyses against the baseline and follow-up measures as shown in studies by Akinwuntan et al. \textsuperscript{141} and Patomella and colleagues \textsuperscript{142,143}. 
Self-report measures

The selection of the rating measures in this thesis was done in order to capture measures of executive functions, impulsive personality traits, driving self-efficacy, functional abilities and driving behaviour in daily living. Some of the rating measures have previously been explored in stroke and TBI (AQ\textsuperscript{6} and ADSES\textsuperscript{53,85}), but to our best knowledge, the DBQ, BRIEF-A and UPPS have not been explored in the context of driving after stroke or TBI.

A methodological concern is whether rating of driver behaviour and higher-level mental processes may be susceptible to under-reporting because of social desirability effects\textsuperscript{144}, especially during a clinical driving assessment. Validity issues by means of underreporting of symptoms and risky behaviours on the rating measures included in papers I-III (DBQ, ADSES, AQ, BRIEF-A, SDPQ and UPPS) have not been addressed in any stroke and TBI driving studies. One study of healthy drivers concluded that bias caused by socially desirable responses is relatively small in DBQ responses\textsuperscript{145}. To reduce potential underreporting on the rating measures included at baseline in paper I-III, the participants were explicitly told that none of the rating measures were included in the MDA decision-making process.

Further, the validity of self-ratings in a brain injured sample needs to be interpreted with caution due to potential awareness deficits, which most likely extends to at least some of the participants. The majority of the participants though, most likely had intact awareness because awareness deficits were addressed specifically in each case during the driving assessment (standard clinical practice) and also assessed formally with the Awareness Questionnaire. These procedures are described in all the papers Procedures sections. In addition, intact awareness of deficits that may compromise driving safety is a health requirement for driving according to Norwegian law. All of the participants were evaluated against these statutory health requirements to ensure that participants with adequate awareness of driving related deficits were deemed fit to drive after the driving assessment.

Construct validity

A major challenge in neuropsychological research on higher-level functions such as executive functions, impulsive personality traits and perceived functional abilities (including driving), concerns the variety of definitions of these functions across different psychological disciplines (construct validity). In the studies of older drivers, self-regulation are mostly synonymous with compensatory driving strategies while in the field of social psychology, self-regulation have been defined as a behavioural and emotional response to internal and
external phenomenon. In clinical neuropsychology self-regulation may include aspects of executive functions, impulsive personality traits and self-awareness, while neuroscience studies may define self-regulation as related to inhibitory control and self-monitoring. Because driving research are conducted in all these fields, it has been challenging to formulate and operationalize self-regulation in order to communicate with relevant research fields. In this thesis self-regulation, executive functions, self-awareness and driving self-efficacy were all regarded as higher-level and overarching constructs. Self-regulation was viewed as a behavioural and emotional response influenced by cognitive capacities (i.e., basic cognitive factors and executive functions), personality dispositions (i.e., impulsive personality traits), situational factors (driving context) and attribution processes (e.g., driving self-efficacy), which is a broad definition as described by Hofmann and colleagues. Self-awareness was viewed as an integrating and self-reflective process that mediates the relationships between the capacities and dispositions known to influence self-regulation and self-regulatory behaviour as described by Ownsworth and colleagues.

There is also an on-going debate to what extent DBQ responses measure aspects of driving behaviours that are relevant in the prediction of accident involvement. Therefore, the associations between DBQ responses and accidents were interpreted with caution in Paper I-III, and the main focus were the associations between DBQ and the rating measures (BRIEF-A, UPPS, ADSES and AQ) and the neuropsychological test battery.

5.4 Clinical implications

Currently, MDA decisions rely heavily on performance-based methods (e.g., neuropsychological tests). This study is informative of the benefits of considering post-stroke and TBI survivors’ subjective ratings of own abilities in the understanding of post-injury driver behaviour. As shown in this study, self-rating measurements may provide important supplementary information compared to performance-based methodology (e.g., neuropsychological tests). Rating measurements may serve as a window into the subjective higher-level processes that influence tactical and strategic decisions during real-life driver behaviour. If certain aspects of driver behaviour such as driving violations are unlikely to change after a brain injury, then one might expect that premorbid driving behaviour largely determines post-injury driving behaviour, even for those who have cognitive impairments. This ultimately raises the question as to what extent risky premorbid factors (e.g., aberrant
driving behaviours and impulsive personality traits) should be integrated as part of the clinical driver assessment of brain-injured persons. Moreover, issues regarding self-regulatory deficits in the context of driving are relevant for the fields of neurology and psychiatry, which focus on disorders such as emotionally unstable and antisocial personality disorders, obsessive-compulsive disorder (OCD), Tourette syndrome, bipolar affective disorder, schizophrenia and attention deficit hyperactivity disorder (ADHD). Accidents due to road rage have been associated with increased aggression and psychiatric symptoms. Because increased scores on the BRIEF-A have been associated with emotional distress, as measured by the Symptom Checklist Revised (SCL-90-R), the BRIEF-A (self-report and informant form) may be utilized to measure self-regulatory deficits within psychiatric populations as well. Secondly, if lower driving-self efficacy is associated to an increase of driver mistakes and inattention, clinical interventions such as driving lessons may be recommended for this group.

5.5 Implications for future research

At the onset of the current study there were several research questions in the research field that needed further elaboration and some of the inevitable limitations of previous studies also indicate directions for future research. Future studies should include a standardized set of predictors including demographic variables and cognitive and higher-level functions to predict driver behaviour and accident involvement in stroke and TBI samples to elucidate the most critical driving fitness predictors in order to accumulate knowledge and improve risk assessments. Rating measures of higher-level functions should be systematically explored with objective driver behaviour data, such as accidents rates, simulator and on-road driving performance or driver data from equipped vehicles. In addition, further exploration of awareness of deficits, e.g., by contrasting ratings from patients with significant others’ ratings as predictors of post-injury driver behaviour would be an interesting path for future driving research. Due to the small sample sizes that usually are included in stroke and TBI driving studies, multicenter studies are needed.

Four possible paths for future research are:

1) Future studies need to further explore the potential interaction effects between premorbid risk factors and injury-related parameters in the study of post-injury driving behaviour.
2) Few studies have explored whether impaired awareness of driving-related deficits might improve after systematic rehabilitation/training with e.g. driving simulators.

3) Few driving studies have included detailed neuroimaging techniques to increase the understanding of the most critical brain-circuits in the understanding of risky post-injury driving behaviour.

4) Few studies have explored systematically the benefits of including informant/significant others’ ratings to predict post-injury driver behaviour with standardized questionnaires like the BRIEF-A, AQ or ADSES.
6. Conclusions

There are three main findings in this thesis. First, it was observed that baseline ratings of higher-level functions (e.g., executive functions, impulsive personality traits, perceived functional abilities and self-efficacy), were significantly associated with multiple post-injury driving parameters. Because performance-based neuropsychological tests often may fail to assess higher-level functions, rating measures are important to consider supplementary to performance-based methodology.

Second, there were no significant changes in driver behaviour, driving self-efficacy or perceived functional abilities from baseline to follow-up. This suggests that many of the participants had a post-injury driving capacity comparable to their pre-injury levels. It also suggests that for those participants that did not change driver behaviour but had cognitive deficits, premorbid factors (e.g., driving style and personality traits) and/or impaired awareness of deficits influenced post-injury driving self-efficacy and driving behaviour. Compared to the healthy populations and pre-injury estimates, the participants did not report increased accident rates.

Third, driving self-efficacy was related to baseline ratings of executive functions in daily living (BRIEF-A), impulsive personality traits (UPPS) and driving parameters such as post-injury driving mistakes and inattention (DBQ), increased use of compensatory driving strategies and shorter driving distances. This suggests a mediating role of self-efficacy between self-regulatory mechanisms and driving behaviour that involves self-awareness processes.

Summarized, these results are consistent with the assumption that some aspects of driver behaviour and perceived driving capacity after s stroke and TBI are quite resistant to change including how confident the participants are during driving compared to pre-injury estimates (self-efficacy). It was demonstrated that ratings measures were associated with post-injury driver behavior more profound than performance-based neuropsychological tests, thus rating measures may add significantly to the understanding of driver behaviour and may be beneficial to include in clinical driving assessments and future studies. Further evidence of self-rating measures compared to performance-based methods as predictors of risky driver behavior, crashes and near misses is needed.
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